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The Paradoxical Effect of Intercity Transportation and Communications Infrastructure on Urban Concentration: The Dispersion-Concentration Model

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Abstract

This study examines the effect of intercity transportation and communications infrastructure on urban concentration on a sample of 84 countries between the years 1960 and 2010. By comparing the effects of interregional transportation and communications infrastructure on primacy and urbanization, I find that (1) such investments promote population dispersion amongst connected areas and (2) population concentration from unconnected locations into connected ones. Therefore, intercity transportation and communications infrastructure is only effective at reducing excessive concentration when the dispersion effect exceeds the concentration effect.

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1. Introduction

The increase in the level of urbanization worldwide over the past century is unstoppable, from a 13% of the world's population living in urban areas in 1900 to over a 50% in 2006 (United Nations World Urbanization Prospects, 2005; Cohen 2005). For the first time in history, most people in the world live in cities or towns, and if this trend continues, in 2050 the urban population will reach a remarkable 70% (United Nations World Urbanization Prospects, 2005). This relentless trend towards urbanization has been commonly referred to as the arrival of the "urban millennium" (United Nations World Urbanization Prospects, 2005). Such rapid urban growth is fundamentally driven by the transformation of countries' economies from agricultural activities into increasingly industrial and service-based activities, which are much more efficient in close spatial proximity (Davis and Henderson, 2003). However, agglomeration of economic activity increases efficiency only to a degree, because at some point the costs of higher rental prices and congestion in high-density locations outweigh the benefits of low transportation costs (Davis and Henderson, 2003).

The urban economics literature finds that there is a systematic tendency across countries to underestimate the costs of agglomeration, which leads to excessive concentration in large urban areas, particularly in the largest city (Ades and Glaeser, 1995; Henderson & Becker, 2000; Duranton and Puga, 2003; Davis and Henderson, 2003; Henderson 2004a). Studies also find that the negative effects of such overconcentration are significant, leading to large losses in productivity and economic growth rates (Henderson, 1999a; Henderson 2003). In light of these serious consequences, finding effective policy instruments to reduce congestion has become a central question in the urban economics literature. Previous research suggest that investment in ITCI, that is intercity transportation and communications infrastructure, might be the solution to this problem, as it makes locations with smaller populations more competitive (Williamson, 1965; Wheaton and Shishido 1981; Lee, 1997; Henderson, Kuncoro, Nasution, 1996; Henderson 1999a, Davis and Henderson 2003). However, in spite of such widely documented dispersion effect, as countries expand their interregional transportation networks, concentration in urban areas continues to rise. The purpose of this paper is to explain the causes of such paradox, in order to provide further information on what policies are effective at reducing concentration.

2. Literature Review

Transportation and communications infrastructure networks induce changes in the population distribution because they affect the ratio of economies and diseconomies of agglomeration, that is, the benefits and costs to economic agents, primarily firms, of locating in areas with large populations (Henderson, Kuncoro, Nasution, 1996; Henderson 1999a; Henderson, Lee & Lee 2001, Davis & Henderson, 2003). Specifically, ITCI reduce the benefits of concentration, which originate in the savings of transportation and communication costs over space, and make spatial proximity advantageous. The literature on economies of agglomeration identifies four main advantages to economic agents of locating in populated areas. First, firms benefit from knowledge spillovers, such as shared information regarding production techniques, suppliers, customers, market conditions etc. (Marshall, 1890, Jacobs 1969). Second, both firms and workers benefit from low transportation costs; producers minimize transportation costs of goods by having a large population nearby and workers minimize commuting costs by living in the same city where firms are located. In turn, the higher diversity of industries and specialized employees in populated areas produces a third benefit, which is that labor markets function better (Helsley

& Strange 1990; Krugman 1991). This not only means that there is better matching between firms and workers, but also that producers are more efficient by having access to the services they might need from firms in other industries, such as financial, advertising and legal services, suppliers etc. (Dixit & Stiglitz 1977; Rahman & Fujita 1990).

In spite of these important benefits, economic activity does not converge to a single location. This is because in addition to economies of agglomeration, there are at least three disaggregating forces or diseconomies of agglomeration. First, as cities become larger, wages and especially rent become increasingly costly due to the scarcity of land and firms' competition for workers (Henderson 1999a). Second, the limits in technical skills to manage megacities create congestion, resulting in severe problems of pollution and long commuting costs for workers (Wheaton & Shishido, 1981; Henderson 1999a; Accetturo, 2008). Henderson (1999b) shows in a study of 100 cities of 15-20 different countries that if the population of urban areas increases from 25,000 to 2.5 million, the costs of rent and commuting increase by 115%. Finally, the high cost of living and lower quality of life offsets some of the benefits of higher wages in cities, which reduces the firms' competitiveness in attracting the most qualified workers (Muth 1969; Fujita & Owaga 1982).

The location decision of economic agents depends on whether a location's economies of agglomeration are greater or smaller than their diseconomies of agglomeration. In other words, when the benefits of a large population outweigh the costs, it is efficient for economic agents to concentrate in a populated area. Once the costs derived of a large size equal its benefits, no further concentration is efficient. What the urban economics literature finds, however, is that economic agents systematically locate in large cities well beyond the optimal level of concentration, a phenomenon known as "urban bias" (Ades & Glaeser, 1995; Henderson 1999a, Henderson 2003). There are two primary causes of urban bias.

First, whereas a reduction in transportation costs can be easily estimated, congestion and pollution are unpriced or underpriced negative externalities (Henderson, 2004). Such negative externalities increase with population; hence they are comparatively more underpriced in large cities than in small towns. Second, decision-makers are disproportionately located in large urban areas and have greater awareness of investment opportunities in those cities than in other locations (Henderson, 1998; Ades and Glaeser 1995). In addition, they have an incentive to increase living standards in the cities where they live rather than other areas. As a result, resources tend to be excessively centralized in large cities. The consensus in the urban economics literature is that the losses in productivity derived from inefficiently large cities are substantial (Henderson 1999a; Henderson 2003). Henderson (1999a) found that such losses can reach up to 1.5 annual percentage points of economic growth, an effect similar in magnitude to having significantly deficient investments in human and physical capital (Henderson, 2004a).

The urban economics literature finds that investment in transportation and telecommunication infrastructure is the key policy instrument to reduce excessive concentration, as ITCI reduces the benefits of agglomeration and makes hinterland locations more competitive. Indeed, when economic agents can transport goods and obtain information at low cost without the need of close spatial proximity, agglomeration is less beneficial; especially considering that there are also costs in concentration. Research in urban economics supports this theoretical prediction. There have been different approaches to the study of transportation and communications infrastructure and urban concentration. Some have studied this relationship more indirectly, by looking at the connection between economic development, measured in GDP per capita, and agglomeration (Williamson, 1965; Wheaton & Shishido, 1981; Parr 1985; Hansen, 1990, El-Shakhs 1992). They find that at early stages of development countries can only invest in public infrastructure in a few large cities, and conserve on spending that would instead be allocated to connect cities or create new cities. However, at later stages of development, countries can invest in transportation and communications infrastructure, which allows small and medium-sized cities to become more competitive. This process drives decentralization.

Other studies look at the relationship between transportation and communications infrastructure and urban concentration more directly. Henderson, Kuncoro, Nasution (1996) studied the effect of the development of major road networks from Jakarta to Bobatek, Bekasi and Tangerand (known together as Jabotabek) in Indonesia. The study found that, after the investment in the road network, Jakarta's share of employment in the manufacturing sector dropped drastically, from a 57% in 1986 to 44% in 1991, and that employment moved to the cities that were connected to Jakarta through the road network. Similarly, Henderson, Lee & Lee (2001) found that Korea's large investment in telecommunications since the late 1970s was followed by very rapid interregional convergence in competitiveness, which generated decentralization from Seoul to other smaller cities. Finally, Henderson (1999a) conducted a panel study from 1965 to 1995 for about 80 countries on the effect of transportation infrastructure on urban concentration. In line with previous studies, he found that increasing road and telephone line density networks has a significant effect in reducing concentration. Thus the conclusion from the all the research on this subject for the past four decades is clear: Investment in ITCI produces population dispersion.

In spite of the diversity of approaches in this research, there is one more aspect that is common to all of these studies: they all use primacy, or the largest city's share of the urban population, as a measure of concentration. The reason for this common choice is that what has consequences for economic growth and quality of life is not urbanization per se, but the form that urbanization takes (Davis and Henderson, 2003; Henderson 2003). In other words, there is no evidence that concentration of the population in urban or rural areas affects economic growth rates, what affects growth rates is whether the population in cities is clustered in one or a few excessively concentrated urban areas as opposed to a system of medium-sized efficient cities. Therefore, it makes sense to study problems of overconcentration by looking at how policies affect the concentration of a large oversized city with respect to the rest.

However, there are at least two reasons why only using primacy to study the effects of policies on concentration is significantly limiting. First, many countries have multiple large centers where a significant part of the population is concentrated. Examples include Shanghai, Beijing, Wuhan and Hong Kong in China, San Francisco, Los Angeles and San Diego in California, Sydney and Melbourne in Australia, or Madrid, Barcelona and Valencia in Spain. As a result, restricting the study of excessive concentration to one city ignores the problems of overpopulation that other cities might have. Even if the population decentralizes from the largest city, if the recipients of such reduced populations are other oversized cities, productivity losses will persist. The second reason why using primacy is considerably limiting is that transportation and communications infrastructure do not connect all locations equally (Williamson, 1965, Wheaton & Shishido, 1981; Krugman, 1996, Henderson 2004a; Henderson 2004b). Indeed, the high costs involved in large infrastructure projects means that such projects will be more profitable to connect large cities, where there are greater economies of scale. If these investments reduce the cost of access to other markets, locations where there are a greater proportion of such investments should become relatively more competitive than locations where there are a smaller proportion of those investments. As a result, the dispersion effect of ITCI should happen amongst connected locations, and there should be a concentration effect from the unconnected locations into the connected ones.

Since primacy only considers the ratio of the population in the largest city with respect to other populated and connected areas, using this measure should only show the dispersion effect of transportation infrastructure. In order to make the concentration effect of transportation infrastructure visible, a variable that separates between a set of better and worse connected locations is needed. Hence, in this study I will compare the effect of transportation infrastructure on both primacy and urbanization, as urban areas are comparatively better connected than rural areas (Williamson, 1965, Wheaton & Shishido, 1981; Krugman, 1996, Henderson 2004a; Henderson 2004b). If there were just a dispersion effect, increases in investments in transportation and communications infrastructure should reduce both primacy and urbanization, as they are both measures of concentration. However, I hypothesize that interregional transportation infrastructure will reduce primacy and at the same time increase urbanization. In other words, we should see a dispersion effect from the largest city to other connected locations and a concentration effect from less well connected rural locations into better-connected urban ones. The rationale for using the urbanization variable is thus not to study changes in urbanization *per se*, but to examine whether transportation infrastructure produces concentration in larger cities that that have greater economies of scale. The existence of such economic force would have implications that are directly relevant to the form that urbanization takes, that is, whether the population in cities is highly concentrated in a few areas or more evenly spread over various medium-sized centers.

2. Theory

2.1. Main Assumptions

In this section, I create a model for understanding the economic forces behind population distribution, based on the findings of previous literature and the new insights this paper brings. I begin from the assumption that the concentration of natural resources and quality of living conditions are unequally distributed in space, which causes some areas to attract a greater amount of economic activity and population than others in the first place. The second main assumption is that different types of economic activity are dependant on location to different degrees. For example, activities such as agriculture or mining can only take place in certain locations, whereas manufacturing and services are usually much less constrained by proximity to a particular set of resources or geographic conditions. The third assumption I make is that when location is a choice, economic agents, firms and workers, seek to establish themselves in areas where they can maximize profit or income, respectively.

A key way in which location can be a factor for profit-maximization is by minimizing transportation and communication costs. For example, lower transportation costs allows firms to deliver their products or services to customers faster and at a lower transaction cost. Additionally, workers can have a greater disposable income by spending less time and money on commuting costs. Finally, lower communication costs allows firms to exchange ideas and obtain more efficient production techniques more easily, which increases the marginal productivity of labor.

2.2. Economies and Diseconomies of Agglomeration & Optimal Population

The economics geography literature states that due to these important benefits derived from low transportation and communication costs, spatial proximity is desirable. This implies that location-independent economic activity is more efficient in more populated locations, as economic agents are able to interact with one another without having to incur in high intercity transportation costs. These benefits derived from city size, or economies of agglomeration, increase exponentially, since when an economic agent locates in a given area, it lowers transportation and communication costs to all other economic agents in that location. Because of that, the benefits of city size are self-reinforcing; that is, when an economic agent move into a particular location the incentive for others to move as well increases. However, just as increases in city size generates benefits it also creates costs or diseconomies of agglomeration. This is because as a city grows in population, it also tends to grow in size, thus increasing the intra-city transportation costs. In addition, more firms compete for workers and the same scarce land, which increases rental prices. As with economies of agglomeration, the costs associated to city size also increase exponentially, because whenever an economic agent locates in a given area, it also raises commuting, rental and labor costs for everyone else.

It is important to stress the difference in exponential growth pattern between the economies and diseconomies of agglomeration. According to the economics geography literature, the exponential growth in economies of agglomeration is initially much greater than the exponential growth in diseconomies of agglomeration (Henderson, 1999a; Henderson 2003). As a result, up to a certain point, there is an increasing divergence between the slopes of the economies and diseconomies of agglomeration curves, and concentration is increasingly more efficient. However, once a given location has become very large, the costs of agglomeration increase much faster than the benefits, and the slopes of economies and diseconomies of agglomeration are increasingly convergent. The equations for economies and diseconomies of agglomeration for a given city A can thus be expressed as:

$$EA_A = \delta\left(\alpha^{N_A^Q}\right) \tag{1}$$

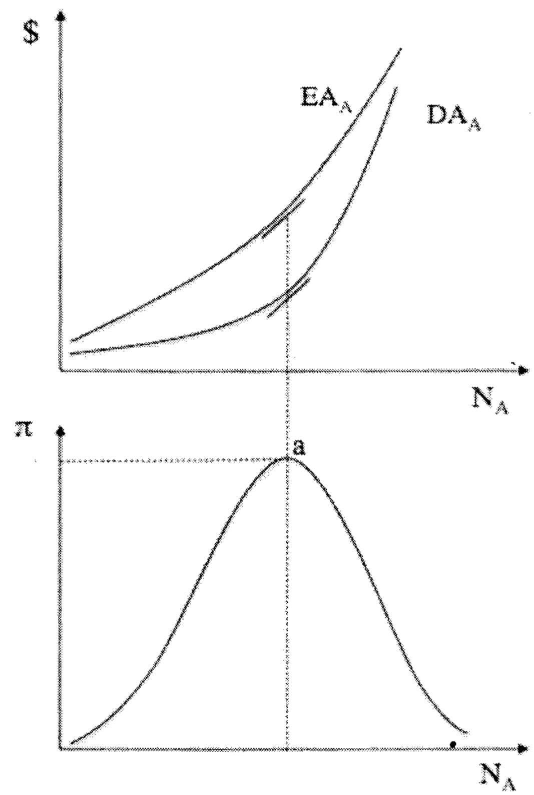
$$DA_A = \beta^{N_A^P} \tag{2}$$

where EA_A and DA_A are economies and diseconomies of agglomeration for city A, respectively, and N_A represents the population of city A. The term δ on the equation for economies of agglomeration is a value between 0 and 1 that indicates the extent to which the economic activity in a given location A is location independent, with 0 being completely location dependent and thus having no economies of agglomeration, and 1 being fully location independent, and thus having large economies of agglomeration[1]. The other terms in the equation capture the relationship of initial divergence and later convergence of the economies and diseconomies of agglomeration curves. First, in order for the slope of EA_A to initially exceed the slope of DA_A we assume that $\alpha > \beta$. In order for DA_A to exceed the slope of EA_A at some point we assume that the exponents on the population term N_A are $Q = 1$, whereas $P > 1$. In addition, in order to insure that the slope of DA_A surpasses the slope of EA_A only at high values of N_A, we assume that $(\alpha - \beta) > (P - Q)$. In other words, the difference in the bases of the equations exceed the difference in the exponents on the population term N_A. I show these relationships in the following set of graphs:

[1] Broadly, the literature on this subject assumes that economies of agglomeration primarily exist for manufacturing and services, and to a much lesser extent for agriculture, which is much a more location dependent type of economic activity (Henderson 1998; Henderson 2003; Davis & Henderson, 2003).

Figure 1: Economies and Diseconomies of Agglomeration

& Optimal Population



As the graph shows, the economies and diseconomies of agglomeration curves are initially increasingly diverging and at some point become increasingly convergent. The graphs also show that the *optimal population* for a city occurs at the point where the marginal economies of agglomeration MEA_A equal the marginal diseconomies of agglomeration MDA_A, that is when the marginal net economies of agglomeration $MNEA_A$ equal zero such that:

$$MEA_A = \alpha^{N_A} \log(\alpha)\delta \quad (3)$$

$$MDA_A = \beta^{N_A^q} \log(\beta) q N_A^{q-1} \quad (4)$$

$$MNEA_A = MEA_A - MDA_A \quad (5)$$

$$MNEA_A = \alpha^{N_A} \log(\alpha)\delta - \beta^{N_A^q} \log(\beta) q N_A^{q-1} \quad (6)$$

$$\max(\Pi) \rightarrow MEA_A = MDA_A \quad (7)$$

$$\max(\Pi) \rightarrow \alpha^{N_A} \log(\alpha)\delta = \beta^{N_A^q} \log(\beta) q N_A^{q-1} \quad (8)$$

$$\max(\Pi) \rightarrow MNEA_A = 0 \quad (9)$$

$$\max(\Pi) \rightarrow MNEA_A = \alpha^{N_A} \log(\alpha)\delta - \beta^{N_A^q} \log(\beta) q N_A^{q-1} = 0 \quad (10)$$

However, the relevant question in urban economics is not optimal population but *optimal concentration.* Indeed, even if a city still has marginal economies of agglomeration that exceed its marginal diseconomies of agglomeration, economic activity will be more efficient if it is located in an area with an even greater difference between its marginal economies and diseconomies of agglomeration. Similarly, even if a city's marginal diseconomies of agglomeration exceed its marginal economies in a series of cities, productivity loses will be minimized if economic activity is located in that city in which marginal costs of agglomeration surpass the marginal benefits by the smallest difference. Hence, the *optimal concentration* of a city A depends on its *relative* marginal economies and diseconomies of agglomeration MEA_{AB} and MDA_{AB}. For simplifying purposes, let us consider a country which population is composed of only two cities, city A and city B. The optimal concentration of city A is thus given by:

$$\max(\Pi) \rightarrow MEA_A - MDA_A = MEA_B - MDA_B \quad (11)$$

$$\max(\Pi) \rightarrow \alpha^{N_A} \log(\alpha)\delta_A - \beta^{N_A^q} \log(\beta) q N_A^{q-1} = \alpha^{N_B} \log(\alpha)\delta_B - \beta^{N_B^q} \log(\beta) q N_B^{q-1} \quad (12)$$

$$MNEA_{AB} = MEA_{AB} - MDA_{AB} \quad (13)$$

$$MNEA_{AB} = (MEA_A - MDA_A) - (MEA_B - MDA_B) \quad (14)$$

$$MNEA_{AB} = (\alpha^{N_A}\log(\alpha)\delta_A - \beta^{N_A^q}\log(\beta)qN_A^{q-1}) - (\alpha^{N_B}\log(\alpha)\delta_B - \beta^{N_B^q}\log(\beta)qN_B^{q-1}) \quad (15)$$

$$\max(\Pi) \rightarrow MNEA_{AB} = 0 \quad (16)$$

2.3. The Problem of Excessive Concentration

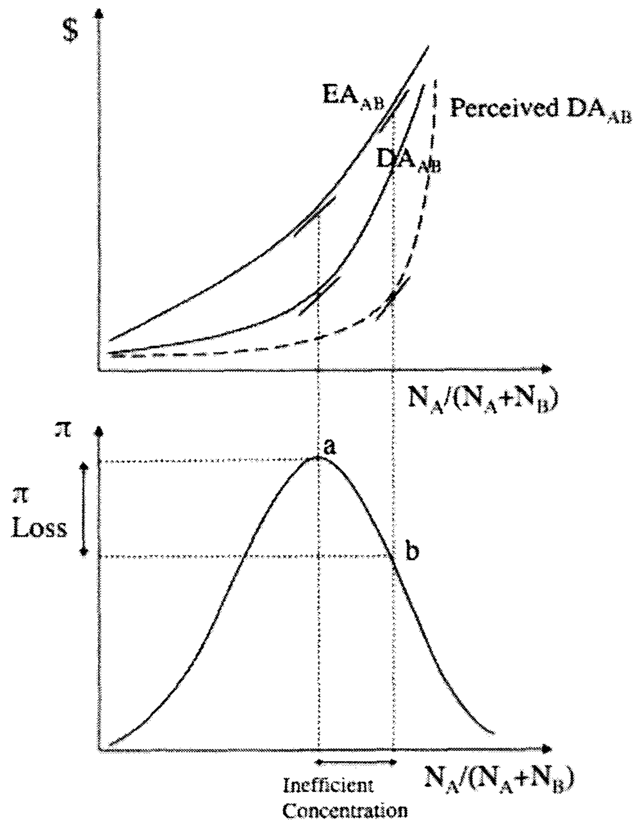
If we assume that the economic activity of city *A* is more independent of location than the economic activity of city *B*, such that $\delta_A > \delta_{B,}$ then city *A* should reach a higher population than city *B*, such that $N_A > N_{B.,}$ until the point at which the relative net marginal economies of agglomeration $MNEA_{AB}$ equals zero. Indeed, if governments and economic agents correctly estimated economies and diseconomies of agglomeration, all locations would always have efficient sizes. However, econometric studies show that there is a systematic trend for economic agents to underestimate diseconomies of agglomeration, which leads to a systematic overpopulation of the largest cities (Ades & Glaeser, 1995; Henderson 1999a: Henderson 2003). There are two main reasons for the systematic underestimation of diseconomies of agglomeration.

First, congestion and pollution are negative externalities that are unpriced or underserpriced and that are much higher in more populated areas, hence they are comparatively much more underpriced in large cities (Henderson, 2004a). Second, decision-makers tend to be disproportionately located in the larger locations and they are better informed of opportunities for investments in such locations than in other areas (Ades & Glaeser, 1995; Henderson 1999a: Henderson 2003). Additionally, they have an incentive to increase living standards where they live, so that they can directly benefit from these investments (Henderson 2004a). The combination of underpricing of negative externalities, information and incentive structure asymmetries induces decision-makers to have a preference for locating their private or public economic activity in the larger cities in which they live in. Hence, there is a discrepancy between *perceived* diseconomies of agglomeration[2] and *real* diseconomies of agglomeration, such that:

$$Perceived\ DA_A < DA_A \tag{17}$$

Since diseconomies of agglomeration are much greater in very populated areas than in less populated areas, there is a bias towards excessive population concentration in large urban areas, which prevents cities from achieving efficient sizes. In the following set of graphs we can observe the previously discussed determination of optimal city size as well as the problem of overconcentration.

Figure 2: The Problem of Excessive Concentration



2 Perceived diseconomies of agglomeration is simply one way to model the different forces that lead to excessive concentration, not a literal description of the problem. In reality, there are other factors that also lead to overconcentration, such as the coordination failure problem, that is, workers and firms are too small to start new cities, and so they all cluster in existing locations.

2.4. Spatial Dependency: The Impact of ITCI

Since there is a systematic trend towards excessive population concentration in large cities, which causes large productivity losses (Henderson 1999; Henderson, 2003), finding effective policies to reduce this problem has become a central question in the economics geography literature. The consensus in the urban economics literature is that the key policy instrument to reduce the problem of excessive concentration is intercity transportation and communications infrastructure. However, in order to understand why that is the case, first it is important to explain how ITCI can affect the concentration of cities.

In order to make the model I have been developing more realistic, it is very important to incorporate the concept of *spatial dependency*. Spatial dependency is the idea that any given location's absolute economies of agglomeration is also dependant on its position with respect to all other locations. Hence, for example, if a small city is close to a very populated area, its economies of agglomeration are still very high, as economic agents have very low intercity transportation costs to an area where there is high density. Similarly, even if a particular city has a large population, if it is very far away from a group of other large cities that are closer to each other, its economies of agglomeration may not be as high as that of those other cities. Hence, we can redefine economies of agglomeration for a given city A as the sum of its population N_A and the population of other locations N_B, N_C, N_D, N_E etc. divided by the intercity transportation ITC costs to each of those locations. However, as I mentioned earlier, for simplifying purposes, I consider a country composed of only two cities A and B. Hence, a city A economies of agglomeration is given by:

$$EA_A = \delta_A \left(\alpha^{N_A^Q + \frac{N_B^Q}{ITC_{AB}}} \right) \tag{18}$$

Similarly, the economies of agglomeration for city B is given by:

$$EA_B = \delta_B \left(\alpha^{N_B^Q + \frac{N_A^Q}{ITC_{BA}}} \right) \tag{19}$$

It is important to note that, for obvious reasons, the intercity transportation costs between cities A and B are equal regardless of the direction, such that $ITC_{AB} = ITC_{BA.}$ The intercity transportation costs between two cities A and B increase as a function of distance d_{AB}, and decrease with intercity transportation and communications infrastructure $ITCI_{AB}$, such that:

$$ITC_{AB} = \frac{d_{AB}}{ITCI_{AB}} \tag{20}$$

Since $ITCI$ can only reduce the intercity transportation costs generated by distance in the first place, the value of d_{AB} for two locations will always be greater than their corresponding $ITCI_{AB}$, hence ITC_{AB} will always be greater than one. Mathematically:

$$d_{AB} > ITCI_{AB} \tag{21}$$

$$ITC_{AB} > 1 \tag{22}$$

Since the effect of increasing $ITCI$ is to reduce the intercity transportation costs ITC, $ITCI$ also increases indirectly the economies of agglomeration of the connected locations, because economic agents in both cities now have lower intercity transportation costs to each other markets. In fact, as the ITC become closer and closer to one due to increasing $ITCI$, each of the cities economies of agglomeration grows as though the population in the other location was part of the city's own population. Because of that, reducing intercity transportation costs through ITCI has a similar effect as bringing the cities closer into space.

One more aspect that is worth mentioning is that I assume that there is no spatial dependency for diseconomies of agglomeration. This is a fairly realistic assumption, as for a given city, increases in population in other cities or towns should not increase its congestion or rental costs of that city, except when the two cities are very close or right next to each other. That is perhaps the key advantage of linking cities through ITCI, that, unlike population growth in cities, it increases the economies of agglomeration without increasing the diseconomies of agglomeration.

2.5. Asymmetric Returns of ITCI: The Dispersion Effect

Numerous econometric studies find evidence for what I call in this paper *the dispersion effect*, that is, the transfer of economic activity and population that occurs when a large city is connected through *ITCI* with a smaller city (Williamson, 1965; Wheaton & Shishido, 1981; Henderson 1999a; Henderson, 2003). The reason is conceptually straightforward: connecting two cities through transportation and communication channels makes a smaller connected city *B* more competitive, as economic agents in that location have more equal access to the greater market of the larger city *A*. In other words, although the absolute economies of agglomeration of both cities increase, the relative economies of agglomeration of the larger city *A* falls, because a reduction in intercity transportation costs between the two cities benefits the smaller city *B* to a greater extent than it benefits city *A*. This makes sense: a reduction in transportation cost to a larger market is more beneficial than an equivalent reduction in transportation costs to a smaller market. As a result, for two cities of different sizes, an equal reduction in transportation costs between them produces asymmetric returns. Using the model I proposed, the relationship is mathematically unambiguous:

The effect of a better transportation or communications infrastructure between two locations is to decrease intercity transportation costs by the same amount, such that:

$$\uparrow ITCI_{AB} \rightarrow \downarrow ITC_{AB} \tag{23}$$

$$\uparrow ITCI_{BA} \rightarrow \downarrow ITC_{BA} \tag{24}$$

$$\Delta ITC_{AB} = \Delta ITC_{BA} \tag{25}$$

However, a reduction in intercity transportation costs to a larger city increases economies of agglomeration by more than an equivalent reduction in intercity transportation costs to a smaller city. As before, the economies of agglomeration of cities *A* and *B* are given by:

$$EA_A = \delta_A \left(\alpha^{N_A^Q + \frac{N_B^Q}{ITC_{AB}}} \right) \tag{18}$$

$$EA_B = \delta_B \left(\alpha^{N_B^Q + \frac{N_A^Q}{ITC_{BA}}} \right) \tag{19}$$

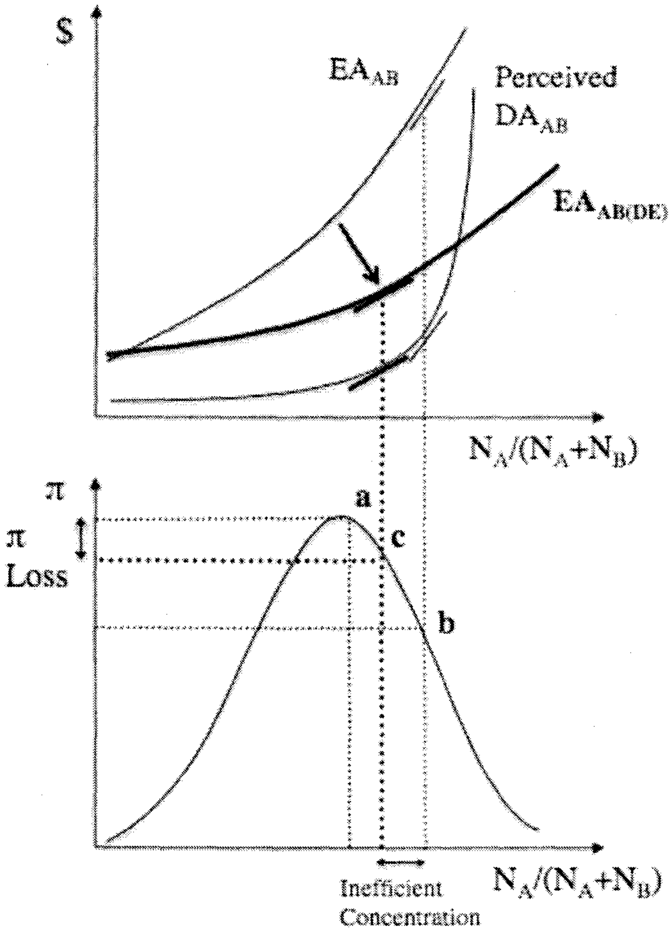
$$N_A > N_B \rightarrow \left(\frac{N_A^Q}{ITC_{BA} \downarrow} \right) > \left(\frac{N_B^Q}{ITC_{AB} \downarrow} \right) \tag{26}$$

$$\downarrow ITC_{AB} = \downarrow ITC_{BA} \rightarrow \Delta EA_A < \Delta EA_B \tag{27}$$

$$NEA_A - NEA_B < 0 \rightarrow NEA_{AB} < 0 \tag{28}$$

As these mathematical relationships show, linking a large city *A* with a smaller city *B* makes the relative economies of agglomeration of city *A* fall, because the absolute economies of agglomeration of city *B* increase by more than the absolute economies of agglomeration of city *A*. The result of this is that the relative economies of agglomeration and its perceived diseconomies of agglomeration cross at a lower point, thus leading to a more efficient level of concentration and reducing productivity loses. This phenomenon can be observed in the following graph, in which we move from a point *b* of large productivity loses to a point *c*, at which productivity loses are substantially reduced.

Figure 3: The Dispersion Effect of ITCI



2.6. The Concentration Effect of ITCI

In addition to a dispersion effect, I hypothesize that intercity transportation and communication infrastructure also produces a concentration effect. It is important to clarify that this effect does not refer to the gain in population by a smaller connected city *B* from the larger city *A* it is connected to. That is simply the dispersion effect considered from the perspective of location *B*. I refer to such phenomenon as the dispersion effect regardless of whether it is considered from the perspective of location *A* or *B* because both cases describe the same event of a transfer in population from a more populated location to a smaller one.

The dispersion effect thus only involves redistribution of the population amongst locations connected by ITCI. Conversely, the concentration effect involves a net gain in population of connected locations relative to unconnected ones. This effect, which previous research had not identified, occurs because economic agents in both *A* and *B*, by reducing their transportation costs to each other's markets, increase their relative economies of agglomeration with respect to other unconnected locations *C*. The main reason why some cities do not get connected or get worse connections through ITCI is economies of scale (Williamson, 1965; Wheaton & Shishido, 1981; Krugman, 1996, Henderson, 2004a; Henderson2004b). The large costs involved in large infrastructure projects means that such investments become more profitable as the size of the connected locations increase. Thus, the comparatively greater connection and access to markets of locations *A* or *B* increase incentives for economic agents in *C* to locate in one of those larger locations. We can observe this result mathematically:

First, we assume that $\delta_A > \delta_B > \delta_C$ so that $N_A > N_B > N_C$

For a location *C*, intercity transportation costs to *A* and *B* have not changed: Hence:

$$ITC_{CA(t+1)} = ITC_{CA(t)} \tag{29}$$

$$ITC_{CB(t+1)} = ITC_{CB(t)} \tag{30}$$

Hence, the absolute economies of agglomeration of city *C* have also not changed:

$$EA_{C(t+1)} = EA_{C(t)} \tag{31}$$

However, as I explained earlier, the improvement of the connection between city *A* and city *B* through $ITCI_{AB}$ increased the absolute economies of agglomeration of both city *A* and *B*. As a result, both the relative economies of agglomeration of cities A and B increase relative to that of *C*.For cities *A* and *C*:

$$\downarrow ITC_{AB} \rightarrow \Delta EA_{AC} > \Delta EA_{CA} \tag{32}$$

$$\downarrow ITC_{AB} \rightarrow NEA_{AC} > NEA_{CA} \tag{33}$$

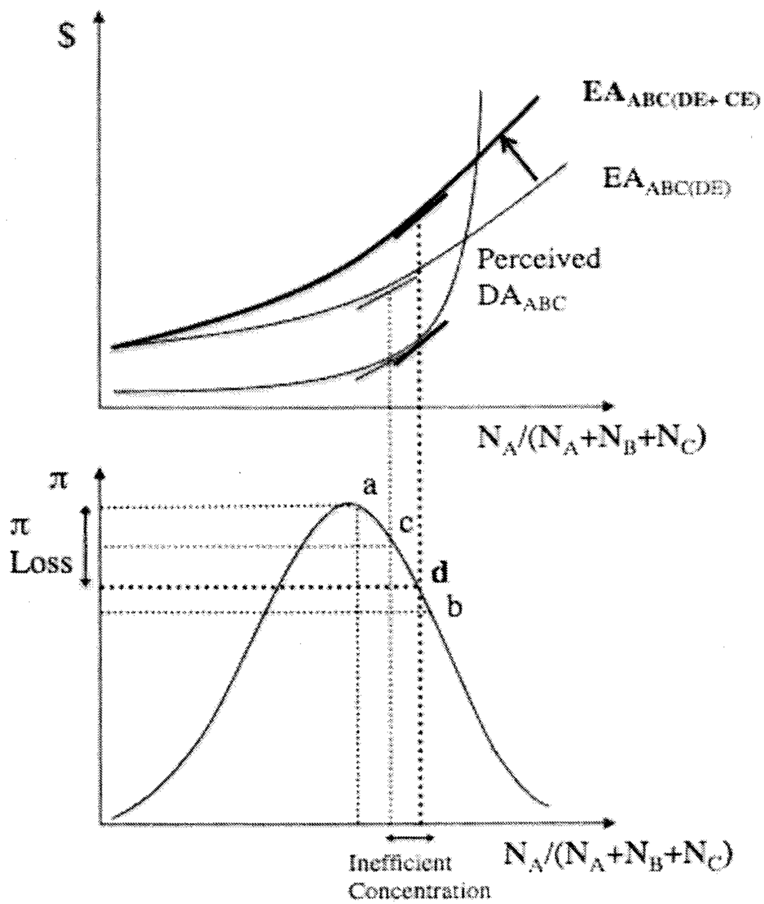
Similarly, for cities *B* and *C*:

$$\downarrow ITC_{AB} \rightarrow \Delta EA_{BC} > \Delta EA_{CB} \tag{34}$$

$$\downarrow ITC_{AB} \rightarrow NEA_{BC} > NEA_{CB} \tag{35}$$

Hence, in addition to the dispersion effect, *ITCI* makes the locations it connects *A* and *B* relatively more competitive than the locations it does not connect. This, in turn, produces population concentration from the unconnected locations *C* into the connected locations *A* and *B*. This can be observed in the following graph:

Figure 4: The Concentration Effect of ITCI



As the graph shows, if we consider both the dispersion and concentration effects, economies of agglomeration of location *A* shifts up somewhat and it intersects its perceived diseconomies of agglomeration at a higher point than estimated by just considering the dispersion effect. As a result, when we consider the impact of both effects, the loss in concentration and congestion will be smaller than predicted by only taking into account the decentralizing effects of *ITCI*. This is shown in the discrepancy between points *d* and *c*. Since for the largest city *A*, the dispersion and concentration effects have opposite directions (unlike in the case of city *B*), whether the population in the largest city increases or decreases depends on the relative magnitude of the dispersion *DE* and concentration effects *CE*. Thus, for city *A*:

$$|DE|>|CE| \rightarrow \Delta N_A > 0 \tag{36}$$

$$|DE|<|CE| \rightarrow \Delta N_A < 0 \tag{37}$$

However, regardless of the relative magnitudes of the dispersion and concentration effects, it is certainly true that:

$$DE + CE > DE \tag{38}$$

Hence, calculations that only consider the dispersion effect will overstate the reduction in congestion and increase in profits by the magnitude of the concentration effect.

2.7. The Guiding Equation

I construct my guiding equation based on the theory about the determinants of concentration discussed above. Such determinants are the distribution of natural resources, the percentage of the economy devoted to manufacturing and services, ITCI and resource centralization or urban bias. In addition, since previous literature discusses that a certain level of income is required to invest in infrastructure in the first place, I also include GDP per capita in the equation. Thus the guiding equation is the following:

$$PopulationConcentration = \alpha + \beta_1 NR + \beta_2 Sector + \beta_3 TC + \beta_4 GDPpc + \beta_5 RC + \varepsilon \quad (39)$$

where *NR* refers to natural resources, *Sector* stands for the manufacturing and services' share of GDP, *TC* refers to transportation and communication channels, *GDPpc* stands for income per capita and *RC* refers to resource centralization. The main variable of interest in this paper is transportation and communication channels *TC*, as this study's goal is to examine its effectiveness as a policy instrument for reducing concentration. Based on the theory discussed above, I predict that the sign of the coefficient on ITCI will depend on the measure of concentration used. Specifically, when using primacy, the coefficient on transportation and communication channels should be negative, as there is a dispersion effect from larger locations to smaller connected locations. This is also the result that studies using such measure of concentration find. However, if the measure of concentration is urbanization, the coefficient of transportation and communications channels should be positive, thus showing the concentration effect from less well connected areas to connected ones.

With respect to the other independent variables, I expect a negative coefficient for the distribution of natural resources when using primacy, as the concentration of economic activity in one location becomes less efficient as resources are spread. However, the expected sign of the coefficient for this variable when using urbanization is ambiguous. Indeed, a moderate degree of resource decentralization allows for economic activity to be located in various efficient sized clusters, thus allowing for greater urbanization than if all resources were in one inefficiently large location. At the same time, when resources are widely dispersed, urbanization should decline. Economic activity in manufacturing and services is much more efficient in close spatial proximity, hence I expect a positive coefficient for urbanization.

The effect of manufacturing and services on primacy will depend on the stage of urbanization. Based on Williamson (1965) hypothesis, at initial stages of the sectoral shift, when countries lack resources to invest in multiple urban locations, primacy should increase. However, at later stages of the sectoral shift, when countries can invest in multiple urban locations, the largest city's share of urban population should decline a greater proportion of the population moves to urban areas. This hypothesis also assumes a strong association between sectoral specialization and income per capita, which many studies find support for (Davis and Henderson, 2003). As a result, it is likely that these two variables may be collinear. Finally, I hypothesize resource centralization or urban bias will increase both primacy and urbanization, as concentration of resources in large locations should make less populated areas relatively less competitive.

4. Data & Summary Statistics

In order to empirically test the concentration and dispersion effects, I created a panel dataset that includes 70 countries and coverage for the period between 1960-2009 every 5 years, using most of the same variables that Henderson (1999a) used for his research. As I mentioned earlier, the main difference is that I use two measures of population concentration, primacy and urbanization, as my dependent variables. Both variables are widely used in the urban economics literature but only primacy has been used for studying the effect of policies on excessive concentration. The reason for such choice is that productivity losses are caused by whether particular locations have excessive concentration, as opposed to the degree of urbanized population (Henderson 1999a; Henderson, 2003; Henderson 2004b). The purpose of using the urbanization variable is thus only to test whether transportation infrastructure produces concentration from less populated areas into more populated ones. If interregional transportation infrastructure really has a dispersion effect, it should be present regardless of the measure of population concentration. This concentration effect is directly relevant to the form that urbanization takes, which is the aspect that affects economic growth rates (Henderson 1999a; Henderson, 2003). I obtained the data for these variables from the World Development Indicators.

In order to measure ITCI, I obtained panel data for roads and railways (in km) from World Development Indicators and fixed telephone lines (per 100 people) data from the International Telecommunications Union. The WDI road and railway data only covers the period from 1980 to 2010, but I was able to obtain additional road data from 1963-1979 from the International Road Federation. Both sources used the same definition and measurement for roads, so I merged the data I had for both time periods to create a dataset with coverage from 1963-2010. Another transformation I did to the road and railway data is to standardize them to a common scale to control for country size, by dividing them by the land area of their respective countries, as Henderson (1999, 2003) did in his study. I obtained such land area data from the CIA World Factbook. In order to account for natural types of transportation channels that have a similar function as ITCI, I obtained data for waterways (in km), also from the CIA World Factbook. As with roads and railways, I then transformed the data to waterways density by dividing the variable by land area. I also use the land area data to measure the distribution of natural resources, as prior research indicates that as land area increases natural resources become more scattered, thus promoting population dispersion (Rappaport and Sacks, 2001).

With respect to sectoral specialization, I obtained data for agriculture's percentage share of GDP from the World Development Indicators and then transformed this data to the manufacturing and services' share of economic activity by subtracting the data to one hundred. The data I collected for real GDP per capita (in dollars) comes from the World Development Indicators as well, and I transformed the data to reflect income in thousands of dollars, which is much more informative than individual dollars. In order to measure resource centralization or urban bias, I obtained data for the share of central government consumption and openness to trade from the Penn World Tables. The link between concentration and openness is not evident. The economic geography literature suggests that greater trade increases incentives for policymakers to pursue efficient allocation of resources, as there is a threat that international producers might move to other countries (Henderson, 2004a). Additionally, I constructed a dummy variable for whether the largest city is the capital, by comparing data for countries largest cities and countries capitals from Nation Master.

Prior to computing the summary statistics for these variables, I used several methods to clean the data, such as removing any former countries (e.g. Czechoslovakia, East Germany etc.), regions or areas that are not countries (e.g. high income countries, European Union, Atlantic Ocean etc.) as well as countries that had data with impossible ratios, such as having more than 100% of urbanization, primacy, central government share of consumption, manufacturing and services share of GDP, or fixed telephone lines per 100 people. In total, there were 175 geographic areas that fulfilled one of these criteria and were removed from the dataset. Before these changes were made, the variables that used ratios had distributions that were highly skewed to the right. After the data was cleaned, all the ratio variables had very symmetrical normal distributions. Excluding geographic areas also had the effect of reducing the size of the dataset and hence the number of observations. However, I was able to gain many observations by giving uniform labels to countries that had been named differently by different data sources. In total, there were about 50 countries that had been given different names by the different data sources, and some cases countries had numerous different names, as in the case of South Korea.

In computing the descriptive statistics, I disaggregated the data into time and cross-country variation, in order to show how much of the panel variation occurs in each of those two dimensions. Table 1 includes the total variation of the data, and Tables 2 and 3 show the cross-country and time variation of the data, respectively. All three tables are in arithmetic scale, as they are much more informative in such format than in logarithmic scale. Nonetheless, I included a table with values in logarithmic scale, in order to be able to compare values with previous studies. I contrasted the values in logs I obtained with that of Henderson (1999a) study, and overall the variables have very similar means and standard deviations, in spite of the fact that the study covers a greater time period (1960-2010, as opposed to 1960-1995). The dummy variable for whether the largest city is the capital was not included in any of the summary statistics tables, and the country invariant variables such as waterways and land area of countries were not included in the time-series table. The most striking aspect common to all tables using the arithmetic scale is the enormous difference in unit scale across variables, for example rail density ranges between 0 and 0.12, whereas land area ranges between 2 and 27400000. When the data is transformed to logs these differences in scale are largely reduced, however, there are still important differences in range of variation amongst the independent variables. For example, the standard deviation of land area is 3.02 percentage points, more than twelve times than that of manufacturing and services share of GDP, which is only 0.22 percentage points. By comparing the values in tables 2 and 3 we can also observe that the variation in the data is much greater across countries than across time, which is consistent with the lack of large differences between the descriptive statistics in this study and Henderson's (1999a).

Nevertheless, time variation has the advantage that it provides information about how all independent variables affect the evolution of the concentration measures. I show the change over time in population concentration, measured in primacy and urbanization, in Figure 5. The comparison of the urbanization and primacy trends reveals a striking fact: although the average largest city's share of urban population has been consistently declining, the share of the population concentration in urban areas has been consistently rising. Moreover, the increase in the concentration in urban areas has a substantially steeper slope than the decrease in concentration in the largest city. In fact, the figure shows that the average level of urbanization across countries crosses the 50% benchmark around the early 1990s. It is important to distinguish this measure from world urbanization, which considers the percentage of the total world's population living in urban areas. According to the United Nations (2007) world urbanization surpassed the 50% benchmark in 2006, about 15 years later than the urbanization cross-country average. This discrepancy suggests that less populated countries are more urbanized, as their impact is small on total world urbanization and large on the cross-country average, which gives equal weight to small and large countries.

Figures 6 and 7 show the relationship between road density and primacy and urbanization, respectively. The variables are shown in logarithmic scale, as the range of variation in road density is so narrow that plotting the variable in arithmetic scale would crowd together the data. As the graphs show, the strength of these correlations is modest in both cases, -0.12 in the case of road density and primacy and 0.36 in the case of road density and urbanization. However, the most remarkable aspect is that the correlations of the concentration measures and road density have opposite signs. This discrepancy is shown more clearly in Figure 8. These correlations are consistent with the theoretical prediction that ITCI produces population dispersion amongst connected locations and population concentration from the unconnected areas into the connected areas. However, since the figure only shows a correlation, it is possible that these differing trends are explained by the influence of other factors. I explore this question in the following section.

5. Analysis

5.1. Estimation Issues & Estimation Equation

In order to be consistent with previous literature, I use road density as my measure of intercity transportation infrastructure. However, there is an endogeneity problem in using such variable, as roads are highly concentrated in urban areas. In other words, roads are both a type of inter and intra city transportation infrastructure. Since urban growth and intra-city transportation infrastructure are positively correlated, the causality relationship between urban concentration and transportation infrastructure occurs in both directions. Henderson (1999a) acknowledges this problem and deals with it by including urbanization as an independent variable in the primacy regression, as an instrumental variable for intracity road investments. However, such technique does not seem ideal. The best way to deal with this problem would be to have variables that disaggregated data for inter and intra city public capital. Since no such data is available, railway density seems to be a good option to measure ITCI, since railways are primarily used for intercity transportation purposes, whereas roads are largely used for both inter and intra city functions. I will explore this possibility in a robustness check.

I computed the pairwise correlations amongst the independent variables to test for multicollinearity. I report these values on Table 5. There is very high collinearity between all the public capital variables, especially between road and railway density, which is over .80. This suggests that countries make investments in different types of public capital simultaneously. As a result, any of these variables may be used to measure public capital, and when used they should be regressed separately, not together. Income per capita and the GDP share of manufacturing and services have a very high positive correlation of 0.77. This is to be expected, as it is widely documented in the economic development literature that production in manufacturing and services activities is far greater than that of agricultural activities. GDP per capita also has a high level of collinearity with all the public capital variables, especially fixed telephone lines, which is almost 0.90. As a result of this high collinearity with both the public capital variables and sectoral specialization in manufacturing and services, I decided to drop the variable from the regression. Specialization in manufacturing and services has a very strong theoretical justification as a determinant of economies of agglomeration; hence I had to maintain that variable in the regression. The theoretical justification for income per capita is, however, primarily limited to the effect of growth in investments in public capital, which I include in the regression. There are no strong theoretical reasons to believe that growth in other kinds of economic activity (e.g. the human genome project) have significant effects on urban concentration.

I tested for heteroskedasticity and serial correlation using the Wooldridge and Wald tests, respectively, and in both cases I obtained significant results. Both of these results are not surprising. Significant heteroskedasticity may have been produced by the inclusion of numerous countries with very different sizes, as shown in the large standard deviations of land area and urban population. Variations in small countries should be much greater than variations in large countries, as any small change in a given variable is relatively much greater in a small country than in a large country. Serial correlation may be due to the fact that I lagged all the policy variables (road density, central government consumption and openness), by one period, that is five years. This is also the approach used in Henderson's (1999a, 2003) research, and the theoretical justification for such choice is that the effect of policy decisions is not immediate. Since no further research has been conducted on the exact lag of these effects, a one period lag (5 years) is used as a default. I corrected these estimation problems of significant heteroskedasticity and serial correlation by using robust standard errors in my regressions. Besides these issues, I checked for unit roots by using the Fisher test, but found no significant evidence for non-stationary. Finally, I decided to use a double-log form for my estimation equations, both for consistency with previous literature and because it spreads the data of variables that have a narrow range of variation, such as the public capital variables. Therefore, I express my estimation equations for primacy and urbanization as follows:

$$\text{Log (PRIMACY)}_i = \alpha+\beta_1\text{Log(RD)}_{(t-1)i} + \beta_2\text{Log(SECTOR)}_i + \beta_3\text{Log(GOV)}_{(t-1)i} + \beta_4\text{Log(OP)}_{(t-1)i} + \beta_5\text{Log(WD)}_i + \beta_6\text{Log(LA)}_i + \beta_7\text{ (CAPITAL)}_i + \beta_8\text{Log(URB)}_i + e_i \quad (40)$$

$$\text{Log (URBANIZATION)}_i = \alpha+\beta_1\text{Log(RD)}_{(t-1)i} + \beta_2\text{Log(SECTOR)}_i + \beta_3\text{Log(GOV)}_{(t-1)i} + \beta_4\text{Log(OP)}_{(t-1)i} + \beta_5\text{Log(WD)}_i + \beta_6\text{Log(LA)}_i + \beta_7\text{ (CAPITAL)}_i + e_i \quad (41)$$

where *RD* is road density, *SECTOR* is the percentage of GDP that is devoted to manufacturing and services, *GOV* is central government consumption, *OP* is openness to trade, *WD* is waterway density, *LA is* stand for land area[3], and *CAPITAL* is the dummy variable for whether the country's largest city is the capital.

5.2. Main Results

[3] I specified the country invariants waterway density and land area, as opposed to running the regression with fixed effects. This is because there are many country invariants, which do not explain urban concentration, hence running the regression with fixed effects drops the adjusted R-squares.

I present my results in terms of the percentage change of one standard deviation of the dependent variable per one standard deviation increase in each independent variable in Table 6[4]. This is the technique that Henderson (1999a) uses to interpret results, which is an essential element to control for different ranges of variation of the variables. For example, a one percent increase in a variable such as GDP share of manufacturing and services is equivalent to increasing it by more than four standard deviations. However, a one percent increase in land area would be an increase of less than a third of its standard deviation. Hence, the raw coefficients overstate the impact of variables with low standard deviations and understate the effect of factors with large ones. Nevertheless, I included the raw coefficients in Table 10 in the appendix section.

The effect of road density on primacy is in line with the theoretical prediction and consistent with previous literature. Increasing road density by one standard deviation reduces primacy by almost 13%, very similar to what Henderson (1999a) found[5] . The p-value is 0.059, thus this result is statistically significant at the 10% level. However, an even more significant result is the effect of road density on urbanization, which is positive and statistically significant at the 1% level. Increasing road density by one standard deviation increases population in urban areas by 15% of a standard deviation in urbanization[6]. This result is not only consistent with the theoretical prediction of a concentration effect, but in

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[4] The adjusted coefficients were obtained with the formula $\%\Delta\sigma_Y = \beta_{X_k} / [(1/\sigma_{X_k})*100] / \sigma_Y$, where σ refers to the standard deviation, x_k to a given independent variable *k*, y to the dependent variable and β_{X_K} is the raw coefficient of variable x_k.

[5] Henderson (1999a) found that a one standard deviation increase in road density reduces primacy by 10% of its standard deviation.

[6] The samples in the urbanization and primacy regressions are not exactly equal, since this type of macro level data tends to be very unbalanced. As happens with previous panel data studies (Henderson, 1999), this leads us to be cautious in comparing coefficients across regressions. However, this seems to be a better option than making all samples exactly equal, as that would result in the loss of a substantial amount of observations.

fact suggests that such concentration effect in cities is stronger than the dispersion effect from the primate city to other urban areas. If investments in ITCI only had the effect of making hinterland locations more competitive, as the urban economics literature suggests, the effect of roads should be to reduce urbanization. The results provided here suggest otherwise and are consistent with the idea that ITCI has the effect of inducing population concentration into the locations it connects from the locations it does not connect. Small locations, such as rural areas, often lack economies of scale to make investments in public capital cost-effective and are thus often not connected or connected by less expensive types of infrastructure. Hence, when better public capital is located elsewhere, the incentive for economic agents to move to that area increases.

The coefficients of other variables are generally in line with theoretical predictions. Waterway density, as road density, strongly reduces primacy, about 26% of its standard deviation, and the effect is significant at the 5% level. This makes sense: theoretically, waterways should have a similar effect to that of ITCI of facilitating transportation and communication, thus promoting population dispersion. However, it is noteworthy that waterways, unlike public capital, do not seem to promote significant concentration in urban areas. Why? A possible explanation is that waterways, unlike public capital, is not systematically planned to connect locations of a certain size. Both small towns and large cities can benefit from waterway connections. Thus, there is no reason why denser networks of rivers, lakes and seas should significantly increase urbanization. Land area, another geography variable, also strongly reduces primacy, as expected. When resources are more scattered, it becomes more costly to concentrate in a single location. By the same token, when a country's territory is not very large, and all the resources and land are concentrated in a small area, the population tends to cluster. As an extreme example to illustrate this point, in Singapore there is virtually no room for the population to spread outside of the city, hence the whole population is clustered in the same area. The significantly positive effect of land area on urbanization is less clear. It is possible that having a very large land area requires having multiple large cities as centers of different regions, thus reducing primacy and increasing urbanization. Some examples that would fit this explanation are Canada, China and Australia.

Also in line with expectations, sectoral specialization in manufacturing and services has a very large positive effect in increasing urbanization, about a 41% increase of its standard deviation, statistically significant at the 1% level. This result is consistent with the idea that industrial and service activities are much more efficient in high density, where there are knowledge spillovers and a large demand nearby. The effect of specialization in manufacturing and services has a positive but insignificant effect on primacy. As discussed in the theory section, the relationship between sectoral specialization and primacy is ambiguous. It is possible that at initial stages of industrialization, most of the population clusters in the primate city. However, as the city reaches its peak population and other urban clusters develop, further industrialization and movement to urban areas reduces the largest city's share of urban population. In other words, since primacy is a ratio that has the total urban population as the denominator, if urban population increases in areas other than the largest city, primacy will decrease, even if the population in the largest city does not fall or grows by a smaller magnitude. For this reason, the coefficient on urban population is negative and economically and statistically significant in the primacy regression.

With respect to the variables that measure resource centralization, the effects of increasing openness to trade is negative for primacy and positive for urbanization, as expected. However, these coefficients are not statistically or economically significant, as

Henderson (1999a) found. The coefficients for central government consumption have coefficients with signs contrary to expectations, however, the effects also insignificant. It is possible that the effect of government centralism is primarily captured by the dummy variable for whether the primate city is the capital. The effect of being the capital increases primacy by over 36% of its standard deviation, very similar to what Henderson (1999a) found, however this result is not statistically significant. This effect is, however, economically and statistically significant for urbanization. If the largest city is the capital, urbanization increases by over 27% of its standard deviation, and the effect is significant at the 5% level. Indeed, since urbanization includes the population of the largest city, if the population in the largest city increases the urban population will also increase is part of that growth is driven from migrants from rural areas.

5.3. Robustness

For the first robustness check, I transformed the population concentration measures into two new variables, the share of the total population in urban areas other than the primate city and the largest city's share of the total population[7]. I then performed regressions using the same independent variables against these two new measures, which I present in Table 7. I begin by discussing the regression on secondary urban areas. If the dynamics of the dispersion and concentration effect really work as theoretically predicted, the increase in secondary urban areas should exceed the increase in urbanization. This is because in addition

[7] To obtain these measures, I simply multiplied primacy by urbanization to obtain the population share of the largest. I then subtracted that number to urbanization to obtain the share of the population in secondary urban areas, that is, the urbanized share of the population excluding the primary city.

to the concentration effect from the unconnected rural areas into the connected network of urban areas, secondary urban areas should also absorb the reduction in the population of the primate city produced by the dispersion effect. The results from the robustness check show exactly that. A one standard deviation increase in road density increases the population share in secondary urban areas by over 25.62% of its standard deviation, compared to the 15.33% increase in population share in urban areas, and the effect is significant at the 1% level. Hence, this is consistent with the idea that the dispersion and concentration effects have the same direction for connected secondary urban areas.

However, this paper's theory section also predicts that the dispersion and concentration effects have opposite directions for the largest city. In other words, theoretically, the largest city loses population with respect to other connected cities and gains population from unconnected towns or cities. Hence, its reduction of the population should be smaller with respect to the total population, which considers both connected and unconnected areas than with respect to urban areas, which only considers connected locations. The results support this conclusion. A one standard deviation increase in road density reduces the largest city's share of the total population by 9.59% of its standard deviation, compared to a 12.73% reduction in a standard deviation of primacy, an the effect is significant at the 10% level. As predicted, the loss in population in the primate city produced by the dispersion effect is somewhat offset by the increase in population of the concentration effect. Thus, although the dispersion effect is dominant, the reduction in population in the primate city is substantially smaller when both effects are considered. By this measure, only considering the dispersion effect overstates the reduction in population of the largest city by about 25%, a substantial discrepancy.

For my second robustness check, I used rail density to measure public capital, and regressed it against all four measures of concentration. I show the results of these regressions on Table 8. Rail density has the advantage that, unlike roads, it has a primarily intercity transportation function, and thus reduces the endogeneity associated with including intracity transportation infrastructure. However, rail density also has the disadvantage of comprising a relatively small portion of transportation infrastructure investments compared to roads, and thus it does not fully capture the variation in ITCI. Because each measure of public capital has different pros and cons, a comparison of their effects can be very informative. Overall, the effects of rail density are very consistent with those of road density. As with roads, railway density reduces primacy and the largest city's population share, and at the same time increases urbanization and the share of the population of secondary urban areas. However, there are also some important differences. First, rail density shows a much stronger dispersion effect than roads. Increasing rail density by one standard deviation reduces primacy by over 28% of a standard deviation of primacy, an effect more that is more than twice as strong as that observed with roads. The effect is significant at the 1% level. At the same time, rail density shows a weaker concentration effect, as it increases urbanization by about 9.27% of its standard deviation, compared to the 15.33% observed with roads, and the effect is significant at the 10% level.

However, the most surprising fact is that, contrary to expectations, the increase in population share produced by railway density is somewhat weaker for secondary urban areas than in all urban areas. A one standard deviation increase in rail density increases the share of secondary urban areas by 8.9% of its standard deviation, and the effect is statistically significant at the 10% level. A possible explanation for this result is that the concentration effect in the largest city is much stronger than that produced in secondary urban areas. This can occur when the primate city is well connected to other locations but those other locations are not well connected to each other. An example of such a possibility is the Spanish High Speed Rail System, which connects all the province capitals to Madrid, the capital city, but does not connect those other cities directly to each other. For example, Madrid is connected directly to both Barcelona and Valencia; the second and third largest cities of the country, but such cities are not directly connected to each other (ADIF, 2010) , even though they are in closer spatial proximity (CIA World Factbook). If the largest city is at the center of the transportation infrastructure network, economic agents in that city have disproportionately better access to other markets, thus inducing a comparatively stronger concentration effect. The results for the largest city's share of the population support this proposition. Increasing rail density by one standard deviation reduces the share of the population of the largest city by 21.37%, about 7 percentage points less than the effect on primacy. The difference in results between roads and railways suggests thus might be due to the different structure of the transportation infrastructure networks. Railways might be planned as a network with a clearer center, whereas road networks may be more comprehensive and have a less defined principal distributor. Thus, different types of ITCI may favor cities of different sizes to different degrees.

As a final robustness check, I regressed fixed telephone lines, another type of ITCI, against all four measures of concentration. I show these regression results on Table 9. The variable is significantly multicollinear with both manufacturing and services share of GDP and urban population. Thus I dropped urbanization from the primacy and largest city's share of the population. However, I maintained sectoral specialization in the regression, as it is an absolutely essential variable. The results are again very consistent with the pattern found in the regressions using road and railway density as measures of public capital. Increasing fixed telephone lines reduces population concentration in the largest city relative to other urban areas, and at the same time promotes population concentration from rural areas into urban areas. However, the results of these regressions are overall much stronger than in those using roads and railways. A one standard deviation increase in fixed telephone lines reduces primacy by 23.44% percent of its standard deviation, and increases urbanization by 36.19% of its standard deviation. Both effects are statistically significant at the 1% level.

Nevertheless, the most striking aspect of these regressions is the fact that fixed telephone lines actually increases the largest city share of the total population by about 12% of its standard deviation. This would mean that for the largest city, the concentration effect exceeds the dispersion effect. In other words, the largest city would gain more population from unconnected rural areas than it would lose to connected urban areas. As a result, investments made in fixed telephone lines would exacerbate congestion problems in the primate city instead of alleviating them. However, there is an important reason why these results should be interpreted with caution. Fixed telephone lines, unlike roads and railways, are measured per 100 people, not in kilometer density. It seems that measuring public capital by the coverage of network controls better for intracity infrastructure than measuring it in terms of percentage of the population. This is because, due to the greater distance between cities than within them, ITCI should have a greater weight on the network density measure than intracity infrastructure. When this is measured in terms of population, however, such effect disappears. As a result, fixed telephone lines should have a greater endogeneity problem than the other two variables. Since there are more fixed telephone lines in more populated areas than less populated ones, these results likely overstate the concentration effect and understate the dispersion effect.

As was the case with roads and railways, this discussion shows that each measure of ITCI has its own limitations. Therefore, regression results using of any one of them have to be interpreted prudently. It is, however, on the *comparison* of regression results using different measures of public capital that stronger conclusions can be drawn. And indeed, from such comparison, there is a clear convergence in some key aspects. First, all regression results show that public capital produces a significant dispersion effect from the largest urban area to other urban areas, and a significant concentration effect from rural areas into urban areas. Also, regression results using all three measures show that the population share of the largest city is reduced by less when compared to both connected urban areas and unconnected rural areas than when compared only to connected urban areas. In addition, the results show that public capital produces a greater increase in share of the population of secondary urban areas than in the largest city. This supports the theoretical prediction that the dispersion and concentration effects have the same positive direction for secondary urban areas, whereas for the largest city the former effect has a negative direction and the latter a positive one. The discrepancies of the regression results thus have more to do with the absolute and relative magnitudes of the concentration and dispersion effects, not with their existence.

6. Conclusion

The purpose of this study is to examine and deepen our understanding of the effect of ITCI on urban concentration. The question has become of increasing importance in the economics geography literature, as policymakers seek to find solutions to the problem of excessive urban concentration, which occurs systematically across countries (Ades & Glaeser, 1995; Henderson 1999a, Henderson 2003). The costs of such inefficient population distribution are severe; as studies find that excessive concentration reduce economic growth rates significantly, up to 1.5 percentage points of GDP (Henderson, 1999a). For the past four decades, the consensus in urban economics has been that investment in interregional transportation and communications infrastructure is the key policy instrument to solve this problem. The reason is clear: ITCI reduces the cost of access to the market of the largest city for hinterland locations, thus making them more competitive. This study also finds support for such dispersion effect, but points out that only considering such distribution phenomenon is an incomplete explanation for the effect of public capital on the population concentration.

In a nutshell, the main contribution of this study is a simple idea: economic agents in the largest city also benefit from the lower cost of transportation to the market of a smaller city. They benefit to a lesser extent than the smaller city to which it has been connected to, but they benefit nonetheless. Thus, when ITCI connects two locations, they both become more desirable locations to do business. Because the increase in competitiveness is greater for the smaller city than the larger city, the relative competitiveness of the larger city falls with respect to the smaller city, which explains the move of firms and workers to the less populated city. However, the relative competitiveness of both increase with respect to all unconnected locations. This explains why firms and workers move from those unconnected locations into the connected ones; the concentration effect. I use primacy and urbanization, two different measures of population concentration, to capture these effects. The dispersion effect is best captured with primacy because it compares the share of the largest urban area to smaller connected urban areas. The concentration effect is best captured with urbanization because it shows how the effect of public capital differs for urban and rural areas, which differ in economies of scale and hence the cost-effectiveness of investments in public capital. If investment in public capital only had the effect of promoting dispersion from more populated locations to less populated ones, the direction of the effect should be negative for both measures of concentration. The results of this paper, however, show otherwise: investments in ITCI promote dispersion only amongst the locations it connects and induces concentration from the locations that are left unconnected into the connected ones. The implication of this conclusion is a paradoxical one: a reduction in transportation costs can increase incentives for population concentration. This is because it not only matters whether the costs are reduced; it also matters where they are reduced.

The implications of not taking into account the concentration effect are severe. After all, if policymakers believe that investments in ITCI only promote population dispersion, they will continue to place such investments where it intuitively make sense: in very populated areas where there are large economies of scale. If reducing congestion to raise productivity is one of the goals of the investment, they will underachieve or even exacerbate the problem. Does this imply that policymakers should not invest in ITCI as much? No. Instead, taking the concentration effect into account means that investments in public capital need to connect a sufficient number of locations for the dispersion effect to be significantly greater than the concentration effect. Indeed, in the extreme example of a public capital network in which all locations were connected, there would be no concentration effect. However, that would not be desirable, as some level of concentration significantly increases productivity (Henderson 1999a, Henderson 2003). Hence, depending on whether policymakers want to encourage or discourage concentration in a set of locations, they should connect more or fewer locations. Since the research in the urban economics literature documents that the problem tends to be excessive concentration, in general, policymakers should plan to connect more locations with public capital than they currently are. This is a relevant policy recommendation to current policy proposals, such as President Obama's proposed high-speed rail network in the United States, which, not surprisingly, only connects the largest cities of broad land areas (US Department of Transportation, 2010).

This paper also raises a set of new important questions for future research. For example, this paper uses urban areas as the group of locations with high economies of scale and rural areas as the group of locations with low economies of scale. Such categorization is useful as an approximation, but there may be a better way to separate well-connected areas from less well-connected ones. This is especially true for case studies, in which there may be more accurate data about the location of investments in public capital. Furthermore, the broad classification in itself of a network of connected locations may be further explored. As was mentioned in the robustness results using railway density, there may be different types and structures of public capital networks that affect cities differently. Some types of ITCI networks may connect all locations fairly evenly, whereas others may provide an asymmetric number of connections to a city or a set of cities. Hence, it may not only matter whether a city is connected to a public capital network, but also its position in the network. For example, a city like Paris, France, which is surrounded by a number of populated areas, may benefit more from its fairly central position in the network than a city like Berlin, which is on a more peripheral region of Europe.

Finally, the fact that a city's productivity depend in part of how it coordinates its connections with other cities raises an even deeper theoretical question related to game theory. For example, policymakers in a given city may want to push for public capital connections with more populated locations, in order to attract some of that economic activity into their city. However, the governments of larger cities may want to avoid such connections or only pursue them when the concentration effect exceeds the dispersion effect, in order to not lose economic activity. In addition, governments of different cities may decide to connect their cities to increase their relative competitiveness with respect to cities in other regions. Since the prosperity in cities and regions depends in their coordination with policymakers in other areas, there will be conflicts of interest. Thus, policymakers in different areas will have to come to agreements so that mutually beneficial investments in ITCI are made.

Table 1 - Summary Statistics - Total Variation

Variable	Observations	Mean	Std. Dev.	Min	Max
Primacy	1044	28.71	14.44	2.52	76.16
Urbanization	1494	49.41	23.67	3.10	100.00
Rail density	645	0.62	1.54	0.00	25.00
Road density	395	0.03	0.03	0.00	0.12
Fixed telephone lines	1254	13.57	17.04	0.00	89.20
GDP per capita	1415	9.96	11.68	0.29	82.75
Manufacturing & services share of GDP	946	82.17	15.05	24.68	99.57
Government	1205	59.37	16.26	3.55	99.85
Openness	1205	70.10	43.47	1.97	293.95
Waterway density	688	0.02	0.03	0.00	0.18
Land area	1291	1798308	4836967	2	27400000

Table 2 - Summary Statistics - Cross Country Variation

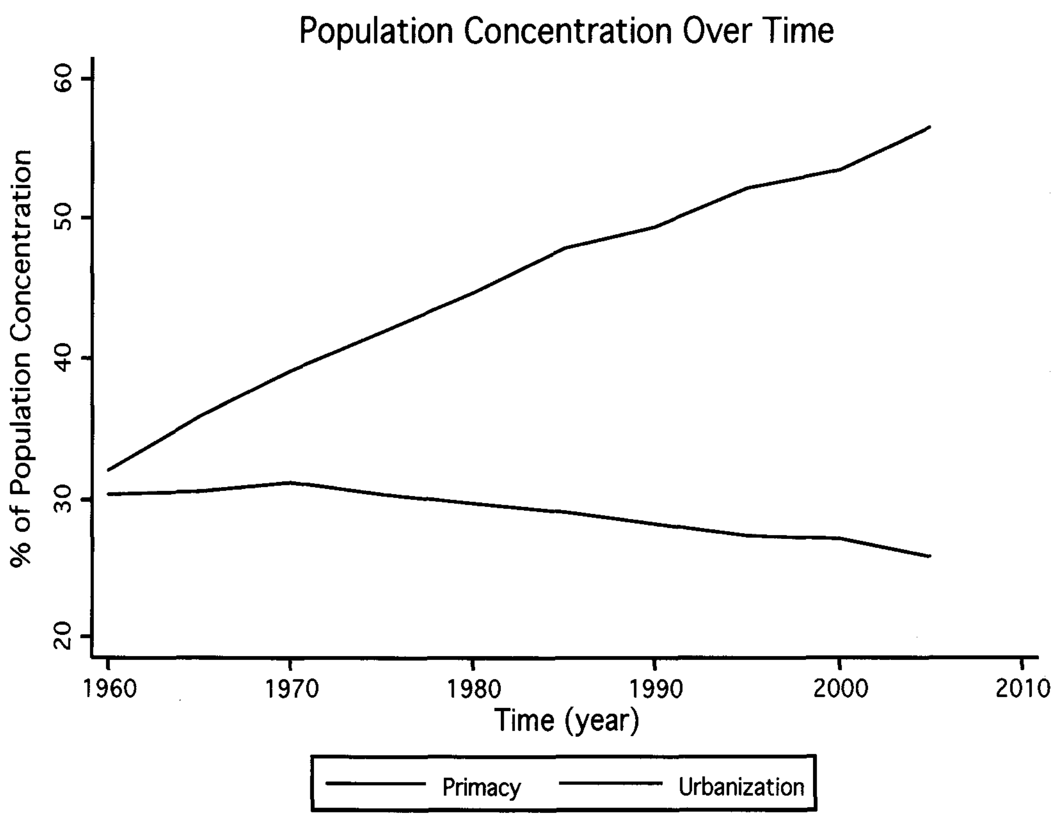
Variable	Observations	Mean	Std. Dev.	Min	Max
Primacy	1144	28.64	13.85	3.47	61.98
Urbanization	1643	50.14	22.07	8.25	100.00
Rail density	1017	0.03	0.03	0.00	0.12
Road density	1534	0.72	2.16	0.01	25.27
Fixed telephone lines	1654	16.01	16.20	0.07	62.66
GDP per capita	1717	102.22	110.57	6.27	603.92
Manufacturing & services share of GDP	1539	82.94	13.12	34.88	99.01
Government	1549	58.95	14.38	10.01	88.61
Openness	1549	73.78	37.54	4.28	207.74
Waterway density	957	0.02	0.03	0.00	0.18
Land area	1735	1625596	4555919	2	27300000

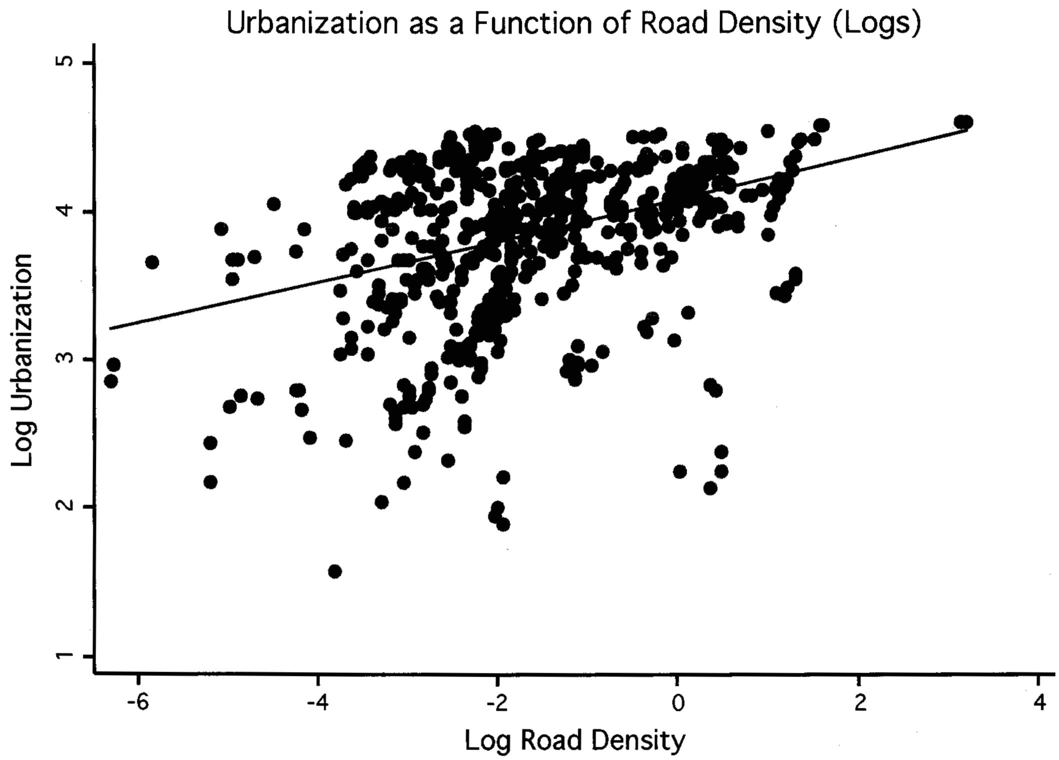
Table 3 - Summary Statistics - Time Variation

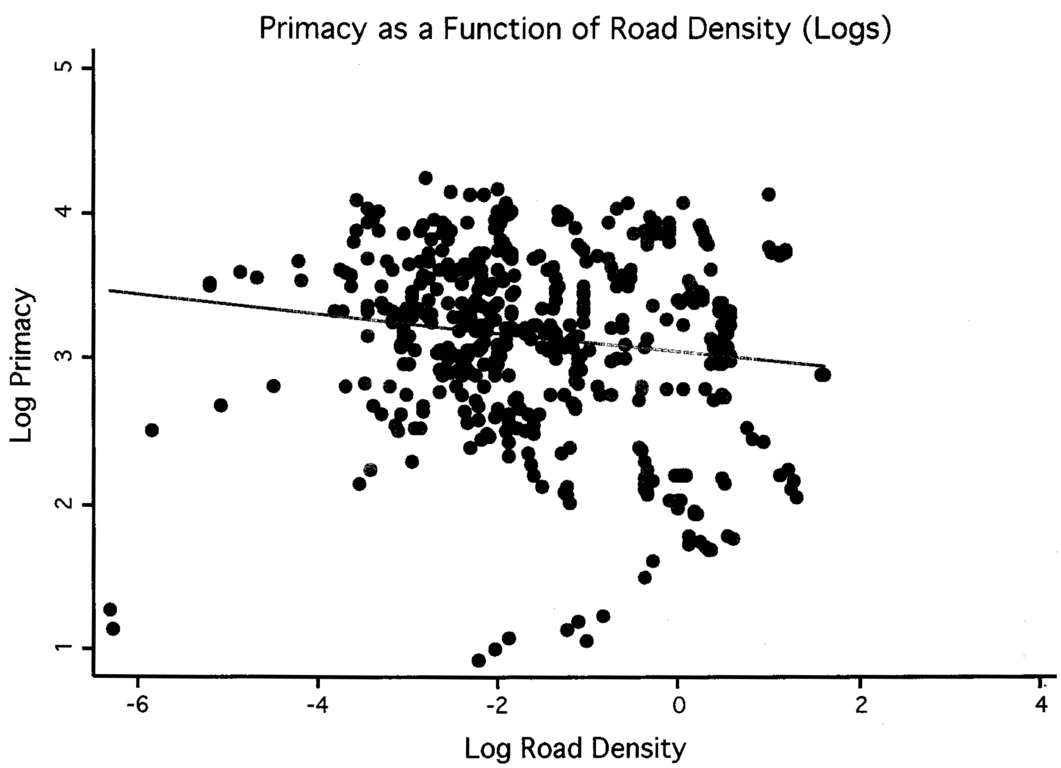
Variable	Observations	Mean	Std. Dev.	Min	Max
Primacy	1749	31.48	0.92	30.04	32.67
Urbanization	1749	46.13	6.53	34.76	54.99
Rail density	1048	0.02	0.00	0.02	0.03
Road density	1575	0.59	0.22	0.33	0.98
Fixed telephone lines	1749	10.66	5.73	3.51	19.72
GDP per capita	1749	86.00	20.90	47.45	119.72
Manufacturing & services share of GDP	1757	77.16	6.90	62.86	85.55
Government	1749	65.98	3.09	62.70	71.99
Openness	1749	73.44	12.00	54.62	96.24

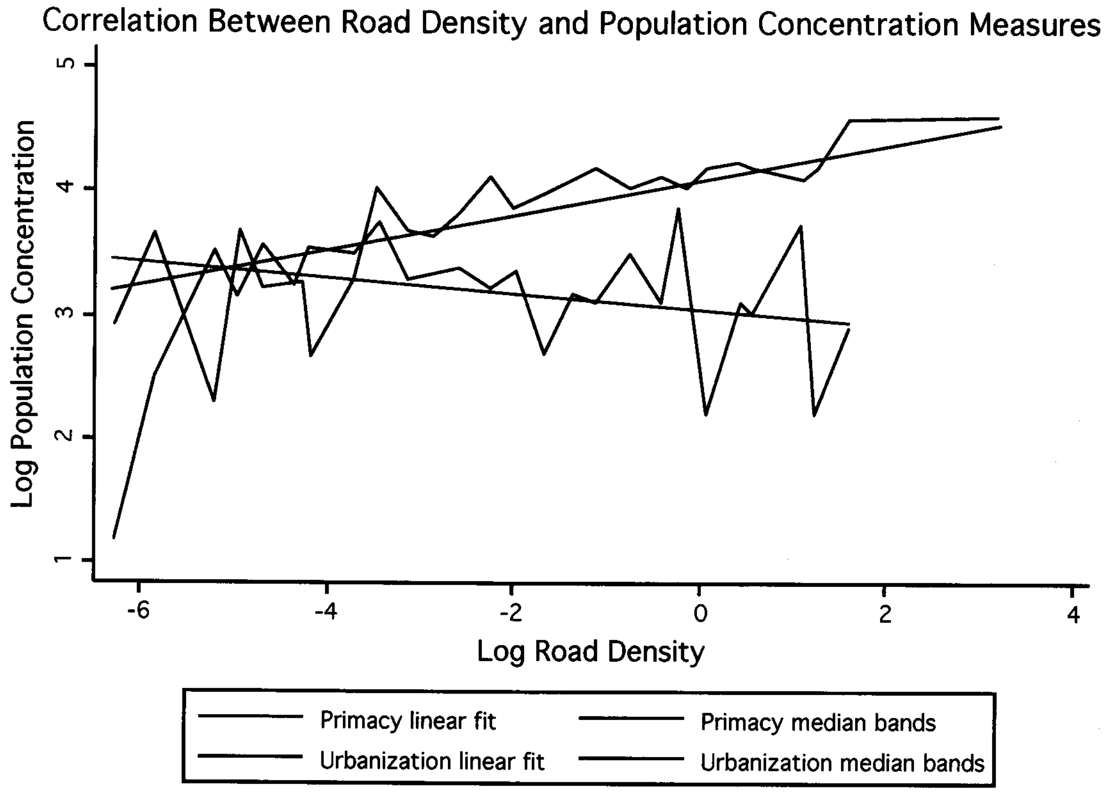
Table 4 - Total Variation (Logs)

Variable	Observations	Mean	Std. Dev.	Min	Max
Log primacy	1044	3.21	0.60	0.92	4.33
Log urban concentration	1494	3.74	0.63	1.13	4.61
Log road density	645	-1.51	1.46	-6.30	3.22
Log rail density	395	-4.42	1.39	-8.18	-2.09
Log fixed telephone lines	1253	1.46	1.86	-4.02	4.49
Log GDPpc	1415	4.00	1.14	1.07	6.72
Log manufacturing & services share	946	4.39	0.22	3.21	4.60
Log government	1205	4.03	0.36	1.27	4.60
Log openness	1205	4.03	0.73	0.68	5.68
Log waterways	688	-5.09	1.40	-9.98	-1.69
Log land area	1291	11.72	3.02	0.69	17.13




Urbanization as a Function of Road Density (Logs)
Log Urbanization
Log Road Density
1
2
3
4
5
-6
-4
-2
0
2
4


Primacy as a Function of Road Density (Logs)
Log Primacy
Log Road Density
1
2
3
4
5
-6
-4
-2
0
2
4



Correlation Between Road Density and Population Concentration Measures
Log Population Concentration
1
2
3
4
5
-6
-4
-2
0
2
4
Log Road Density
Primacy linear fit
Primacy median bands
Urbanization linear fit
Urbanization median bands

Table 5 - Pairwise Correlations

	Log road density	Log rail density	Log FTL	Log GDPpc	Log government	Log openness	Log waterways	Log land area
Log road density	1							
Log rail density	0.8263	1						
Log FTL	0.6288	0.5764	1					
Log GDPpc	0.5514	0.5106	0.8698	1				
Log government	0.044	-0.1428	-0.226	-0.4143	1			
Log openness	-0.0157	0.0576	0.1817	0.1724	-0.2381	1		
Log waterways	0.2397	0.2653	0.142	0.1613	-0.1172	0.1223	1	
Log land area	-0.5111	-0.5762	-0.2489	-0.2508	0.0795	-0.4646	-0.332	1

Table 6 - Main Results - Adjusted Coefficients

Variable	Log primacy	Log urbanization
Log road density (t-1)	-12.728	15.333
	(1.890)	(3.56)**
Log manufacturing & services GDP share	7.738	40.939
	(1.310)	(9.33)**
Log share of central government consumption (t-1)	-2.882	5.130
	(0.660)	(1.800)
Log openness (t-1)	-3.296	1.622
	(1.110)	(0.680)
Log waterway density	-26.388	3.131
	(2.47)*	(0.630)
Log land area	-79.077	19.726
	(3.28)**	(2.18)*
Capital city dummy variable (1 if largest city is the capital)	36.271	27.414
	(1.340)	(2.30)*
Log national urban population	-43.724	
	(5.85)**	
R-squared	0.28	0.59
Observations	310	351
Number of group (country)	64	81

Notes: Absolute value of z statistics in parentheses

* Significant at 5%; ** significant at 1%

Table 7 - Robustness Check 1 - Adjusted Coefficients

Variable	Log secondary urban areas	Log largest city population share
Log road density (t-1)	25.624	-9.586
	(5.84)**	(1.890)
Log manufacturing & services GDP share	33.488	5.828
	(8.05)**	(1.310)
Log share of central government consumption (t-1)	2.894	-2.171
	(0.880)	(0.660)
Log openness (t-1)	2.023	-2.483
	(0.920)	(1.110)
Log waterway density	8.162	-19.874
	(1.740)	(2.47)*
Log land area	49.247	-59.555
	(4.54)**	(3.28)**
Capital city dummy variable (1 if largest city is the capital)	8.094	27.317
	(0.690)	(1.340)
		46.419
		(8.26)**
R-squared	0.64	0.41
Observations	310	310
Number of group (country)	64	64

Notes: Absolute value of z statistics in parentheses

* Significant at 5%; ** significant at 1%

Table 8 – Robustness Check 2- Adjusted Coefficients

Variable	Log primacy	Log urbanization	Log secondary urban areas	Log largest city population share
Log rail density (t-1)	-28.380	9.273	8.935	-21.373
	(2.95)**	(1.740)	(1.680)	(2.95)**
Log manufacturing & services GDP share	-7.627	13.564	17.121	-5.744
	(1.780)	(4.84)**	(5.57)**	(1.780)
Log share of central government consumption (t-1)	7.326	-5.130	-15.015	5.518
	(1.450)	(1.700)	(4.07)**	(1.450)
Log openness (t-1)	4.029	5.331	4.505	3.034
	(1.520)	(2.56)*	(2.32)*	(1.520)
Log waterway density	-30.629	1.342	6.033	-23.068
	(2.49)*	(0.220)	(1.110)	(2.49)*
Log land area	-98.847	28.386	27.105	-74.444
	(3.42)**	(2.17)*	(1.99)*	(3.42)**
Capital city dummy variable (1 if largest city is the capital)	69.856	36.817	-3.035	52.610
	(2.25)*	(2.53)*	(0.220)	(2.25)*
Log national urban population	-73.013			24.360
	(6.82)**			(3.02)**
R-squared	0.29	0.30	0.45	0.27
Observations	205	229	205	310
Number of group (country)	53	61	53	64

Notes: Absolute value of z statistics in parentheses

* significant at 5%; ** significant at 1%

Table 9 - Robustness Check 3 - Adjusted Coefficients

Variable	Log primacy	Log urbanization	Log secondary urban areas	Log largest city population share
Log fixed telephone lines (t-1)	-23.440	36.190	34.600	12.004
	(6.58)**	(15.37)**	(14.63)**	(3.84)**
Log manufacturing & services GDP share	-5.443	19.995	21.359	12.269
	(1.590)	(8.19)**	(8.79)**	(4.05)**
Log share of central government consumption (t-1)	-7.687	0.627	1.538	-4.070
	(2.45)*	(0.37)	(0.69)	(1.48)
Log openness (t-1)	5.616	-4.751	-4.505	-0.276
	(2.10)*	(2.81)**	(2.54)*	(0.11)
Log waterway density	-30.394	5.367	12.244	-18.277
	(2.72)**	(1.27)	(3.06)**	(1.91)
Log land area	-76.036	10.585	27.869	-47.720
	(3.10)**	(1.45)	(3.14)**	(2.28)*
Capital city dummy variable (1 if largest city is the capital)	40.973	11.475	-9.864	36.296
	(1.480)	(1.120)	(0.980)	(1.530)
R-squared	0.27	0.74	0.78	0.24
Observations	430	510	430	430
Number of group (country)	67	84	67	67

Notes: Absolute value of z statistics in parentheses

* Significant at 5%; ** significant at 1%

Table 10 - Main Results - Raw Coefficients

Variable	Log primacy	Log urbanization
Log road density (t-1)	-0.052	0.066
	(1.89)	(3.56)**
Log manufacturing & services GDP share	0.209	1.165
	(1.31)	(9.33)**
Log share of central government consumption (t-1)	-0.048	0.09
	(0.66)	(1.80)
Log openness (t-1)	-0.027	0.014
	(1.11)	(0.68)
Log waterway density	-0.112	0.014
	(2.47)*	(0.63)
Log land area	-0.156	0.041
	(3.28)**	(2.18)*
Capital city dummy variable (1 if largest city is the capital)	0.216	0.172
	(1.34)	(2.30)*
Log national urban population	-0.415	
	(5.85)**	
Constant	5.364	-2.095
	(5.60)**	(3.32)**
R-squared	0.28	0.59
Observations	310	351
Number of group (country)	64	81

Notes: Absolute value of z statistics in parentheses

* significant at 5%; ** significant at 1%

Table 11 - Robustness Check 1 - Raw Coefficients

Variable	Log secondary urban areas	Log largest city population share
Log road density (t-1)	0.139	-0.052
	(5.84)**	(1.89)
Log manufacturing & services GDP share	1.201	0.209
	(8.05)**	(1.31)
Log share of central government consumption (t-1)	0.064	-0.048
	(0.88)	(0.66)
Log openness (t-1)	0.022	-0.027
	(0.92)	(1.11)
Log waterway density	0.046	-0.112
	(1.74)	(2.47)*
Log land area	0.129	-0.156
	(4.54)**	(3.28)**
Capital city dummy variable (1 if largest city is the capital)	0.064	0.216
	(0.69)	(1.34)
Constant	-3.297	0.585
	(4.05)**	(8.26)**
		0.76
		(0.79)
R-squared	0.64	0.41
Observations	310	310
Number of group (country)	64	64

Notes: Absolute value of z statistics in parentheses

* significant at 5%; ** significant at 1%

Table 12 – Robustness Check 2 - Raw Coefficients

Variable	Log primacy	Log urbanization	Log secondary urban areas	Log largest city population share
Log rail density (t-1)	-0.122	0.042	0.051	-0.122
	(2.95)**	(1.74)	(1.68)	(2.95)**
Log manufacturing & services GDP share	-0.206	0.386	0.614	-0.206
	(1.78)	(4.84)**	(5.57)**	(1.78)
Log share of central government consumption (t-1)	0.122	-0.09	-0.332	0.122
	(1.45)	(1.70)	(4.07)**	(1.45)
Log openness (t-1)	0.033	0.046	0.049	0.033
	(1.52)	(2.56)*	(2.32)*	(1.52)
Log waterway density	-0.13	0.006	0.034	-0.13
	(2.49)*	(0.22)	(1.11)	(2.49)*
Log land area	-0.195	0.059	0.071	-0.195
	(3.42)**	(2.17)*	(1.99)*	(3.42)**
Capital city dummy variable (1 if largest city is the capital)	0.416	0.231	-0.024	0.416
	(2.25)*	(2.53)*	(0.22)	(2.25)*
Log national urban population	-0.693			0.307
	(6.82)**			(3.02)**
Constant	7.19	1.805	1.697	2.585
	(6.89)**	(3.34)**	(2.16)*	(2.48)*
R-squared	0.29	0.30	0.45	0.27
Observations	205	229	205	205
Number of group (country)	53	61	53	53

Notes: Absolute value of z statistics in parentheses

* significant at 5%; ** significant at 1%

Table 13 – Robustness Check 3 - Raw Coefficients

Variable	Log primacy	Log urbanization	Log secondary urban areas	Log largest city population share
Log fixed telephone lines (t-1)	-0.075	0.122	0.147	0.051
	(6.58)**	(15.37)**	(14.63)**	(3.84)**
Log manufacturing & services GDP share	-0.147	0.569	0.766	0.44
	(1.59)	(8.19)**	(8.79)**	(4.05)**
Log share of central government consumption (t-1)	-0.128	0.011	0.034	-0.09
	(2.45)*	(0.37)	(0.69)	(1.48)
Log openness (t-1)	0.046	-0.041	-0.049	-0.003
	(2.10)*	(2.81)**	(2.54)*	(0.11)
Log waterway density	-0.129	0.024	0.069	-0.103
	(2.72)**	(1.27)	(3.06)**	(1.91)
Log land area	-0.15	0.022	0.073	-0.125
	(3.10)**	(1.45)	(3.14)**	(2.28)*
Capital city dummy variable (1 if largest city is the capital)	0.244	0.072	-0.078	0.287
	(1.48)	(1.12)	(0.98)	(1.53)
Constant	5.346	1.143	-0.46	1.74
	(6.47)**	(2.91)**	(0.82)	(1.83)
R-squared	0.27	0.74	0.78	0.24
Observations	430	510	430	430
Number of group (country)	67	84	67	67

Notes: Absolute value of z statistics in parentheses

* significant at 5%; ** significant at 1%

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