Measurement of Accessibility and Its Applications*

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Abstract
Access to markets and social services is a major determinant of economic status and welfare. Measurement of access is therefore of great importance for policy analysis and planning of interventions. The objective of this article is to expose readers to a new way of measuring and visualising accessibility—a potential accessibility index—and its applications. This index gauges connectivity of a specific location to large cities while taking into account the population of the cities or other destinations of interest and the transportation facilities to reach them. The potential accessibility index is used in the empirical literature to test the hypotheses from the 'New Economic Geography' regarding the impact of market access on regional economic growth. Along with recent developments in poverty mapping, this index has also been used to investigate the spatial relationship between poverty and market access. Accessibility indexes are gradually gaining acknowledgement of policy makers and development practitioners as important monitoring instruments of development. For example, a rural access indicator is part of the results measurement system for the World Bank's International Development Association (IDA) programmes.

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1. Introduction

Improved access to social services, infrastructure and markets is an important element of rural development and poverty alleviation. Poor access, especially in rural areas is associated with a range of development problems—children face difficulties in reaching educational facilities; residents have severe problems

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in getting to health facilities for both emergency and non-acute treatment; farmers have less incentive to exploit the full agro-ecological potential of remote farming areas due to problems in reaching markets; or they face low farm gate prices offered by traders. From a policy analysis perspective, it then becomes important to devise ways of measuring access—across space and over time. New ways of collecting and analysing geographically explicit data have also given rise to new ways of measuring and visualising accessibility. The objective of this article is to promote the use of accessibility indexes that summarise the connectivity of a specific location to large cities and towns—an indicator of potential accessibility to urban centres.

The potential accessibility index is constructed based on the assumption that the benefit of access to an urban centre increases with the population size of the centre, and declines with distance, travel time or cost. Improvements in geographic information systems (GIS) have opened up new ways to measure accessibility. A typical way to assess accessibility has traditionally been to conduct a household survey and ask each household (typically the household head) in the sample how far urban centres are from the household. This is, for instance, the approach taken in measuring the Rural Access Indicator, which is defined as the proportion of the population in a given geographic area that lives further than 2 km from an all-weather road. This measurement assumes that the respondent is able to judge distances precisely and, for more complex concepts of accessibility, that they know all urban centres with travel time to reach them. However, as field experiments have shown, this is not always the case (Roberts et al. 2006; see also BITS 2004 and Sarkar and Dash 2007 for studies in the Indian context). A household head might not even know the travel time to reach the closest city simply because he or she rarely has to go there.

An alternative approach is to measure accessibility directly from geo-referenced databases. In many developing countries, an increasing number of road networks and locations of cities and villages are digitised and referenced according to the location code system (or simply, 'geo-referenced'; see also Gibson and McKenzie 2008). Using these databases, a standard commercial GIS packages (like ArcGIS) can easily calculate the shortest route between an origin site and a destination such as a large city or the closest major road. Estimates of feasible travel speed, taking into account the road conditions, can then convert distances into estimates of travel time.

The latter approach based on GIS databases is more objective than the traditional approach in that it leaves little room for subjective judgement. Another attractive feature of this approach is related to how the results are shown. A table with 10,000 villages' access indicators is almost incomprehensible. Instead, the GIS-based accessibility index is presented in a map that identifies geographical patterns of villages suffering from lack of access to infrastructure.

Potential accessibility indexes are becoming increasingly popular in the empirical literature that tests the impact of market access to regional economic growth and poverty reduction. For example, potential accessibility indexes have been used to test hypotheses from 'New Economic Geography' on externalities from urban agglomeration, such as whether access to urban agglomeration helps local firms improve their productivity. Also, along with recent developments in poverty mapping, the indexes are used to examine the spatial relationship between poverty and market access.

This article is organised as follows. Section 2 will review the literature on the concept of accessibility and applications of potential accessibility indexes. Section 3 will describe the definition of a potential accessibility index and illustrate the mechanics of how to construct the index. Section 4 will introduce results from some applications of the accessibility index. Section 5 will conclude with a discussion of potential uses of the maps and some caveats.

2. Literature Review

2.1 Concept of accessibility

Accessibility, in the context of this article, is a general term used to describe the ease by which a target location can be reached by a specific group of people. Distance is an important component for determining accessibility, but it 'clearly involves much more than geometry' (Johnston 1986). Goodall (1987) states that the concept 'summarizes relative opportunities for contact and interaction', and Geertman and van Eck (1995) argue that the concept of accessibility should be used as 'an indicator of rural deprivation'. Following Deichmann (1997), we summarise the concept as follows—Accessibility can be defined as the ability for interaction or contact with sites of economic or social opportunity. Such target sites could be public services, employment opportunities, or markets. Spatial accessibility is determined by geographic location in relation to target locations, and by the transportation facilities that are available to reach those destinations.

More specific definitions and measures of accessibility can be defined depending on the objective of analysis. Some might want to see the accessibility from the supply side, for example, how many households one health facility can cover. Others want to see it from the demand side, for example, how far is a health facility from a village or a household. Also, some care about the distance to a closest target site only, while others care about the sum of a size attribute at all target locations within a specified distance—for instance, how many students live in villages that are less than 5 km from a school. How to measure distance is an important factor defining the accessibility index. The distance to a facility can be measured by a straight line between the origin and the destination or as the travel time along the existing transport network. Needless to say, the selection of target sites is also a critical factor in defining an accessibility index.

This article showcases a specific indicator, often called a *potential accessibility index* (sometimes simply called market potential), that measures accessibility to major cities and towns from an origin. This index calculates total population—or another size attribute such as total purchasing power or output—in a number of cities and towns within a given threshold distance, inversely weighted by travel time from the origin. The travel time is projected based on detailed transport network data.

The concept of the potential accessibility index is related to standard models in the international trade literature (for example, Evenett and Keller 2002). In a classic gravity model, which has been commonly used in the analysis of trade flows between regions and countries, the interaction between two places is proportional to the size of the two places as measured by population, employment or some other index of social or economic activity, and inversely proportional to some measure of separation such as distance. The closer two countries are and the larger they are, the more trade is expected to flow between them. Similarly, the closer a farmer, for instance, is to a larger market centre or to several medium sized centres, the greater the opportunities for trade and commerce.

The potential accessibility index, when computed using a geographically explicit model of the transport network, has a clear advantage over a simpler distance measure like the straight-line distance, which was often used in studies related to agglomeration economies and economic geography (for example, Hanson 1998). The straight-line distance is misleading since the time and effort required to move between two locations with the same distance are assumed to be identical, which is unrealistic in many developing countries with topography and sparse transport networks of uneven quality. Feasible travel speed and

thus travel times will vary depending on each type of network link. For example, a place located near a national highway will be more accessible than one on a rural, secondary road.

2.2 Potential accessibility and 'New Economic Geography'

Market access is critical for rural development and poverty alleviation. The literature on 'New Economic Geography' provides theoretical backgrounds of the linkage (for example, Henderson et al. 2001; Krugman 1999). For example, a large city often contains both large markets and industry hubs. Proximity to the large city therefore tends to reduce transportation and/or search costs of selling final products and acquiring intermediate goods. In addition, a thick labour market helps workers find employers, and vice versa. Furthermore a local concentration of economic activities may facilitate information spillovers. As a result, improving accessibility to large cities or markets allows rural communities to take advantage of economic and employment opportunities.

The same literature suggests that urban agglomeration does not necessarily provide positive externalities and as a result, proximity to a large city can turn into a disadvantage. Once the city size outgrows management capacity, congestion and high input prices like those of land trigger negative impact on local and neighbouring economies.

In summary, although a potential accessibility index is often treated or interpreted as a measure of access to economic opportunities, whether proximity to large cities is an advantage in economic development is an empirical question. In fact, many empirical studies explore the relationship between market access, and social and economic development. Some of the results will be illustrated in Section 4.

2.3 Potential accessibility and poverty mapping

Accessibility indexes have a close conceptual and substantive relationship with poverty maps. Bigman and Deichmann (2000) illustrate how the standard FGT measures of poverty can be applied to the measurement of accessibility. Lack of access is then seen as a measure of deprivation, where the 'access gap', for instance, is the distance from an acceptable level of accessibility. Substantively, lack of access is often highly correlated with poverty. Where poverty is predominantly a result of isolation from markets and employment opportunities, it is not surprising to see a close correlation. The comparison might help local and central governments identify what areas should be prioritised in terms of public investment for transportation infrastructure.

Recent developments in poverty mapping enabled us to examine the relationship between accessibility and poverty. Poverty mapping is an exercise to estimate poverty incidence at the level of disaggregation where typical household income and expenditure surveys cannot produce statistically reliable poverty estimates. There are many different methodologies, but a small area estimation method (developed by Elbers et al. 2003) is gaining increasing support from policy makers and development practitioners. This methodology aims to produce a poverty map by taking advantage of strengths of both population census, and a household income and economic survey. The latter includes income and expenditure data but its limited sample size prevents one from estimating poverty incidence at the sub-state or sub-province levels. On the other hand, a population census does not have a problem of sampling error but usually does not have income or expenditure data. The small area estimation method prepares a consumption model from a household survey and applies the model to impute statistically reliable

income or expenditure data for all census households, which are then used to estimate poverty and inequality statistics at the sub-state or sub-province levels. The imputation process is fairly complex, particularly due to the large size of population census data. The World Bank has recently developed new software, PovMap2, to reduce the computational burden. PovMap2 is free and downloadable at http://iresearch.worldbank.org/PovMap/index.htm. Finely disaggregated potential accessibility index and poverty estimates give enough variation to identify the spatial relationship between market access and poverty incidence. An example from Sri Lanka poverty mapping will be presented in Section 4.

A final remark is that the potential accessibility index is not just useful to examine the spatial relationship between poverty and market access, but can be used to improve statistical accuracy of poverty maps. As discussed earlier, the accuracy of poverty maps relies on how well the consumption model can predict the actual income or expenditure. Since potential accessibility indexes are often closely correlated with poverty, including them in the consumption model can improve its prediction and the accuracy of the resulting poverty maps. The drawback of this approach is that one then needs to be careful in using the accessibility index in subsequent analysis of the determinants of poverty, since it has already been employed to predict small area poverty rates.

3. Brief Description of How to Construct the Index

The simplest formula for a potential accessibility index (I_i) is

$$I_i = \sum_j \frac{S_j}{T_{ij}^{\alpha}}$$

where, S_j is a size indicator at target j (for example, population of large cities/towns), and T_{ij} is the distance (or travel time) between origin i and target j.[1] By varying α, the functional form of the impact of travel time on the potential accessibility can be changed. A high α implies that the influence of nearby cities diminishes very quickly, while a low α means that even cities and towns far away exert an influence on a location. This is similar to the distance exponent in the gravity trade model discussed earlier.

GIS plays a key role in constructing potential accessibility indices. For example, to estimate the travel time from the origin to a target city or town, GIS software needs to locate the target site, assess all possible routes between the site and the origin, and search for a route with the shortest travel time taking into account road conditions. Consideration of travel time is particularly important if the road network consists of many different types of roads. For example, travelling along a concrete road is faster than travelling along a mud track. If a longer route has better roads as a whole than the shortest route, travel time of the longer route can be less than that of the shortest route, and can be used for calculating the potential accessibility index. The more detailed a road network database, the more accurate the estimate of travel time, which improves the quality of the accessibility index. But at the same time, the computational burden rises dramatically.

Some programmes are available to estimate accessibility indicators. Deichmann (1997) adds a detailed description of a utility programme 'Access', which can be run under Unix or on a PC running Windows. Farrow and Nelson (2001) prepared a set of tools for the Environmental Systems Research Institute, Inc. (ESRI) ArcView software to construct a potential accessibility index. Several commercial GIS

packages also provide functions for network analysis. These programmes help overcome the computational burden.

Creating a road network database may be the most time-consuming manual work if it does not already exist. This involves tracing of roads from a paper map, such as a topographical base map. Digitising national or state highways is usually easier since the number of these roads is limited, while digitising local or village roads is often a challenging task. However, the latter exercise is critical to improve accuracy of travel time estimation. Fortunately, standard digital road maps are now available in many countries. These are often created by capturing streaming coordinate data from a global positioning system receiver that is mounted in a car or other vehicle.

An example of the creation of an accessibility map is described in World Bank (2005), where potential accessibility to 185 major cities and towns in Sri Lanka was estimated. An island-wide road network data set distinguishes between two levels of roads (see Figure 1). With this road network and locations of the target cities and towns, the travel time from each location in Sri Lanka to all target cities and towns was estimated. From this information, the average accessibility index at the Divisional Secretary (DS) level was computed. The results are shown in Figure 2. Since the index has no meaningful unit (it is a sum of population weighted by travel time), it is simply presented as a scale from low to high. The accessibility is very high in Colombo city and its neighbourhood. Also, even though some areas are relatively far away from Colombo City, the estimated potential accessibility is high because these areas are connected by main roads.

The World Bank has recently also produced a map of potential accessibility for West Bengal. The road network database includes far more detailed information. For example, it includes four different levels of roads from state highways to village roads. Using the road network database, the potential accessibility to 125 municipalities (which are comprised of large cities) is calculated for all villages and then aggregated to the Tehsil (or block) level (see Figure 3). Note that a darker colour in this map corresponds to a lower value of the accessibility index. The accessibility index is very high in Kolkata city and its neighbourhood. It also suggests that there are some urban centres in the east and the north. On the other hand, the coastal areas (in the south) and most of Purulia district (in the east) appear to be least connected to large cities and towns.

4. Caveats

Although a potential accessibility index restricts subjective judgement by relying on GIS databases, data problems can have an impact on the results. For example, suppose a village is not directly connected by any road included in the road network database. This does not mean there is no road in the village. Certainly, there should be multiple roads in the village, but they are not recorded in the road network database. In this case, an analyst needs to make assumptions on how long it takes to reach the closest road in the network database. Also, the average speed for each level of roads is often determined without careful assessments. Engineering designed speed provides a guideline. But in reality, the average speed is difficult to estimate since many factors like weather, festivals and accidents can affect the traffic. Therefore, it is important to check the robustness of the results to slight changes in parameters, like average speed and adjustments for missing information in the road network database.

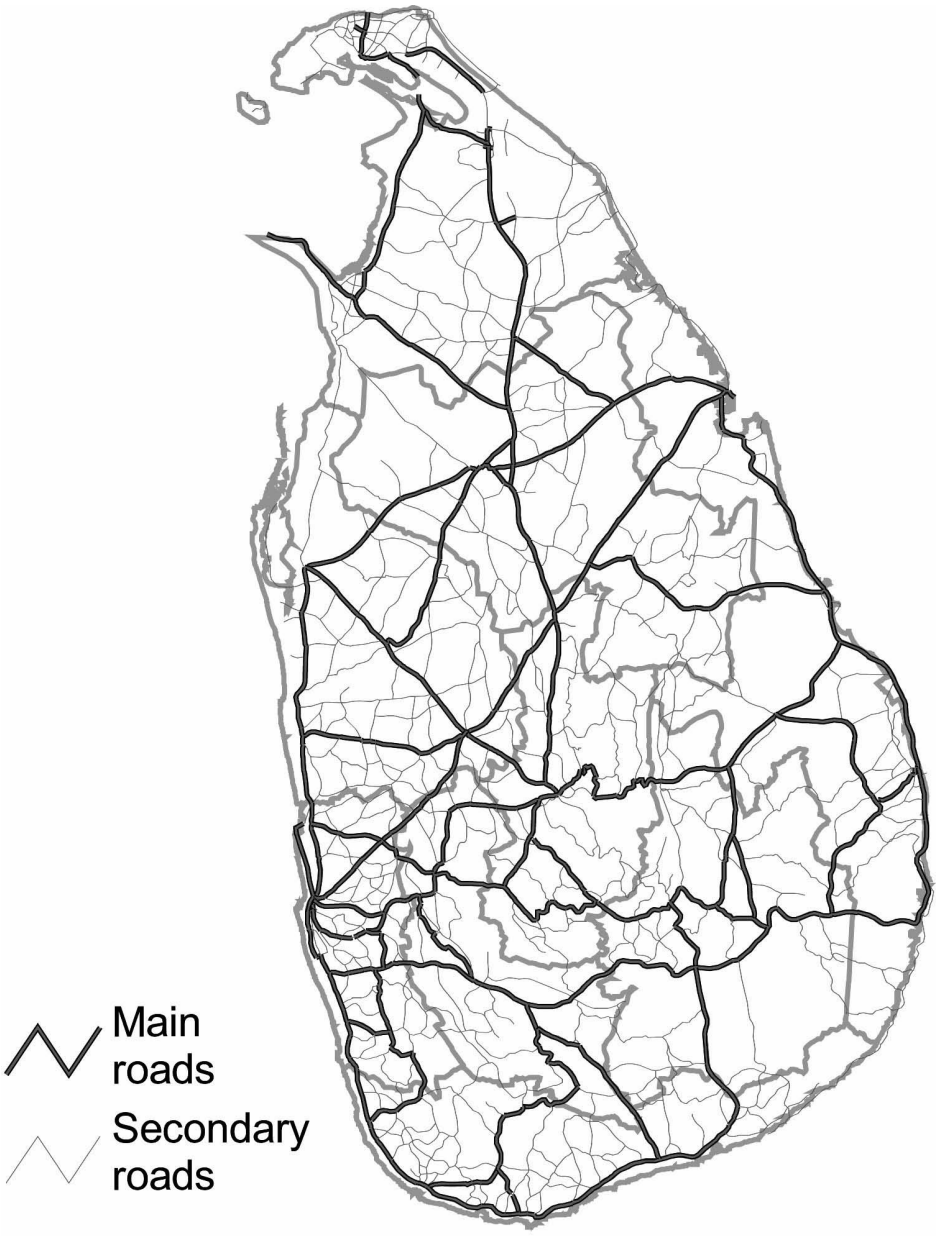

Figure 1. A Road Network in Sri Lanka
Source: ISCGM (2005).

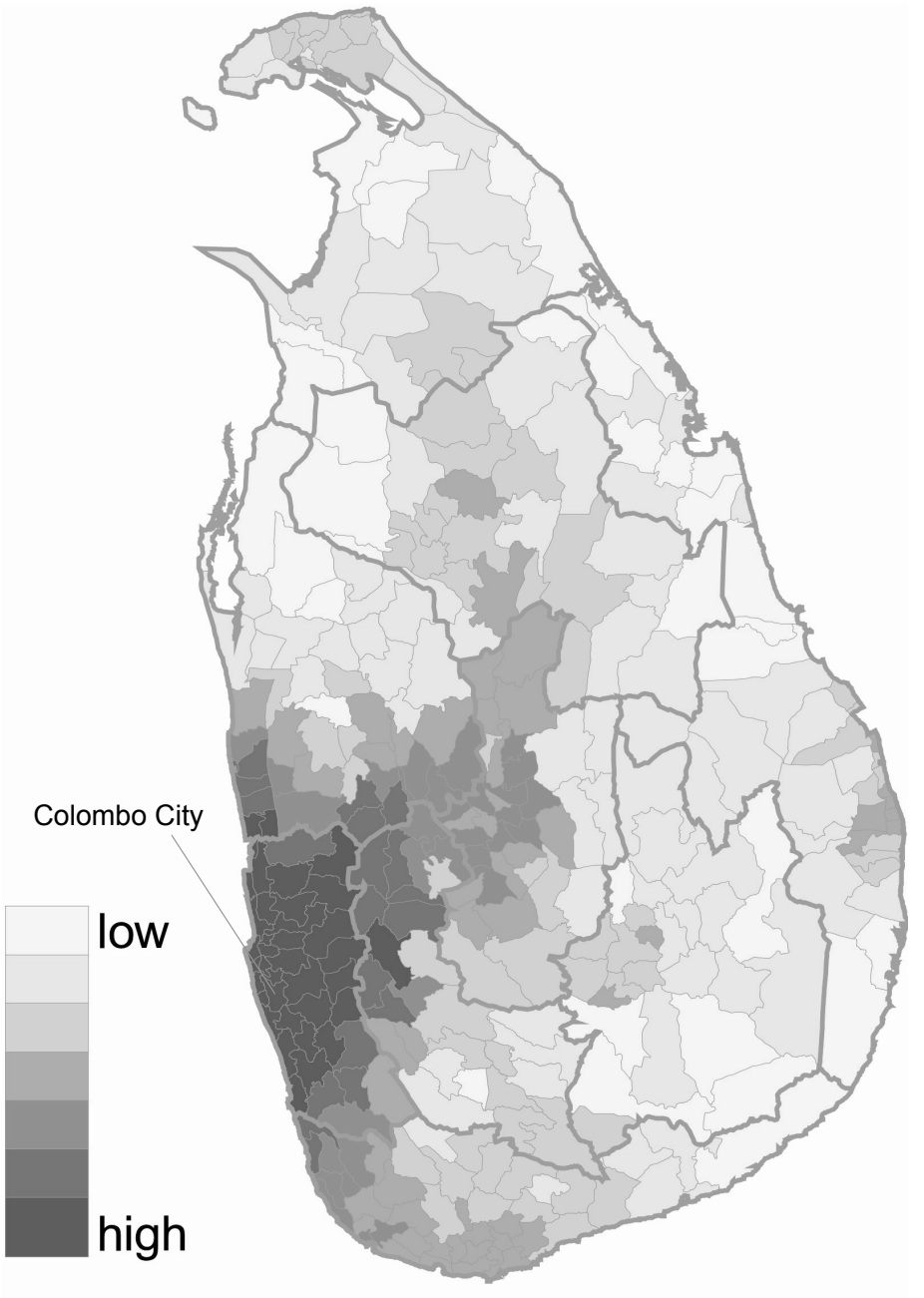

Figure 2. A Map of Potential Accessibility in Sri Lanka
Source: World Bank (2005).

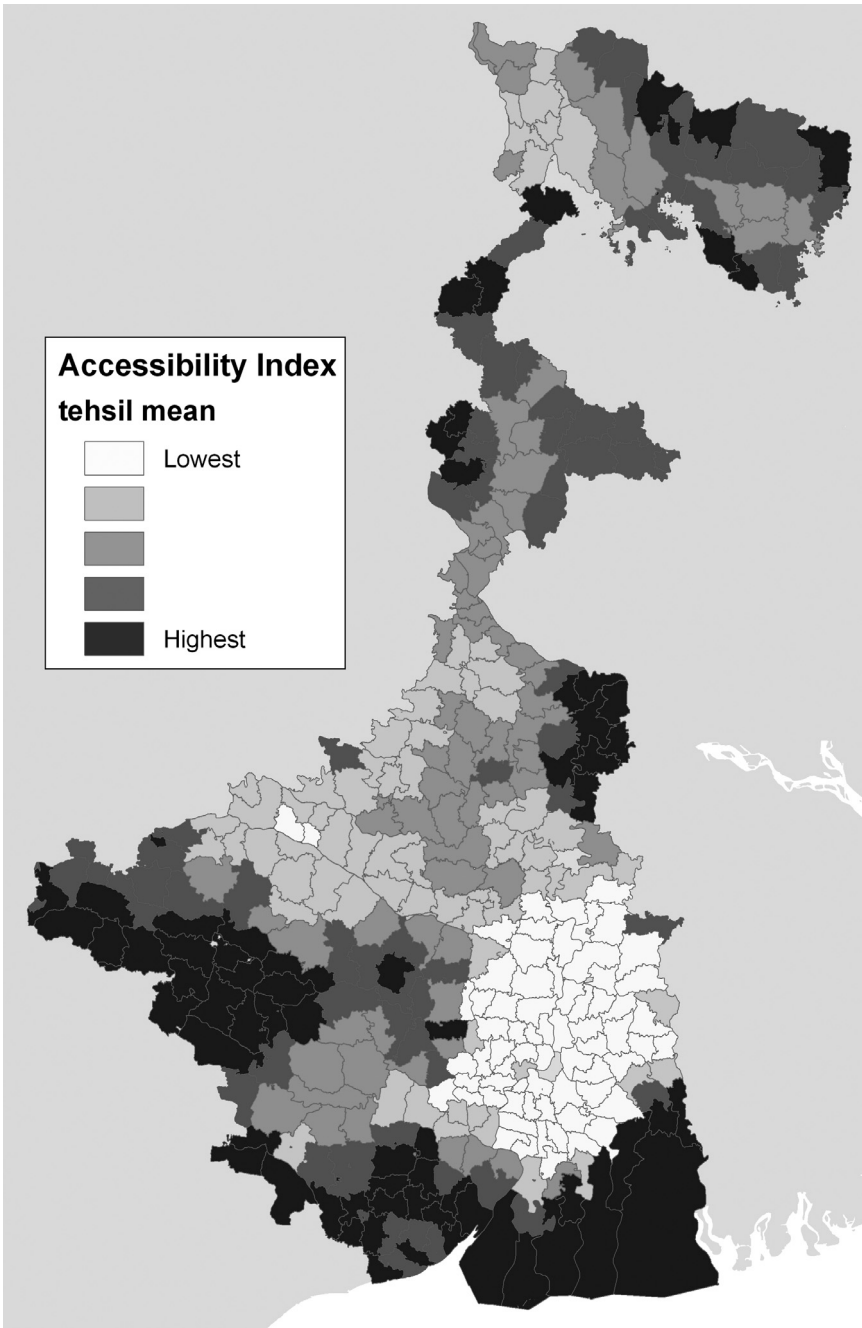

Figure 3. A Map of Potential Accessibility Index for West Bengal
Source: World Bank staff estimation based on Survey of India village boundary map for West Bengal.

5. Applications of the Potential Accessibility Index

This section illustrates some interesting applications of the potential accessibility data, in terms of:

1. analysis of economic reliance on a dominant city,
2. studies of the impact of market access to productivity of local firms and
3. a study of the spatial relationship between market access and poverty.

5.1. Economic reliance on a dominant city

The comparison between the potential accessibility index and the distance to a dominant city is sometimes useful to visualise the degree of economic reliance on a dominant city. Figures 4a and 4b illustrate this by using a potential accessibility map and a map of the distance to Kolkata city.

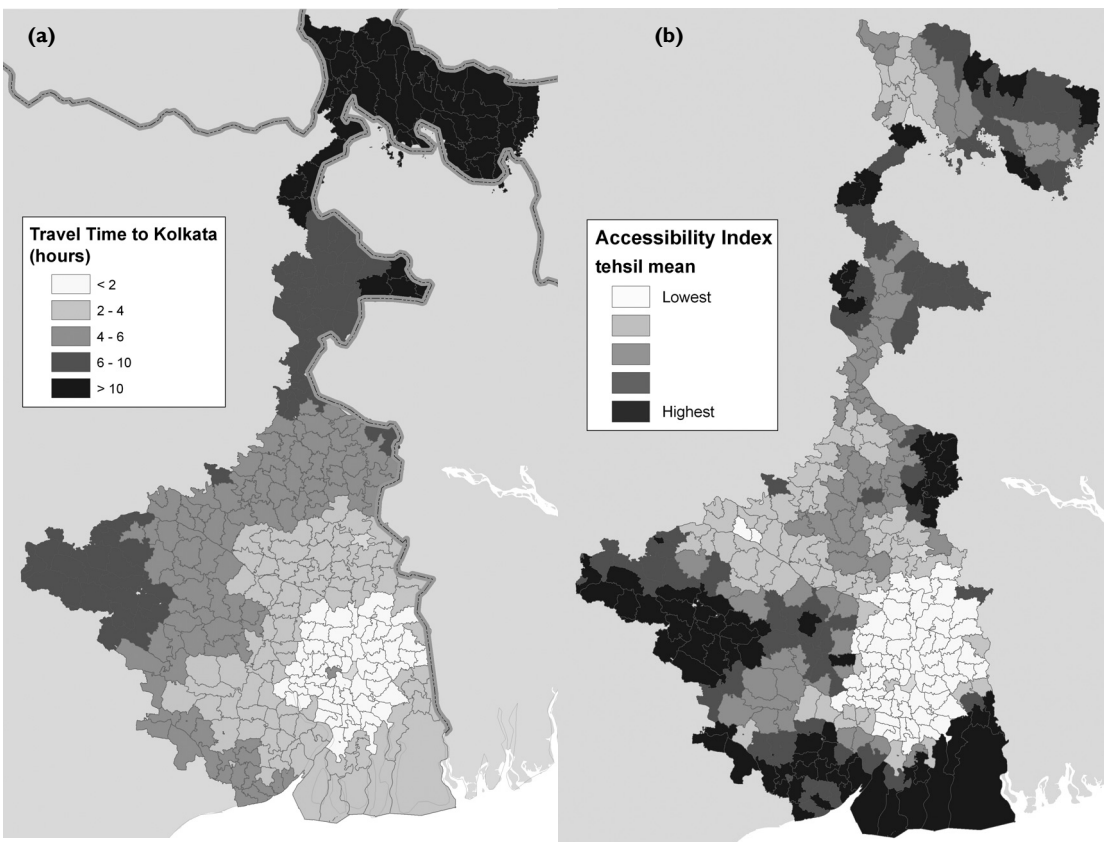

Figure 4 (a and b). Comparison between a Map of Potential Accessibility and a Map of Estimated Travel Time to Kolkata for West Bengal

Source: World Bank staff estimation based on Survey of India village boundary map for West Bengal.

In the case of West Bengal, Kolkata is the largest city in the state, but there are many other cities that are likely to form regional economic hubs. This is clear by comparing a map of the potential accessibility, which includes all major cities, with a map of travel time to Kolkata. The northern areas are definitely furthest from Kolkata while they are not necessarily most isolated according to the potential accessibility map. Some mid-size cities in the northern areas are closely located and linked by major roads, which increases the potential accessibility index. Another population mass is located in the east of the centre of the state. These important population masses are not captured by a map of distance to Kolkata only.

In Sri Lanka, the same comparison suggests a different story. A map of the potential accessibility illustrates that Colombo and its neighbourhood represent a single dominant urban centre in Sri Lanka (see Figures 5a and 5b). In fact, the comparison of these two maps confirms this since the accessibility index appears to decline with increasing distance to Colombo City almost monotonically.

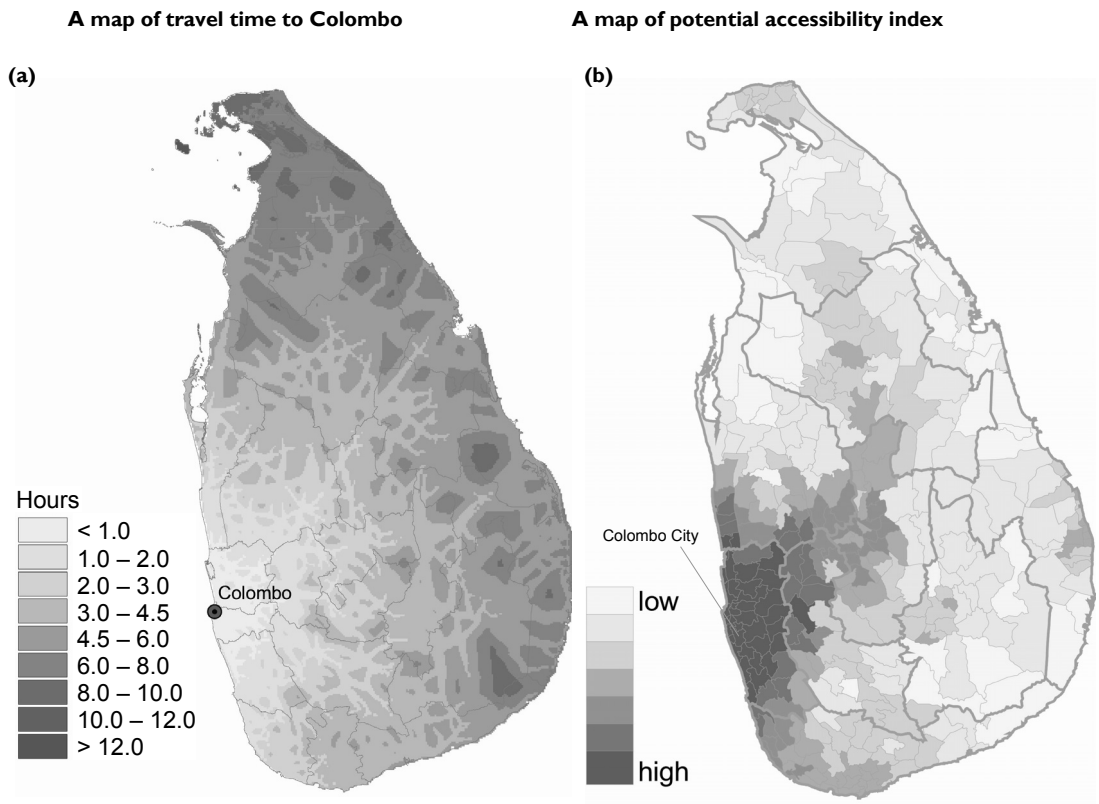

Figure 5 (a and b). Comparison between a Map of Potential Accessibility and a Map of Estimated Travel Time to Colombo in Sri Lanka

Source: World Bank (2005) and World Bank staff estimation.

5.2 Market access and productivity/competitiveness of local firms

As mentioned in the literature review, whether market access improves productivity or competitiveness of local firms is an empirical question. 'New Economic Geography' suggests that improved market access help local firms benefit from urban agglomeration, but also shows that under certain circumstances, an increasing market access may not necessarily have a positive effect on the productivity of firms. Congestion and increasing factor prices may outweigh the benefits from larger markets. This subsection illustrates some interesting results from empirical studies.

Lall et al. (2004) examined the contribution of access to markets on economic productivity in the context of India. They constructed a plant or factory level data set from the Annual Survey of Industries for 1994–95 collected by the Central Statistical Office of India, and also created a nation-wide potential accessibility index. They found that the net benefits of access to markets are positive and statistically significant for two industrial sectors—machine tools, and electronics and computer equipment. A 10 per cent improvement in market access will be associated with an approximately 1.5 per cent increase in plant output for machine tools and a 1.7 per cent increase for electronics and computer equipment, without additional plant level production inputs. They also found statistically significant *negative* effects of market access for the beverages and tobacco industry [Standard Industrial Codes (SIC)] 22) which tend to be more spread out (closer to their customers) and depend much less on agglomeration benefits. The variation across industries suggests benefits from urban agglomeration depending on what products are produced.

Deichmann et al. (2004) examined the contribution of market access to labour productivity in the context of Mexico. They used firm level data for 1999 and also created a nation-wide potential accessibility index to see the contribution to labour productivity. The empirical analysis suggests that a 10 per cent improvement in market access will be associated with a 6 per cent increase in labour productivity. They also found that the impact appears to be bigger among micro firms (with 1–15 workers). If the sample is restricted for the micro firms, a 10 per cent improvement in market access will be associated with a 13 per cent increase in labour productivity.

Lall et al. (2008) used the potential accessibility index to study the impact of market access from a slightly different angle. They test whether increased market access raises inflow of private investment to a city. After controlling for other factors, they found that a 10 per cent increase in potential accessibility increases a city's share of national private manufacturing investment by 5.7 per cent. This result suggests that the private sector is willing to take advantage of urban agglomeration and thus make investment to locations with high market access. This study also found that the impact of market access can be more important than that of improving local infrastructure, suggesting that the effects of inter-regional transport infrastructure improvements are considerably stronger than those of local infrastructure supply.

5.3 Market access and poverty

With improvements in methodology for poverty mapping and potential accessibility indexes, it becomes easier to test whether better market access is associated with lower poverty incidence. Subsection 5.2 suggests that improved market access appears to enhance productivity of firms and attract inflow of private sector investment (at least in the context of India). Both are likely to expand economic opportunities including those of the poor; implying a possible negative correlation between poverty and market access.

In Sri Lanka, the Department of Census and Statistics and the World Bank produced a poverty map using a small area estimation method to illustrate poverty incidence at the sub-district level. In Sri Lanka, the official poverty estimates are produced at the district level where consumption data from household income and expenditure surveys are representative. The poverty map could successfully produce statistically reliable poverty estimates for DS divisions, which are one administrative unit below the district and roughly correspond to tehsils (or blocks) in India's census location code system.

The World Bank also produced a potential accessibility map to see its relationship with the poverty map. Figure 6 (a and b) indicates a high correlation between poverty and potential accessibility. It suggests that the highly populated area of Colombo and its neighbouring areas record far lower poverty rates than other areas, confirming that proximity to the urban centre is positively associated with a lower poverty incidence.

It is worth noting that Figure 6 suggests only a correlation rather than a causal relationship. Also, it is not known yet whether this correlation is a result of urban agglomeration or other factors that happen to concentrate in Colombo City and its neighbourhood, like good infrastructure. Clarifying these issues will be certainly useful for policy makers although careful empirical specifications will be needed for this.

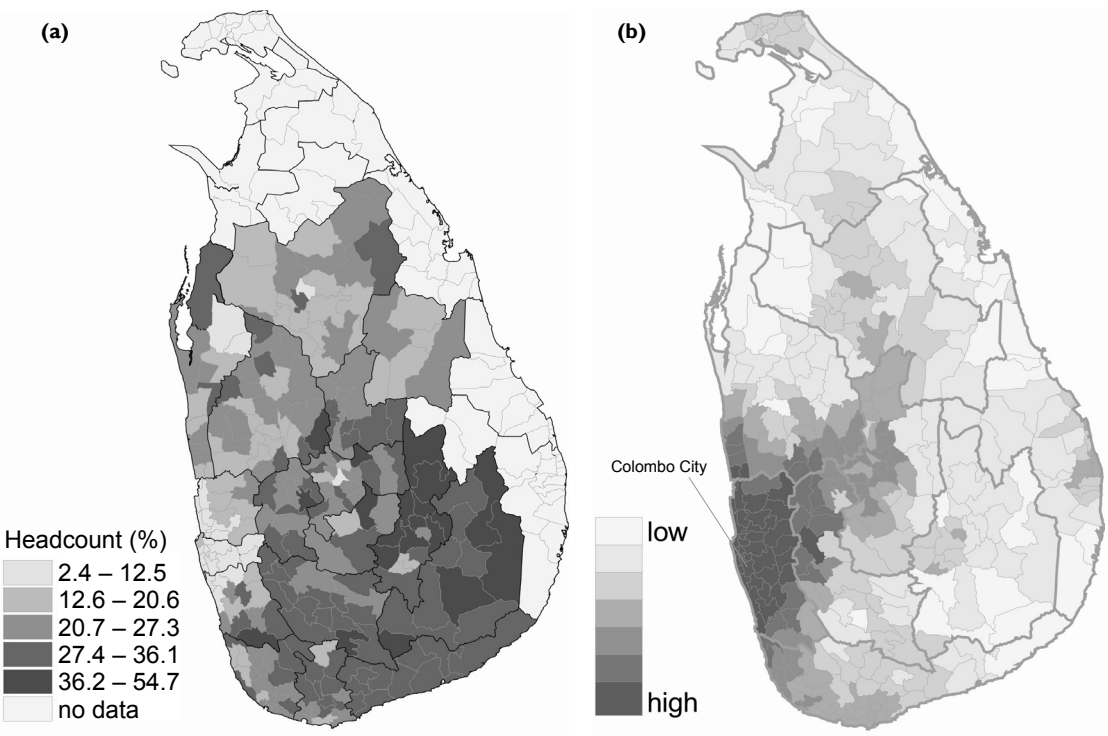

Figure 6 (a and b). Comparison between a Map of Potential Accessibility and a Poverty Map in Sri Lanka
Source: World Bank (2005).

5.4 A potential accessibility index as a monitoring instrument of regional development

Tracking the accessibility index can serve as a monitoring instrument for measuring the effectiveness of public investment spent on expanding the road network and improving road conditions. As shown in subsection 5.3, the potential accessibility index depends on two main factors: (*i*) transportation infrastructure and (*ii*) geographical distribution of population in urban centres. Therefore, in general, improving road conditions and expanding the road network improves the accessibility index. But, it is not always the case. For example, if public investment is spent for connecting a village with another village, an improvement in the accessibility index would be limited. This type of public investment might serve for other objectives, but it has a limited impact on both villages' access to markets and employment opportunities. In this case, alternative access indicators that focus more on intra-rural connectivity are more appropriate.

Tracking the accessibility index will also provide information on the functionality of the existing road networks. For example, all urban centres do not grow uniformly. Some grow but others might experience economic downturns. As a result, even if the existing road network performed well in the past, it might not perform well now due to geographically unbalanced growth. Tracking the accessibility index is useful for policy makers to know how geographical patterns of economic activities are shifting and also how the existing transportation infrastructure is performing.

To make the tracking of the accessibility index a regular monitoring instrument, governments need to create a framework for creating and updating GIS databases of the road network, other transportation infrastructure, and population data. Currently, a population census is conducted by the Office of Registrar General of India (ORGI) every 10 years in India. Survey of India provides and updates digitised boundaries of various levels of administrative units. However, the task of updating digital road network data sets is less clearly assigned. The main responsibility lies at the state level where capacity varies from state to state.

6. Conclusion

An indicator of potential accessibility to urban centres is a useful way to consolidate different sources of GIS databases, which include locations of large cities and towns with their population and a road network with road conditions for all segments. It is constructed based on the assumption that the benefit of access to an urban centre increases with its population, and declines with distance, travel time or cost. However, the influence of accessibility and market access is not the same everywhere. If cities are poorly managed, leading to congestion, high factor prices, grime and crime, then proximity to an urban place may even have a negative effect on economic growth and welfare. A combination of accessibility maps and maps of other social indicators like poverty maps can provide useful insights into these relationships.

Constructing a database of the accessibility index requires substantial computational resources. For each site, we need to find the shortest route from the origin site to each destination and compute travel time. This procedure needs to be repeated for all urban centres in order to calculate the potential accessibility index, that is, an average population figure weighted by the travel time. If the interest is in creating a map of the potential accessibility index at the village level, **we need to repeat the calculation of the shortest route for all villages**. Creating a detailed map of the potential accessibility index becomes feasible thanks to continuing improvements in computational capacity of personal computers and GIS software.

Examples introduced in this paper used only the road network as a transportation infrastructure. However, other means of transportation, especially railroads, are also important. Incorporating both road and railroad networks is a challenging task but not impossible. For example, Spiekermann and Wegener (2007) produced an accessibility index using both road network and railroad systems in European Union member countries.

Also, tracking the accessibility index can be useful for infrastructure investment planning. What areas are suffering a lack of access to urban centres? What type of investment would be cost-effective? Can the existing road network handle a significant expansion of economic activities? By tracking the accessibility index, policy planners will get some levels of answers for the above questions. However, it is worth noting that regular updates of transportation and population data will be essential.

Coordination across states and sharing databases with neighbouring countries would help improve the reliability of the indicator. Maps of both Sri Lanka and West Bengal were prepared without taking into account the impact of access to urban centres in other countries and states. For the island nation of Sri Lanka this is a minor problem, but West Bengal shares borders with other states as well as Bangladesh. Many villages near the state border and Bangladesh might have business with urban centres in the neighbouring states and in Bangladesh, respectively. The road network and location of urban centres in the neighbouring states will improve the accuracy of the West Bengal accessibility index map. Improving accessibility maps will thus require coordination among states.

Finally, benefits of the potential accessibility index map will be augmented if it is combined with other GIS databases. In the case of Sri Lanka, the close visual correlation between the poverty map and the potential accessibility map suggests that poverty incidence is negatively associated with the proximity to large cities and towns. It is certainly useful to combine the potential accessibility map with other GIS databases like agro-climatic information, topographic maps, and locations of key infrastructure. For West Bengal, the India Development Foundation, PAN Network and the World Bank are currently producing an atlas including a potential accessibility map. The atlas will no doubt provide more useful policy implications of the accessibility map.

Note

1. There are many different formulae to compute a potential accessibility index. They differ on how to estimate the distance (whether to use travel time or distance) and also how to measure the degradation of the impact in distance. Often the negative exponential function is used. The formula shown in the main text assumes that the degradation of the impact will decline proportionately with travel time.

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