IGAD
Livestock
Policy
Initiative

Pro-Poor Livestock Policy Initiative
A Living from Livestock

Accessibility Mapping and Rural Poverty in the Horn of Africa

Francesca Pozzi, Tim Robinson
and Andrew Nelson

A Living from Livestock

IGAD LPI Working Paper No. 02-10
PPLPI Working Paper No. 47

CONTENTS

Figures

Tables

PREFACE

This working paper has been prepared jointly for the Intergovernmental Authority on Development Livestock Policy Initiative (IGAD LPI) and the Pro-Poor Livestock Policy Initiative (PPLPI).

The IGAD LPI was established by IGAD in collaboration with FAO and with financial support from the European Commission. Its main objective is to enhance the contribution of the livestock sector to sustainable food security and poverty reduction in the IGAD region. The initiative works towards the core outputs of IGAD's programmes on policy harmonization, agriculture and the environment and regionally integrated information systems. The work described in this paper contributes towards making available standardised spatial data to help analyse policy options, to target policy interventions and to evaluate their impact – contributing to the evidence base underpinning pro-poor livestock policies.

This paper examines the links between poverty and accessibility. Access to services and markets are important contributors to poverty, as better access can lead to more efficient agricultural production, better market opportunities, diversification of rural economies and improvement of living conditions. Quantitative measures of accessibility are thus useful to help understand the spatial distribution of poverty and to target interventions. In spite of it being widely recognised that poorer people tend to live in remote areas, the detailed nature of the relationship between poverty and accessibility has not been described or explained in any detail.

In this paper we describe different measures of accessibility (Section 2) and then explore the links between accessibility and poverty, through a number of poverty indicators in Uganda (Section 3).

Disclaimer

Authors

Francesca Pozzi conducted this work as a consultant to the IGAD LPI. Her research interests focus on the use of GIS, remote sensing and statistical tools to analyze poverty distribution and the linkages between poverty and livestock, agriculture, population distribution and the environment.

Timothy Robinson works for the Pro-Poor Livestock Policy Initiative (PPLPI), based FAO's Livestock Information, Sector Analysis and Policy Branch (AGAL). He is responsible for the development of information systems in PPLPI and also for operations in the Horn of Africa, including the IGAD LPI, for which the work reported here was conducted.

Andrew Nelson is a geographer with interests in accessibility modeling, population mapping and the spatial analysis of environmental and socio-economic variables.

For more information visit the PPLPI website at: http://www.fao.org/ag/pplpi.html
or contact: Joachim Otte - Programme Coordinator of the Pro-Poor Livestock Policy Facility
Email: Joachim.Otte@fao.org Tel: +39 06 57053634 or Tim.Robinson@fao.org Tel: +39 06 570 54901 Fax: +39 06 57055749
Food and Agriculture Organization - Animal Production and Health Division Viale delle Terme di Caracalla 00100 Rome, Italy

Acknowledgements

The authors are particularly grateful to Jordan Chamberlin and William Wint for their comments and inputs to the methodology. The work described here was initiated under the IGAD Livestock Policy Initiative but has benefited from significant additional inputs, both financial and technical, from the Pro-Poor Livestock Policy Initiative (PPLPI).

The poverty data used in the analysis were prepared and provided by Thomas Emwanu of the Uganda Bureau of Statistics (UBOS) for an earlier PPLPI study of poverty mapping in Uganda. The authors are grateful to Thomas for his ongoing assistance.

Keywords

Market, accessibility, cost-distance function, friction surface, travel time, livestock, poverty, policy.

Date of publication: 06 January 2010

For more information visit the PPLPI website at: http://www.fao.org/ag/pplpi.html
or contact: Joachim Otte - Programme Coordinator of the Pro-Poor Livestock Policy Facility
Email: Joachim.Otte@fao.org Tel: +39 06 57053634 or Tim.Robinson@fao.org Tel: +39 06 570 54901 Fax: +39 06 57055749
Food and Agriculture Organization - Animal Production and Health Division Viale delle Terme di Caracalla 00100 Rome, Italy

ABBREVIATIONS

CIAT	International Center for Tropical Agriculture
CIESIN	Center for International Earth Information Network
CPRC	Chronic Poverty Research Center
DCW	Digital Chart of the World
DMA	United States Defence Mapping Agency
ESRI	Environmental Systems Research Institute
FGT	Foster-Greer-Thorbecke poverty indicators
GIS	Geographic Information System
GLOBE	Global Land One-kilometre Base Elevation Model
GPW	Gridded Population of the World
GRUMP	Global Rural and Urban Mapping Project
IGAD	Intergovernmental Authority on Development
LPI	Livestock Policy Initiative
NGA	National Geospatial-Intelligence Agency
NIMA	National Imagery and Mapping Agency
ONC	Operational Navigation Chart
PPLPI	Pro-Poor Livestock Policy Initiative
SAE	Small Area Estimate
UBOS	Uganda Bureau of Statistics
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNHS	Uganda National Household Survey

EXECUTIVE SUMMARY

It is widely recognized that poverty is a multidimensional concept and that both environmental and socio-economic factors contribute to the wellbeing of people. A better understanding of the geographical factors associated with poverty will allow poverty reduction strategies to be developed that focus on modifying those factors or that help people to adapt to deal with them, thereby enabling households living in poor areas to improve their standard of living. Among these factors, market accessibility plays an important role, especially in rural areas, where better access to population centres and markets can lead to diversification of rural economies. Poor market access has been highlighted as one of the priority causes of poverty in Uganda (Government of Uganda, 2000 and 2002).

This paper examines the relationships between poverty and accessibility for some 5,500 rural households in Uganda, by exploring the relationships between welfare, measured in terms of household expenditure and poverty head count, and a) measures of physical distance and travel time to markets and roads, and b) different measures of the potential for interaction, estimated in terms of population density and indices of proximity.

Results show that distance and travel time to roads are not highly correlated with welfare, while distance and travel time to population centres are highly correlated with wealth indices: welfare decreases rapidly as access to population centres gets worse. It appears that access to intermediately sized centres of population is relatively more important than is access to very small, local markets, or to much larger population centres.

Expenditure and poverty head count are also strongly correlated with population density and with indices of proximity: people are far better off when there is a high potential for interaction with other people. Whilst the directions of causality are difficult to demonstrate, this analysis reveals the nature of these correlations and the important predictive power of accessibility measures in poverty mapping.

1. INTRODUCTION

Poverty measures can be based either on economic indicators, such as income or expenditure, or on social indicators such as life expectancy, under-five mortality, or nutritional status. Such indicators are usually measured through household surveys (see for example Ravallion, 1996). Monetary estimates, such as income or consumption expenditure, are favoured by economists as the indicators of choice to measure the economic status of a household and, of the two, consumption expenditure estimates are generally considered more robust (Deaton and Zaidi, 2002; World Bank, 2003). Economic measures of household wealth can be used directly (e.g. Rogers *et al.* 2006; Robinson *et al*. 2007) but are often compared to thresholds that distinguish the poor from the non-poor, so-called poverty lines, to create poverty indices, such as those among the "Foster-Greer-Thorbecke" (FGT) class of poverty indicators (Foster *et al.*, 1984; Foster and Shorrocks, 1988). The most widely used is the "head count index" (Foster *et al.*, 1984), which is calculated as the proportion of households classified as poor; for which the income or expenditure measures fall below the chosen poverty line.

However, it is well understood that poverty is a multidimensional concept and that the wellbeing of a population depends both on monetary and non-monetary factors (Bourguignon and Chakravarty, 2003; CPRC, 2005). In recent years attempts have been made to include more explicitly the multidimensionality of poverty in its measurement and analysis (Bibi, 2005; Dercon, 2005; UNDP, 2006) and a variety of analytical techniques have been used to investigate spatial correlates of poverty at a range of scales (Emwanu *et al.*, 2003; Kristjanson *et al*., 2005; Rogers *et al*, 2006; Benson *et al.*, 2005; Benson *et al.*, 2007, Okwi *et al.*, 2007; Robinson *et al.*, 2007).

In order to develop appropriate poverty reduction strategies it is important to understand its spatial distribution. A better understanding of the geographical factors associated with poverty will facilitate better-targeted poverty reduction strategies that focus on modifying those factors, or empowering people to cope with them, thereby enabling households living in poor areas to improve their standards of living (Benson *et al.*, 2007).

The importance of spatial factors in determining poverty distribution has been emphasized by Crump (1997), Jalan and Ravallion (1997), and Dercon (2001), among others. Jalan and Ravallion (1997) postulated that low mobility and structural differences between regions in terms of natural resource endowment, infrastructure and access to services result in 'spatial poverty traps'. A widely applied approach to the analysis of poverty distribution is the small area estimation (SAE) technique for poverty mapping developed by the World Bank (Ghosh and Rao, 1994; Hentschel *et al.*, 1998). SAE produces geographically disaggregated indicators of welfare by exploiting statistical links between survey (low household coverage with much detailed) and census (complete household coverage with limited detail) data. The detailed relationships found within the survey data, between the welfare measure and a set of predictor variables that are common to the census, are extended to the census data. Both survey and census data tend to be socio-economic in nature and the SAE approach exploits the internal correlations within such datasets – relating a composite welfare estimate, such as per capita expenditure, with a suite of variables that are indicators thereof, such as type of housing, type of fuel used for cooking, and source of drinking water.

Poverty maps produced by SAE provide a description of the spatial distribution of poverty and inequality based on the selected welfare indicators. Rogers *et al.* (2006) and Robinson *et al.* (2007) developed a technique that combines household survey data with a suite of spatially explicit environmental variables, based on the assumption that poverty is largely a function of several interlinked factors including, for example, agricultural activities, human and animal diseases, natural resources, and access to markets.

Market access was one of the most important correlates of household expenditure in Uganda that was identified in the environmental approach to poverty mapping (Rogers *et al.*, 2006; Robinson *et al.*, 2007). In this paper we take that forward to explore the detailed relationships between poverty and market accessibility.

The importance of accessibility as a contributing factor to poverty in general has been widely proposed (e.g. Dixon-Fyle, 1998; Bird and Shepherd, 2003; Rogers, 2003; Shinyekwa *et al.* 2003; Yao, 2003; CPRC, 2005; Dercon, 2006; Bird *et al.*, 2007) and, in Uganda, is considered by the government to be one of the priority causes of poverty (Government of Uganda, 2000 and 2002). Access to markets is particularly important in rural areas, as better access to population centres and markets can lead to diversification of rural economies by opening up markets to villagers who wish to sell their labour, artisanal products or agricultural produce. Remote areas, which are far from centres of economic and political activities and poorly connected, both physically and in terms of communication, are likely to have high concentrations of chronic poverty (CPRC, 2005). Furthermore, in remote regions, market imperfections limit agricultural productivity and households' ability to accumulate capital and other assets (CPRC, 2005).

Markets are fragmented in many developing countries, providing the function of coordination only within a limited geographic area. These become barriers to transactions on a large scale and inhibit the efficient flow of information among market participants, especially those in distant locations, thus limiting the scope for productivity improvements and constraining the potential for rural-based growth (Yao, 2003). In rural areas that are distant from major towns, the irregular availability of small or periodic produce markets at a parish or sub-county level renders people vulnerable to shocks - particularly when cash might be urgently required in the household (Government of Uganda, 2000).

Despite these important links between market access and poverty only a handful of studies has explicitly analyzed the relationship between the two, and these have produced variable results. In Vietnam, for example, Minot *et al.* (2003) and Epprecht *et al.* (2007; 2009) found a significant, albeit weak, correlation between poverty rates and proximity (distance and travel time) to small towns, but a much less significant one with proximity to large urban centres. Farrow *et al.* (2005) examined the links between food poverty and a range of environmental and economic variables at the district level in Ecuador and found greater access to markets to be associated with lower levels of food poverty, although only access to provincial capitals proved to be significant. In Tanzania, Minot (2005) found rural poverty rates to be closely related to the distance to regional centres and travel times to primary, secondary and tertiary towns. In Ethiopia, Dercon and Hoddinott (2005) explore the links between rural households and market towns using data from 15 rural villages and found that access to local market towns affected economic activity and welfare in rural areas, and that improved market access significantly increased consumption outcomes.

In this paper we first describe a number of different measures of accessibility in the IGAD region (Section 2). These include a generic market access layer that was produced as an input to a regional poverty mapping exercise (which will be described in a separate, forthcoming IGAD LPI working paper); distance and travel times to roads and markets; and various measures of the potential of the population for interaction (population density and a derived proximity index). We then explore the relationships between these measures of accessibility and two indicators of poverty in Uganda: a) per capita expenditure and b) poverty head count (Section 3).

2. MEASURES OF ACCESSIBILITY

The term 'accessibility' refers to the distance to a location of interest and the ease with which it can be reached (Goodall, 1987). Travel time and destination choice are central to the definition of accessibility: the less time, and the more numerous and varied destinations are, the higher the level of accessibility (Handy and Niemeier, 1997). Although factors other than distance or travel time - the quality and cost of services provided, for example - also determine actual use of services, geographic parameters have been shown to be significant in predicting service utilization, especially in rural areas (Bigman and Deichmann, 2000).

There are several ways to measure accessibility (reviewed in Pozzi and Robinson, 2008). In this section we describe a number of accessibility measures for the IGAD region, including straight-line distances to roads and to populated places, travel time to roads and to populated places and finally, an index of proximity as a measure of the potential for interaction amongst people.

2.1 Distance to Roads and Markets

A simple definition of accessibility is the shortest distance from any demand point in a study area to the closest facility (e.g. a city, market or hospital). Such a measure considers only the spatial relationship between a given location and the service centre, but not the services provided at that centre, nor the choice of transportation or the quality of the transportation network. It further assumes that people will use the closest facility, when in reality that might not be the case. However, as a simple indication of the distance to points of interests or roads, this measure can provide some general indication of the remoteness of some areas, especially at regional level.

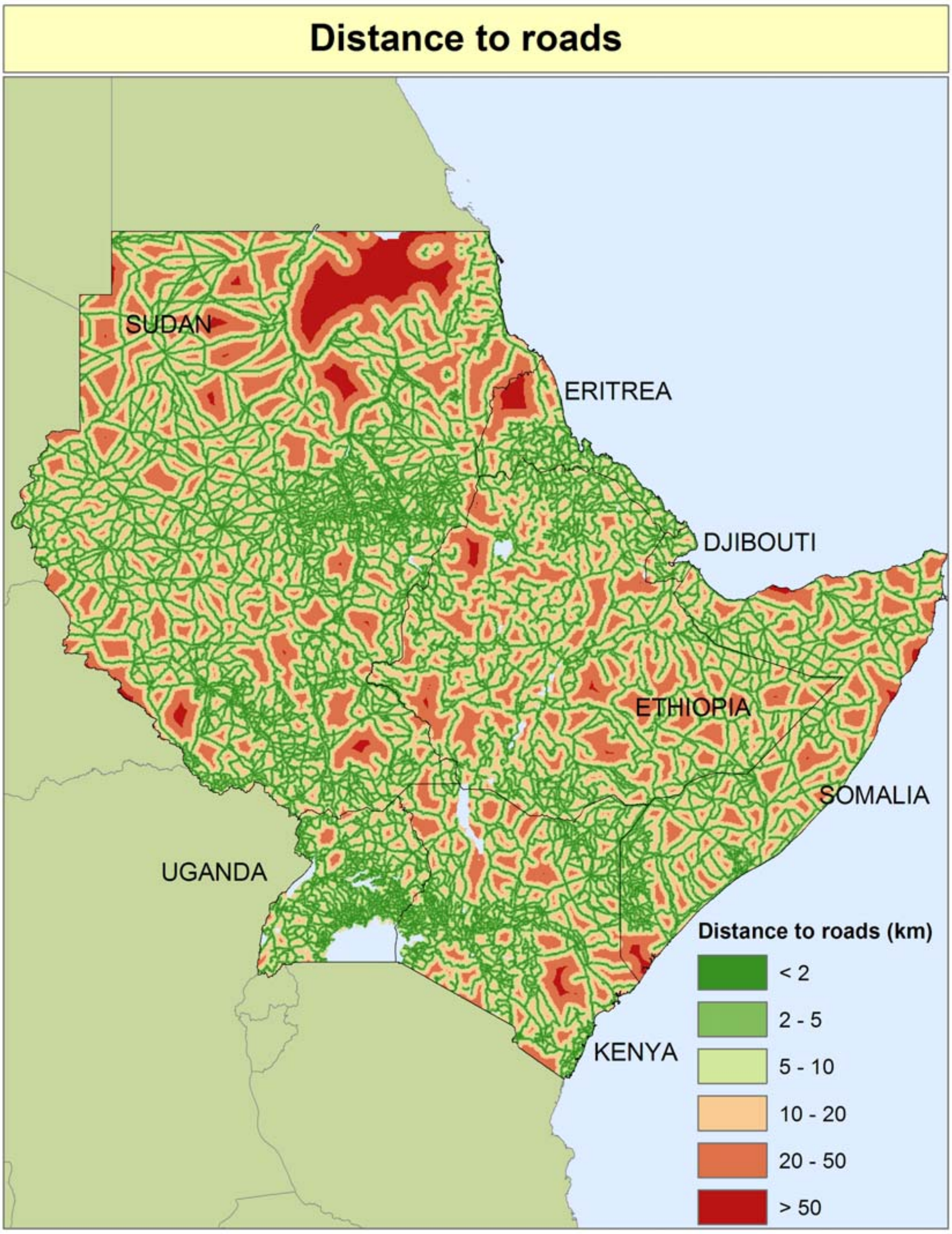
Using standard GIS software we calculated the straight-line distance to roads and to markets in the IGAD region.

Road network data were extracted from the Vector Map Level 0 (VMap0). VMap0, released by the National Imagery and Mapping Agency (NIMA)[1] in 1997, is an updated and improved version of the Digital Chart of the World (DCW). The DCW is a vector base map of the world at a scale of 1:1,000,000 that was commissioned by the US Defence Mapping Agency (DMA) and developed in 1992 by the Environmental Systems Research Institute, Inc. (ESRI). The primary source for this database was the Operational Navigation Chart (ONC) series, co-produced by the military mapping authorities of Australia, Canada, United Kingdom, and the United States. Some collateral sources have been used to add extra information about road and railway connectivity through selected urbanized areas. VMap0, available as a National Geospatial-Intelligence Agency (NGA) Vector Product Format, also at 1:1,000,000, was converted to ArcInfo format and the road layer was classified into three categories: (i) primary; (ii) secondary; or (iii) unknown.

The result for the IGAD region is shown in Figure 1.

[1] The National Imagery and Mapping Agency (NIMA) was created in 1996 from the merge of the US Defence Mapping Agency (DMA) and several other agencies. In 2004, NIMA was renamed as National Geospatial-Intelligence Agency (NGA), with the primary mission of collection, analysis, and distribution of geospatial intelligence (GEOINT) in support of national security.

Figure 1: Distance to roads in the IGAD region.



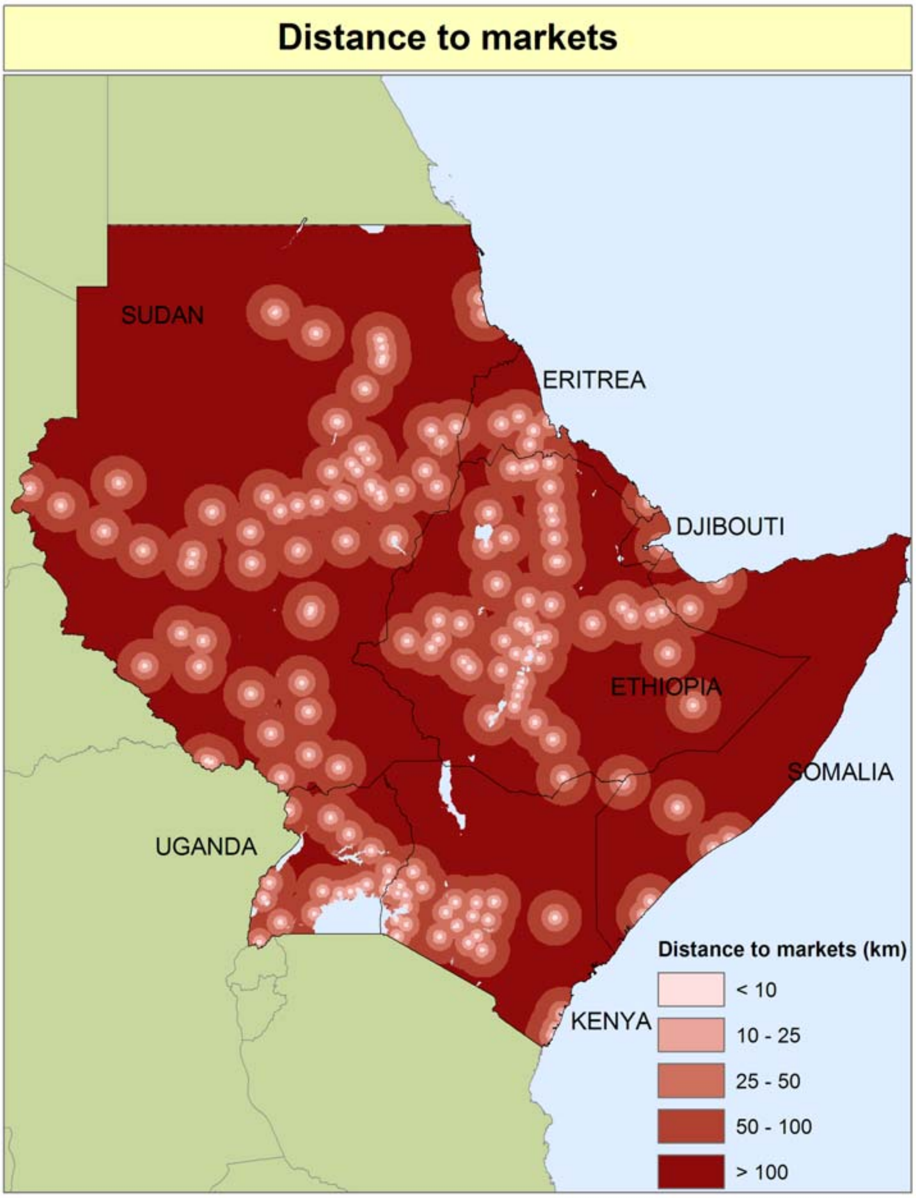
Source of road data: NIMA VMap Level 0.

In a similar fashion, we calculated distance to markets, defined as towns with a population of 25,000 or more in the year 2000, selected from the human settlements database provided by CIESIN, Columbia University (CIESIN, 2004). The human settlements database is one of many available from the Global Rural and Urban Mapping Project (GRUMP) (Balk *et al.*, 2004) and comprises a global dataset of about 55,000 cities and towns with populations of 1,000 or more. Each point has geographical coordinates and associated tabular information on its population and data sources. Population data were gathered primarily from official statistical offices (census data), and supplemented with data from other sources, such as gazetteers. Where the records for populated places did not include latitude and longitude coordinates, those were taken from the NIMA database of populated places.

Unfortunately, the database does not provide a full coverage of cities in the Horn of Africa. Large areas in Somalia, for example, are uncovered, meaning not that there are no markets or towns in these regions, but that data were not available from the database we used. Whilst additional information is available for specific countries these were not included in order to retain consistency in the regional model.

Figure 2 shows distance to markets in the IGAD region.

Figure 2: Distance to markets in the IGAD region.



Source of market data: Places populated by 25,000 people or more from the Global Rural and Urban Mapping Project (CIESIN, 2004).

2.2 Access to Roads and Markets

Distance may not be the most appropriate measure of accessibility, especially where the quality of the transport network is highly variable or where the cost of using public transport must be taken into account. Travel cost or travel time might provide more realistic measures.

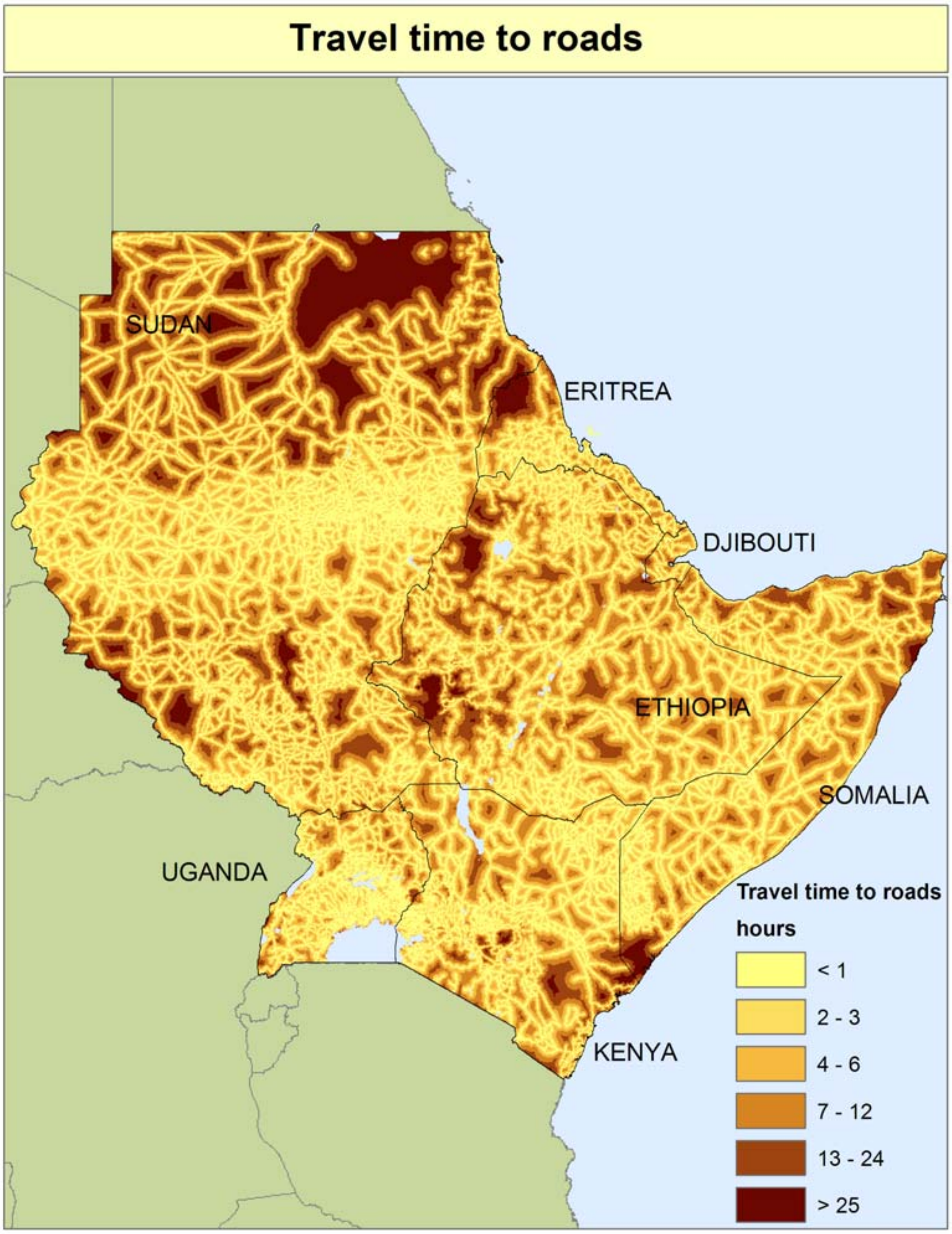
Pozzi and Robinson (2008) describe the methodology used to create the market accessibility surface of the IGAD region, based on a cost-distance algorithm (reported, for example, by Juliao, 1999; Ritsema van Eck and de Jong, 1999; Nelson, 2000; ESRI, 2004; You and Chamberlain, 2004; Longley *et al.*, 2005). The cost-distance function estimates, for each cell, the time required to reach the nearest destination (e.g. populated place) along the least costly route. Travel time is calculated over a friction surface that takes into account the road network, land cover and slope. Roads and land cover are classified according to estimated travel speeds, while slope is included as a speed-reducing factor (people walk and cycle more slowly up-hill). The baseline model used to generate the accessibility surface for the IGAD region (estimating travel time to populated places of 25,000 people or more) assumed on-road travel by motorized vehicle and off-road travel by pedestrian movement.

With the objective of generating a regionally consistent accessibility surface (as an input to a regional poverty model, described in a separate, forthcoming IGAD LPI Working Paper), it was necessary to make a number of simplifications and assumptions, determined largely by the availability of regionally consistent datasets on markets and road networks. Limitations of the accessibility maps may be (i) inherent to the model itself (e.g. the assumption that people travel to the nearest market); (ii) dependent on data availability (e.g. lack of detailed information on markets and their attributes, lack of good road databases, inconsistency of data across for the region, and issues of seasonality, security, and costs of transportation); and (iii) related to the classification of data (e.g. estimated traveling speeds over different land cover and road types).

Using the same cost-distance function, we also estimated the travel time to reach the nearest road over a friction surface that takes into account land cover and slope, assuming on-foot travel over the different land cover types. This is subject to many of the same potential sources of error as the market accessibility cost-distance calculations, such as the estimates of travelling speeds over different land cover types, so the assumptions need to be duly considered when interpreting the results.

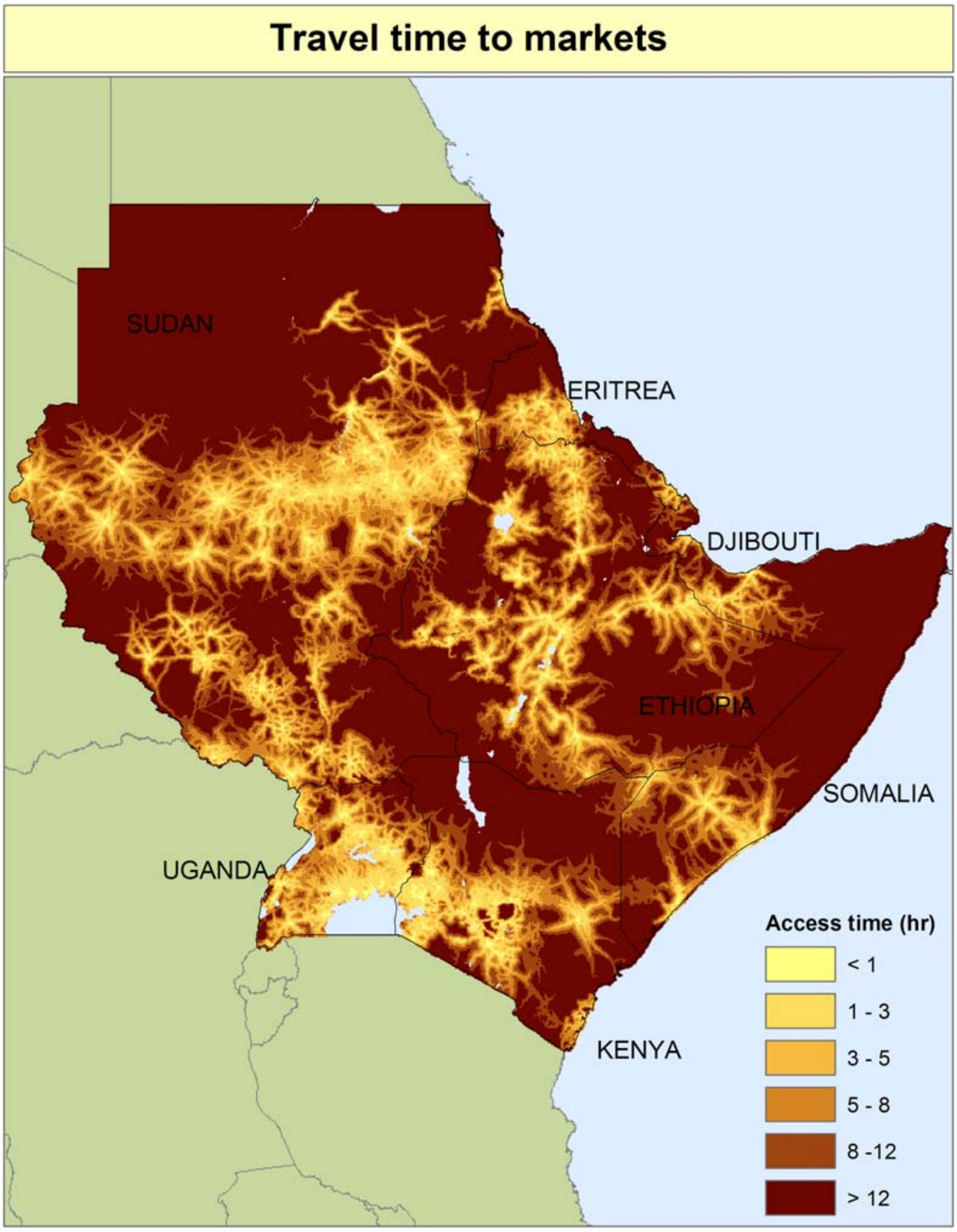
Road and market accessibility in the IGAD region are shown in Figures 3 and 4 respectively.

Figure 3: Access to roads in the IGAD region.



Source of road data: NIMA VMap Level 0; Global Land Cover 2000, The Land Cover Map for Africa in the Year 2000 (Mayaux *et al.*, 2000); Global Land One-kilometer Base Elevation (GLOBE Task Team, 1999).

Figure 4: *Access to markets in the IGAD region.*



Sources: Places populated by 25,000 people or more from the Global Rural and Urban Mapping Project (CIESIN *et al.*, 2004); NIMA VMap Level 0; Global Land Cover 2000, The Land Cover Map for Africa in the Year 2000 (Mayaux *et al.*, 2000); Global Land One-kilometer Base Elevation (GLOBE Task Team, 1999).

2.3 Potential for Interaction

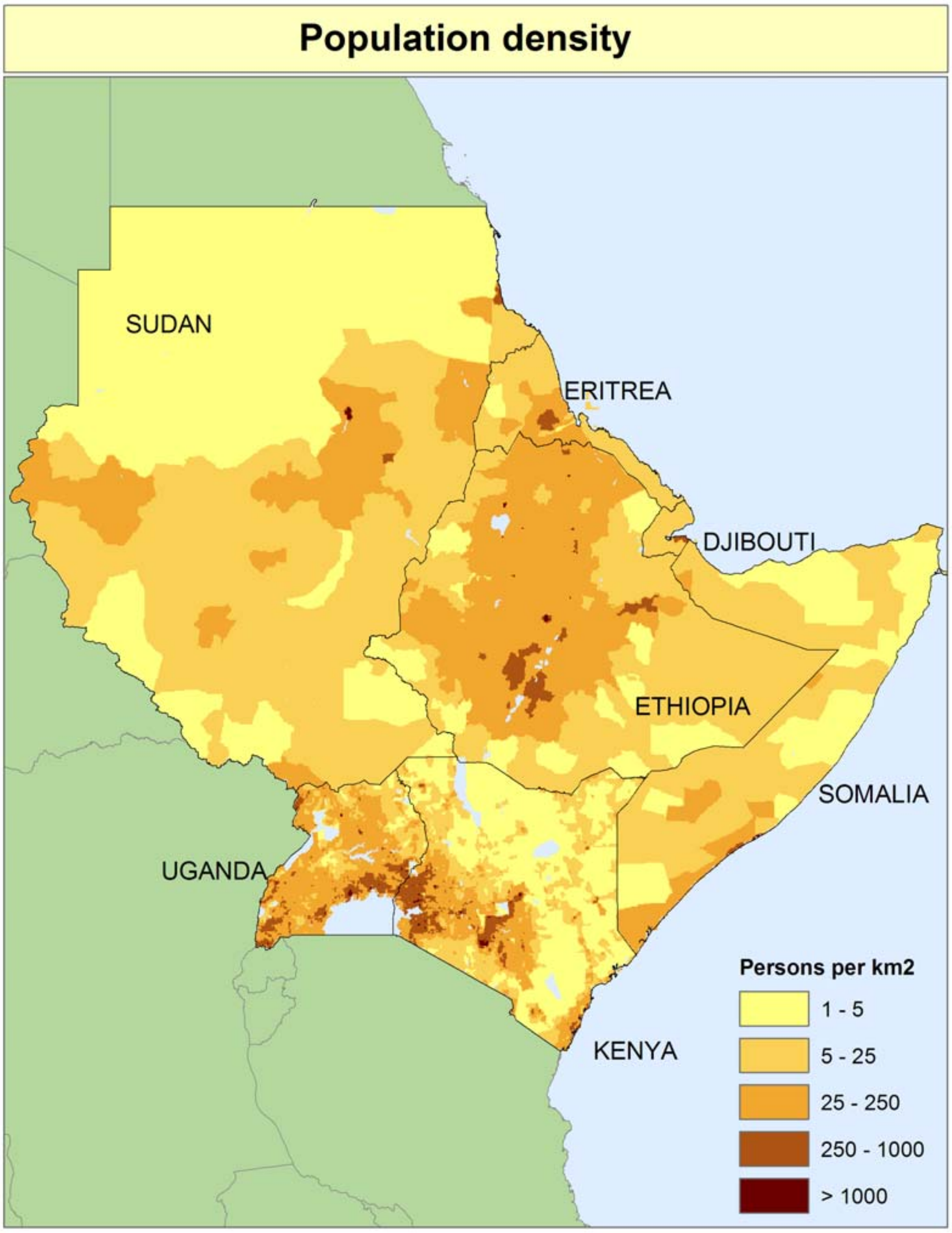
As well as the distance or the time required to travel to specific destinations, accessibility can be thought of in terms of potential for interactions or contacts among sites of economic or social opportunity (Deichmann, 1997); the closer people are to each other, the more potential there is for interaction and exchange. Based on this idea, we present here three different measures of the potential for interaction: (i) a standard population density surface; (ii) a “population potential” surface; and (iii) a travel time-weighted population potential surface.

2.3.1 Population Density and Population Potential

The simplest measure of the potential for interaction is population density. Figure 5 shows population density in the IGAD region, from the Gridded Population of the World (GPW), version 3 (CIESIN and CIAT, 2005). The GPWv3 is the third edition of a large-scale data product that maps the spatial distribution of human populations across the globe. The purpose of the GPW project is to provide a spatially disaggregated population layer that is compatible with datasets from social, economic, and earth science fields. The output is unique in that the distribution of human population is converted from national or sub-national spatial units (usually administrative units) of varying resolutions, to a series of geo-referenced quadrilateral grids at a resolution of 2.5 arc minutes (Balk and Yetman, 2004).

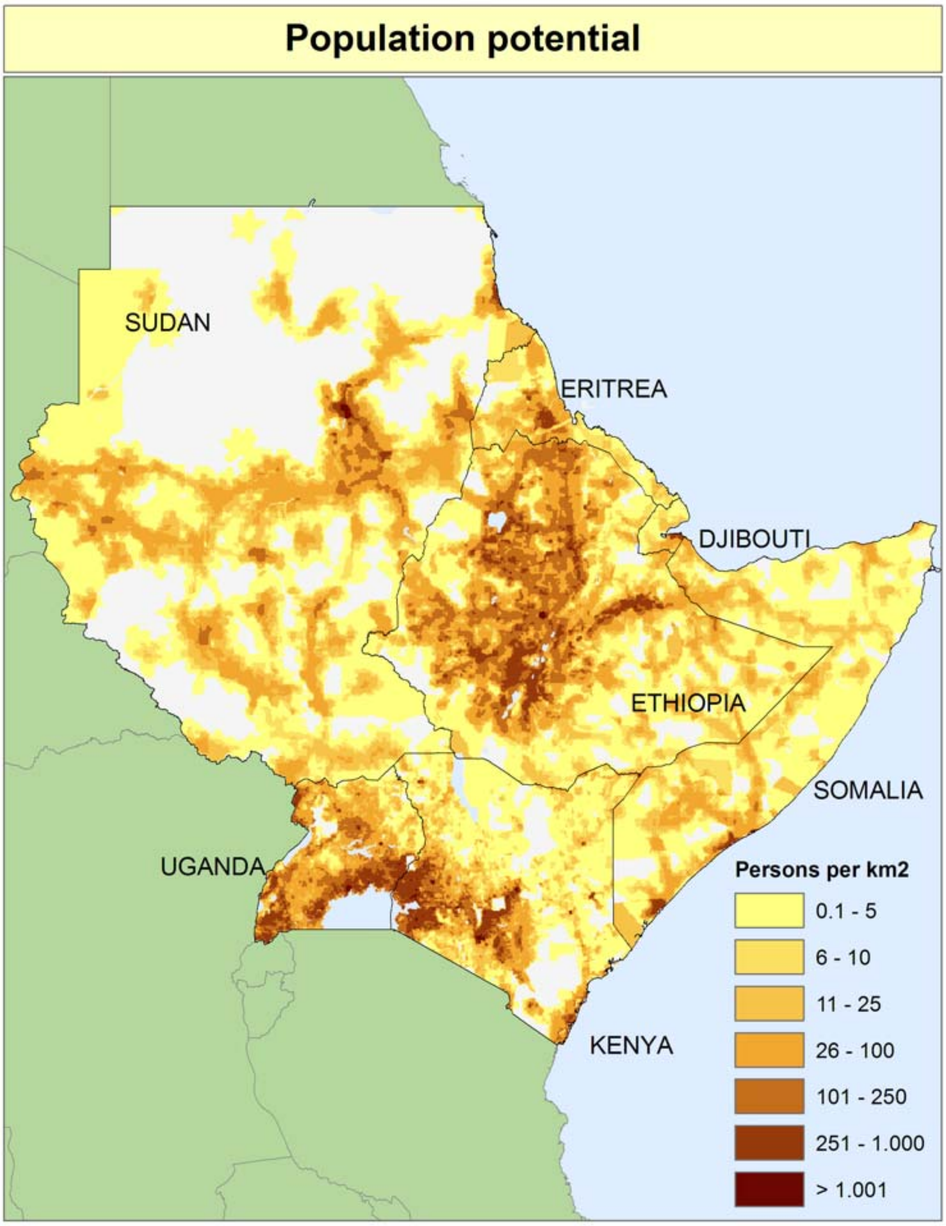
In a parallel effort, UNEP and CIESIN (2004) used accessibility measures to refine models of population distribution at regional scales. The approach used information on settlements, transport infrastructure and other features important in determining population distribution to compute a simple measure of accessibility for each node in a network. Such measures, termed ‘population potential’, are the sum of the population of towns in the vicinity of the current node weighted by a function of distance. The accessibility measure is then used to ‘reallocate’ population within each region (population totals are redistributed in proportion to the accessibility index measure for each cell), preserving the population totals from the administrative units in the original census (Nelson, 2004). The results are shown in Figure 6.

Figure 5: Population density in the IGAD region.



Source: Gridded Population of the World, version 3 (CIESIN and CIAT, 2005).

Figure 6: Population potential in the IGAD region.



Source: Africa Population Distribution database (UNEP and CIESIN, 2004).

2.3.2 Travel Time-weighted Population

An index, commonly used to measure how accessible one location is to other locations, is the 'accessibility index' - sometimes referred to as the potential for interaction (ESRI, 2004). For example, a person living within one mile of two markets has a higher accessibility to services than a person living within two miles of the same markets. This index belongs to the class of the gravity models (e.g. Wilson, 1971; Geertman and Ritsema van Eck, 1995; Handy and Niemeier, 1997; Kwan, 1998; Bigman and Deichmann, 2000), and is based on the principle that the effect of one location on another is directly proportional to its supply and inversely proportional to its distance. The attractiveness of a location is an index that combines all the factors that make it attractive to people. In the case of a market it could be the number of people that come to that location or the volume of commodities traded, for example.

Since we are interested in the potential for interactions among people rather than the relative attractiveness of particular markets or facilities, we have applied this concept to the population at large. To do so we used a cost surface to estimate, for each cell, how many people occur within “x” hours travel of each location and then weighted that population by a function of travel time to the cell.

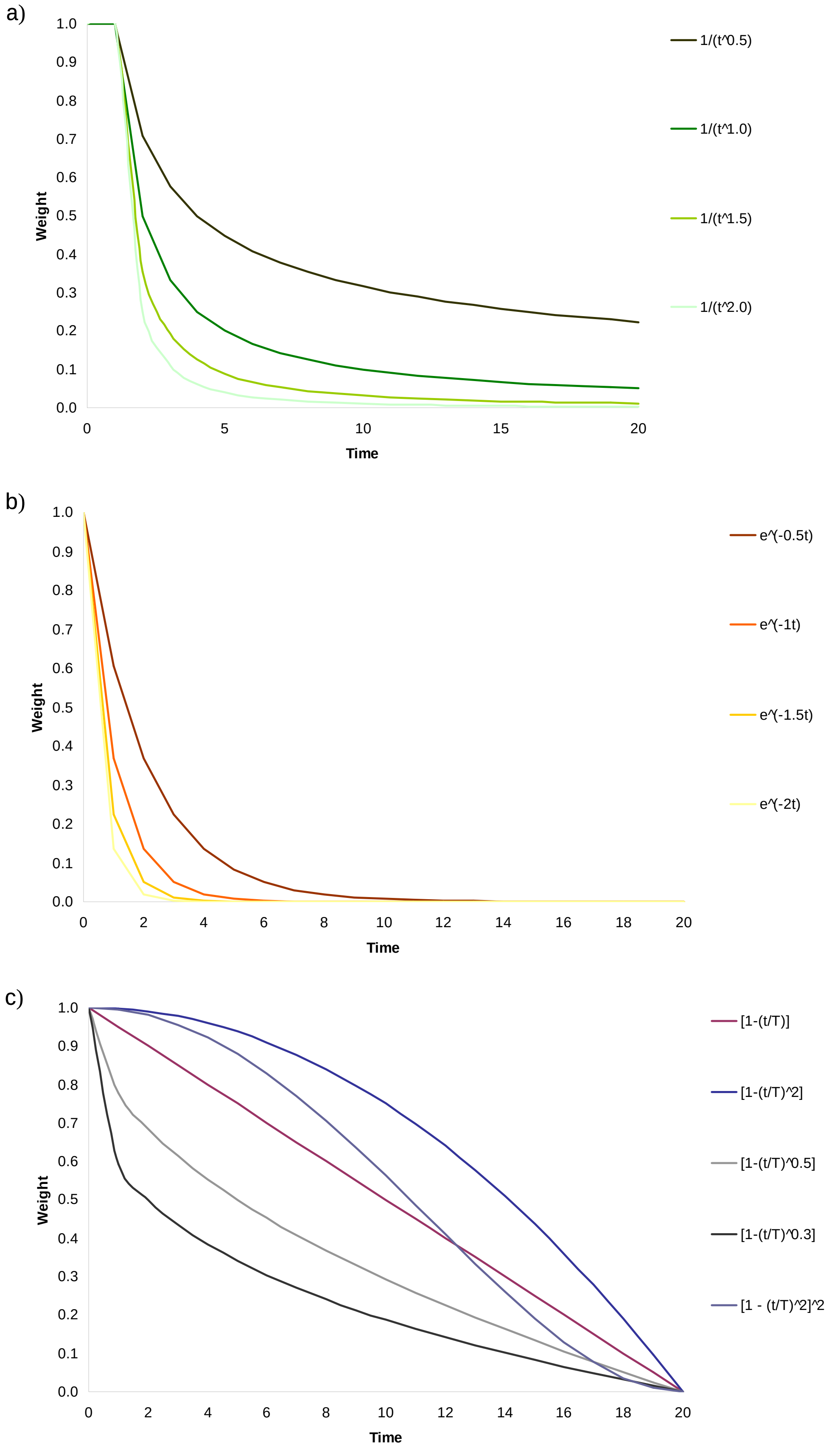
To decide, in the context of poverty assessment, how best to weight the population as a function of distance we first looked at Uganda, for which we have reliable point locations for 5,532 rural household from the 2002/2003 Uganda National Household Survey (UNHS)[2]. First, a 1 km grid was superimposed on the 5,532 rural households. Due to the clustering of the households, all the households were covered by only 2,207 grid cells. An Arc/Info AML script was developed to compute the travel time to each of these 2,207 cells and in turn to compute the population and distance-weighted population living within a given travel time of each household. Fourteen distance-weighting schemes were compared. In addition to ‘no weighting’, schemes included (i) inverse distance; (ii) exponential; and (iii) kernel functions. Table 1 shows the distance weighting equations, where *W* is the weight, *t* is the travel time from the household and *T* is the travel time cut-off. Figure 7 shows these schemes graphically using, merely for convenience of display, a time cut-off of 20 minutes. In all cases the weighting tends from 1 to 0 as travel time from the household increases.

Table 1: Distance weighting schemes considered in the analysis.

Inverse distance		Exponential		Kernel density	
1)	$W = \frac{1}{t^{0.5}}$	5)	$W = e^{-0.5\frac{t}{T}}$	9)	$W = \left(1 - \left(\frac{t}{T}\right)\right)$
2)	$W = \frac{1}{t^{1}}$	6)	$W = e^{-\frac{t}{T}}$	10)	$W = \left(1 - \left(\frac{t}{T}\right)^{2}\right)$
3)	$W = \frac{1}{t^{1.5}}$	7)	$W = e^{-1.5\frac{t}{T}}$	11)	$W = \left(1 - \left(\frac{t}{T}\right)^{0.5}\right)$
4)	$W = \frac{1}{t^{2}}$	8)	$W = e^{-2\frac{t}{T}}$	12)	$W = \left(1 - \left(\frac{t}{T}\right)^{\frac{1}{3}}\right)$
				13)	$W = \left(1 - \left(\frac{t}{T}\right)^{2}\right)^{2}$

[2] Households whose geo-location was for one reason or another dubious were eliminated from the database and subsequent analysis.

Figure 7: Weighting schemes: a) inverse distance, b) exponential and c) kernel density.



Five travel time cut-offs were considered (1, 2, 3, 4 and 5 hours). Distance-weighted population estimates for each grid cell were computed for each travel time cut-off and each weighting scheme, resulting in 70 estimates per grid cell and hence each household. Each of the 70 datasets of 5,532 weighted population estimates were binned into deciles. The average weighted population and average welfare measure were computed for each bin, plotted and trend lines fitted to determine the best fitting relationship between weighted population and welfare.

The best fitting trend type across all 70 results was a power trend ($y=mx^c$), fitted to the results from an inverse distance weighting (see Table 1 Equation 3) of the population within four hours. Inverse distance weighting is in fact a classic model of potential accessibility commonly used in spatial interaction models, especially over longer distances and travel times (Deichmann, 1997; Roy, 2004 and de Smith *et al.*, 2006).

The welfare of individual households (i.e. without binning) was also plotted against weighted population and the same travel time cut-off and distance-weighting were, again found to give the best fit, although the R^2 (0.9647 for $y=17{,}675x^{0.0961}$) for the decile results is much higher than at the household level (0.0529 for $y=12{,}935x^{0.112}$).

Having thus identified the most appropriate travel time cut-off and weighting scheme, we computed the travel time-weighted population within four hours of each 1 km grid cell, according to the following formula:

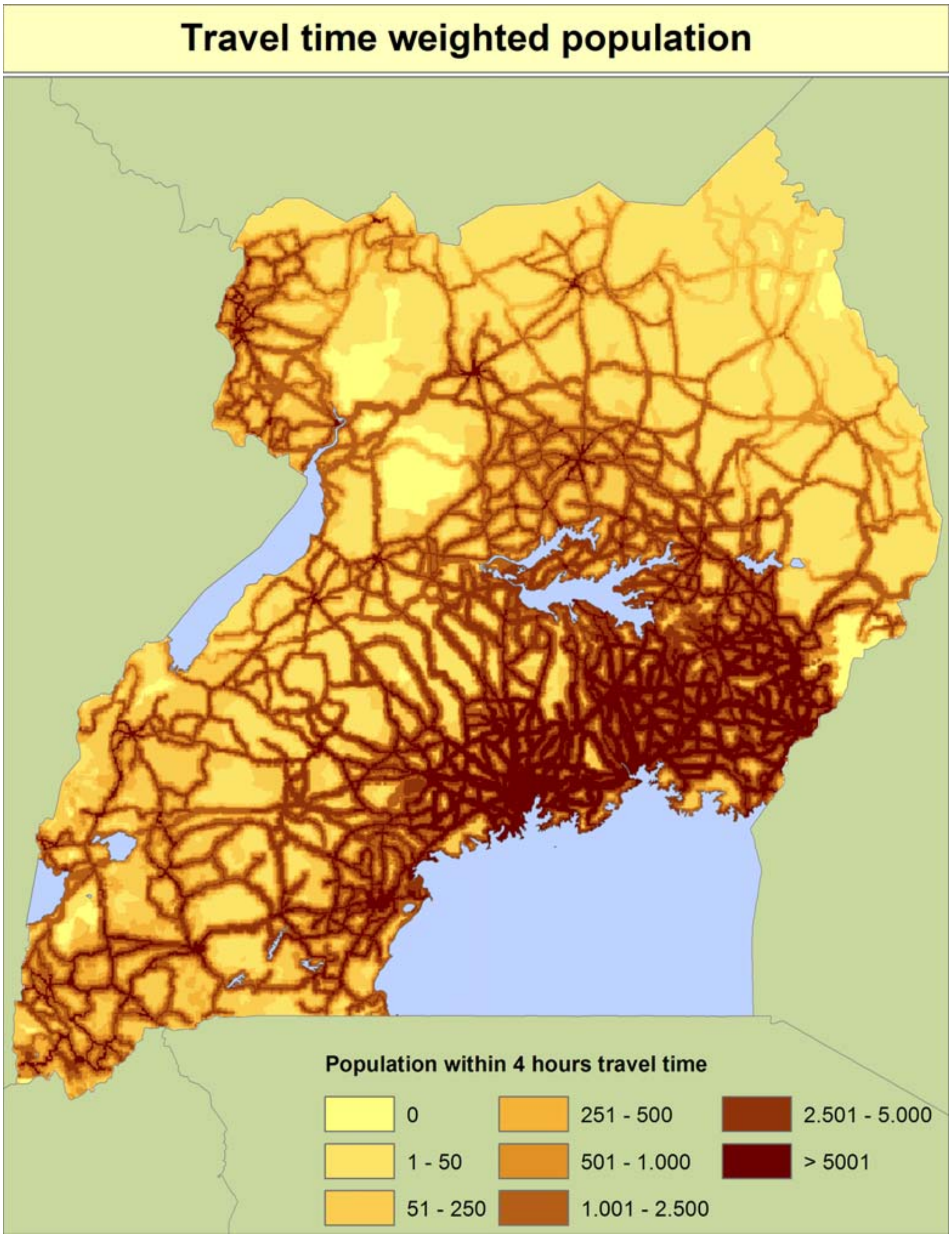
$$Pw_i = \sum_{ij}^{n} \frac{Pop_j}{t_{ij}^{1.5}} \quad \text{if } t_{ij} \leq 240$$

where Pw_i is the accessibility at location i, Pop_j is the population at location j, t_{ij} is the travel time in minutes between locations i and j (minimum 1, maximum 240) and n is the number of locations.

Figure 8 shows the weighted sum of the population (*Pw*) within 4 hours travel time of each pixel, using the $W = 1/t^{1.5}$ weighting scheme (t=time in minutes) for Uganda. This map represents, for each pixel, the number of people – rural and urban - that are within 4 hours travel time from the people residing in that pixel, thus giving an indication of the potential for interaction. Clearly, such population distribution reflects the road network, since it is based on travel time (which in turn is heavily influenced by the road network) and it reveals, perhaps not surprisingly, large differences between areas that are very close to the road network and those that are more remote. It also reflects the increased potential for interaction afforded by proximity to urban centres, with the increased density patterns in and around Kampala being particularly striking.

Calculating the travel time-weighted population for each cell of a 1 km grid is, computationally, extremely heavy – it took some 500 hours to run the model just for Uganda (on a high-specification workstation) and was estimated to take 10,000 hours to run a model for the entire IGAD region. Since comparisons against welfare estimates were to be made only for Uganda (see Section 3) a map was produced only for Uganda at this stage.

Figure 8: Travel time-weighted population in Uganda, where weight is $W = 1/t^{1.5}$ *for t in minutes up to a limit of 4 hours.*



Source: Calculations by the authors.

3. ACCESSIBILITY AND POVERTY

On the assumption that poverty is related in some way to accessibility we have computed a variety of indices of accessibility. In this section we explore relationships between these measures and welfare in Uganda. The accessibility indices used are those described above: i) distance to roads (Figure 1); (ii) distance to markets, defined as populated places with > 25,000 people (Figure 2); iii) travel time to roads (Figure 3); iv) travel time to markets (Figure 4); v) rural population density (not shown, as Figure 5 includes both rural and urban population); and vi) travel time weighted population, which includes both urban and rural people (Figure 8).

In order to decide on the population threshold to use when determining populated places to use as targets (i.e. markets) we carried out some preliminary analyses exploring the effect of including populated places of different sizes on the strength of correlation between access to those markets and welfare. The results, reported in Annex A, explains the selection of a population threshold of 25,000 people, used to determine market centres in the final analysis.

Poverty estimates were taken from the 2002/2003 Uganda National Household Survey (UBOS, 2003). For each of some 5,500 geo-referenced (see Footnote 2) rural households there is an estimate of monthly consumption expenditure per adult equivalent. Expenditure data can be combined with regionally-explicit poverty lines - the minimum level of income deemed necessary to achieve an adequate standard of living – to create jaggregate indices of welfare. The most commonly used of these are those among the 'Foster-Greer-Thorbecke' (FGT) class of poverty indicators (Foster *et al.*, 1984; Foster and Shorrocks, 1988), which can be summarised as:

$$\frac{1}{N}\sum_{i=1}^{Q}(z_i - y_i)^{\alpha}$$

where N = the total population, z_i is the poverty line, y_i is the welfare indicator for individual i and Q is the total population below the poverty line. In the present analysis the simple head count index was used, for which a = 0.

For each of household location we extracted the accessibility measures and combined them with the two welfare estimates from the household surveys. Households were ranked separately for each accessibility measure and divided into deciles. For each decile the average of the accessibility measure was calculated and, against this, was plotted a) the average consumption expenditure per adult equivalent (for which standard errors were estimated), and b) the aggregate head count index. Power trend lines were fitted in each case and R^2 values used to estimate the goodness of fit of the data to the trend lines.

The results of the comparisons are shown in Figures 9, 10 and 11 with the list of equations and R^2 values provided in Table 2.

Table 2: Trend line equations and coefficients of determination (R^2) for the measures of welfare and accessibility in Uganda.

	Expenditure		Poverty Head count	
Distance to roads	$y = 32935e^{-1E-05x}$	$R^2 = 0.0933$	$y = 35.552e^{2E-05x}$	$R^2 = 0.0661$
Distance to markets	$y = 49021x^{-0.123}$	$R^2 = 0.8006$	$y = 23.423x^{0.1406}$	$R^2 = 0.6712$
Travel time to roads	$y = 32881e^{-0.0209x}$	$R^2 = 0.1931$	$y = 37.113e^{0.0206x}$	$R^2 = 0.0557$
Travel time to markets	$y = 36703x^{-0.1345}$	$R^2 = 0.8347$	$y = 31.49x^{0.1803}$	$R^2 = 0.8655$
Population density	$y = 18180x^{0.1078}$	$R^2 = 0.9168$	$y = 82.497x^{-0.1477}$	$R^2 = 0.9228$
Weighted population	$y = 17286x^{0.0811}$	$R^2 = 0.7425$	$y = 96.284x^{-0.1249}$	$R^2 = 0.7802$

Wealth indices are correlated only weakly with distance (Figure 9.a and b, $R^2 = 0.09$ and 0.07) and travel time (Figure 10.a and b, $R^2 = 0.19$ and 0.06) to roads. In comparison, expenditure and poverty rates are much more strongly correlated with distance (Figure 9.c and d, $R^2 = 0.8$ and 0.67, respectively) and travel time (Figure 10.c and d, $R^2 = 0.83$ and 0.86, respectively) to markets (defined as places populated with 25,000 or more people).

Both expenditure and poverty head count show very strong correlations with rural population density (Figure 11.a and 11.b respectively, $R^2 = 0.92$ in both cases). Wealth indices are also strongly correlated with our index of accessibility – which includes the weighted influence of populations further afield (Figure 11.c and d, $R^2 = 0.74$ and 0.78, respectively for expenditure and head count). Correlations with the index of accessibility were less strong than those observed with rural population density.

Figure 9: Relationships between estimates of welfare - mean monthly per adult equivalent expenditure (with standard errors shown) in the left hand graphs and poverty head count in the right hand graphs - and distance-based accessibility measures in Uganda: distance to roads (a and b) and distance to markets (c and d).

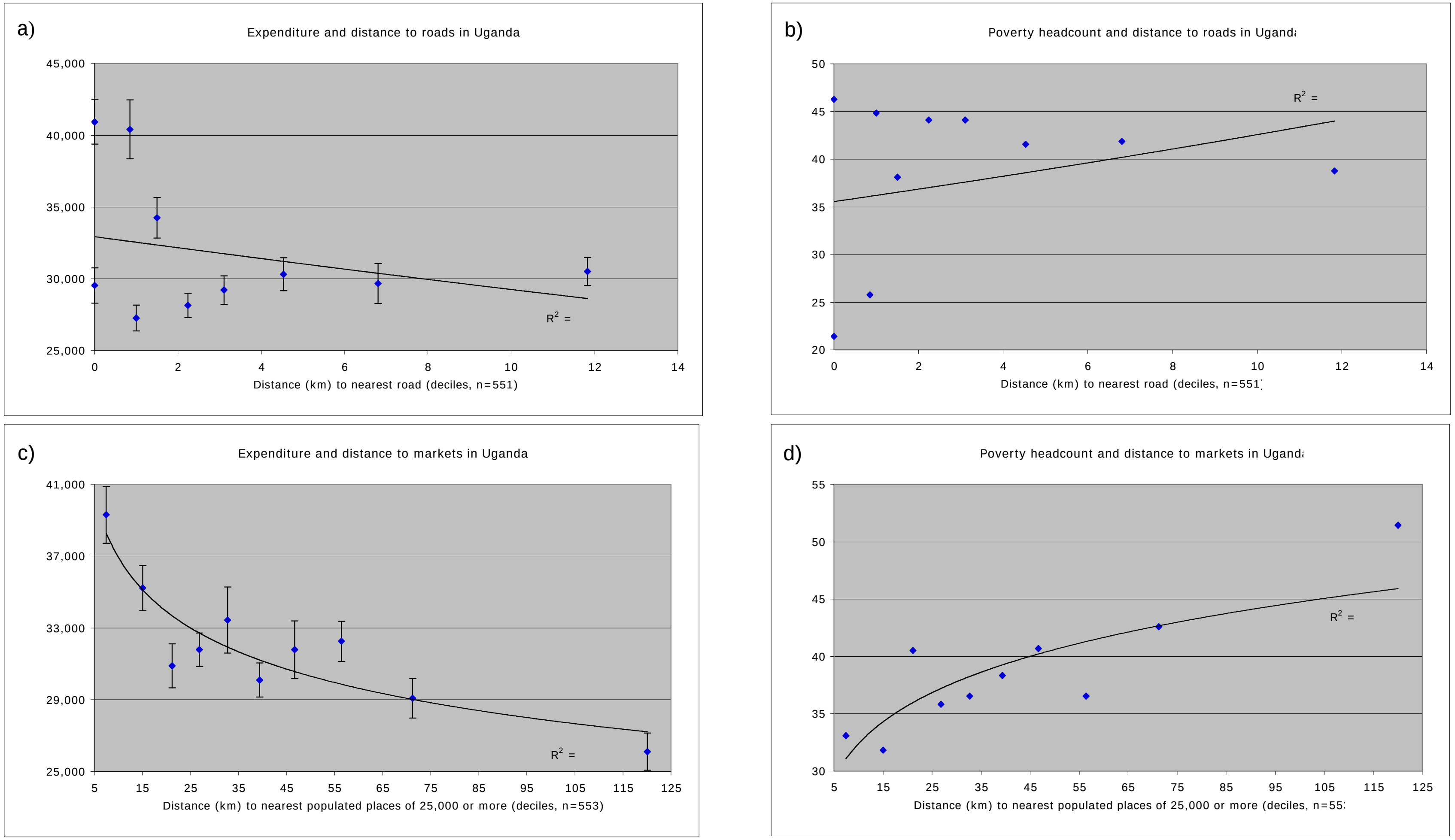


Figure 10: Relationships between estimates of welfare - mean monthly per adult equivalent expenditure (with standard errors shown) in the left hand graphs and poverty head count in the right hand graphs - and travel time-based accessibility measures in Uganda: travel time to roads (a and b) and travel time to markets (c and d).

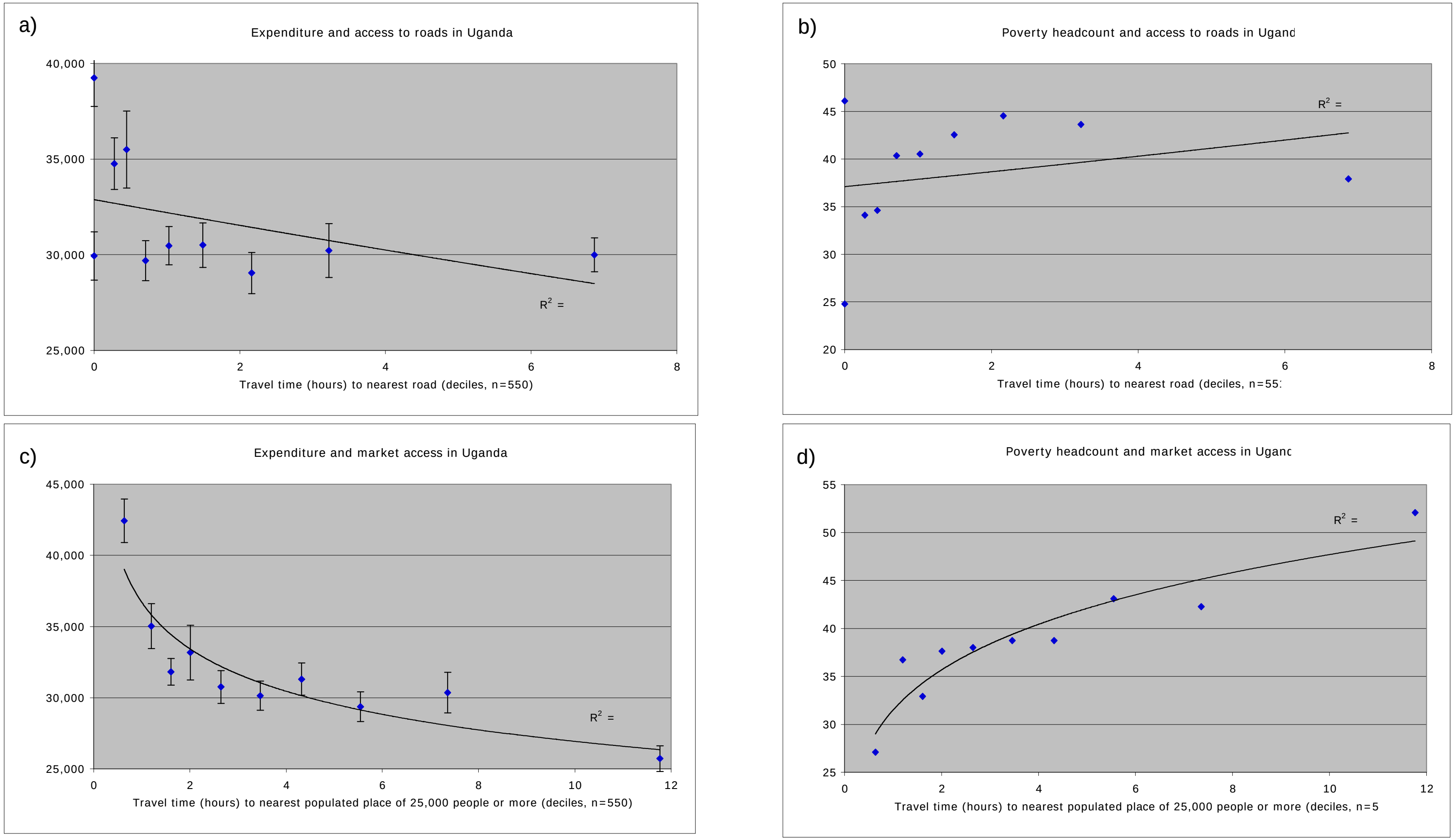
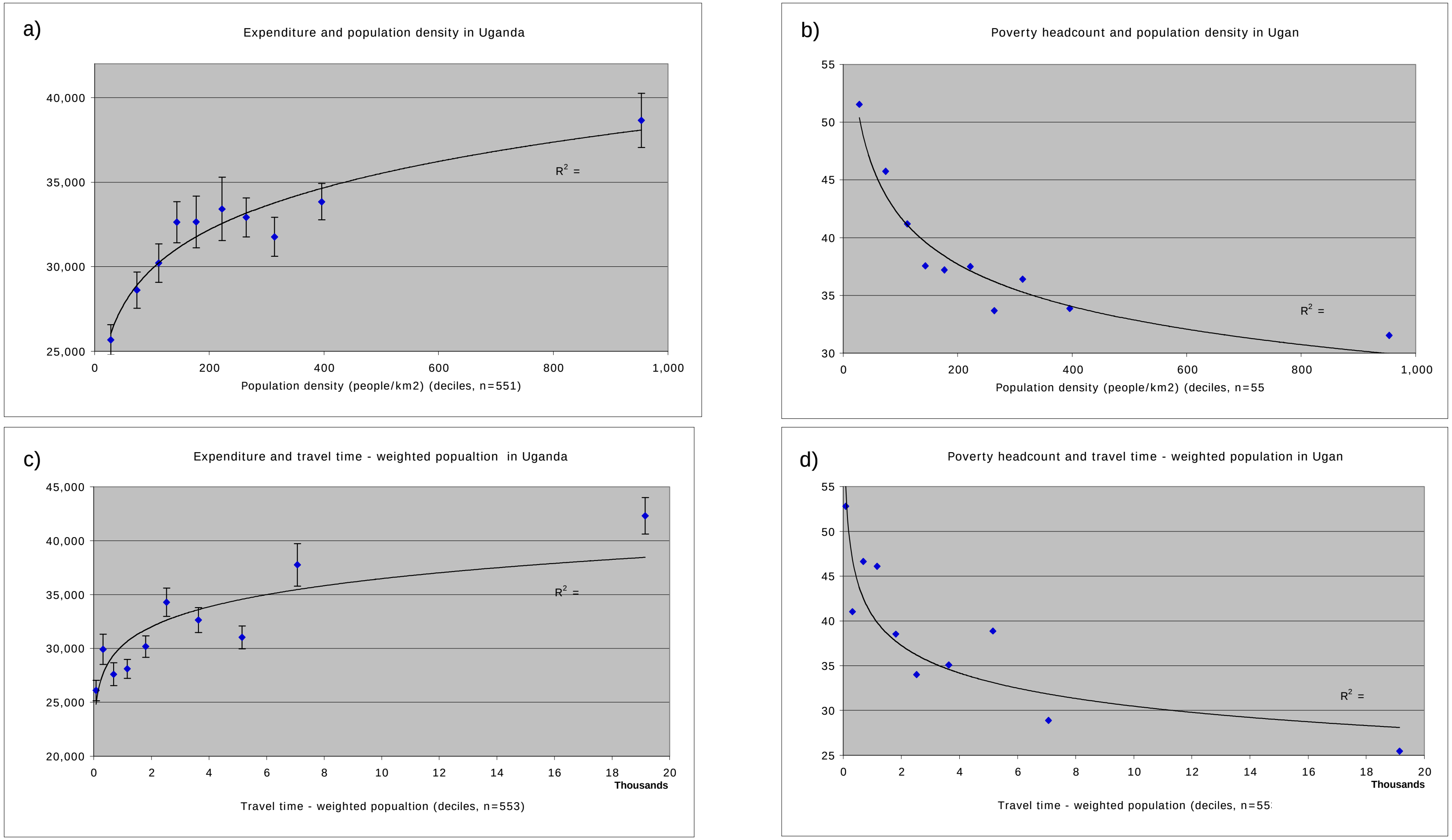


Figure 11: Relationships between estimates of welfare - mean monthly per adult equivalent expenditure (with standard errors shown) in the left hand graphs and poverty head count in the right hand graphs - and population-based accessibility measures in Uganda: rural population density (a and b) and travel time weighted population (c and d).



4. DISCUSSION

A number of observations can be made from the results presented in Figures 9-11 and in Table 2. The first striking factor is that proximity to roads is less important than proximity to what the road leads to: the markets or opportunities to interact. Simply being close to the transportation network is not sufficient. Factors that may result in this effect could include, for example, the sparsity of population centres, the poor quality of roads, and poor access to and high cost of transportation.

A further striking factor is that travel time estimates perform far better than distance estimates in terms of their correlation with welfare indicators. Travel time is essentially economic distance; it is a better representation of the real cost of travelling from A to B than is Euclidean distance and thus it may be a better indicator of the advantages of living in a given location, in terms of access to economic opportunities.

In this context some inferences may also be drawn from the results presented in Annex A. The comparative analysis shows welfare to be highly correlated with travel time to centres populated with between 15,000 and 50,000 people – 25,000 being chosen as optimal for reasons given in the annex, though the results are very similar for population centres in this range. This points away from the importance of very small, local population centres, and away from very large, national centres, but rather towards intermediately-sized centres of population as being important in terms of accessibility and poverty. These results show similar patterns to those found by other authors (e.g. Minot *et al.*, 2003; Minot, 2005; Farrow *et al.*, 2005; Epprecht *et al.*, 2009), who observed the best relationships between poverty and accessibility to occur with medium-sized towns or regional centres.

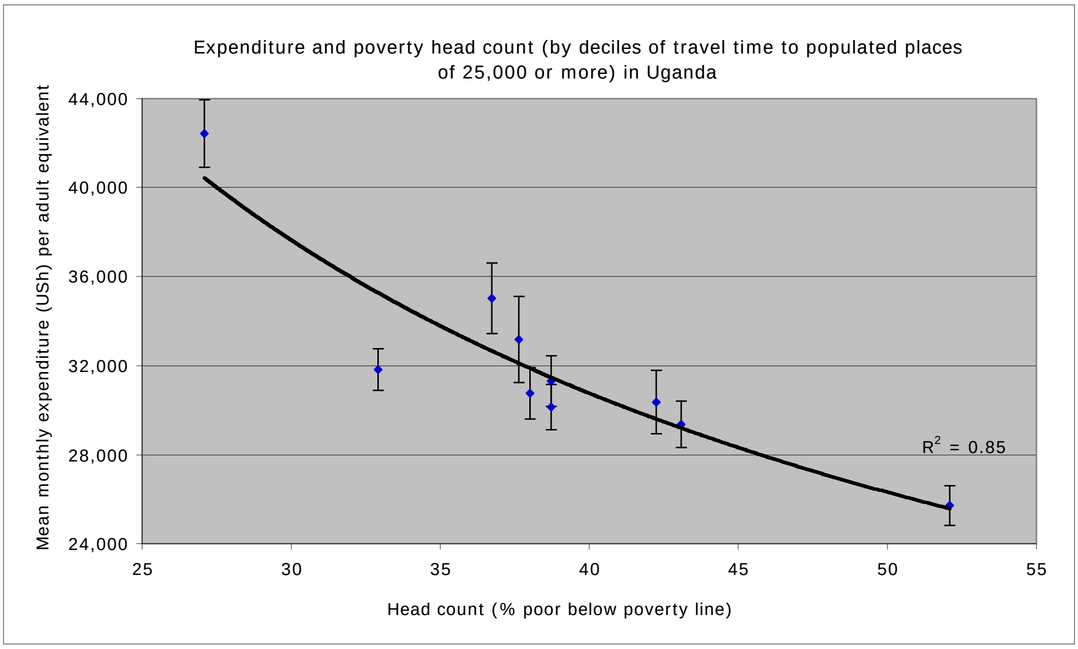
Both welfare estimates have the best average correlation with travel time to centres populated with more than 25,000 and more than 50,000 people and show a very characteristic pattern. The trend lines in Figures 10.c and 10.d (for the threshold of 25,000 people used in the analysis) show low poverty rates (< 30%) and high average monthly expenditures (c. 40,000 Ush per adult equivalent) for travel times of less than one hour. This deteriorates extremely rapidly to about two hours travel time, where poverty rates exceed 35% and average monthly expenditures have dropped to c. 33,000 Ush per adult equivalent. The decline in welfare continues, but more gradually, with increasing travel time: by 8 hours poverty rates are in the region of 45% and average monthly expenditures have dropped to less than 28,000 Ush per adult equivalent. The most dramatic changes in welfare with travel time are fairly immediate: people within an hour or so of populated centres are much better off than those more remotely placed. This confirms the general understanding that close proximity to markets could play an important role in poverty alleviation, and suggests that the development of smaller, regional markets is as influential if not more so than access to major urban centres. Indeed, since universal proximity to major centres is simply not possible, improving access to more local but important markets would appear to provide better options for poverty alleviation.

It came as some surprise that the actual rural population density performed considerably better than the travel time weighted aggregate population estimates within 4 hours travel time. We expected a stronger influence of the population in surrounding areas. One explanation may be that the distance weighted population estimates reflect the potential interaction, but perhaps this potential is not being fully realised or if it is then it does not result in tangible financial benefits. The distance weighted estimates are also strongly influenced by large concentrations of population, such as Kampala, and these may not be as important as interactions at smaller but more local markets. It may well be that the rural population does not participate strongly in these larger urban markets, which are possibly served mainly by industrial production systems and imported agricultural produce. Another explanation may be that our definition of accessibility is still too crude. Travel time is certainly a more relevant measure than distance, but a measure of the actual cost of travel from A to B would be better still to determine the "affluent population or even the surplus cash within x dollars travel cost of a location". Estimates of rural transport costs and its availability, i.e. what transport options are available to different proportions of the neighbouring population (possibly from census data) may paint a more realistic picture of the potential interactions.

What is very clear though, from these results, is that welfare is very highly correlated with population density. The trend lines in Figures 11.a and 11.b show high poverty rates, approaching 50%, and very low average monthly expenditures (c. 27,000 Ush per adult equivalent) in areas where population density is about 50 people km^{-2}. This situation improves rapidly as population densities increase to about 200 people km^{-2}, where rural poverty rates are down to about 38% and average monthly expenditures have increased to c. 32,000 Ush per adult equivalent. Welfare improvements continue as population density increases beyond 200 people km^{-2}, but more gradually.

In general, both for travel time and population-based indicators of accessibility, poverty head count provides somewhat better correlations to accessibility than does expenditure. One would expect these two welfare estimates to be correlated, and this indeed is seen, for example, in Figure 12 in which the correlation between the two measures is shown, plotted by decile of travel time to areas populated with 25,000 or more people. This correlation is not perfect, however, and nor would one expect it to be. For example, the poverty head count may be lower than what would be expected from average expenditure levels in situations where there is a high level of inequality and some households have high expenditures, pushing the average expenditure up in spite of a high proportion of households falling below the poverty line. Differences in the strength of correlation between the two welfare estimates used here, with respect to accessibility variables, are not great so it would be advisable to consider both, if available, and to use the results that are best suited to the purpose at hand. Advantages of using expenditure, for example, include that standard errors can be estimated and that it is a continuous monetary estimate of welfare so that factors such as aggregate purchasing power can be evaluated. The poverty head count has the advantage that it is a commonly used estimate, it is widely understood by policy makers, and it is readily applied to the population at large. Other aggregate indicators of welfare could also be evaluated for groups of households in different accessibility ranges, and some of these may be better suited to particular purposes. If, for example, it is important to account for differences in the degree of poverty among individuals, then 'poverty gap' indices may be estimated, as some function of the summed differences between the poverty line and the estimated expenditures of each household. Examples include the poverty gap index (Foster *et al.* 1984); the squared poverty gap index (Foster *et al.* 1984); the Sen index (Sen 1976); and the re-normalised Sen index (Shorrocks 1995).

Figure 12: Relationships between mean monthly per adult equivalent expenditure (with standard errors shown) and poverty head count in Uganda, by decile of travel time to populated places of 25,00 or more people.



5. CONCLUSIONS

A number of studies has examined the correlation between market access and poverty in different countries (e.g. Minot *et al.*, 2003; Farrow *et al.*, 2005; Minot, 2005; Dercon and Hoddinott, 2005; Bird *et al.*, 2007; Epprecht *et al.*, 2009), but the results have not always been clear, and also suggest that different relationships between welfare and market access may occur in different locations. Differences in the findings among the studies may also be methodological in origin - different definitions of what constitutes a market; different road coverages; different travel time algorithms; different geographical scales of analysis, for example. One interesting finding common to many of these studies, and also found here, is that poverty is more strongly correlated with travel time to medium-size towns, rather than to local markets or to large capitals (e.g. Minot *et al.*, 2003; Farrow *et al.*, 2005; Minot, 2005).

In Vietnam, Minot *et al.* (2003) and Epprecht *et al.* (2009) found a significant, albeit weak, correlation between poverty rates and proximity (distance and travel time) to small towns, but a much less significant one with proximity to large urban centres. Farrow *et al.* (2005) found that greater access to markets in Ecuador, at the district level, was associated with lower levels of food poverty, although only access to provincial capitals proved to be significant. In Tanzania, Minot (2005) found that rural poverty rates appeared to be closely related to the distance to regional centres and travel times to primary, secondary and tertiary towns. In Ethiopia, Dercon and Hoddinott (2005) explored the links between rural households and market towns using data from 15 rural villages and found that access to local market towns affected economic activity and welfare in rural areas and also that improved market access significantly increased consumption outcomes.

The results of this study, conducted at the household level, confirm some of these findings. Physical distance and travel time to markets are strongly correlated with poverty (both expenditure and poverty head count), while distance and travel time to roads appear to be much less so. The analysis shows very clear indications that people living closer to markets tend to be wealthier, and that this tails off rapidly with travel time, beyond about two hours. Population density shows an even stronger correlation with welfare in Uganda. These results reflect they key arguments of the 2009 World Development Report (World Bank, 2009), which states that "agglomeration", i.e. high density and proximity to markets, is a key driver for development, and that population density is the most important dimension at the local level, followed by distance to markets, while at the national level distance to markets becomes the most important factor.

This analysis clearly elucidates the relationships between welfare and market access in Uganda. Whilst causality is impossible to infer from such an analysis, and many factors that are correlated with one another may interact (market centres are likely to have evolved close to areas with high potential for agricultural production, for example), we have clearly demonstrated that the correlations between welfare and market access are dramatic in effect and statistically very strong. It seems reasonable and logical that improving access to people and to markets, for example by increasing the number of market and transportation infrastructures, should play an important role in defining strategies for poverty reduction. However, it would be difficult to isolate the likely effects of improving accessibility on poverty reduction. Whilst Hine and Riverson (1982), in a cross-sectional study of 33 villages in Ghana, found little evidence that agriculture was adversely affected by poor access, Dercon and Hoddinott (2005), using data from 15 villages in Ethiopia, found that improved market access did significantly increase consumption outcomes.

Here, we have produced regional accessibility maps for the IGAD region, related both to markets and to population, and demonstrated that these variables show very strong correlations with welfare, in Uganda at least. These variables should prove to be extremely valuable in mapping and analysing welfare across the region as a whole.

REFERENCES

Balk, D. and Yetman, G. 2004. The global distribution of population: evaluating the gains in resolution refinement. Working Paper, CIESIN, Columbia University. Palisades, NY. Available at http://sedac.ciesin.columbia.edu/gpw/docs/gpw3_documentation_final.pdf

Balk, D., Pozzi, F., Yetman, G., Deichmann, U. and Nelson, A. 2004. The distribution of people and the dimension of place: methodologies to improve the global estimation of urban extents. Working Paper, CIESIN, Columbia University. Palisades, NY. Available at http://sedac.ciesin.columbia.edu/gpw/docs/UR_paper_webdraft1.pdf

Benson, T., Chamberlin, J. and Rhinehart, I. 2005. Why the poor in rural Malawi are where they are: An analysis of the spatial determinants of the local prevalence of poverty. Food Consumption and Nutrition Division (FCND) Discussion Paper 198. Washington DC: International Food Policy Research Institute (IFPRI). Available at http://www.ifpri.org/publication/why-poor-rural-malawi-are-where-they-are-0

Benson, T., Epprecht, M. and Minot, N. 2007. Mapping where the poor live. 2020 Focus Brief on the World's Poor and Hungry People. Washington, DC: International Food Policy Research Institute (IFPRI).

Bibi, S. 2005. Measuring poverty in a multidimensional perspective: A review of literature. Poverty and Economic Policy PMMA Working Paper 2005-07.

Bigman, D. and Deichmann, U. 2000. Spatial indicators of access and fairness for the location of public facilities. In Bigman, D. and Fofack, H (eds.), 2000. Geographic targeting for poverty alleviation. Methodology and application. Washington, DC: World Bank Regional and Sectoral Studies.

Bird, K. and Shepherd, A. 2003. Livelihoods and chronic poverty in semi-arid Zimbabwe. World Development **31**, No 3, pp: 591–61.

Bird, K., McKay, A. and Shinyekwa, I. 2007. Isolation and poverty: the relationship between spatially differentiated access to goods and services and poverty. Paper presented at the International Workshop "Understanding and addressing spatial poverty traps", Stellenbosch, South Africa, 29 March 2007.

Bourguignon, F. and Chakravarty, S.T. 2003. The measurement of multidimensional poverty. *Journal of Economic Inequality*, **1**, pp: 25-49.

Center for International Earth Science Information Network (CIESIN), Columbia University; International Food Policy Research Institute (IFPRI); The World Bank; and Centro Internacional de Agricultura Tropical (CIAT). 2004. Global Rural-Urban Mapping Project (GRUMP), Alpha Version: Settlement Points. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw . (Downloaded on 10 May 2006).

Center for International Earth Science Information Network (CIESIN), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT). 2005. Gridded Population of the World Version 3 (GPWv3): Population Density Grids. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw . (Downloaded on 2 June 2008).

Chronic Poverty Research Center (CPRC), 2005. The chronic poverty report 2004-05. Manchester: Institute of Development Policy and Management/CPRC.

Crump, J.R. 1997. Teaching the political geography of poverty. *Journal of Geography*, **96**(2): 98-104.

De Smith M.J., Goodchild, M.F. and Longley, P.A. 2006. Geospatial Analysis. Troubador.

Deaton, A. and Zaidi, S. 2002. Guidelines for constructing consumption aggregates for welfare analysis. Living Standards Measurement Study Working Paper No. 135. Washington DC: the World Bank.

Deichmann, U. 1997. Accessibility Indicators in GIS. Department for Economic and Social Information and Policy Analysis. United Nations Statistics Division. pp 24.

Dercon, S. 2001. Assessing Vulnerability. Publication of the Jesus College and CSAE, Department of Economics, Oxford University.

Dercon, S. 2005. Poverty measurement, in Clark D. A. (ed.) The Elgar Companion to Development Studies (Edward Elgar).

Dercon, S. 2006. Rural poverty: Old challenges in new contexts. Oxford: Global Poverty Research Group Working Paper 72.

Dercon, S. and Hoddinott, J. 2005. Livelihoods, growth, and links to market towns in 15 Ethiopian villages. Food Consumption and Nutrition Division (FCND) Discussion Paper 194. Washington DC: International Food Policy Research Institute (IFPRI). Available at http://www.ifpri.org/publication/livelihoods-growth-and-links-market-towns-15-ethiopian-villages-0

Dixon-Fyle, K. 1998. Accessibility Planning and Local Development. Development Policy Department, International Labour Office, Geneva.

Emwanu, T., Okwi, P.O., Hoogeveen, J.G. and Kristjanson, P. 2003. Where are the poor? Mapping patterns of well-being in Uganda, 1992-1999. Kampala: Uganda Bureau of Statistics, 90 pp.

Environmental Systems Research Institute (ESRI). 2004. Arc/Info Help Documentation, ArcDoc version 9.0.

Epprecht, M., Heinimann, A., Minot, N., Müller, D. and Robinson, T. 2007. From statistical data to spatial knowledge – Informing decision making in Vietnam. *Information Development* **23,** 193-204.

Epprecht, M., Müller, D. and Minot, N. 2009. How remote are Vietnam's poor? An analysis of spatial patterns of poverty and inequality in Vietnam's society. Submitted to *Annals of Regional Science*.

Farrow, A., Larrea, C., Hyman, G. and Lema, G. 2005. Exploring the spatial variation of food poverty in Ecuador. *Food Policy* **30**, 510–531.

Foster, I. and Shorrocks, A. 1988. Poverty orderings. *Econometrica* **56**, 173-177.

Foster, I., Greer, I. and Thorbecke, E., 1984. A class of decomposable poverty measures. *Econometrica* **52**, 761-766.

Geertman, S.C.M. and Ritsema van Eck, J.R. 1995. GIS and models of accessibility potential: an application in planning. *International Journal of Geographic Information Systems* **9,** 67-80.

Ghosh M., and Rao, J.N.K. 1994. Small area estimation: an appraisal. *Statistical Science* **9,** 55- 93.

GLOBE Task Team and others (Hastings, D.A., P.K. Dunbar, G. M. Elphingstone, M. Bootz, H. Murakami, H. Maruyama, H. Masaharu, P. Holland, J. Payne, N.A. Bryant, T.L. Logan, J.P. Muller, G. Schreier, and J.S. MacDonald), eds., 1999. The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0. National Oceanic and Atmospheric Administration, National Geophysical Data Center, 325 Broadway, Boulder, Colorado 80303, U.S.A. Digital data base on the World Wide Web (URL: http://www.ngdc.noaa.gov/mgg/topo/globe.html) and CD-ROMs.

Government of Uganda, Ministry of Finance, Planning and Economic Development (MFPED), 2000. Uganda Partecipatory Poverty Assessment Report. Kampala, January 2000.

Government of Uganda, Ministry of Finance, Planning and Economic Development (MFPED), 2002. Deepening the understanding of poverty; Second Participatory Poverty Assessment Report. Kampala, December 2002.

Goodall, B. 1987. A Dictionary of Modern Human Geography. Penguin Books. England.

Handy, S.L. and Niemeier, D.A. 1997. Measuring accessibility: an exploration of issues and alternatives. *Environment and Planning A* **29,** 1175-1194.

Hentschel, J., Lanjouw, J.O., Lanjouw, P. and Poggi, J. 1998. Combining Census and Survey Data to Study Spatial Dimensions of Poverty. Policy Research Working Paper No. 1928, The World Bank Development Research Group and Poverty Reduction and Economic Management Network. Washington DC: The World Bank.

Hine, J.L. and Riverson, J.D.N. 1982. The impact of feeder road investment on accessibility and agricultural development in Ghana. Department for International Development, Transport Research Laboratory Report PA1122/82.

Jalan, J. and Ravallion, M. 1997. Spatial poverty traps? Policy Research Working Paper 1862. Washington DC: The World Bank.

Juliao, R.P. 1999. Measuring accessibility using GIS. Proceedings of GeoComputation99, Fourth International Conference on GeoComputation, Fredericksburg, USA, 25-28 July 1999.

Kristjanson, P., Radeny, M., Baltenweck, I., Ogutu, J. and Notenbaert, A. 2005. Livelihood mapping and poverty correlates at a meso-level in Kenya. *Food Policy* **30**, 568–583.

Kwan, M. 1998. Space-Time and integral measures of individual accessibility: A comparative analysis using a point-based framework. *Geographical Analysis*, **30**, no.3, pp. 191-216.

Mayaux, P., Bartholomé, E., Cabral, A., Cherlet, M., Defourny, P., Di Gregorio, A., Diallo, O., Massart, M., Nonguierma, A., Pekel, J-F., Pretorius, C. Vancutsem, C. and Vasconcelos, M. 2000. The Land Cover Map for Africa in the Year 2000, GLC2000 database, European Commission Joint Research Centre. http://www-gem.jrc.it/glc2000 (Downloaded on 10 May 2006).

Minot, N. 2005. Are poor, remote areas left behind in agricultural development: The case of Tanzania. Markets, Trade and Institutions Division (MTID) Discussion Paper No. 90. Washington DC: International Food Policy Research Institute (IFPRI). Available at http://www.ifpri.org/publication/are-poor-remote-areas-left-behind-agricultural-development

Minot, N., Baulch, B. and Epprecht, M. 2003. Poverty and Inequality in Vietnam: Spatial patterns and geographic determinants. Hanoi: International Food Policy Research Institute and Institute for Development Studies.

Nelson, A. 2000. Accessibility, transport and travel time information. *CIAT Hillsides Project Report*. Available at http://gisweb.ciat.cgiar.org/cross_scale/download/2.5_web.pdf

Nelson, A. 2004. African Population Database Documentation. Available online at http://www.na.unep.net/globalpop/africa/

Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W. 2005. Geographic Information Systems and Science (second edition). Chichester: Wiley. pp. 517.

Okwi, P.O., Ndeng'e, G., Kristjanson, P., Arunga, M., Notenbaert, A., Omolo, A., Henninger, N. Benson, T., Kariuki, P. and Owuor, J. 2007. Spatial determinants of poverty in rural Kenya. *PNAS* **104,** 16769-16774.

Pozzi, F. and T. Robinson, 2008. Accessibility mapping in the Horn of Africa: Applications for livestock policy. IGAD LPI working paper No.11-08. Available at http://www.igad-lpi.org/publication/working_papers.htm

Ravallion, M. 1996. Issues in measuring and modeling poverty. *Economic Journal* **106,** 1328-1343.

Ritsema van Eck, J.R., and de Jong, T. 1999. Accessibility analysis and spatial competition effects in the context of GIS-supported service location planning. *Computers, Environment and Urban Systems* **23**:75.

Robinson, T., Emwanu, T. and Rogers, D. 2007. Environmental approaches to poverty mapping: an example from Uganda. *Information Development* **23,** 205-215.

Rogers, D. 2003. Using satellite data to map poverty and disease burdens. Proceedings of EthioForum 2002 Conference, Addis Abeba, January 2002.

Rogers, D., Emwanu, T. and Robinson, T. 2006. Poverty mapping in Uganda: An analysis using remotely sensed and other environmental data. PPLPI Working Paper No. 36. Rome: Food and Agriculture Organization of the United Nations.

Roy, J. R. 2004. Spatial interaction modelling: A regional science context. Springer.

Sen, A. (1976) Poverty: an ordinal approach to measurement. *Econometrica* **46,** 437-446.

Shinyekwa, I., Bird, K. and Okidi, J. 2003. Spatial differentiation in access to goods and services in Uganda. DRAFT Chronic Poverty Research Centre Working Paper. Manchester: Institute of Development Policy and Management/CPRC.

Shorrocks, A. (1995) Revisiting the Sen poverty index. *Econometrica* **63,** 1225-1230.

Uganda Bureau of Statistics (UBOS). 2003. National Household Survey 2002/2003. Report on the Socio-economic survey.

United Nations Development Programme (UNDP) International Poverty Center (IPC). 2006. What is poverty? Concept and measures. Poverty in Focus, December 2006.

United Nations Environment Programme (UNEP) and Center for International Earth Science Information Network (CIESIN), Columbia University. 2004. Africa Population Distribution Database, online at http://grid2.cr.usgs.gov/globalpop/africa/index.php3 accessed on 20 may, 2007.

Wilson, A.G. 1971. A family of spatial interaction models, and associated developments. *Environment and Planning A* **3,** 1-32.

World Bank. 2003. Measuring living standards: Household consumption and wealth indices, quantitative techniques for health equity analysis. Technical Note # 4. Washington DC: The World Bank.

World Bank. 2009. World Development Report 2009: Reshaping Economic Geography. Washington DC: The World Bank.

Yao, X. 2003. Infrastructure and poverty reduction – making markets work for the poor. Economic and Research Department Policy Brief No. 14. Manila: Asian Development Bank.

You, L. and Chamberlain, J. 2004. Spatial analysis of sustainable livelihood enterprises of Uganda cotton production. Environment and Production Technology Division (EPTD) Discussion Paper No. 121. Washington DC: International Food Policy Research Institute (IFPRI). Available at http://www.ifpri.org/publication/spatial-analysis-sustainable-livelihood-enterprises-uganda-cotton-production

ANNEX A: WELFARE AND ACCESS TO MARKETS

Accessibility models are highly dependent on the distribution of the selected targets which, in this case, depends on the population threshold selected above which a populated place is included as a 'market'. By varying the threshold, the distribution and number of markets and thus the distance and time to access them will vary considerably. We investigated the effect of 'market size' by looking at the correlations between household expenditure and poverty head count, with travel time to populated places of different sizes.

Different markets datasets were produced by selecting places populated by at least 5,000 (n = 64); 10,000 (n = 47); 15,000 (n = 32); 20,000 (n = 23); 25,000 (n = 19); 50,000 (n = 10); 100,000 (n = 2); and 250,000 (n = 1) people. For each market dataset travel time to the nearest populated centre was estimated for each 1 km grid square in Uganda, using the methods described in the main body of paper. Values of household expenditure and travel time to markets were extracted for the 5,532 (see Footnote 2) rural households from the 2002/2003 Uganda National Household Survey (UNHS), using each threshold. Households were ranked by travel time, separately for each market dataset, and divided into deciles. For each decile the average of the accessibility measure was calculated and, against this, was plotted a) the average consumption expenditure per adult equivalent (for which standard errors were estimated), and b) the aggregate head count index. Power trend lines were fitted in each case and R^2 values used to estimate the goodness of fit of the data to the trend lines.

Table A1 shows the coefficients of determination (R^2) between household expenditure and poverty head count against travel time to populated places. Figure A1 shows these coefficients of determination graphically, for each market dataset. Figures A2 and A3 show, respectively, household expenditure and poverty head count plotted against travel time to populated places.

The R^2 values show the correlations between welfare and accessibility to vary considerably depending on the chosen threshold of population size. The strength of the correlation increases rapidly with market size (determined by population thresholds) going from 5,000 to 15,000; then increases only gradually (with very little difference) going from 15,000 to 50,000; and then deteriorates with population thresholds greater than 50,000.

From this analysis it is evident that welfare is highly correlated with travel time to centres populated with between 15,000 and 50,000 people. These results show similar patterns to those found by other authors (e.g. Minot *et al.*, 2003; Minot, 2005; Farrow *et al.*, 2005; Epprecht *et al.*, 2009), who found the best relationships between poverty and accessibility when considering medium-sized towns or regional centres.

In general the poverty head count produced better correlations than average expenditure. Overall, taking average values of R^2 for both expenditure and poverty head count, market sizes of 25,000 and 50,000 people gave the best correlations. Of these, the smaller threshold of 25,000 people was favoured because a) it included a greater number of market centres and b) because it performed best in terms of correlation with household expenditure – which is the welfare indicator that has been used in the environmental approach to poverty mapping (Rogers et al., 2006; Robinson et al., 2007).

In all cases, however, there are very clear indications that welfare reduces rapidly as market access becomes worse.

Table A1: Coefficients of determination (R^2) between household expenditure and poverty head count against travel time to populated places in Uganda.

Populated places (>)	n	Coefficient of determination (R^2)		
		Expenditure vs travel time	Head count vs travel time	Average
5,000	64	0.53	0.58	0.56
10,000	47	0.60	0.68	0.64
15,000	32	0.80	0.85	0.83
20,000	23	0.76	0.86	0.81
25,000	19	0.83	0.87	0.85
50,000	10	0.81	0.89	0.85
100,000	2	0.70	0.67	0.69
250,000	1	0.79	0.79	0.79

Figure A1: Plots of the coefficients of determination (R^2) between household expenditure and poverty head count against travel time to populated places in Uganda.

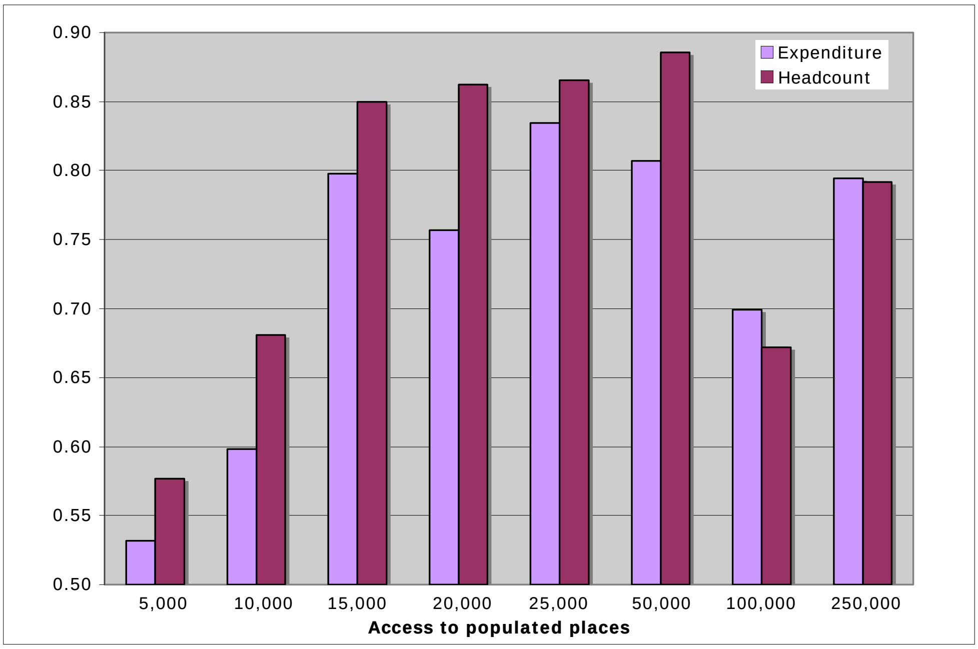


Figure A2: Travel time to populated places of different thresholds plotted against household expenditure (with standard error shown) in Uganda.

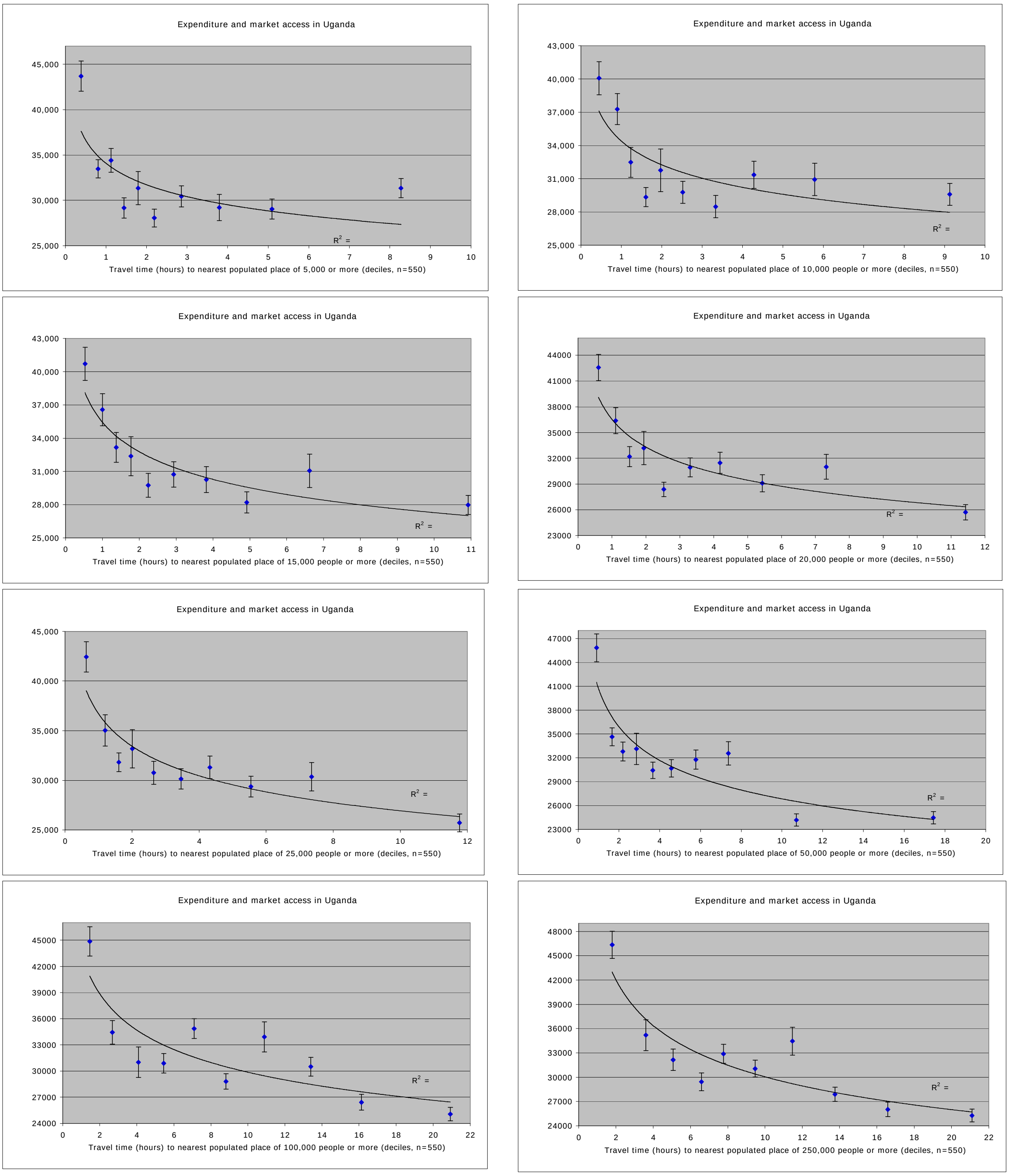


Figure A3: Travel time to populated places of different thresholds plotted against poverty head count in Uganda.