Transport in a congested city:

A computable equilibrium model applied to Kampala City

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Abstract: This paper develops and applies a quantitative model of internal city structure to analyse the impacts of transport improvement in Kampala, Uganda. Using a Spatial Computable General Equilibrium Model we develop a simulated version of a city in which firms and households choose their location decisions according to the cost of commuting and transporting goods across the urban space. In a rapidly developing city, with congested transport infrastructure, new and improved transport routes lead to both direct and indirect effects for the city’s residents. The model captures the direct impacts of transport changes on commuting times, and the indirect impacts on the price of goods and services, rents, and wages. It also captures the important long-term impacts on land use within the city, as both firms and residents adjust their location choices in response to these price changes, leading to greater economic benefits of transport investments through economies of scale and agglomeration effects. The results show that transport investments that increase speeds of travel within the city result not only in an increase in the welfare of these directly affected residents, but also on residents without access to vehicles. The relative size of the impacts on these two groups vary according to the location of the transport investment, the ease with which firms and residents can relocate across the urban space, and the size of the agglomeration effects for different industries within the city.

Keywords: city, urban, urban growth, transport, congestion, computable equilibrium.

JEL classification: O14, O18, R1, R3, R4

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1. Introduction

Kampala, in common with many other developing country cities, faces acute transport problems. The population of Kampala has increased from just 775,000 in 1990 to around 1.9 million today, and the wider city, known as the Greater Kampala Metropolitan Area (GKMA), is estimated to be home to over 4 million people. This growth has no signs of slowing; the UN predicts that the population will more than double again by 2030. The increase in population brings with it an increasing demand for urban transport. The Ministry of Transport estimates that 40% of journey times within the city during rush hour are spent at standstill. As the demand for transport within the city is expected to rise both with the increase in population and with increasing incomes, without substantial investments in urban infrastructure, these conditions can only be expected to worsen.

Transport problems of this magnitude are likely to have major implications for the overall economic performance of the city. ‘Connectivity’ – firm-to-worker, firm-to-firm, and firm-to-consumer – is reduced, and with it both the livability and productivity of the city. The objective of this paper is to explore these implications. The tool we use is a computable spatial general equilibrium model, designed to capture features of a city in a developing economy, and applied to Kampala city. For the 96 parishes in the city, together with combined areas outside the city, we have data on variables including residence by educational attainment and occupation, as well as employment by sector and skill. We calibrate the model to this data, inferring patterns of movement of people, goods and services. Transport improvements change the costs of movement, and we study the impact of these changes on wages, prices, real incomes, and the long-run location of firms and households. Improvements bring direct benefits – savings in travel costs to users of affected routes. We quantify these and, more importantly, look at the induced changes in behaviour that flow from them. We thereby present results both for constant land-use, and for the wider effects that occur as the city reorganises itself in response to better connectivity, this potentially leading to fuller benefit from economies of scale and agglomeration.

We look at two major experiments to reduce congestion in the city. First, the recent development of a Northern Bypass around the city, increasing the speed of connection between western and eastern parishes, and increasing access for parishes along and near the bypass.
route. Second, the improvement of the existing road network resulting in increased travel speeds along major axes within the city.

The results show substantial impacts of both experiments on the utility of urban residents. The direct effect of the urban transport improvements are focused on those with access to motorized transport whose commuting costs decrease. Other residents immediately receive some indirect benefit through decreased prices reducing the cost of living. In the medium term however, as population begins to relocate across the urban space, the effects are more widely felt, and utility increases are felt among all urban residents. High-income residents can locate further from their jobs as the commuting speeds are faster, reducing the pressure on land nearer the jobs and allowing low-skilled workers to move in, increasing their connectivity and reducing their commuting costs.

In the long term, as firms and people are able to update their location decisions, the full benefits of the experiments are felt. The effects are often substantially higher than the short term impacts; the long-term improvement in total urban welfare is up to 8 times as high as the short term effect following the construction of the Northern Bypass, and 3 times as high for the improvements to the existing transport network. The ease with which firms can chose to relocate across space therefore has a large role in whether or not the full benefits of transport projects can be achieved.

Of particular note are the increased utilities both for residents directly using the transport project and other residents within the urban space. In fact, low-income residents may under some circumstances experience greater welfare growth that high-income residents following the construction of a bypass or other road improvements. With agglomeration effects, improved connectivity within the city allows firms to better reap the benefits of economic density, boosting total factor productivity. In line with a recent study by Duranton (2015), we impose stronger agglomeration effects within the informal sector. If this were the case, the increased clustering in the provision of local services following a transport improvement boosts productivity within this sector, and in turn, wages of low-skilled workers who are intensely employed in local service provision. This wage effect can lead to utility gains that surpass those felt by the high-skilled workers with direct access to the improved roads.

These results suggest the importance of looking beyond the direct users of transport projects when measuring their potential impacts. The wider benefits of transport improvements (and
conversely, costs of neglecting infrastructure and increased congestion) may be felt right across the urban area. The location of the project at stake, the ease with which firms and people are able to relocate across the urban space, and the size of agglomeration effects within industries in the particular city will all influence the beneficiaries of the project and the scale of their welfare gains.

We should emphasise that our results are not predictions on the effects of actual policy changes. They are illustrative of the sorts of changes that can be brought about by transport improvements (and conversely, the damage caused by poor transport systems), and of the factors that are key in determining the costs and and benefits of transport improvements. They highlight that the benefits of a specific transport improvement may be felt beyond the direct users, and that the spatial pattern of land use within a city is crucial in understanding how a transport project may influence economic outcomes.

The paper is organised as follows. Section 2 of the paper sets out the model; 2.1 provides a descriptive overview, before the concise but complete technical statement of the general form in 2.2. This may be omitted by readers whose interest is primarily the application. Section 3 outlines the data we use and provides further information on Kampala city. Section 4 gives the results of our two principal applications of the model, the Northern Bypass construction, and a general urban road improvement program, along with the combination of both projects. Section 5 concludes.

2. The computable equilibrium model.

2.1 Model outline: The model is based on dividing the city under study into a number of geographical units or cells, each of which can contain residential and productive activity. There are several different types of household (differentiated according to skill), and two different types of housing – formal and informal. There are multiple production sectors, differentiated according to aspects including tradability of output, input composition, firm scale, and propensity to agglomerate. All households and firms make location decisions, competing for scarce land and hence determining land rents across the city. Households’ location decisions are based on income opportunities (proximity to jobs, given commuting costs), the costs of goods and services, the cost of housing, and location specific amenity parameters. Producers’ location decisions are driven by the cost and proximity of inputs (labour and intermediates),
access to markets (more important the less readily tradable their output), the cost of land, and location-sector specific productivity parameters.

The equilibrium solves for prices and the ensuing choices of households and producers such that supply equals demand for labour, goods, services, and land. Thus, the choice of place of residence and place of work is endogenous, with prices (that of land in particular) adjusting in response to demand for space. In some of the cases we study\(^1\), the allocation of land between alternative uses is not necessarily ‘perfect’; i.e. even within a cell, land rents earned by different types of land use (commercial, formal or informal residential) are not necessarily equalised.

‘Connectivity’ enters the model in three distinct ways. First, workers travel from place of residence to place of work, this being more costly (and more time consuming) the further the journey and the worse the roads along which they travel; it also depends on transport mode (motorised or walking), which we assume to be a function of income\(^2\). Second, goods and services have to be delivered from firms to households, the costs of which vary across sectors according to the tradability of their output. Third, in some variants of the model we allow for agglomeration economies, i.e. positive productivity spillovers between firms, the strength of which depends on their proximity. The transport experiments we look at in this paper are assumed to have their direct impact only on motorised commuting and the cost of moving goods and services.

Application of the model involves two stages, calibration and simulation. Simulation involves taking the complete model, changing parameters (such as transport costs) and re-computing the equilibrium. These are the experiments that we report in section 4. A prior stage is calibration. This involves taking some parameters from secondary sources (e.g. some details of technology or preferences) and calibrating others (productivity and amenity values) such that the model exactly fits the base data that we have available. This data is discussed in section 3. The remainder of this section sets out the technical ingredients of the general model.

\(^1\) In this paper, we focus on the case where there is perfect allocation of land between firms and residents at equilibrium. However, in the short term, as people and firms slowly adjust to price changes, misallocations of land may still arise.

\(^2\) In the application in this paper, for simplification, high-skilled workers have access to motorized transport, and low-skilled works can walk, with no cross-over between the two groups.
2.2 Model specification

**Geography:** The city contains $I + 1$ geographical cells, labelled by subscripts $i, j$. Of these, $I$ are in the city and one (denoted 0) is the rest of the world. The area of cell $i$ is $G_{i}$. Cells differ in their connection to the transport network, their amenity value and their productivity values. Households and firms are distributed endogenously across these cells, and a matrix of ‘distances’ links cells. This matrix underpins different sorts of distance costs – for commuting, for shipping goods, and for the spatial decay of productivity spillovers.

**Product differentiation and production:** There are $S$ productive sectors, labelled by superscripts $s = 1, 2 ... S$. These are all monopolistically competitive, producing differentiated products as modelled by Dixit-Stiglitz.\(^3\) Thus, the number of active firms in sector $s$ at cell $i$ is $n_i^s$. Each charges producer price $p_i^s$, and shipping output from cell $i$ to $j$ incurs iceberg trade cost factor $T_{ij}^s$ which varies according to the sector. Products from the rest of the world arrive at price $p_0^s$ and have $n_0^s$ varieties. The elasticity of substitution between varieties in sector $s$ is $\sigma^s$ and each cell, $j$, is potentially supplied from all cells. The CES price index for sector $s$ products delivered to cell $j$ is therefore,

$$P_j^s = \left[ \sum n_i^s (p_i^s T_{ij}^s)^{-\sigma^s} + n_0^s (p_0^s)^{-\sigma^s} \right]^{1/(1-\sigma^s)}.$$  

(1)

Demand for a single sector $s$ variety produced in $i$ and sold across all cells $j$ is $x_i^s$, given by

$$x_i^s = \sum_j (p_j^s)^{-\sigma^s} (T_{ij}^s)^{-\sigma^s} E_j^s (P_j^s)^{\sigma^s - 1}$$

(2)

where $E_j^s$ is cell $j$ expenditure on sector $s$.

Each cell $i$ sector $s$ firm maximises profits, $\Omega_i^s = p_i^s x_i^s - c_i^s \left[ x_i^s + F^s \right]$, where the second term is cost of production, with constant marginal cost $c_i^s$ and fixed cost $c_i^s F^s$. Profit maximising price is a constant mark-up over marginal cost,

\(^3\) This section draws on the standard properties of the multi-location Dixit-Stiglitz model of competition. Details and derivations are in Fujita et al. (1999).
\[ p_i^s = \sigma^s c_i^s l(\sigma^s - 1). \]  

(3)

Firms make zero profits if they sell a fixed level of output \( \bar{x}^s = F^s(\sigma^s - 1). \) Free entry and exit of firms gives condition:

\[
\text{If } n_i^s > 0, \quad x_i^s = \bar{x}^s, \quad \text{else } n_i^s = 0, \quad x_i^s < \bar{x}^s. \tag{4}
\]

Costs \( c_i^s \) are a Cobb-Douglas function of prices of intermediates, land and labour. Intermediates are composite goods with price indices \( P_i^s. \) There are different sorts of labour, indexed by superscript \( \ell \) and with wage rates \( w_i^\ell. \) The price of commercial land is \( R_i, \) so the sector \( s \) cost function in cell \( i \) is

\[
c_i^s = \frac{1}{a_i^s} (R_i)^{\alpha_{ss}} \prod_{j} (w_j^\ell)^{\alpha_{\ell\ell}} \prod_{z} (P_z)^{\alpha_{zz}}. \tag{5}
\]

Exponents in this expression sum to unity. The productivity of each sector in each place is captured by \( a_i^s. \) This is a sector-cell specific shift factor \( A_i^s \) together with possible sector-specific agglomeration economies which depends on the number of firms in the sector, weighted by some measure of proximity, \( \theta_{ij}^s, \) so

\[
a_i^s = A_i^s \cdot f \left( \sum_j \theta_{ij}^s n_j^s \right). \tag{6}
\]

It follows from this structure that each sector’s supply and demands are as follows:

- **Value of output supplied by cell \( i: \)** \( p_i^s n_i^s x_i^s \)
- **Value of intermediate \( s \) demanded in cell \( i: \)** \( \alpha^s p_i^s n_i^s x_i^s \)
- **Value of labour type \( \ell \) demanded in cell \( i: \)** \( \alpha^\ell p_i^s n_i^s x_i^s \)
- **Value of commercial land demanded in cell \( i: \)** \( \alpha^{Gs} p_i^s n_i^s x_i^s \)

**Households:** There are different types of households (=workers) indexed by \( \ell, \) and the city population of households of type \( \ell \) is \( L^\ell. \) These households choose consumption bundles, and also make discrete choices of where to live (cell \( i), \) work (cell \( j), \) and what sort of housing to occupy (type \( h). \) Household utility is given by
\[
\begin{align*}
\mathbf{u}_{ij}^{\ell} &= (w_{ij}^\ell + m_{ij}^\ell)\mathbf{B}_{ij}^\ell t_{ij}^\ell \left[ (q_{ij}^\ell)^{\beta_1} \cdot \prod_s (p_{ij}^s)^{\beta_s} \right].
\end{align*}
\]  

(7)

The first element in the numerator is income, with wage income depending on labour type and place of work, \(w_{ij}^\ell\), whilst allowing for other income transfers to be more general, \(m_{ij}^\ell\). The second term, \(B_{ij}^h\), is the amenity value of living in housing of type \(h\) in location \(i\), so that \(B_{ij}^h = z_i h^h\), a combination of a local amenity value and a housing quality value. The third term, \(t_{ij}^\ell\), represents commuting costs, again different for different worker types (some walk, others drive); these costs impact utility directly, thus \(t_{ij}^\ell \leq 1\), smaller the greater the distance travelled. The denominator is the price index. This is Cobb-Douglas across goods and housing, where the price of a unit of housing space of type \(h\) in cell \(i\) is \(q_{ij}^h\). Exponents sum to unity, and we add generality by allowing these shares to depend on both housing type and household type.

Individuals choose where to live and work and how to be housed. These discrete choices are captured by a logistic choice function giving the probability that an individual of type \(\ell\) living in \(i\) will work in \(j\) and live in house type \(h\), \(\pi_{ij}^{\ell h}\).

For each \(\ell\):

\[
\pi_{ij}^{\ell h} = \exp (\lambda u_{ij}^{\ell h}) / \left\{ \sum_h \sum_i \sum_j \exp (\lambda u_{ij}^{\ell h}) \right\}, \quad \sum_h \sum_i \sum_j \pi_{ij}^{\ell h} = 1. \tag{8}
\]

This is implemented by having just two types of housing, \(h = 1, 2\). Thus, if total city population of workers of type \(\ell\) is \(L^\ell\), the number living in houses of type \(h\) in cell \(i\) is \(L_i^{\ell h} = L^\ell \sum_j \pi_{ij}^{\ell h}\), and the total number working in cell \(j\) is \(L_j^\ell = L^\ell \sum_h \left( \pi_{ij}^{\ell 1} + \pi_{ij}^{\ell 2} \right)\).

Given the total number of households of each type, the wages and prices they face, and their location choices, consumer demand for goods and housing and their supply of labour are:

For each \(\ell\):

Value of demand for sector \(s\) in cell \(i\):

\[
L^\ell \sum_j \left( \pi_{ij}^{\ell 1} \beta_{s}^{\ell 1} + \pi_{ij}^{\ell 2} \beta_{s}^{\ell 2} \right)(w_{ij}^\ell + m_{ij}^\ell)
\]

Value of demand for housing type \(h\) in cell \(i\):

\[
L^\ell \sum_j \pi_{ij}^{\ell h} (w_{ij}^\ell + m_{ij}^\ell)
\]

Supply of labour in cell \(j\):

\[
L_j^\ell = L^\ell \sum_h \left( \pi_{ij}^{\ell 1} + \pi_{ij}^{\ell 2} \right)
\]
**Housing, construction and land allocation:** Housing of type \( h \) at location \( i \) provides \( g_i^h \) units of housing space per unit land area (so \( g_i^h \) is the floor area ratio; we will sometimes refer to it as height). Construction costs per unit land are \( c_i^h \left( g_i^h \right)^{\gamma^h}, \gamma^h > 1, \ h = 1, 2 \). The distinction we seek to capture between the two house types is that between formal \((h = 1)\) and informal \((h = 2)\). The former has higher cost level \( c_i^h \), but lower elasticity of cost with respect to height, \( \gamma^h \).

The two types may also yield different amenity values \( B_i^h \) (preceding subsection). If the land rent (per unit land) earned on housing of type \( h \) in cell \( i \) is \( R_i^h \) then the price of a unit of housing, \( q_i^h \), is given by

\[
q_i^h = \left\{ R_i^h + c_i^h \left( g_i^h \right)^{\gamma^h} \right\} / g_i^h . \tag{9}
\]

The proportion of area \( \bar{G}_i \) that is built with residential type \( h \) is denoted \( \psi_i^h \), so the supply of housing of type \( h \) in cell \( i \) is \( \bar{G}_i \psi_i^h g_i^h \). Equating the value of supply and demand for housing, \( \psi_i^h \) solves

\[
q_i^h \bar{G}_i \psi_i^h g_i^h = \sum_j \sum_{\ell} L_{\ell j} \sum_{j} \pi_{ij}^{\ell h} \beta_{ij}^{\ell h} \left( w_i^\ell + m_{ij}^\ell \right) . \tag{10}
\]

Equations (9) and (10) can be thought of as giving values of \( q_i^h \) and \( \psi_i^h \), given \( R_i^h \) and \( g_i^h \).

Rents, \( R_i^h \), come from land market clearing. Commercial demand for land is given above, so adding residential use and equating supply and demand gives

\[
\bar{G}_i = \sum_{\ell} \alpha_{\ell}^{Gs} n_i^\ell p_t^\ell x_t^\ell / R_i + \sum_{h} \bar{G}_i \psi_i^h . \tag{11}
\]

If land markets are perfect then land rents are equalised across all uses, \( R_i^h = R_i \), for all \( h \). We allow for the possibility of institutional and other barriers by imposing parameter \( \Psi_i^h \) measuring the rent premium to housing of type \( h \) relative to commercial use, in which case

\[
R_i^h = \Psi_i^h R_i \quad \text{(complementary slack with } \psi_i^h) . \tag{11'}
\]
Residential space per unit land, $g_i^h$, may be set by regulation or by free market optimisation. If the latter, it is chosen to maximise rents per unit land, $R_i^h = q_i^h g_i^h - c_i^h (g_i^h)^{y_i}$, giving first order condition

$$g_i^h = \left( q_i^h / c_i^h \right)^{y_i / (y_i - 1)} .$$  \hspace{1cm} (12)

Equations (9) – (12) give the housing and land allocation part of the model, i.e. house prices, $q_i^h$, land rents $R_i^h$, shares of each cell used by houses of each type, $\rho_i^h$, and the floor space of houses, $g_i^h$.

Construction also creates demand for inputs from the rest of the economy. Construction uses labour and intermediate inputs and is Cobb-Douglas so unit cost $c_i^h$ is

$$c_i^h = K_i^h \prod_\ell \left( w_\ell^i \right)^{\mu^h_\ell} \prod_s \left( P_s^i \right)^{\mu^h_s}$$  \hspace{1cm} (13)

where exponents sum to unity and parameter $K_i^h$ is the cost parameter. The derived demands that come from this are:

The value of cell $i$ construction sector demand for inputs in sector $s$: $G_i \sum_h \rho_i^h \mu^h c_i^h (g_i^h)^{y_i}$

The value of cell $i$ construction sector demand for labour of type $\ell$: $G_i \sum_h \rho_i^h \mu^h c_i^h (g_i^h)^{y_i}\ell$

**Profits, rent and government:** To close the model we need to distribute firms’ profits and land rents to households. For this baseline version of the model we make the simple assumption that this income is distributed to households in a lump sum manner. This gives a value for the ‘other income’ of each household, $m_{ij}$. The simplest form is equal division,

$$m_{ij} = m = \left[ \sum_n \sum_s n_s^i \Omega_i^s + \sum_h G_i \left( R_i (1 - \sum_h \rho_i^h) + \sum_h R_i^h \rho_i^h \right) \right] \sum_i L_i .$$  \hspace{1cm} (14)

The first term in square brackets is total profits (equal to zero in the full equilibrium), and the other terms are commercial and residential land rents.

In future versions of this model government will be added, spending money on goods and services and raising revenue from a variety of tax instruments.
**Equilibrium and market clearing:** Demand for goods, land and labour comes from households, firms, the construction sector and (for goods) also ‘exports’ from the city. Thus, the value of spending on sector $s$ products at location $i$ is $E_{i}^{s}$,

\[
E_{i}^{s} = \sum_{i} L_{i}^{f} (w_{i}^{f} + m_{i}^{f}) \sum_{i} \left( \pi_{i}^{f1} \beta^{f1} + \pi_{i}^{f2} \beta^{f2} \right) + \sum_{i} \alpha \xi_{i} n_{j}^{s} p_{j}^{s} x_{i}^{s} \\
+ \bar{G}_{i} \sum_{h} \psi_{i}^{h} \mu_{i}^{h} c_{i}^{h} \left( g_{i}^{h} \right)^{h} + X(p_{i}^{f})
\] (15)

The terms are final demand, intermediate demand, demand from the construction sector, and a function giving the value of export demand as a decreasing function of price. Market clearing equates this to the value supplied, as given by the production sector, equations (1) – (4).

For each type of labour, the value of demand comes from firms and the construction sector,

\[
w_{i}^{f} L_{i}^{f} = \sum_{i} \alpha \xi_{i} n_{j}^{s} p_{j}^{s} x_{i}^{s} + \bar{G}_{i} \sum_{h} \psi_{i}^{h} \mu_{i}^{h} c_{i}^{h} \left( g_{i}^{h} \right)^{h}.
\] (16)

Market clearing equates this with the spatial allocation of labour, as described above.

**Calibration and simulation:** Equations (1) – (16) contain 16 types of endogenous variables, and the solutions of these equations give the equilibrium of the model. Thus, given the functional forms outlined above, estimates of elasticities/factor shares, productivity and amenity parameters, and geography (cell areas and the distance decay matrices) the solution of the model gives values of all the endogenous variables, i.e. the locations of firms and households, their supplies and demands, and equilibrium prices, incomes, and utilities.

The calibration process works in the reverse direction. Given observations on firms and households and estimates of some parameters (typically elasticities/factor shares and some aspects of geography), calibration solves for values of the productivity and amenity parameters that make the model solution consistent with observed values.
3. Data and Background

The availability of high quality data at a highly disaggregated level enables us to calibrate this model of Kampala District and the Greater Kampala Metropolitan Area (GKMA).

Population and households: Figure 1 below shows the population density of Kampala District. While the urban area spreads over a larger extent, which now includes surrounding towns including Wakiso, Kira, and Entebbe, Kampala District itself is the core of the city. Kampala contains 96 parishes, each covering on average 1.9 square kilometres of land. This area falls under the Kampala Capital City Authority (KCCA) which has significant local regulatory, fiscal and planning powers.

Figure 1: Population Density

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4 The wider area, Greater Kampala Metropolitan Area, is used for additional analysis not reported in this paper. Much of the land on the fringes of the city is still used for agricultural purposes.
The 2002 population census provides a detailed report of population across the urban area. To apply this data to the model, the population is divided into two types: high skilled and low skilled\(^5\). These are defined using occupation categories in the population census questionnaire. High-skilled workers represent 28% of the total population, as detailed in Table 1 below. They enter as separate factors of production into the firms’ production functions, and in consequence are paid a different wage to low skilled workers. The endogenous wages are an outcome of the calibration. High-skilled workers are assumed to have access to motorized transport and therefore can travel between cells at a faster speed. Low-skilled workers can only travel on foot, resulting in lower travel speeds, and higher costs of commuting between any pair of cells.

At the household level, the tenure status of the household is reported\(^6\) along with housing characteristics to distinguish between different types of floor, wall and ceiling\(^7\). Within Kampala District, there are 1.2 million residents.\(^8\)

**Firms and production:** On the production side, the broad picture is given in Figure 2, which maps urban employment. Employment in Kampala is dominated by the provision of local services, including retail, hairdressing, and food services. Local, non-tradable, services represented 64% of all jobs in 2002, growing to 76% in 2011. These are sometimes referred to as the “informal sector” as many of these business have only one employee and are in practice self-employed entrepreneurs who are frequently not registered. Business, or tradable, services represent 11% of all jobs, with 10% of jobs in manufacturing and the remaining jobs in construction and government. In addition to the large number of employees working in local services, firms in Kampala are particularly small. Over 55% of firms have just one employee, and another 36% have between 2 and 4 employees. Of the remaining firms, nearly all are small, with between 5 to 49 employees, and only 0.2% of firms employ 50 or more people. Employment is highly concentrated in the area surrounding the CBD.

\(^5\) Using a typology close to the International Standard Classification of Occupations, the high skilled group include the major occupational groups 1 to 4 (Managers, Professionals, Technicians and associate professionals and Clerical support workers) while the low skilled group include groups 5 to 9 (Service and sales workers, Skilled agricultural, forestry and fishery workers, Craft and related trades workers, Plant and machine operators, and assemblers and Elementary occupations).

\(^6\) Data on tenure type is not available for 4 parishes in Kampala District, and a further 2 in the Greater Kampala Metropolitan Area.

\(^7\) Housing types are divided between solid wall buildings (concrete, cement block, stones, burnt or stabilised bricks) and non solid wall buildings (unburnt bricks with cement, unburnt bricks with mud, wood, mud and pole, others).

\(^8\) Data will be revised using the 2014 census following its publication in late March 2014, increasing this number to 1.9 million.
Firms are identified using the Census of Business Establishments, established by the Ugandan Bureau of Statistics (UBOS) in 2002 and 2011. This census captures information of every fixed-location firm in urban areas. For each firm, there are precise geographical coordinates, and firm employment numbers, as well as four digit ISIC codes. There are 322,000 jobs in Kampala District in 2011. The firm level information is then aggregated to the parish level, providing employment numbers by sector for all 96 parishes in Kampala District\(^9\).

Table 1 below provides summary statistics at the parish level for the city of Kampala.

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\(^9\) In the simulation and calibration of the model, the number residents is scaled down to match the number of jobs available in the city. The units can then be thought of as households, with one job per household.
Table 1: Summary Statistics, Kampala District

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. dev.</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>1.87</td>
<td>1.70</td>
<td>0.14</td>
<td>7.88</td>
</tr>
<tr>
<td>Share of Area Built-up</td>
<td>0.76</td>
<td>0.19</td>
<td>0.35</td>
<td>1.00</td>
</tr>
<tr>
<td>Population density</td>
<td>9806</td>
<td>8275</td>
<td>200</td>
<td>32989</td>
</tr>
<tr>
<td>Share of low-skilled</td>
<td>0.72</td>
<td>0.15</td>
<td>0.18</td>
<td>0.93</td>
</tr>
<tr>
<td>workers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Share of high-skilled</td>
<td>0.28</td>
<td>0.15</td>
<td>0.07</td>
<td>0.82</td>
</tr>
<tr>
<td>workers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employment density</td>
<td>4754</td>
<td>12072</td>
<td>7</td>
<td>84147</td>
</tr>
<tr>
<td>(employment/km²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Share of workers in</td>
<td>0.03</td>
<td>0.06</td>
<td>0.00</td>
<td>0.40</td>
</tr>
<tr>
<td>government</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Share of workers in</td>
<td>0.10</td>
<td>0.09</td>
<td>0.00</td>
<td>0.55</td>
</tr>
<tr>
<td>manufacturing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Share of workers in</td>
<td>0.76</td>
<td>0.14</td>
<td>0.26</td>
<td>1.00</td>
</tr>
<tr>
<td>non-tradable services</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Share of workers in</td>
<td>0.11</td>
<td>0.11</td>
<td>0.00</td>
<td>0.49</td>
</tr>
<tr>
<td>tradable services</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>96</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The model is run with three different production sectors: manufacturing, business services, and local services. Both business services and manufacturing are tradable, with local services selling only on the city market. Additionally the construction sector exists to build residential space, using inputs from all three production sectors. Only one type of building is included in the current model; the results will be further developed in the future to account for differences between formal and informal building technologies. At equilibrium, when firms and people are allowed to freely choose their location within the city, there are is no land misallocation.

Consumption shares across consumer goods and housing space are assumed constant across these two population groups. These are estimated using data in the Uganda National Housing Survey 2012. The consumption shares, input-output matrices for each of the three production sectors, and the construction sector, are documented below in Table 2.
Table 2: Consumption shares and input-output value coefficients

<table>
<thead>
<tr>
<th></th>
<th>Space</th>
<th>Manufacturing</th>
<th>Business Services</th>
<th>Local Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption Shares</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Land</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing input</td>
<td>0.1</td>
<td>0.05</td>
<td>0.1</td>
<td>0.15</td>
</tr>
<tr>
<td>Business Services</td>
<td>0.05</td>
<td>0.05</td>
<td>0.1</td>
<td>0.15</td>
</tr>
<tr>
<td>Local Services</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.2</td>
</tr>
<tr>
<td>Construction input</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Goods and services can be exported and imported, at a base price of 1, against which all prices, rents and wages within the city are relative. The number of varieties available to import are set so that the total import values for each sector approximately match the country level trade values reported by the WTO. Total exports represent approximately 30% of GDP, with exports split equally between manufacturing and business services, and with two thirds of imports in manufacturing and a third in business services.

Finally, the presence of agglomeration effects may lead to increased total factor productivity for well-located firms. This is captured in the costs at which firms are able to produce, as documented in the model above. Initially, we calibrate the model with no local spillovers, and estimate the impacts of our transport experiments under these conditions. However we then repeat the process with increasing returns to scale. Spatial decay is modelled exponentially, with a decay parameter of 3, so that the impact at 30 minutes travel time is just under a quarter of that at close proximity. We impose an elasticity of 1% across all sectors (IRS(1)), and then with an elasticity of 3% in the manufacturing and business service, and 5% for local services.

\[ \sum_{i} e^{-3d_{ij}} n_{ij} \]

10 Agglomeration effects in cell is for sector s are calculated according to the following expression, with d representing the travel duration between cells i and j in hours, and \( \eta_s \) is the elasticity. \[ \sum_{i} e^{-3d_{ij}} n_{ij} \]
(IRS(2)). This last set-up is consistent with the result in Duranton (2015) who estimates agglomeration effects in Colombia, and finds that these effects are particularly strong in the informal economy, which typically includes small scale local service providers.

**Connectivity and transport:** Connectivity between parishes in the city is based on the road network extracted from Open Street Maps on October 6th, 2015. A network analysis was used to construct the travel cost between all pairs of parishes in the city.\(^{11}\) The roads were categorized according to their type, and different travel speeds were applied to different roads. Initially these speeds were set to 15km/hour along primary roads, 10km/hour along secondary roads, and decreasing speeds for categories of roads beneath these. These speeds are set to reflect the high levels of congestion in Kampala, as documented in recent travel surveys including one by the Ministry of Works and Transport (2012). In the experiments outlined in Section 4 below, these speeds are adjusted to reflect changing transport networks in the city. Detailed travel speeds are documented in Table 6 in the Appendix, with both congested and non-congested speeds reported.

Geographical data on the city of Kampala comes from shapefiles provided by the Kampala Capital City Authority (KCCA) and represents the city in 2013 when gathered for the new Kampala Physical Development Plan.

To reflect the variations in modes of transport across residents in Kampala, we assume that there are two travel speeds. High-skilled workers have access to motorized transport, resulting in higher travel speeds. Low-skilled workers travel on foot; the travel network is mapped at pedestrian speeds across the whole city. The spatial decay parameter is set so that a 30 minute journey to and from work results in a 5% utility loss\(^ {12}\). In addition, we assume that goods and services are transported using the road network.

**Calibration:** The model is initially simulated with amenity and productivity parameters set to one, meaning that no cell has a particular advantage above the others, apart from through their

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\(^{11}\) We used the network analysis origin destination matrix from ArcGIS to calculate the fastest travel time between each origin and destination on the network using different travelling methods (walking, baseline driving speed, fast driving speed and congested roads driving speeds). The locations on the network correspond to the centroids of each parishes. If the centroids were not located on a road, we added the time to walk to the closest road using the shortest path (the Euclidean distance from the centroid to the closest road) to each distance and duration pairs. See appendix for detailed travel speeds.

\(^{12}\) With travel times measured in hours, spatial decay parameter for residents is set to 0.1. For goods, the parameter is set to 0.025 for business services, 0.05 for manufacturing and 0.1 for local services.
access to the transport network. This initial simulation gives results that deviate from observed data. The next step is calibration, which calculates the productivity parameters and amenity parameters which rationalise (or ‘explain’) these deviations. For example, employment is much higher in the hinterland of the city than the real data suggests; calibration quantifies this in terms of low productivity parameters.

The city is calibrated to match the observed data on employment by sector, and residential location by type. The calibration generates three productivity parameters and two amenity parameters for each parish in the city. When we allow for increasing returns to scale, part of these productivity parameters are explained by the presence of local spillovers. From the calibration, when the land and labour markets clear, prices, rents, wages, transfers, and in turn real incomes and utilities can be measured.

Maps showing the calibrated spatial layout of the city are shown in section 6 below, which corresponds to the observed layout of the city in terms of employment and residential densities. There is a steep rent gradient between the CBD and the fringes of Kampala District. In consequence, the construction sector provides different amounts of residential space, with the price of space varying by a factor of 5, roughly consistent with the levels observed in Henderson et al. (2016) for Nairobi. This is turn in reflected by low population densities in the CBD, which then rise steeply at short distances away from the centre. In particular, low-skilled workers locate in neighbourhoods to the South, West and North of the CBD, with high-skilled workers more scattered between neighbourhoods across the city.

Employment, particularly of high-skilled workers, is focused in the centre of the city. Manufacturing jobs are located particularly to the South West, along the route towards Entebbe airport. Business Service jobs are denser to the North East, with local services spread throughout the urban area. High-skilled workers earn just over three times the wage of low-skilled workers on average. High-skilled workers are employed by the three productive sectors plus the government, with 20% in manufacturing, 32% in business services and 47% in local services. Low-skilled workers are employed solely by the three productive sectors, with 82% working in local services.

From this baseline spatial equilibrium of the city, we then ‘shock’ the transport network, to change the cost of travel between cells within the city. The resultant effects are then observed on prices, and in turn, on rent gradients and urban land use. These results are simulated under
constant returns to scale, and the two sets of agglomeration economies outlined above, IRS(1) and IRS(2).

4. Transport improvements:

4.1 *Experiment 1: The Northern Bypass*

Following an announcement in 2002, an EU-funded Northern Bypass was built around Kampala. In 2009, the first 15km of this bypass was opened. While the initial intention of the route was to provide an alternative road for freight traffic travelling through Kampala, in 2011 the European Commission conducted a travel study which found that heavy goods vehicles accounted for only 10 to 14% of the bypass traffic. The bypass, at a distance of just 8-10km from the CBD, is carrying increasingly large numbers of passenger traffic. Private vehicles and minibuses are using the bypass for short trips in order to skirt around the urban core. Figure 3 below shows the location of the bypass relative to the city and other major roads.

The provision of a high quality road around the centre of the city reduces the travel speeds between parishes to the west, north and east of the CBD. The baseline of a congested urban city is then compared to a city under which all other road speeds are held constant, but the Northern Bypass provides a high speed connection across the North of the city, with motorized vehicles able to travel at 60km/hour along the route. There is no direct impact of the bypass on pedestrians, i.e. low-skilled urban residents.
The results of this experiment are documented for each worker type in Table 3, with maps in Section 6 below. The first column in Table 3 gives the growth in total utility for workers of a specific type. This is then split into a growth in their income, and a first-order approximation of the impact on their cost of living, which includes both the impact on prices of goods and services at the point of consumption, and on commuting costs within the city. The growth in incomes is due to both an increase in wage income and an increase in lump sum transfers – city rents, plus firm profits, minus the cost of staffing the fixed size government. Across both the high-skilled and low-skilled, income from transfers represents just 12.5% of total income.

Initially, we observe the short term effects on welfare, as residential location and firm location are held constant. Here high-skilled residents are directly affected by the policy, as their travel times across certain pairs of parishes within the city reduce. However, the reduced travel costs also impact prices, both through the price of goods and services at parishes throughout the city as the cost of shipping decreases, and in turn, through firms responding to the lower price index by adjusting their output and prices to remain competitive. In consequence, firms adjust their input values, and wages shift. High-skilled workers observe a 0.7% increase in their utility, of which 0.1% is attributable to higher wage incomes and increased transfers from positive firm
profits, and the remaining 0.6% is due to lower travel costs and reduced prices. Low-skilled workers, despite not being directly impacted by the reduced travel times, observe a 0.5% utility increase, of which 0.3% is through a reduction in the cost of living; while their travel times to and from work do not change, the prices of goods and services decrease, leading to improved welfare.

We then allow a more medium-term effect of residents being able to adjust their location decisions in response to this transport shock, while holding firm location constant. The impacts on utility are greater, 3.5% for high-skilled workers and 1.1% for low-skilled workers, five and two times that experienced in the short term respectively. The effect again is predominantly through the cost of living. Now high-skilled workers can relocate within the city, to take better advantage of the reduced commuting times along the new bypass route. This leads to increased rents and high-skilled population densities in the region around the bypass, and lower rents in the centre and to the south. As shipping costs across the city fall, reducing the price index, firms respond to this change by adjusting wages. Low-skilled workers also experience a positive impact on their cost of living, as the rents and prices they face reduce substantially.

We next allow for both firms and people to adjust their location decisions, capturing the long-term impact of the transport investment. These changes are detailed in the maps in Section 6. When these general equilibrium effects are included, the growth in total utility of the low-skilled residents nearly matches that of the high skilled residents, despite the low-skilled residents not being directly affected by the transport investment. As the bypass increases the connectivity of parishes near the bypass route for high-skilled workers, these residents seek to move into these areas, increasing land rents. Land intensive manufacturing firms move southwards, with business services employment increasing west of the centre. Low-skilled workers follow the high-skilled residents and local services by moving north within the city. The full spatial relocation of land results in an equilibrium under which both types of worker are substantially better off; high-skilled workers has a 2.9% utility increase, and low-skilled workers have a similar increase of 2.8%, through a substantial reduction in the cost of living, and a 0.4% income rise.

We then examine how the spatial readjustment of the city would differ in the presence of agglomeration effects. In IRS(1), these are set to be equal across all sectors. The effects are
documented in column three of the maps in Section 6. Firms begin to cluster further within space, with manufacturing firms moving towards the east, and business services towards the south. High-skilled employment moves with this, whereas the north of the city sees an increase in local services and low-skilled employment in the local services sector. In consequence, low-skilled residents locate in the north of the city, away from the manufacturing and business services jobs, but near the jobs provided by local services, which are the main source of low-skilled employment. While the agglomeration effects lead to greater income gains, particularly for the low skilled, the reduction in the cost of living is near zero. The cost of shipping manufacturing and business services into this area are relatively high, increasing the local prices. The result is only a 1.8% increase in total utility for the low skilled. The high-skilled workforce see a similar utility gain to that under constant returns to scale, however now a large share of this is attributable to income increases rather than improvements in the cost of living; they have relocated away from the bypass where they had most to gain in terms of lower commuting costs, towards the east and south where there is the space for manufacturing to benefit from agglomeration economies.

Finally, we repeat the experiment assuming higher agglomeration effects, particularly for local services IRS(2). This last specification results in particularly large utility impacts of the bypass on low-skilled workers, despite the bypass only directly impacting high-skilled workers. As the agglomeration effects in local services are strong, and local services are costly to transport across the city, the bypass, through reducing travel costs, allows local services to cluster more in the centre of the city where there are good connections to surrounding areas. Manufacturing clusters further in the northeast of the city, with business service focusing to the south and west. The details of this reallocation of land are documented in columns 4 of the maps in Section 6. Firms are able to reap the benefits of agglomeration economies to increase their productivity, resulting in increased incomes. The incomes of high-skilled workers rise 5.6%, and low-skilled by 6.6%, leading to sharp utility gains. However these do not map as directly into higher utility levels as before; utility rises for both worker types, however increased prices detract from this effect. Of particular interest is that low-skilled workers are benefitting most from the transport investment. It is therefore very important for the agglomeration effects within the city to be well understood to be able to determine how a policy which only directly affects one group of residents, may have impacts on others within the urban area.
Table 3: Real income gains: Experiment 1: Bypass

<table>
<thead>
<tr>
<th>Factors allowed to move</th>
<th>Returns to Scale</th>
<th>Type</th>
<th>Utility</th>
<th>Income (≈ 87.5% wage based)</th>
<th>Cost of Living</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pop, Firms</td>
<td>CRS High Skilled</td>
<td>0.7% 0.1% 0.1% 0.5%</td>
<td>-0.6%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pop, Firms</td>
<td>CRS Low Skilled</td>
<td>0.5% 0.2% 0.1% 0.5%</td>
<td>-0.3%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pop, Firms</td>
<td>CRS High Skilled</td>
<td>3.5% 0.2% 0.2% 0.4%</td>
<td>-3.4%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pop, Firms</td>
<td>CRS Low Skilled</td>
<td>1.1% 0.2% 0.2% 0.4%</td>
<td>-0.9%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pop, Firms</td>
<td>IRS(1) High Skilled</td>
<td>2.9% 0.2% 0.2% 0.5%</td>
<td>-2.7%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pop, Firms</td>
<td>IRS(1) Low Skilled</td>
<td>2.8% 0.4% 0.4% 0.5%</td>
<td>-2.4%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pop, Firms</td>
<td>IRS(2) High Skilled</td>
<td>3.4% 5.6% 5.5% 7.4%</td>
<td>+2.3%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pop, Firms</td>
<td>IRS(2) Low Skilled</td>
<td>6.3% 6.6% 6.4% 7.4%</td>
<td>+0.3%</td>
<td></td>
</tr>
</tbody>
</table>

4.2 Experiment 2: Reduce Congestion

Rather than a specific transport investment that affects one area of the city, Experiment 2 focuses on a general investment in the current transport network, reducing congestion throughout the city and leading to increased travel speeds. The details of the changes are documented in the appendix. Travel speeds along primary roads are assumed to rise from 15km/hour to 30km/hour, and along secondary roads from 10km/hour, to 20km/hour. These increased speeds directly affect high-skilled residents who have access to motorized transport, and the shipping of goods and services around the city.

As the transport improvement occurs throughout the city, the impacts on utility are far greater than under Experiment 1. The short term effect, when neither firms nor residents can change their location choice, leads to a 5.2% increase in utility for high skilled residents, and 3.4% for low skilled residents. Much of this effect is through reduced costs of living, as commuting costs decrease for high-skilled residents, and prices fall for all residents. However, some of the effect is also through wage and transfer income.
When we allow the population to relocate across the urban space, the differences in utility rise sharply. High skilled workers seek to reap the benefits of far higher travel speeds on major roads, relocating to these areas and experiencing a 19.1% utility growth, predominantly through a reduction in the cost of living that can be explained by lower commuting costs. Low-skilled residents however also experience a 5.8% utility increase, as their cost of living further improves, and their incomes rise.

Once firms and residents can both relocate throughout the city, the increase in utility for low-skilled residents reaches 7.9%, while it remains stable for high-skilled residents. Rents increase on the fringes of the city, as shown in section 6. These areas are now better connected, located along major roads which link to other corners of the urban area. Land in the city centre is increasingly occupied by firms who want to connect with markets all over the city. Land on the fringes has higher population densities, particularly among high-skilled workers. As manufacturing and business services increase in concentration near the centre of the city, high-skilled employment rises in these areas. In turn, local services increase near the areas of increased population density on the fringes of the city, increasing low-skilled employment. Low-skilled workers are located closer to their jobs, reducing their travel costs, and high-skilled workers are better connected to their jobs through improved road transport links.

When we allow for increasing returns under IRS(1), the impact on incomes rises for both high and low-skilled workers. Manufacturing and business services in particular begin to cluster more, benefitting from the agglomeration effects that boost total factor productivity. Local services tend to cluster less than the other sectors, as the high cost of transporting the services across the city ensures their location close to residential neighbourhoods.

Under IRS(2), when agglomeration effects are particularly strong for local services, local services begin to cluster further in the centre and to the north west of the city centre. The positive agglomeration economies counteract the costs of shipping services around the city, leading to productivity gains in this sector. As local services use low-skilled labour intensively as an input into production, wages of low-skilled workers rise, and the income effect results in particularly large utility growth for low-skilled residents at 11.2%. High-skilled workers also experience a utility growth of 15.3%, however this is lower than what would be expected without agglomeration effects, due to a smaller improvement in their cost of living.
Table 4: Real income gains: Experiment 2: No congestion

<table>
<thead>
<tr>
<th>Factors allowed to move</th>
<th>Returns to Scale</th>
<th>Type</th>
<th>Utility</th>
<th>Income Total</th>
<th>Wage</th>
<th>Transfers</th>
<th>Cost of Living</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pop, Firms</strong></td>
<td>CRS</td>
<td>High Skilled</td>
<td>5.2%</td>
<td>1.1%</td>
<td>1.0%</td>
<td>3.0%</td>
<td>-4.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low Skilled</td>
<td>3.4%</td>
<td>1.4%</td>
<td>1.0%</td>
<td>3.0%</td>
<td>-2.0%</td>
</tr>
<tr>
<td><strong>Pop, Firms</strong></td>
<td>CRS</td>
<td>High Skilled</td>
<td>19.1%</td>
<td>1.3%</td>
<td>1.2%</td>
<td>3.3%</td>
<td>-17.8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low Skilled</td>
<td>5.8%</td>
<td>1.8%</td>
<td>1.4%</td>
<td>3.3%</td>
<td>-4.0%</td>
</tr>
<tr>
<td><strong>Pop, Firms</strong></td>
<td>CRS</td>
<td>High Skilled</td>
<td>19.2%</td>
<td>1.6%</td>
<td>1.5%</td>
<td>2.2%</td>
<td>-17.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low Skilled</td>
<td>7.9%</td>
<td>2.0%</td>
<td>1.9%</td>
<td>2.2%</td>
<td>-5.9%</td>
</tr>
<tr>
<td><strong>Pop, Firms</strong></td>
<td>IRS(1)</td>
<td>High Skilled</td>
<td>19.5%</td>
<td>2.4%</td>
<td>2.4%</td>
<td>2.5%</td>
<td>-17.1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low Skilled</td>
<td>7.5%</td>
<td>2.5%</td>
<td>2.5%</td>
<td>2.5%</td>
<td>-5.1%</td>
</tr>
<tr>
<td><strong>Pop, Firms</strong></td>
<td>IRS(2)</td>
<td>High Skilled</td>
<td>15.3%</td>
<td>6.8%</td>
<td>6.7%</td>
<td>8.7%</td>
<td>-8.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low Skilled</td>
<td>11.2%</td>
<td>7.8%</td>
<td>7.6%</td>
<td>8.7%</td>
<td>-3.4%</td>
</tr>
</tbody>
</table>

4.3 Experiment 1: The Northern Bypass and Reduced Congestion Combined

Following experiments 1 and 2, the model is used to simulate a combination of both transport improvements. This allows us to study the city with reduced congestion and a new bypass, and to observe to what extent the combination of the two experiments leads to greater welfare gains.

The results indicate higher utility gains than under Experiments 1 and 2, except for low-skilled workers under IRS(2). Here a slightly lower improvement in the costs of living compared to under Experiment 2 results in an 11% compared to 11.2% utility improvement. The distributional impacts of the improvement in transport across the city are partially offset by the additional provision of a bypass, although the difference is minimal.
Table 5: Real income gains: Experiment 3: Bypass and No Congestion

<table>
<thead>
<tr>
<th>Factors allowed to move</th>
<th>Returns to Scale</th>
<th>Type</th>
<th>Utility</th>
<th>Income</th>
<th>Cost of Living</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>Wage</td>
<td>Transfers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pop, Firms</td>
<td>CRS</td>
<td>High Skilled</td>
<td>5.4%</td>
<td>1.2%</td>
<td>1.1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low Skilled</td>
<td>3.5%</td>
<td>1.4%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Pop, Firms</td>
<td>CRS</td>
<td>High Skilled</td>
<td>20.4%</td>
<td>1.4%</td>
<td>1.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low Skilled</td>
<td>6.1%</td>
<td>1.9%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Pop, Firms</td>
<td>CRS</td>
<td>High Skilled</td>
<td>20.3%</td>
<td>1.7%</td>
<td>1.6%</td>
</tr>
<tr>
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<td>Pop, Firms</td>
<td>IRS(1)</td>
<td>High Skilled</td>
<td>20.5%</td>
<td>2.4%</td>
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<tr>
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<td>Low Skilled</td>
<td>8.1%</td>
<td>2.5%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Pop, Firms</td>
<td>IRS(2)</td>
<td>High Skilled</td>
<td>16.0%</td>
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<td>Low Skilled</td>
<td>11.0%</td>
<td>7.8%</td>
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5. Conclusions

As city governments in developing countries respond to rapid urbanisation by investing in the maintenance and upgrading of current transport systems and by constructing new roads and public transit systems, it is vital to have a clear understanding of the potential consequences of the choices they make. This paper aims to address this by constructing a detailed general equilibrium model of a city and applying it to Kampala, Uganda, arguably the East African city with the best available geographically detailed data. In doing so, we are able to observe the potential impacts of transport projects not solely on the groups directly concerned by the construction, e.g. the drivers who use a new road, or the bus riders who use a BRT system. We are also able to capture both the short term impacts in terms of prices and wages across the city, and the longer term adjustments that people and firms may make in terms of their locational choices.

Changes in the urban landscape take time, and so we analyse the impacts of transport projects in three stages: the immediate effect, when firm and household location is taken as given, the medium term effect, when residents can relocate to other areas of the city where they face better connectivity to employment opportunities or lower costs of living in terms of rents and prices,
and the long term, when firms can relocate along with households, choosing to construct plants, workshops and shopfronts in different neighbourhoods. The differences between these three set-ups highlight how the speed of adjustment within a city can impact the consequences of a transport improvement. If development and planning policies are such that it is very difficult for firms to relocate in response to changes in connectivity, the full potential benefits of projects may not be reaped. This is particularly the case under a situation with increasing returns to scale, whereby agglomeration effects increase the productivity of firms if they are able to cluster within the urban space. These effects can lead to particularly large income gains from transport projects if local policy allows firms to respond to the changing urban landscape.

The most striking result of this paper is that the benefits of transport projects are felt far beyond the most directly affected groups. A new bypass reduces the travel times for high-income individuals, increasing their utility. But in turn, there is a direct fall in the cost of living for others within the city. As people adjust their location decisions, and as firms relocate, the incomes of both high-income and low-income groups may rise. In fact, the total utility growth for low-income groups may in some circumstances exceed the utility growth for high-income groups. The relative size of the effects on different groups of residents within the city depends not only on the commuting costs for the groups concerned, but also on the size of the agglomeration effects of different productive sectors. Our simulations include a case with strong agglomeration effects in the provision of local services, a sector consistent with much of the informal economy in many developing country cities. As local services employ large numbers of low-skilled workers, when these agglomeration effects were able to dominate the dispersive forces resulting from the need to locate local services near to the consumer, the clustering of businesses created large productivity effects and higher wages for low-skilled workers.

This result stresses the need to understand agglomeration forces in African cities, and to have some quantitative assessment of the relative size of such forces across industries. Those industries with stronger agglomeration effects benefit most from increased connectivity and economic density, leading to income gains for their labour force. To be able to estimate the potential beneficiaries of transport investments, we need to be able to look beyond the impact on the direct users, to understand the industries that will be affected and the workers who may gain as a result.
6. Maps

Maps 1

Base Levels

<table>
<thead>
<tr>
<th>Growth, CRS, %</th>
<th>Growth, IRS(1), %</th>
<th>Growth, IRS(2), %</th>
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</thead>
</table>

Experiment 1: Bypass - Rent
Maps 2

Base Levels

<table>
<thead>
<tr>
<th>Growth, CRS, %</th>
<th>Growth, IRS(1), %</th>
<th>Growth, IRS(2), %</th>
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</thead>
</table>

Experiment 1: Bypass – High Skilled Population Density, ppl/km²

Experiment 1: Bypass – Low Skilled Population Density, ppl/km²
Maps 3

Base Levels

Growth, CRS, %

Growth, IRS(1), %

Growth, IRS(2), %

Experiment 1: Bypass – High Skilled Employment Density, ppl/km²

Experiment 1: Bypass – Low Skilled Employment Density, ppl/km²
Maps 4

**Base Shares**

**Change in Share, CRS**

**Change in Share, IRS(1)**

**Change in Share, IRS(2)**

Experiment 1: Bypass – Manufacturing Employment Density, Percentage Point Changes

Experiment 1: Bypass – Business Services Employment Density, Percentage Point Changes
Maps 5

Base Shares  Change in Share, CRS  Change in Share, IRS(1)  Change in Share, IRS(2)

Experiment 1: Bypass – Local Services Employment Density, Percentage Point Changes
Maps 6

Base Shares  Change in Share, CRS  Change in Share, IRS(1)  Change in Share, IRS(2)

Experiment 2: No Congestion - Rent
Maps 7

**Base Levels**

**Growth, CRS, %**

**Growth, IRS(1), %**

**Growth, IRS(2), %**

Experiment 2: No Congestion – High Skilled Population Density, ppl/km²

Experiment 2: No Congestion – Low Skilled Population Density, ppl/km²
Maps 8

**Base Levels**

<table>
<thead>
<tr>
<th>Growth, CRS, %</th>
<th>Growth, IRS(1), %</th>
<th>Growth, IRS(2), %</th>
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<tbody>
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<tr>
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<tr>
<td>Experiment 2: No Congestion – Low Skilled Employment Density, ppl/km²</td>
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</table>
Experiment 2: No Congestion – Manufacturing Employment Density, Percentage Point Changes

Experiment 2: No Congestion – Business Services Employment Density, Percentage Point Changes
Maps 10

Base Shares | Change in Share, CRS | Change in Share, IRS(1) | Change in Share, IRS(2)

Experiment 2: No Congestion – Local Services Employment Density, Percentage Point Changes
7. References


Duranton, Gilles. 2015. Agglomeration effects in Colombia. Journal of Regional Science


Ministry of Works and Transport, Average Travel Time and Vehicle Cost in Greater Kampala Metropolitan Area (GKMA), 2012

Open Street Map Data for Uganda, accessed October 2015.


World Bank, Kampala City Council, Government of Uganda, Pre-Feasibility studies for the development of a long term integrated bus rapid transit system for Greater Kampala Metropolitan Area, Final Report, May 2010
8. Appendix

Table 5: Travel Speeds

<table>
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<tr>
<th>Road type</th>
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<th>Non Congested</th>
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<td>Bridleway</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Living Street</td>
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<td>8</td>
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<tr>
<td>Motorway</td>
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<td>30</td>
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<td>Path</td>
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<td>5</td>
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<td>Road</td>
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