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Can migration reduce benefits of spatial programs? A model of congestion externalities with evidence from South Africa *

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ABSTRACT

This paper demonstrates that migration lowers welfare gains from new local public goods (like electricity, hospitals or schools) by congesting inelastically supplied local amenities. Our simple model shows that the structure of the market for local amenities matters for welfare: Program-induced migration will be higher and congestion externalities larger when markets for local amenities (like land) are missing. To illustrate, we estimate welfare bounds for a location-based program using a recent example that provides consistent estimates of income and population effects of household electrification in South Africa. We provide new evidence that this program led to significant congestion in local schools. Then, we use our model to show that migration in response to household electrification reduced local welfare gains by half. Our paper argues that because of congestion externalities, evaluations of spatial programs should account for migration. Moreover, we show how this might be done without land price data and when markets for land and other local amenities are missing. [160 words]

Keywords: rural infrastructure, migration, congestion effects, welfare, program evaluation, South Africa
JEL: O18, O15, R13, H43, H54, H23

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1. Introduction

Governments in poor countries spend large fractions of GDP on programs with spatial components, like transport, sanitation and energy infrastructure, schools, hospitals and clinics, and irrigation facilities. The most recent data indicate that African countries spend between 6 and 12% of GDP on spatial projects (Briceno-Garmendina, Karlis and Foster, 2008) and in the three years following 2006, multilateral lending to developing countries for infrastructure investments increased from USD20 billion to USD50 billon (Lin and Doemeland, 2012). A key feature of most of these projects is that new public goods are created in specific areas of a country, changing the relative attractiveness of certain regions for inhabitants. This paper asks: can migration responses to such spatial programs undermine the welfare gains from local infrastructure investments? How can evaluations of location-based projects account for this migration response?

Although migration occupies a central position in older theories of structural change and development (e.g. Lewis-type models show how rural to urban migration contributes to economic growth (Rogers and Williamson, 1982; Williamson, 1988)), more recent work related to evaluating the developmental impacts of spatial programs tends not to account for migration. In estimating the impact of different kinds of spatial programs, the recent literature has focused on measuring outcomes directly affected by the new infrastructure investment for a set of incumbents.[1] While these approaches give us some insight into the effects of such spatial programs, they are not informative about how migration could alter the overall gains from a program of infrastructure investment. This omission becomes particularly important when other local public goods are in short supply: any migration response to location-based investments may end up congesting access to these other public goods. We focus on measuring and accounting for congestion effects generated by migration responses

[1] Among many recent examples: Devoto et al. (2011) measure the impacts of subsidized private tap connections in urban Morocco on water usage, health, self-reported well-being, and time use; Dinkelman (2011) estimates the impact of household electrification on home production technologies, employment, and earnings in rural South Africa; Kremer et al. (2011) measure the impact of subsidized spring protection on disease incidence in rural Kenya; Cattaneo et al. (2009) estimate the impact of switching from a dirt floor to a cement floor on child health, child cognition, and adult happiness in urban Mexico; Duflo and Pande (2007) measure the impact of irrigation dams on agricultural output and rural poverty in India; Donaldson (2010) estimates the impact of Indian railroad expansion on agricultural prices and income levels and variability; and Banerjee, Duflo, and Qian (2012) estimate the effect of transportation infrastructure on regional output.

to spatial programs in this paper.

One way to account for migration responses to spatial programs (and any resulting congestion) is to follow traditional approaches from the urban economics and local public finance literatures (Glaeser, 2007, 2008). For example, in Roback's (1982) model, the value of place-based policies (including any congestion effects) can be estimated as long as land markets operate well and wage and land price data exist.[2] Indeed, many authors have applied this idea in US contexts, where land and labor markets exist and operate well. For example, Black (1999) measures the value of school quality by estimating how differences in otherwise-identical school neighborhoods are capitalized in housing prices, Davis (2008) examines how construction of a power plant reduces land values in a county, and Busso, Gregory, and Kline (2012) use land rents as a component of their estimated effects of federal Enterprise Zone policies. In theory, these methods could be used to evaluate the impact of place-based policies in poor countries. In practice, the lack of good quality land rent data, and the lack of land markets in many places (Udry, 2011) makes this infeasible.

In this paper, we use a model of location choice to draw out the relationship between migration and place-based policies and to obtain easily applied formulas for estimating the welfare impact of a policy in the presence of migration.[3] Our spatial equilibrium model has individuals choosing between an urban or rural area, and responding to improvements in privately-consumed public goods in rural areas by migrating back to these areas. We derive two main insights from the model. First, we show that more people migrate to an area benefiting from a spatial program when there are no markets for local amenities, and in particular, no functioning land market. Without the information captured in land prices that could alert people to congestion externalities, too many people migrate in response to a place-based development program. Second, with no amenity market, the welfare benefits of the spatial program for incumbents and for movers are lower than they would be if an

[2]See Moretti (2011) for an extended discussion of the standard spatial equilibrium model and the implications of local producitivity shocks on wages, land rents, and hence individual welfare.

[3]Of course, policy-makers may take into account the effects of their placement decisions on migration. Feler and Henderson (2011) document how Brazilian municipalities strategically withhold the provision of public infrastructure — water services — to urban informal settlements in a direct attempt to deter inmigration. The question of how governments decide where to target spending is beyond the scope of this paper.

amenity market existed — a version of the tragedy of the commons.[4]

We use our model to illustrate how researchers might account for these welfare-reducing congestion effects by constructing welfare bounds for the impact of a place-based program. These bounds (in versions of the model both with and without amenity markets) are functions of the population and income responses to the program. These elasticities can be consistently estimated by system GMM if there is exogenous variation in the availability of the program.

We illustrate using a recent example from the literature. Dinkelman (2011) looks at the effects of new household electrification on employment in rural South Africa using plausibly exogenous variation in the cost of grid expansion as an instrument for electricity projects. We show empirically that migration into electrifying areas is substantially higher than migration into non-electrifying areas and present new results that households and public schools become congested in communities that are electrified. We use our model and the exogenous variation in electricity roll-out to estimate the average welfare impact of rural household electrification for each household, accounting for congestion externalities. Taking migration into account reduces the welfare benefit of the program by a factor of almost two. This exercise illustrates the feasibility of accounting for migration responses to spatial programs when markets for local amenities are missing as well as when markets exist but when amenity price data are poor quality. Both of these situations are likely to occur in developing countries.

Our paper makes four main contributions. First, we highlight how migration can be of first order importance in understanding welfare impacts of spatial programs in developing countries, where local public goods are inelastic in supply.[5]. The fact that migration is a key component of any spatial equilibrium is well-known in the local public finance and urban economics literatures but has fallen off the agenda of development economists. We believe that future urbanization and development of rural areas in poor countries is likely to bring migration and related congestion issues to the fore once more.[6]

[4]Although we do not pursue this argument here, programs that stem the flow of out-migration from rural areas may also undermine the potential for agglomeration externalities (typically thought to arise in urban settings) to grow the economy. Evidence for agglomeration externalities in developed countries is scant, and non-existent for developing countries (Quigley, 2008).

[5]We could think about this as only a problem of the short run. However, since there is no guarantee that governments in developing countries will be able to increase the supply of local public goods given enough time, the short run case seems to be relevant.

[6]More than three quarters of the urban population in Africa live in slums; future urbanization trends in

Second, we use our simple model to make a novel theoretical point. We show that migration responses to spatial programs are inefficiently large when markets for local amenities or public goods do not exist, and in particular, when land markets are missing. When congestion effects do not show up in the price of accessing local amenities (as would be the case in standard urban models of spatial equilibrium), too many people move in response to an improvement in locational amenities. This is much more likely to occur in developing countries where property rights are commonly unspecified (e.g. land sales are prohibited in Ethiopia, tenure is communal in rural parts of South Africa and formal land titling is lacking in large parts of India) and where access to services like education and health care are not typically fee-for-service.

Third, we illustrate how researchers might account for these welfare-reducing congestion effects in such settings. By computing welfare bounds of local programs as a function of (consistently estimated) income and population responses to these programs, we show that it is feasible to account for migration when markets for local amenities are missing as well as when markets exist but when amenity price data are poor quality. This approach starts with a simple model of spatial equilibrium tailored to the specific project. We could learn much more about the effects of spatial programs in poor countries from using information about migration, rather than treated this response as a nuisance. Researchers conducting randomized controlled trials may be particularly well-placed to measure migration externalities, if they collect appropriate data on population densities.

Finally, we provide the first empirical evidence from a developing country context that congestion effects exist, and can be quantitatively large. While congestion externalities are important in urban economics, they have not received a lot of attention in the development literature (Quigley (2008)).[7] Migration was so large in the South African electrification case that it almost wiped out welfare gains from the initial infrastructure investment. Education seemed to be a key channel through which this congestion affected welfare.

these areas will continue to put pressure on existing urban areas (Cohen, 2006).

[7]Usher (1977) examines the theoretical effects of international migration on access to public property. Rosenzweig and Wolpin (1986), in a study of family planning policies, show that program evaluation is difficult when there is selective migration in response to the policies and heterogeneity in the policies' treatment effects but do not explore the impact of migration on access to other publicly available services.

Although we propose a general and constructive approach to accounting for migration in evaluations of spatial programs, our work has several caveats. First, we ignore agglomeration externalities arising from higher-density settlements (usually in cities), partly for tractability and partly because our focus is on migration into and within rural areas. The literature provides no evidence for agglomeration effects in poor countries. Second, our model is a partial equilibrium model. We assume that overall migration effects are small enough so that general equilibrium effects in other parts of the economy (related to out-migration) are ignorable. We also ignore the question of how to optimally finance local programs through taxation.[8] To highlight how congestion affects welfare, we focus on estimating welfare gains from local programs in the places where these local programs occur. Fourth, our analysis is static; we do not consider the dynamic effects of place-based policies. Finally, we do not address the question of how to optimally allocate spatial policies.

The paper begins by describing our simple two-period model of location choice under the assumption that there is no market for the local amenity. We derive equilibrium conditions for period 1 and describe the new equilibrium after a local infrastructure project is implemented in period 2. The characteristics of this new equilibrium depend on whether we allow a market for the local amenity in the second period. We derive a formula for the compensating variation of the program in each case, and derive welfare bounds for the impact of the program that include migration elasticities. The bounds arise because we do not know the distribution of tastes for living in the location that receives the program; the upper bound is reached when in-migrants have as strong a preference as incumbents for living in the program location, and the lower bound is reached when in-migrants are almost indifferent between living in the program location and living elsewhere. We show how to calculate these bounds given consistent estimates of the relevant model parameters. The second part of the paper demonstrates the construction of the bounds for the particular example of rural electrification in South Africa.

[8]Typically, the local public finance literature takes into account both the benefit incidence of local programs as well as the cost incidence in terms of who pays the taxes for funding local programs, for example, Wildasin (1991) and Calabrese, Epple and Romano (2012).

2. Model

This section describes how to value a place-based development program using a simple model of migration. The model adapts the spatial equilibrium model presented in Moretti (2011) to our context. We innovate by comparing the solution to the model for two cases: when there is no market for a given local amenity and when such a market exists. We show that inefficiently high migration and congestion in the local amenity drive a wedge between these two solutions, with implications for welfare effects of the development program.

A. Preferences and endowments

There are two time periods, $t = 1, 2$. In each period, a given consumer i chooses whether to live in an urban area or a rural area.[9] For simplicity, and to match what we are able to do in our empirical work, we assume that different individuals may consider different rural areas as their alternative to the urban location but that the same individual may not consider many different rural areas as possible locations. Consumers are myopic: In each period, they consider only that period's utility in deciding where to live.

In each period, all consumers receive the same utility $\bar{U}$ from living in the urban area. Consumer i's utility of living in the rural area in period t is

$$U_i(c, a) = c^{\alpha} a^{1-\alpha} + \epsilon_i \tag{1}$$

where c_t is a freely tradable consumption good; a_t is a local amenity — a rival, potentially excludable, nontraded good (like schooling, or communal land); and ϵ_i captures heterogeneity in preferences for place, uniformly distributed on the interval $[-s, s]$. The assumption of a uniform distribution gives us tractable expressions for the program's quantitative effect but is not crucial for the qualitative results. The parameter s measures how strongly a consumer is attached to the rural area relative to the city. If s is large, some individuals are strongly attached to the rural area and will only prefer the city given large reductions in c_t or a_t. The taste shock ϵ_i does not change over time for a given individual.[10] In each period, consumers

[9] We use the labels "urban" and "rural" for ease of exposition. However, the core idea is that individuals are choosing between only two places, one of which — the place labeled "urban" — is outside the ambit of the program we are evaluating.

[10] The model does not explicitly include moving costs which could also be heterogeneously distributed in

choose to live in whichever location gives them the highest utility.

Note that preference heterogeneity implies that some individuals will be inframarginal in the spatial equilibrium and hence will not be indifferent between rural and urban locations. These individuals capture (utility) rents in equilibrium; heterogeneity in preferences prevents migration from arbitraging away gains from local infrastructure programs. (See Moretti (2011) and Busso, Gregory, and Kline (2012) for discussion of the role of heterogeneity in spatial equilibrium models.)

Each consumer has a time endowment T_t that she supplies inelastically to the market in exchange for wages w_t. The rural area has a perfectly elastic supply of the consumption good, which we treat as numeraire, and a perfectly inelastic supply A of the amenity. In the first time period, there is no market for the amenity; rather, it is rationed equally across all consumers who choose to live in the rural area. Thus, in the first period, the budget set in the rural area is:

$$c_1 \leq w_1 T_1, \quad a_1 = \frac{A}{N_1}, \tag{2}$$

where N_1 is the number of consumers in the rural area in period 1. In the second period, we investigate two alternative allocation mechanisms for the amenity: quantity rationing (no market for the amenity) and market-based allocation.

B. Production technology

Firms in the rural area are immobile (a reasonable assumption for subsistence farmers) and use effective units of labor as the only input to production: they choose to hire N_t workers and each works for (an inelastic) T_t hours. Capital, land and other amenities do not enter into the production function.[11] These firms sell output on the world market and labor markets are competitive. The rural economy is characterized by an aggregate production function

the population. Introducing moving costs into ϵ would not change the computation of welfare bounds of a program; only the interpretation of these bounds. At one extreme, movers gaining zero utility from moving can be thought of as paying a moving cost equal to their entire utility gain from rural consumption and the rural amenity; at the other extreme, movers with no moving cost enjoy the same gain in utility as the stayers do. In other words, the bounds we compute below contain any heterogeneity in moving costs.

[11] The import of this assumption is that the infrastructure project does not directly affect productivity in the rural area.

that allows either constant or decreasing returns to scale:

$$Y_t = F(N_t T_t) = (N_t T_t)^{\beta} \tag{3}$$

where $\beta \subset (0, 1]$, N_t is the number of consumers in the rural area in period t and T_t is the time endowment that each consumer supplies inelastically to the market. Firms absorb all workers in the economy and pay wages:

$$w_t = F'(T_t N_t) = \beta (T_t N_t)^{(\beta-1)} \tag{4}$$

The choice of production function is general enough to illustrate the key mechanisms of congestion in our model and to derive bounds for the welfare effects of the local program. Note that when $\beta = 1$ (that is, the aggregate production function exhibits constant returns to scale, CRTS), the wage rate is pinned down by the world price of the numeraire and so $w_t = 1$ for all t. CRTS implies that wages cannot change in response to the local program, although incomes may still rise if the program increases T_t and enables individuals to work more hours for the same wage. In contrast, when $0 < \beta < 1$, the decreasing returns to scale (DRTS) production function implies that as firms hire more workers, the wage rate falls ($F''(T_t N_t) < 0$). This provides an additional signal to workers that the benefits of moving are lower as more people move. In order to prevent profits from growing unboundedly as workers enter the locality, we need to additionally assume that for all x, $F'(x) + xF''(x) > 0$.

The main insights from our model do not depend on the choice of production technology. However, to simplify our empirical work, we assume $\beta = 1$ (CRTS). This means all firms earn zero profits and simplofies the computation of welfare bounds. Also, in our specific example, rural electrification did not seem to have an effect on wages, meaning that the CRTS assumption is probably a reasonable one.

C. Equilibrium in period 1: Before the program

An equilibrium in period 1 is a wage w_1, a consumption choice for each consumer, and an assignment of consumers to locations such that, given $\bar{U}$, (i) each consumer's consumption and location choices maximize utility, taking the wage and the amenity rationing as given, and (ii) the labor market clears (which means (4) holds).

The indirect utility of living in the rural area in period 1 is

$$\begin{aligned} U_{i1}^* &= \max_{c,a} c^\alpha a^{1-\alpha} + \epsilon_i \quad \text{s.t.} \quad c \le w_1 T_1, \quad a = \frac{A}{N_1} \\ &= (w_1 T_1)^\alpha \left(\frac{A}{N_1}\right)^{1-\alpha} + \epsilon_i \end{aligned} \tag{5}$$

Thus i chooses to live in the rural area in period 1 if and only if $U_{i1}^* \ge \bar{U}$, or

$$\epsilon_i \ge \bar{U} - [w_1 T_1]^\alpha \left(\frac{A}{N_1}\right)^{1-\alpha} \equiv \bar{\epsilon}_1. \tag{6}$$

This defines a cutoff for the preference shock $\bar{\epsilon}_1$, below which individuals choose to stay in the urban area and above which individuals choose the rural area.

D. Characterizing the impact of the local program

There are many ways to model the impact of a local infrastructure program on local productivity. For any given program, the productivity impacts might work through the production side of the market or through consumers. For example, Suàrez Serrato and Wingender (2011) allow infrastructure spending to directly affect the demand for labor, through government hiring. Moretti (2011) takes a more general approach and allos localized technology shocks to shift the productivity of local firms.

In our empirical example, the new infrastructure (household electrification) operates directly on rural households, plausibly raising time endowments for market work. New access to electricity increases productivity in home production and extends the number of hours available for home and market work. To match this setting, we assume that the local program in our model operates directly on consumers by altering their labor endowments. The rural infrastructure program raises the time endowment in the second period, so individuals earn more primarily because they (inelastically) supply more effective labor units to the market. Firms absorb all of the newly available labor in the rural area ($N_t T_t$) at wage w_t.

We further assume the infrastructure program does not affect urban utility $\bar{U}$. This amounts to assuming that migrants out of the urban area represent a small fraction of the urban population, even though they may be a large fraction of the rural population. This assumption also rules out potential benefits to the urban area arising from people leaving the urban area.

In the next two sections, we characterize the spatial equilibrium that arises after the infrastructure program is implemented. The nature of these post-program equilibria depends on the form of the market for the rural amenity.

E. Equilibrium in period 2 with a missing amenity market

Suppose that, in period 2, the amenity is again rationed across consumers who choose to live in the rural area. Then the equilibrium is identical to that in period 1, except that $T_2 > T_1$; consumer i chooses to live in the rural area in period 2 if and only if

$$\epsilon_i \geq \bar{U} - [F'(T_2 N_2) T_2]^{\alpha} \left(\frac{A}{N_2}\right)^{1-\alpha} \equiv \bar{\epsilon}_2. \tag{7}$$

The fraction of individuals living in the rural area is the same as the probability that $\epsilon_i \geq \bar{\epsilon}_2$. Hence, using the uniform distribution of ϵ_i we can write the local labor supply function,

$$s\frac{2N_2 - P}{P} = [F'(T_2 N_2) T_2]^{\alpha} \left(\frac{A}{N_2}\right)^{1-\alpha} - \bar{U} = -\bar{\epsilon}_2, \tag{8}$$

where P is the total population in the urban and rural areas. The left-hand side of (8) is strictly increasing in N_2, while the right-hand side is, under our assumptions on F, strictly decreasing in N_2 and strictly increasing in T_2. Therefore, the equilibrium population N_2 is strictly increasing in the time endowment T_2 ($\frac{\Delta N_t}{\Delta T_t} > 0$): more people live in the rural area when T is higher (or, $\bar{\epsilon}_2 < \bar{\epsilon}_1$).

Why does anyone move when the new infrastructure raises the time endowment? With the greater labor endowment, individuals can earn higher incomes than they could before and this induces some of them to move from urban to rural areas. Because the indirect utility of the rural area is monotonic in ϵ_i, anyone who chose the rural area in period 1 will continue to choose it when the time endowment rises in period 2. Thus, after the infrastructure program, there are two kinds of people in the rural area: *rural stayers*, who lived in the rural area in period 1 and remain there in period 2, and *movers*, who lived in the urban area in period 1 but move to the rural area in period 2. We will take into account the welfare gains of the program accruing to both rural *stayers and to* movers in constructing our welfare bounds.

F. Equilibrium in period 2 with an amenity market

Suppose alternatively that in period 2, there is a market for the local amenity: it can be bought and sold at price $\hat{r}_2$. For example, land might be traded for a price, or slots in school could be "bought" for a school fee, or private health care might be available. To keep notation clear, we will use hats to denote all variables corresponding to the equilibrium with an amenity market. We assume that the people who lived in the rural area in period 1 (when the amenity was rationed) own equal shares of the amenity endowment. We continue to assume $T_2 > T_1$. We show below that, as in the no-markets case, this assumption implies that no one who lives in the rural area in period 1 moves away in period 2. Thus, we must continue to distinguish between rural stayers and movers into the rural area. The period 2 budget constraints of rural stayers and movers are:

$$\hat{c}_{2,stayer} + \hat{r}_2 \hat{a}_{2,stayer} = \hat{w}_2 T_2 + \hat{r}_2 \frac{A}{N_1} \tag{9a}$$

$$\hat{c}_{2,mover} + \hat{r}_2 \hat{a}_{2,mover} = \hat{w}_2 T_2. \tag{9b}$$

An equilibrium in period 2 with an amenity market is a wage $\hat{w}_2$, an amenity price $\hat{r}_2$, consumption and amenity choices for each consumer, and an assignment of consumers to locations such that, given $\bar{U}$, (i) each consumer's consumption and location choices maximize utility, taking the wage and the amenity price as given, (ii) the labor market clears, and (iii) the amenity market clears. We show in appendix A1 that, in the equilibrium, the indirect utilities of rural stayers and movers are

$$\hat{U}^*_{i2,stayer} = \alpha \left(1 + \frac{1-\alpha}{\alpha} \frac{\hat{N}_2}{N_1}\right) [F'(T_2 \hat{N}_2) T_2]^\alpha \left(\frac{A}{\hat{N}_2}\right)^{1-\alpha} + \epsilon_i \tag{10a}$$

$$\hat{U}^*_{i2,mover} = \alpha [F'(T_2 \hat{N}_2) T_2]^\alpha \left(\frac{A}{\hat{N}_2}\right)^{1-\alpha} + \epsilon_i. \tag{10b}$$

Because stayers collect rents, they have higher indirect utility than movers for any given value of ϵ_i. Therefore, if anyone who started in the rural area moves out, no one will move in — all of the potential in-migrants have lower ϵ_i and would have to pay rent, besides.

The effect of creating a market for the amenity on migration depends on whether T_2 is larger than T_1. If $T_2 = T_1$, creating a market does not change incumbents' budget sets, so we have the following result:[12]

PROPOSITION 1 *If $T_2 = T_1$, then $N_2 = N_1$ regardless of whether there is an amenity market in period 2.*

Proof: See appendix A2. □

However, if $T_2 > T_1$, the number of people who move to the rural area is affected by whether there is an amenity market. First, if $T_2 > T_1$, it cannot be an equilibrium for anyone to move out: Outmigration would mean $\hat{N}_2 < N_1$, but just as in the no-markets case, if $\hat{N}_2 < N_1$, rural incomes in period 2 are at least as large as they were in period 1 (depending on the returns to scale technology). This implies that no one who preferred the rural area in period 1 would prefer the urban area in period 2. Second, a person who was in the urban area in period 1 will move to the rural area in period 2 if and only if $\hat{U}^*_{i2,mover} \geq \bar{U}$, or

$$\epsilon_i \geq \bar{U} - \alpha[F'(T_2\hat{N}_2)T_2]^\alpha \left(\frac{A}{\hat{N}_2}\right)^{1-\alpha} \equiv \hat{\bar{\epsilon}}_2. \tag{11}$$

Depending on the parameters of the model, $\hat{\bar{\epsilon}}_2$ may be larger or smaller than $\bar{\epsilon}_1$. If $\hat{\bar{\epsilon}}_2 \geq \bar{\epsilon}_1$, no one moves to the rural area; the populations remain the same. This would be the case if the increase in income driven by the new infrastructure was exactly offset by an increase in rents to be paid by any movers. If $\hat{\bar{\epsilon}}_2 < \bar{\epsilon}_1$, some people move to the rural area and its population increases. Regardless of the parameters, we have the following result:

PROPOSITION 2 *The migration response to an increase in the time endowment caused by the local infrastructure program is strictly smaller when there is an amenity market, i.e., $\hat{N}_2 < N_2$.*

[12]This is important to establish, because it means that we can compare welfare after the program across the market and no market cases, without worrying about differences in baseline levels of welfare under each of these systems.

Proof: The migration response without an amenity market is strictly positive. If $\hat{\bar{\epsilon}}_2 \geq \bar{\epsilon}_1$, then the migration response with an amenity market is zero, which is strictly less than the response without an amenity market. If $\hat{\bar{\epsilon}}_2 < \bar{\epsilon}_1$, the rural population in period 2 with an amenity market satisfies

$$s\frac{2\hat{N}_2 - P}{P} = \alpha[F'(T_2\hat{N}_2)T_2]^{\alpha}\left(\frac{A}{\hat{N}_2}\right)^{1-\alpha} - \bar{U}. \tag{12}$$

The left-hand sides of (8) and (12) are identical and are both strictly increasing in rural population. Since $\alpha \in (0,1)$ and $F' > 0$, the right-hand side of (12) is strictly less than the right-hand side of (8) for a fixed value of the rural population. Further, the right-hand sides of both equations are strictly decreasing in rural population (α scales down the right hand side of (12)). Thus, the rural population that solves (8) — the no-markets equilibrium population — is strictly greater than the equilibrium population with a market, which solves (12). □

This is the first central result of the paper. Proposition 2 demonstrates more people move into the rural area in response to a local infrastructure program when the amenity market is missing. Put differently: when a market for the amenity exists, the price of the amenity gives consumers information about crowding and acts as a brake on migration. In essence, this is a version of the tragedy of the commons: when individuals move in to a rural area after the program, congestion in the local amenity A is only taken account of when that amenity is priced (i.e. through r_t). In contrast, when the (congestible) amenity can be accessed by anyone in the rural area, the migration response to the program is inefficiently high, which has implications for welfare gains.

G. Welfare

What is the welfare effect of the program? To compute the consumer contribution to welfare, we calculate the compensating variation: the reduction in income, after the program, that would leave the consumer just indifferent between not having the program or having the program but paying for it with a reduction in income.[13] Specifically, for each person in the

[13]This is not uncommon in the local public finance literature, e.g. Calabrese, Epple and Romano (2012). To calculate the equivalent variation, we would need an explicit model of consumers' maximization problem in

rural area in period 2 — both stayers and movers — we ask: For what number k would a $100k\%$ reduction in the rural wage, after the program, return this person to his or her period 1 utility level? The answer depends both on the crowding induced by the project and on the structure of the market for the local amenity.

No amenity market

For rural stayers, we must find the k that solves

$$[(1 - k^{stayer})w_2T_2]^{\alpha} \left(\frac{A}{N_2}\right)^{1-\alpha} = (w_1T_1)^{\alpha} \left(\frac{A}{N_1}\right)^{1-\alpha}. \tag{13}$$

Rearranging terms,

$$-\ln(1 - k^{stayer}) = \ln\frac{w_2T_2}{w_1T_1} - \frac{1-\alpha}{\alpha}\ln\frac{N_2}{N_1}. \tag{14}$$

(14) provides a useful decomposition of the program's welfare impact. Note that the income effect of the program is only the first part of this compensating variation measure of welfare. The argument of our paper is that the migration effect — the second term in (14) — is also important when the migration response to the program, $\ln(N_2/N_1)$, is not small and when the preference for the local amenity does not substantially outweigh the preference for the consumption good ($(1-\alpha)/\alpha$ not too small).

Since any mover has $\bar{\epsilon}_2 \leq \epsilon_i < \bar{\epsilon}_1$,

$$0 \leq -\ln(1 - k_i^{mover}) < -\ln(1 - k^{stayer}). \tag{15}$$

Because all agents in our model have the same income, we can aggregate the compensating variation across individuals:

$$CV = \sum_{stayers} k^{stayer} w_2T_2 + \sum_{movers} k_i^{mover} w_2T_2. \tag{16}$$

the urban area. The compensating variation allows us to side-step this issue, but it does have costs: primarly, it becomes impossible to compare benefits of different types of programs using compensating variation, since the new prices used to value the welfare change are different for each kind of intervention.

The bounds in (15) imply

$$N_1 k^{stayer} w_2 T_2 \leq CV < N_2 k^{stayer} w_2 T_2. \tag{17}$$

At the lower bound, the compensating variation to the marginal mover is zero; at the upper bound, the marginal mover gains just less than the utility gain that rural stayers enjoy. Actually implementing these bounds does not require any information about who is a mover or stayer. Rather, all we need is an estimate of k_{stayer}, which is itself a function of the income effect of the program, the migration effect of the program and α, the relative preference for consumption goods. In section 3, we show that equation (14) is straightforward to estimate from data on the infrastructure program's impact on income and population and describe ways to choose sensible values of α for our specific empirical example.

Note that (17) gives us the consumer component of total social welfare gains from the program. To compute the total welfare gain to a specific rural area, we need to add in the impact of the local infrastructure program on firm profits: $\Delta\Pi = (N_2T_2)^\beta - (N_1T_1)^\beta - (w_2N_2T_2 - w_1N_1T_1)$. Since profits appear in both the upper and lower bounds of the welfare calculation, adding them in only serves to shift the bounds upwards (or not at all if we assume CRTS).Whether profits are positive or zero does not affect Proposition 2.

With an amenity market

For rural stayers, we must find the k that solves

$$\alpha\left(1+\frac{1-\alpha}{\alpha}\frac{\hat{N}_2}{N_1}\right)[(1-\hat{k}^{stayer})\hat{w}_2T_2]^\alpha\left(\frac{A}{\hat{N}_2}\right)^{1-\alpha} = (w_1T_1)^\alpha\left(\frac{A}{N_1}\right)^{1-\alpha}. \tag{18}$$

Rearranging terms,

$$-\ln(1-\hat{k}^{stayer}) = \ln\frac{\hat{w}_2T_2}{w_1T_1} - \frac{1-\alpha}{\alpha}\ln\frac{\hat{N}_2}{N_1} + \frac{1}{\alpha}\ln\left(\alpha+(1-\alpha)\frac{\hat{N}_2}{N_1}\right). \tag{19}$$

Note that this expression has an additional term relative to (14) that reflects the rents the stayers will collect from the movers.

We can now relate the compensating variation with an amenity market to the compensating variation without an amenity market:

$$
\begin{aligned}
-\ln(1-\hat{k}^{stayer}) &= -\ln(1-k^{stayer}) + \left(\ln\frac{\hat{w}_2}{w_2} - \frac{(1-\alpha)}{\alpha}\ln\frac{\hat{N}_2}{N_2}\right) + \frac{1}{\alpha}\ln\left(\alpha + (1-\alpha)\frac{\hat{N}_2}{N_1}\right) \\
&= -\ln(1-k^{stayer}) - \left(\frac{(1-\alpha)}{\alpha}\ln\frac{\hat{N}_2}{N_2}\right) + \frac{1}{\alpha}\ln\left(\alpha + (1-\alpha)\frac{\hat{N}_2}{N_1}\right).
\end{aligned}
\tag{20}
$$

Thus a rural stayer's compensating variation with an amenity market is the compensating variation without the amenity market, plus the difference in consumption between the two states of the world driven by the difference in the migration reponse to the program, plus a term that accounts for the rents the stayers collect from the movers. Recall from proposition 2 that $\hat{N}_2 < N_2$ and that $\hat{w}_2 \geq w_2$. Equation (20) thus implies the following:

PROPOSITION 3 *Rural incumbents' welfare gain from the program is higher when there is an amenity market.*

Proof: Since $\hat{N}_2 < N_2$ and $\alpha \in (0,1)$, the second term in (20) is strictly positive. Since $\hat{N}_2 \geq N_1$, the third term is weakly positive. Therefore, $-\ln(1-\hat{k}^{stayer}) > -\ln(1-k^{stayer})$, which implies $k^{stayer} < \hat{k}^{stayer}$. □

This is the second main result of the paper. When there is a market for the local amenity, the gain for rural incumbents is larger than when there is no market for the local amenity. For consumers then, the welfare gains from the program are larger when other inelastically-supplied local amenities are priced, relative to when they are not.

If there are any movers, they have $\hat{\bar{\epsilon}}_2 \leq \epsilon_i < \bar{\epsilon}_1$; in addition, holding ϵ_i fixed, a stayer has higher welfare than a mover in period 2 since $r_2 > r_1$. Therefore, stayers' compensating variation is strictly greater than movers' compensating variation and, similar to the no-markets case, we have

$$
0 \leq -\ln(1-\hat{k}_i^{mover}) < -\ln(1-\hat{k}^{stayer}). \tag{21}
$$

The aggregate value of the compensating variation for consumers satisfies

$$\hat{N}_1 \hat{k}^{stayer} \hat{w}_2 T_2 \leq \hat{CV} < \hat{N}_2 \hat{k}^{stayer} \hat{w}_2 T_2. \quad (22)$$

Just as in the no-markets case, if we wanted the change in total social wefare after the program is implemented ($\hat{V}$), we would need to add profits $\Delta\hat{\Pi} = (\hat{N}_2 T_2)^\beta - (N_1 T_1)^\beta - (\hat{w}_2 \hat{N}_2 T_2 - w_1 N_1 T_1)$ to both lower and upper bounds.

Equation (21) is important since it indicates that even if all markets exist, we do not need price data to compute welfare bounds. This is an extremely useful result in settings where high quality land price data are difficult to come by, and where measuring population and income responses to local programs is feasible.[14]

Relating welfare bounds without an amenity market to welfare bounds when all markets exist

We have shown that incumbents enjoy higher welfare gains when there is a market for a local amenity. What about overall welfare gains to the locality? In the case of CRTS ($\beta = 1$), the lower bound in the no markets case (in (17)) is strictly lower than the lower welfare bounds in the markets case (in (22)). However, the upper bounds cannot be similarly ordered: the upper bound on welfare could be larger in the no markets case if there is a very large population response to the infrastructure program and if each mover enjoyed almost as much gain to moving as the stayers enjoyed from staying. Alternatively, the upper bound on welfare could be smaller in the no markets case if there was a smaller population response and if the gain in welfare to movers was only marginally positive. With DRTS technology, it

[14] We can of course use land price information if there are land markets and if these prices are observed. In appendix A1, we show that in equilibrium,

$$\hat{r}_2 = \frac{1-\alpha}{\alpha} \frac{\hat{N}_2 \hat{w}_2 T_2}{A}.$$

Substituting this result into (19), and assuming that we also observe a period-1 amenity price $\hat{r}_1$ and a period-1 wage $\hat{w}_1$ such that the period-1 population is a market equilibrium, the compensating variation for a rural stayer can be expressed as

$$-\ln(1 - \hat{k}^{stayer}) = \frac{1}{\alpha} \ln \frac{\hat{w}_2 T_2}{\hat{w}_1 T_1} - \frac{1-\alpha}{\alpha} \ln \frac{\hat{r}_2}{\hat{r}_1} + \frac{1}{\alpha} \ln \left(\alpha + (1-\alpha) \frac{\hat{r}_2}{\hat{r}_1} - (1-\alpha) \frac{\hat{w}_2 T_2}{\hat{w}_1 T_1} \right).$$

is not possible to order the welfare bounds in either the amenity market or no market cases.

In the rest of this paper, we assume that $\beta = 1$, so that profits are zero in all states of the world. Then, the only welfare gains generated by the local infrastructure project are those accruing to consumers.

3. Empirical implementation

Our goal is to estimate the effect of an infrastructure program on consumers' welfare. Equations (14), for the case without amenity markets, and (19), for the case with amenity markets, show that we can estimate this welfare impact if we know the parameter α and have estimates of the program's effect on incomes (w_2T_2/w_1T_1 or $\hat{w}_2T_2/w_1T_1$) and population (N_2/N_1 or $\hat{N}_2/N_1$). The basic idea is that as long as we have causal estimates of the impact of an infrastructure program on incomes and population, we do not need any data on local amenity prices, regardless of whether there is an amenity market or not. This section describes how we obtain such welfare estimates.

A. Estimating income and population impacts

Suppose that for a large number of rural communities j, we have data on income $w_{jt}T_{jt}$ and population N_{jt} at each of two dates $t = 1, 2$. Suppose also that some of these communities received the infrastructure program, while others did not; let I_{jt} be an indicator variable that equals 1 if community j received the program at date t. (In the case of our empirical example, no communities have the program at $t = 1$, so $I_{j1} = 0$ for all j.) We assume

$$\ln\left(w_{jt}T_{jt}\right) = \beta_{0,j} + \beta_1 t + \beta_2 I_{jt} + u_{jt}^{wT}, \tag{23a}$$

$$\ln N_{jt} = \gamma_{0,j} + \gamma_1 t + \gamma_2 I_{jt} + u_{jt}^{N}. \tag{23b}$$

The parameters $\beta_{0,j}$ and $\gamma_{0,j}$ are community fixed effects. The parameters β_1 and γ_1 reflect common trends in income and population across all communities, whether they receive the infrastructure program or not. The parameters β_2 and γ_2 are the effects of the infrastructure program on income and population. Thus, in the no-markets case, the compensating variation for a stayer from equation (14) is

$$-\ln\left(1-k^{stayer}\right)=\beta_2-\frac{1-\alpha}{\alpha}\gamma_2, \tag{24}$$

and in the markets case, from equation (19)),

$$-\ln\left(1-\hat{k}^{stayer}\right)=\beta_2-\frac{1-\alpha}{\alpha}\gamma_2+\frac{1}{\alpha}\ln\left(\alpha+(1-\alpha)\exp\left(\gamma_2\right)\right). \tag{25}$$

(Similar formulas apply to movers in the market and no-market cases.) Finally, the residuals u_{jt}^{wT} and u_{jt}^{N} represent all other factors affecting income and population.

It is clear from the system (23) that we need consistent estimates of β_2 and γ_2 to proceed. This is a challenging empirical problem, since infrastructure project placement is unlikely to be random. In the South African example we use to illustrate, we discuss how an instrumental variables strategy overcomes this endogeneity and identifies the parameters of interest. We estimate the system (23) by system IV-GMM to account for possible correlation between the residuals of the two equations.

Since we want to aggregate the compensating variation across individuals in equations (16) and (22) to estimate the total monetary value of the program, we need to know w_2T_2, the post-program income in communities that receive the program. We can estimate w_2T_2 from a regression of $I_{j2}w_{j2}T_{j2}$ on I_{j2}; this regression should be estimated jointly with the system (23) so that standard errors account for the possible covariance between estimates of β_2, γ_2 and w_2T_2.

We also need to know N_1 and N_2 (or $\hat{N}_2$, if there is an amenity market). In the model, N_1 is the rural area's pre-program population and N_2 is the rural area's post-program population (in the no-markets case). We can observe N_2 directly: it is the total population in areas that received the infrastructure program, after the program is implemented, or

$$N_2=\sum_{j\,:\,\text{received program}}N_{j2}. \tag{26}$$

If population data come from a census (as is the case in our example), then N_2 is not a random variable and need not be estimated jointly with the other parameters. However, if population data come from a survey or from a randomly sampled subset of treated communities, then N_2 should be estimated jointly with the rest of the system using a regression analogous to the mean post-program income regression.

Because other factors besides the infrastructure program may also be changing the rural population, we cannot calculate N_1 from the pre-program populations, N_{j1}. Rather, N_1 should be the counterfactual population that the rural area would have had at $t = 2$ if it did not get the program. That is, for a community j that received the program, we should set

$$N_1(j) = N_{j2} / \exp(\gamma_2). \tag{27}$$

The total population in treated areas, if the program had not taken place, is thus

$$N_1 = \sum_{j:\,\text{received program}} N_1(j) = \sum_j \frac{N_{j2}}{\exp(\gamma_2)} = \frac{N_2}{\exp(\gamma_2)}. \tag{28}$$

Putting together all of our results, the bounds on the compensating variation in the no-markets case (under the assumption of CRTS in production) are

$$\frac{N_2}{\exp(\gamma_2)} \left[1 - \exp\left(-\beta_2 + \frac{1-\alpha}{\alpha}\gamma_2\right)\right] w_2 T_2 \leq CV < N_2 \left[1 - \exp\left(-\beta_2 + \frac{1-\alpha}{\alpha}\gamma_2\right)\right] w_2 T_2. \tag{29}$$

Standard errors for these bounds can be obtained if we have joint estimates of β_2, γ_2, $w_2 T_2$ and N_2. Similar results apply for the markets case, where the bounds can be expressed as:

$$\begin{aligned} \frac{\hat{N}_2}{\exp(\gamma_2)} \left[1 - \exp\left(-\beta_2 + \frac{1-\alpha}{\alpha}\gamma_2 - \frac{1}{\alpha}\ln\left[\alpha + (1-\alpha)\exp(\gamma_2)\right]\right)\right] w_2 T_2 \leq \hat{CV} \\ < \hat{N}_2 \left[1 - \exp\left(-\beta_2 + \frac{1-\alpha}{\alpha}\gamma_2 - \frac{1}{\alpha}\ln\left[\alpha + (1-\alpha)\exp(\gamma_2)\right]\right)\right] w_2 T_2. \end{aligned} \tag{30}$$

The attraction of estimating welfare bounds without using land prices (even when markets exist) is that these bounds will not depend on poor quality land price data. In many developing countries, collecting good quality data on population and on income is more feasible than collecting high quality data on land prices.

B. Three ways to estimate α

The last piece we need before implementing our framework in the South African case is an estimate of α. The welfare bounds in (29) and (30) are functions of the income and migration responses to the program and α. As $\alpha \to 1$, consumer preferences shift towards the consumption good and away from the amenity. This minimizes the negative impact of migration on welfare through crowding of the amenity and moves the welfare bounds for the markets and no markets case towards each other. In the limit, if consumers did not care for the amenity at all, the welfare bounds would be identical regardless of whether there is a market for the amenity or not.

Alternatively, as $\alpha \to 0$, consumer preferences shift towards the amenity and away from the consumption good and the migration response to the program gains a larger weight in the welfare bounds. In both the market and non-market cases, the welfare bounds get wider, admitting a larger range of possible effects of the program.

Clearly, the choice of α affects the calculation of welfare bounds in both markets and no markets cases. Rather than choose an arbitrary value of α for our empirical example, we calibrate a sensible value for this parameter using three different strategies. All of these strategies lead us to a similar value for α for this South African case.

Using the model to derive a lower bound for α

The model allows us to put a lower bound on α. When α is small, amenities are more important and a given level of crowding of amenities causes more disutility. Equations (29) and (30) show that, for any given income and population elasticities, the welfare impact of a program is negative when α is sufficiently small. However, the concept of a spatial equilibrium implies that any program that raises incomes cannot reduce total welfare. Thus, the lower bound for α is the value that makes the program's estimated welfare impact zero. In the no-markets case, the welfare effect of the program is zero when k^{stayer} is zero, or when

$$\alpha = \frac{\ln\left(N_2/N_1\right)}{\ln\left[(w_2T_2)/(w_1T_1)\right] + \ln\left(N_2/N_1\right)} = \frac{\gamma_2}{\beta_2 + \gamma_2}. \tag{31}$$

The expression for the markets case would be derived in the same way, under the condition that $\hat{k}^{stayer}$ is zero. Given estimates of β_2 and γ_2 from the South African case, we estimate the highest lower bound for α is 0.979.

Using national accounts data to benchmark α

Instead of using the model to choose a value for α, we can look for plausible estimates from the data. If local amenities were priced, their share of aggregate expenditure would be $1-\alpha$. Many of these publicly-provided amenities, such as schools and hospitals, are included in measured aggregate expenditure in the national accounts because they are provided by the government. Thus, we can use the ratio of government spending on local services to gross domestic product as an approximation to $1-\alpha$. This approach will likely underestimate $1-\alpha$ because some non-priced amenities — primarily land that is not allocated in the market — are omitted from both the numerator and denominator of the ratio.

We estimated spending on local services and basic infrastructure to be total government spending minus transfer payments, debt and defense spending, and related this balance to annual GDP. In the South African case, national accounts data from 1996 to 2002 suggests that the average value of α is 0.93.[15].

Inferring α ***from cross-sectional variation in incomes and population density***

Since α captures the relative preference for consumption goods, a third way to compute a value for α is to observe the cross-sectional correlation between income (earnings) and population density in the period before the program arrives. Conditional on individuals sorting into high and low density areas (which equates to high and low amenity-share areas in pre-program periods), the relationship between incomes and density tells us something about the marginal rate of substitition of consumption for amenities. This is essentially an hedonic approach to valuing amenities: how much do consumers need to be compensated for to live in more densely settled areas?

To implement this approach in the South African case, we estimate regressions of the log of average community earnings (w_1T_1) on the inverse of household density of the community ($\frac{1}{N_1}$) before electrification and include controls for district fixed effects. Using the coefficient on the density variable as a proxy for the marginal rate of substitution of con-

[15]Data were obtained from quarterly reports for national accounts provided by Statistics South Africa at *http://www.statssa.gov.za/publications/P0441/P04413rdQuarter2003.pdf*

sumption for amenities, we estimate α to be 0.96.[16]

The three different approaches to choosing a value for α in South Africa all produce very similar results: 0.93, 9.96 and 0.97. Since the national accounts method and the hedonics method produce values lower than the largest lower bound suggested by the model, we use a value of α larger than this lower bound: $\alpha = 0.99$. An α this large implies that congestible amenities have only a very small impact on utility. Nevertheless, we find that migration responses are still large enough to appreciably change the evaluation of the place-based program in South Africa.

4. Empirical application: Household electrification in South Africa

We use the example of rural electrification in South Africa to illustrate why it is important to account for migration when evaluating the welfare impacts of spatial programs. As we describe below, well-functioning land markets do not exist in this South African setting. We provide new evidence of congestion in local amenities (schools) after electrification and find that the migration effects behind this crowding reduce the estimated welfare effects of the program by an order of magnitude.

A. Program description and institutional setting

Between 1995 and 2001, roughly 200,000 households in rural KwaZulu-Natal (KZN) benefited from new electricity connections installed and funded by South Africa's national power utility, Eskom.[17] An important aspect of this infrastructure program that makes it amenable to our framework is that Eskom faced strong incentives to meet annual connections targets by prioritizing lowest-cost areas. Since land gradient was one of the key determinants of cost, Dinkelman (2011) devises an instrumental variables strategy using gradient to identify the causal impact of household electrification on economic outcomes. Hence, we have consistent estimates of the effect of rural electrification on employment and on population

[16]Specifically, the marginal rate of substitution is $\frac{(\alpha)}{(1-\alpha)} * \frac{a}{c}$ which we equate to the coefficient in the regression of log earnings on inverse density. We solve out for α using the sample mean values of log earnings and inverse density to proxy for c and a respectively.

[17]See Dinkelman (2011) for a detailed discussion of the program.

effects that we use to construct welfare bounds for this infrastructure investment.

Another feature of the rural KZN context is that most local amenities are unpriced. For example, there is no market-based system for land transactions. Land is largely state-owned or held in trust, often untitled, and communally operated as in many other parts of Africa (Adams, Cousins and Manona (1999)). Local chiefs, kin-based networks or tribal authorities may decide who can access land and for what purposes (residential, cropping, or communal grazing), although details of these allocation mechanisms are unclear.[18] Similarly, the provision of and access to local schools, health clinics and water infrastructure is outside the ambit of the market. The state provides these public goods and services for all residents in a given locality and access is often determined through some type of queue.

In this environment, it would be impossible to observe the value of new infrastructure investments capitalize in land prices, since these land prices do not exist. The contribution of our paper is that it is at least possible to bound the welfare effects of this program.

In our model, A represents these schools, clinics, water infrastructure, traditionally held land and other local amenities. We do not model the allocation of land by local chiefs nor the allocation of places in schools or clinics through a queueing system. Rather, our model simplifies the non-market-based allocation of the local amenity by adopting an "equal sharing" rule: each person in location j receives the share A_j/N_j. This extreme sharing rule allows us to examine what a complete lack of markets for amenities implies for migration responses to local programs. Imperfect markets for these amenities are likely to have similar, although attenuated, effects.

B. Data and empirical methods

Dinkelman (2011) matches community-level Census data from before and after the program with administrative data on the location and timing of electrification projects and with geographic features of the communities (land gradient, distance from roads and towns, and distance from electricity substations) to estimate employment and population impacts of electrification. To provide evidence for congestion in local amenities, we supplement this

[18]Historically, chiefs were supposed to discern good from bad community members and newcomers, and so protect the community from unsavory types (Hall, 2009). In practice, kin networks often receive preferential treatment in the allocation of any land or of better land.

community-level data set with spatially matched data from the National Schools Register of Needs (also before and after electrification) and assign school-level variables to the communities in which the schools are located. The final sample consists of 1,816 rural, former homeland communities in KZN.

Table 1 presents key summary statistics. Between 1996 and 2001, about 20% of these rural communities received Eskom electrification. The employment rate in the baseline period is 10%, an extremely low level of participation. Because of the nature of these ex-homeland areas (poor quality, marginal land), employment opportunities were very sparse (Dinkelman, 2011). At baseline, household density is relatively high — 22 households per square kilometer — and the average household size is under 4, with a wide range (2 to 14). There are on average 0.94 schools per community, also with a wide range: some communities contain no schools while other, larger communities have up to 11 schools. Conditional on having at least one school in the area, average student-teacher ratios (STRs) are high, at 39 for an average community. Some schools serve very small populations and have just four learners per teacher, while other schools are burdened with STRs of over 100.

To compute welfare effects, we value employment gains and migration crowd-out in terms of local monthly earnings. Since the Census does not contain measures of earnings or wages, we use magisterial district-level data from the 2001 October Household Survey to construct average post-program monthly earnings for African workers in 44 areas and assign these averages to each of the 1,816 census communities. Average monthly earnings in 2001 were just over ZAR1,200, or 285USD in 2001 dollars according to the purchasing power parity reported in the Penn World Table (Heston et al., 2011).

The empirical strategy for identifying the impact of the program is motivated by an understanding of Eskom's financial incentives. The main system of equations in Dinkelman (2011) is:

$$\Delta y_{jdt} = \nu_1 + \nu_2 \Delta I_{jdt} + \gamma_d X_{jd0} + \lambda_{dt} + \Delta \epsilon_{jdt} \tag{32a}$$

$$\Delta I_{jdt} = \delta_1 + \delta_2 Z_{jd} + \nu_d X_{jd0} + \mu_{dt} + \Delta \omega_{jdt} \tag{32b}$$

where Δy_{jt} is the change in the outcome variable (employment, or log population) in community j and district d between 1996 and 2001, and $\Delta I_{jt} = 1$ defines whether a community was electrified between 1996 and 2001. X_{jd0} represents controls for baseline characteristics of the community including household density and distance from the initial grid, λ_{jt} and μ_{dt} are district-specific trends and ϵ_{jdt} and ω_{jdt} are community-specific error terms. Since there are good reasons to suspect that electricity projects were not assigned randomly, and to be concerned about correlation between project assignment and unobservable community-level trends (i.e., to suspect that $E[\Delta\epsilon_{jdt}\Delta I_{jdt}] \neq 0$), Dinkelman (2011) instruments for ΔI_{jdt} with community land gradient. Gradient was an important factor affecting the cost of connection and therefore the order in which communities were connected. The identification assumption is that, conditional on controls, employment and population growth trends should not be different across communities with steeper versus flatter land gradients. Dinkelman (2011) provides several robustness checks and a placebo experiment to support the validity of this assumption. Because the IV strategy provides consistent estimates of the parameters necessary in our welfare analysis, we focus on discussing these results.

To estimate the indirect effects of electrification through crowding, we examine the change in household size, student-teacher ratio, and number of learners per school as outcomes in the IV system in (32). Then, to construct welfare bounds for the program, we use estimates of the population and employment effects of the program as reported in Dinkelman (2011).[19]

C. Evidence of congestion in local amenities

Table 2 presents our evidence for congestion in local public goods. In columns (1)-(4), we see the IV estimates of the impact of electrification on household size and household density. In places getting access to electricity between 1995 and 2001, household density increases by more than 100 households per square kilometer (almost five times), while household size increases by almost one person. Relative to average household size (3.62), this is a large (27%) increase.

The next set of columns show the consequences for schooling. Schools become more

[19] The Census data do not contain meausres of hours of work, wages or income. Using a different dataset and an alternative identification strategy, Dinkelman (2011) shows that wages do not rise significantly in response to the new infrastructure. If all response is on the extensive margin, then employment growth (valued by average earnings) gives us the total income gain associated with the program.

crowded in areas getting access to electricity by virtue of gradient: student-teacher ratios increase by more than 26 students on average or about 66% relative to the average STR. The number of school-registered learners in each community increases by a large (but not statistically significant) 239 students. Importantly, there is no evidence that the number of schools in electrifying areas increased over the period. This supports our assumption that other local amenities are supplied inelastically.

These results on crowding in public schools after rural electrification represent some of the first empirical estimates of congestion externalities in a developing country. They indicate a powerful channel through which migration can have negative consequences for incumbents.

D. Welfare bounds

In Table 3, we calculate bounds on the compensating variation associated with the program. First, we estimate (23) jointly using GMM IV and retrieve the employment and population growth impacts of the program (Panel A). As Dinkelman (2011) shows, electrification increases employment in rural KZN through some combination of releasing time from home production into market work, enabling people to make new jobs for themselves in self-employment or small enterprise, and migration. Here, we combine employment data for men and women, and see that electrification raises the overall employment rate by 8.3 percentage points, although this change is not significantly different from zero (t-statistic of 1.63).[20] There is also substantial population growth in electrifying areas, almost 390 log points (over 300%) using the IV results. This was the population increase underlying the crowding of households and schools in Table 2.

Next, we use the estimated employment and population impacts to calculate the welfare bounds in Table 3, Panel B. These bounds are computed under the assumption that $\alpha = 0.99$; in other words, only 1% of utility comes from amenities and 99% from consump-

[20]Separately estimating male and female employment effects, Dinkelman (2011) finds that female employment rises by 9 percentage points in electrified relative to non-electrified areas, and this result is statistically significant at the 10% level. There are no significant impacts on male employment in the Census data. Using an alternative identification strategy and household survey data, she shows that male and female employment increases significantly in electrifying areas: for an average increase in electrification rates (0.15), there is a 1.3 percentage point increase in male employment and men work 1.3 hours more each week, and a 1.8 percentage point increase for women with women working 1.9 hours more per week. The magnitude of these employment responses is consistent with the new work being informal and in self-employment rather than full-time formal sector work.

tion. We use (14) to estimate values for k — the fraction of post-program income that a rural stayer would need to give up in order to keep utility the same before and after the program. We present these estimates ignoring the migration response in column 1, and then taking account of the migration response in column 2.

Under the assumptions of our model, rural stayers would be willing to give up 8% of their income to keep the program. Monetizing this compensating variation by multiplying k by the average monthly earnings in treated areas post-electrification weighted by the increased employment in these areas. The monthly value of the compensating variation for an average rural stayer is about ZAR30 ignoring the migration effect. That is, individuals would be willing to give up ZAR30 per month to retain the program.

In contrast, when we include the migration impact, about half of this welfare gain disappears. The compensating variation of the program is only 4.3% of income, assuming $\alpha = 0.99$. The value of this is only ZAR15 per month.

Finally, we compute the lower and upper bounds on the total monetary value of the compensating variation using information about N_2 and N_1 — the post-program population and the counterfactual population without the program. (Recall that under the CRTS assumption, this is the total social welfare after the program.) In the final two rows, we find that the program was worth between ZAR219,454 and ZAR10.8 million per month in all treated areas if migration is ignored. When we add in the migration effects, the bounds shrink to between ZAR117,476 and ZAR5.7 million per month. Given the standard errors on these bounds, we can reject zero impact of the program when migration is not included. However, once we include the effects of congestion in local amenities induced by the higher population, it is no longer possible to reject that the program had zero impact on overall welfare. This is notable: even when people do not value the amenity very highly (since $\alpha = 0.99$), the value of the program is substantially diminished in the presence of migration.

5. Conclusions

This paper uses a simple model of location choice to show that ignoring migration responses to a program will lead researchers to overestimate the program's welfare benefits to incumbents, and more so in the case where there is no market for important local amenities such as land. With missing markets, migration in response to a spatial program is inefficiently high, and each additional mover increases congestion in any inelastically supplied quasi-public goods. This story of the tragedy of the commons has implications for evaluating location-based programs.

We show how to account for migration by using the structure of the model and consistent estimates of the income and population effects of a place-based program to estimate the compensating variation of the program. Combined with an assumption about preferences for consumption relative to local amenities, we compute upper and lower bounds on the welfare gains from an infrastructure investment. Our approach complements traditional approaches to valuing the impact of place-based programs that rely on measures of land rents. We argue that is it possible to estimate welfare gains from a program when land markets are nonexistent as well as when land markets operate but when land prices are not well-measured. Since these are features common to developing countries, our framework is likely to have broad relevance.

We illustrate the importance of accounting for migration using a specific example from the literature that has a credible identification strategy. In the case of household electrification in South Africa, taking migration into account reduces the compensating variation from the program by a factor of two. Using new data on schools and enrollmentm, we show that crowding in schools was one consequence of the large migration response to the program.

There are several caveats to our work: we do not allow for dynamic effects of programs, for general equilibrium effects on the national price level from local programs, or for agglomeration externalities from changes in population density in either the area that receives a program or areas that send migrants. In addition, our welfare analysis ignores the issue of how to raise tax revenue to pay for a local program (although in many poor countries, international donors may be the most common source of funds for such projects). Broadening the analysis along these dimensions would further sharpen our understanding of how migration changes the costs and benefits of place-based programs in developing countries.

Appendix

A1. Derivation of indirect utilities when there is an amenity market

There are N_1 stayers and $\hat{N}_2 - N_1$ movers, so market clearing for amenities requires

$$N_1 \hat{a}_{2,stayer} + (\hat{N}_2 - N_1)\hat{a}_{2,mover} = A. \tag{A1}$$

Maximization by rural stayers implies

$$\hat{c}_{2,stayer} = \alpha \left(\hat{w}_2 T_2 + \hat{r}_2 \frac{A}{N_1} \right), \quad \hat{a}_{2,stayer} = \frac{1-\alpha}{\hat{r}_2} \left(\hat{w}_2 T_2 + \hat{r}_2 \frac{A}{N_1} \right), \tag{A2}$$

while maximization by movers to the rural area implies

$$\hat{c}_{2,mover} = \alpha \hat{w}_2 T_2, \quad \hat{a}_{2,mover} = \frac{1-\alpha}{\hat{r}_2} \hat{w}_2 T_2. \tag{A3}$$

Rural stayers now collect rent from the local amenity, while movers must pay rent for (or buy) the amenity. Hence, incumbents enjoy a wealth effect associated with the new infrastructure, if there are any in-migrants and if the local amenities are inelastic in supply.

Market clearing for amenities requires

$$N_1 \frac{1-\alpha}{\hat{r}_2} \left(\hat{w}_2 T_2 + \hat{r}_2 \frac{A}{N_1} \right) + (\hat{N}_2 - N_1) \frac{1-\alpha}{\hat{r}_2} \hat{w}_2 T_2 = A \tag{A4}$$

or

$$\hat{r}_2 = \frac{1-\alpha}{\alpha} \frac{\hat{N}_2 \hat{w}_2 T_2}{A}. \tag{A5}$$

Therefore, the indirect utility of a rural stayer is

$$\begin{aligned} \hat{U}^*_{i2,stayer} &= \max_{\hat{c}_{2,stayer}, \hat{a}_{2,stayer}} \hat{c}^{\alpha}_{2,stayer} \hat{a}^{1-\alpha}_{2,stayer} + \epsilon_i \quad \text{s.t.} \quad \hat{c}_{2,stayer} + \hat{r}_2 \hat{a}_{2,stayer} \leq \hat{w}_2 T_2 + \hat{r}_2 \frac{A}{N_1} \\ &= \alpha^{\alpha} \left(\frac{1-\alpha}{\hat{r}_2} \right)^{1-\alpha} \left(\hat{w}_2 T_2 + \hat{r}_2 \frac{A}{N_1} \right) + \epsilon_i \\ &= \alpha \left(1 + \frac{1-\alpha}{\alpha} \frac{\hat{N}_2}{N_1} \right) (\hat{w}_2 T_2)^{\alpha} \left(\frac{A}{\hat{N}_2} \right)^{1-\alpha} + \epsilon_i \end{aligned} \tag{A6}$$

and the indirect utility of a mover to the rural area is

$$\begin{aligned}\hat{U}^*_{i2,mover} &= \max_{\hat{c}_{2,mover},\hat{a}_{2,mover}} \hat{c}^{\alpha}_{2,mover}\hat{a}^{1-\alpha}_{2,mover} + \epsilon_i \quad \text{s.t.} \quad \hat{c}_{2,mover} + \hat{r}_2\hat{a}_{2,mover} \leq \hat{w}_2 T_2 \\ &= \alpha^{\alpha}\left(\frac{1-\alpha}{\hat{r}_2}\right)^{1-\alpha}(\hat{w}_2 T_2) + \epsilon_i \\ &= \alpha\left(\hat{w}_2 T_2\right)^{\alpha}\left(\frac{A}{\hat{N}_2}\right)^{1-\alpha} + \epsilon_i\end{aligned} \tag{A7}$$

A2. Proof of proposition 1

Suppose to the contrary that the rural population either falls or rises. If it falls, the rural wage must rise (if $\beta < 1$) or remain constant (if $\beta = 1$) — but in that case, for people who were in the rural area in period 1, the period 1 consumption bundle would remain feasible in period 2 for any value of $\hat{r}_2$ and would be preferred to living in the urban area, which means all of the initial rural residents would have preferred to stay, contradicting the hypothesis that the rural population falls. Alternatively, if the rural population rises, the rural wage is lower (if $\beta < 1$) than in period 2 or is constant (if $\beta = 1$) — but then anyone who preferred the urban area in period 1 must still prefer it in period 2, when wages are no higher than before and inmigrants must pay rent, contradicting the hypothesis that the rural population rises.

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Table 1: Summary Statistics - South Africa

	N communities	Mean	s.d.	Min	Max
Eskom project areas	1,816	0.20	0.40	0.00	1.00
Employment rate in 1996	1,816	0.10	0.09	0.00	0.93
Household density in 1996	1,816	22	30.48	1	592
Population in 1996	1,816	1,396	1,255	149	16,415
Household size in 1996	1,816	3.62	0.62	2	14
Monthly earnings in 1995 ZAR*	44	1,021	591	240	4,048
Number of schools in 1995~	1,816	0.94	1.18	0	11
Number of learners in 1995~	1,126	863	700	0	5,686
Student/Teacher ratio in 1995~	1,098	39	11	4	116

All statistics are measured in 1996 or earlier; prior to the electrification rollout. *Average monthly earnings are computed from individual level data (October Household Survey 1995) for African workers using sample weights to compute magisterial district level means. ~Data on schools are from the 1995 and 2000 South African Schools' Register of Needs Survey. Data on schools was linked to communities by spatially matching the GPS coordinates of schools in each year with Census community boundaries.

Table 2: Evidence of congestion after rural electrification

	Change in household density		Change in household size		Change in student/teacher ratios		Change in number of learners		Change in number of schools	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Electrification	11.92**	108.1*	0.0259	0.982**	1.22	26.71*	-17.35	238.6	0.018	-0.091
	(5.001)	(63.080)	(0.036)	(0.490)	(1.086)	(13.730)	(22.720)	(241.300)	(0.028)	(0.328)
Constant	-16.7	-43.77*	-1.234***	-1.503***	2.287	-8.994	-43.59	-155.9	0.051	0.082
	(14.920)	(24.030)	(0.108)	(0.187)	(3.400)	(7.326)	(70.450)	(128.600)	(0.085)	(0.125)
N	1,816	1,816	1,816	1,816	1,098	1,098	1,124	1,124	1,816	1816
	0.33		0.12		0.03		0.06		0.06	

Each columns shows output from a separate regression. Every regression includes the full set of community-level controls as in Dinkelman (2011), Tables 4 and 5 columns (4) and (9). Robust standard errors clustered at the main place level, p<0.1*, p<0.05**, p<0.01***. Not all communities have any schools in the baseline year and some data on educators is missing for some schools.

Table 3: Welfare gains from rural electrification in South Africa

A. IV estimates of program impacts		
Effect on income (β_2)	0.083	
	(0.051)	
Effect on population (γ_2)	3.897	
	(1.013)	
B: Welfare bounds		
	Ignoring migration	Including migration
Lower bound on $\alpha = \gamma_2/(\gamma_2+\beta_2)$	0.000	0.979
CV as fraction of income for average rural stayer: k	0.080	0.043
	(0.046)	(0.009)
Monetized CV (ZAR/month)	29.19	15.62
	(18.26)	(4.06)
Upper bound on aggregate CV (ZAR/month)	10,800,000	5,785,381
	(204,167)	(6,762,479)
Lower bound on aggregate CV (ZAR/month)	219,454	117,456
	(154,556)	(6,355,559)

Notes: Panel A presents program impact esimates from GMM-IV estimation of the system in equation (24) of the paper. Panel B presents results relevant to the welfare calculationswhere we ignore migration effects γ_2 (column 1) and for the case where migration effects in response to the program are taken into account (column 2). The value of α used in the calculation of the welfare bounds is 0.99.