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Migration, Congestion Externalities, and the Evaluation of Spatial Investments*

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ABSTRACT

Evaluations of new infrastructure in developing countries typically focus on direct effects, such as the impact of an electrification program on household energy use. But if new infrastructure induces people to move into an area, other local publicly provided goods may become congested, offsetting the benefit of the infrastructure. We use a simple model to show how to measure the net benefit of a place-based program without data on land prices — an indicator that is commonly used to measure congestion in developed countries but that often cannot be used in poor countries because land markets are missing or land prices are badly measured. Our model shows that congestion externalities are especially large when land markets are missing. To illustrate, we estimate the welfare impact of a recent household electrification program in South Africa. Congestion externalities from migration reduced local welfare gains by half.

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1. Introduction

Governments in poor countries spend large sums on programs with spatial components, such as transport, sanitation, and energy infrastructure; schools, hospitals, and clinics; and irrigation facilities.[1] A key feature of most such investments is that they take place in only part of a country, changing the relative attractiveness of certain regions for inhabitants. This paper demonstrates that migration responses to such spatial programs can significantly reduce their benefits and shows how evaluations of location-based projects can account for the impact of migration.

Although migration occupies a central position in older theories of structural change and development — for example, Lewis-type models show how rural-to-urban migration contributes to economic growth (Lewis, 1954; Rogers and Williamson, 1982; Williamson, 1988) — more recent work on evaluating the developmental impacts of spatial programs tends not to account for migration. Rather, the recent literature has focused on measuring incumbents' outcomes along dimensions that new infrastructure investments directly affect, such as the effect of subsidized private tap connections on water use, health, well-being, and time use (Devoto et al., 2011, studying urban Morocco) or the impact of household electrification on home production technologies, employment, and earnings (Dinkelman, 2011, studying rural South Africa).[2] While this approach gives us some insight into the effects of spatial programs, by design it is not informative about how migration could alter the overall gains from a program of infrastructure investment. The omission of migration becomes particularly important when other local, rival publicly provided goods are in short supply: any migration response to one location-based investment may end up congesting access to other such goods. In this paper, we focus on measuring and accounting for the congestion effects generated by migration responses to spatial programs.

[1]The most recent data indicate that African countries spend between 6% and 12% of GDP on spatial projects (Briceño-Garmendia, Smits, and Foster, 2008). In the three years following 2006, multilateral lending to developing countries for infrastructure investments increased from U.S. $20 billion to U.S. $50 billion (Lin and Doemeland, 2012).

[2]Among many other recent examples: 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 cement floors 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 in China.

One way to account for congestion is, following the urban economics and local public finance literatures (e.g., Glaeser, 2007, 2008), to examine a spatial program's impact on land prices. 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. Indeed, many authors have applied this idea in U.S. contexts, where land markets do operate well.[3] In theory, one could employ similar methods to evaluate the impact of place-based policies in poor countries. In practice, the lack of good land rent data and the lack of land markets in many places (Udry, 2012) make this approach infeasible.

This paper uses a simple model of location choice to draw out the relationship between migration and place-based policies and to obtain easily applied formulas for the welfare impact of a policy in the presence of migration. Individuals in our model choose between an urban area and a rural one; infrastructure improvements in the rural area cause people to migrate there.[4] We model congestion by assuming an equal-sharing rule for the allocation of a rival publicly provided good. (Less extreme forms of congestion would produce similar but attenuated quantitative results.) We use our model to show how researchers can account for the welfare-reducing effects of congestion by constructing welfare bounds for the impact of a place-based program. These bounds are functions of the population and income responses to the program, so they can be calculated even without data on land prices. We illustrate the feasibility of our method using a recent example from the literature: Dinkelman's (2011) study of the effects of household electrification on employment in rural South Africa. We show empirically that population growth is substantially higher in electrifying areas than in nonelectrifying areas and present new results that households and public schools become congested in communities that are electrified. We use our model and exogenous variation in

[3]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 (forthcoming) use land rents as a component of their estimated effects of federal Enterprise Zone policies. See Moretti (2011) for an extended discussion of the standard spatial equilibrium model and the implications of local productivity shocks for wages, land rents, and hence individual welfare.

[4]We model congestion in rural areas partly because our application focuses on rural infrastructure. This choice is more generally relevant: Young (2012) provides new estimates from 65 poor and middle-income countries that while 20% of rural-born adults migrate to urban areas, 25% of urban-born adults migrate to rural areas. Moreover, rural areas are more likely to suffer from a lack of formal and informal land markets than urban areas.

electricity rollout associated with variation in the cost of grid expansion to estimate the welfare impact of rural household electrification, accounting for congestion externalities. Taking migration into account reduces the welfare benefit of the program by a factor of almost two.

Our paper makes three 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 publicly provided goods are inelastic in supply.[5] Our paper provides 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 much attention in the development literature (Quigley, 2008).[6]

Second, our model highlights an often-overlooked and important theoretical point: migration responses to spatial programs are too large when land markets are missing. Without the information captured in land prices that could alert people to congestion externalities, there is less of a brake on migration in response to a place-based program. Indeed, with no land market, the welfare benefits of a spatial program for both incumbents and movers are lower than they would be if a land market existed — a version of the tragedy of the commons. This excess migration is much more likely to occur in developing countries where property rights are commonly unspecified — for example, 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 publicly provided services such as education and health care is typically not priced.

Third, we provide a constructive example of how researchers can account for the welfare-reducing effects of congestion in a developing-country setting. By computing welfare bounds for the impact of a local program as a function of income and population responses to the programs, we show that it is feasible to account for migration when land markets are missing as well as when markets exist but price data are of poor quality.

Although we propose a general and constructive approach to accounting for migration

[5]Because there is no guarantee that governments in developing countries will be able to increase the supply of such goods even over long periods of time, this is not merely a problem of the short run.

[6]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.

in evaluations of spatial programs, our work has several caveats. First, we ignore agglomeration externalities arising from higher-density settlements, partly for tractability and partly because our focus is on migration into and within rural areas, while agglomeration effects are typically thought to arise in urban settings.[7] Second, we use a partial-equilibrium model. We assume that overall migration effects are small enough so that the effects of out-migration in other parts of the country are ignorable. Third, we ignore the questions of how to optimally finance local programs through taxation[8] and how to optimally allocate spatial investments; to highlight how congestion affects welfare, we focus on estimating welfare gains from local programs in the places where these local programs occur. Finally, our analysis is static; we do not consider the dynamic effects of place-based policies.

The paper begins by describing our simple two-period model of location choice under the assumption that there is no land market. 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 land market 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 are functions of 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.

[7]Although programs that stem the flow of out-migration from rural areas may also undermine the potential for agglomeration externalities in cities, the evidence for agglomeration externalities is scant in developed countries and nonexistent for developing countries (Quigley, 2008).

[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 that fund local programs. Tiebout (1956) is a classic reference on local public finance; Wildasin (1991) and Calabrese, Epple, and Romano (2012) provide more recent analyses focusing on questions of incidence.

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 the South African context for which we have data. We innovate by comparing the solution to the model for two cases: when there is no land market and when such a market exists. We show that differences in migration responses and in related congestion drive a wedge between these two solutions, so that the development program produces smaller welfare benefits when there is no land market.

To keep the model simple, we design it to match several important characteristics of the South African context. For example, we assume that production has constant returns to scale. We discuss below some ways in which the model could be enriched to apply to other contexts.

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, and choose whichever location gives them the highest utility.

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

$$U_i(c_t, a_t) = c_t^{\alpha} a_t^{1-\alpha} + \epsilon_i \qquad (1)$$

where c_t is a freely tradable consumption good; a_t is person i's share of some local publicly provided good; and ϵ_i captures heterogeneity in preferences for living in the rural area, uni-

[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.

formly distributed on the interval $[-s, s]$. The publicly provided good a_t could be communal land or any other rival, potentially excludable, nontraded good, such as schooling. We assume that it enters directly into utility, rather than serving as a factor of production, both because most of the land in the South African region we study is not suitable for farming and because many of the other local publicly provided goods we have in mind, such as schooling, are at best investments that affect future productivity but not current productivity. For the rest of our analysis, we refer to a_t as land (bearing in mind it could represent any rival publicly provided good that is fixed in supply at the local level).

The taste shock ϵ_i does not change over time for a given individual. Preference heterogeneity implies that some individuals will be inframarginal in the spatial equilibrium and will not be indifferent between rural and urban locations. These individuals capture (utility) rents in equilibrium; heterogeneity in preferences prevents migration from arbitraging away all of the gains from local infrastructure programs.[10] The assumption of a uniform distribution for preferences gives us tractable expressions for the program's quantitative effect but is not crucial for the qualitative results. The parameter s measures how much variation there is in the strength of consumers' attachment to the rural area. If s is large, some individuals are strongly attached to the rural area and will prefer the city only given large reductions in c_t or a_t.

Each consumer has a time endowment T_t that she supplies inelastically to the market. We assume that rural consumers have exogenously given productivity w_t per unit time, regardless of the rural population, and are paid their marginal product when they work. These assumptions suit the South African context because most jobs have roughly constant returns to scale. Under these assumptions, labor income is $w_t T_t$. Also, given our assumptions, employers earn zero profits regardless of the infrastructure investment, so we need to keep track only of consumers' welfare to measure the welfare impact of the investment.[11]

The rural area has a perfectly elastic supply of the consumption good, which we treat

[10]See Moretti (2011) and Busso, Gregory, and Kline (forthcoming) for discussion of the role of heterogeneity in spatial equilibrium models.

[11]Decreasing returns to scale do not change our qualitative results, but in contexts where decreasing returns are important, researchers would want to add this feature to the model to obtain accurate quantitative results. Decreasing returns would also entail keeping track of changes in producer profits in all of the welfare calculations.

as numeraire, and a perfectly inelastic supply A of land. In the first time period, there is no market for land; 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 land: quantity rationing and market-based allocation.

B. Equilibrium in period 1: Before the program

An equilibrium in period 1 is a consumption choice for each consumer and an assignment of consumers to locations such that, given $\bar{U}$, each consumer's consumption and location choices maximize utility, taking the rationing of the publicly provided good as given. The indirect utility of living in the rural area in period 1 is

$$\begin{aligned} U_{i1}^* &= \max_{c,a} c^\alpha a^{1-\alpha} + \epsilon_i \quad \text{s.t.} \quad c \leq w_1 T_1, \quad a = \frac{A}{N_1} \\ &= (w_1 T_1)^\alpha \left(\frac{A}{N_1}\right)^{1-\alpha} + \epsilon_i. \end{aligned} \tag{3}$$

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

$$\epsilon_i \geq \bar{U} - (w_1 T_1)^\alpha \left(\frac{A}{N_1}\right)^{1-\alpha} \equiv \bar{\epsilon}_1. \tag{4}$$

This result 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.

C. Modeling the effect of infrastructure

We assume that the infrastructure program raises income by changing the time endowment, productivity, or both. For example, household electrification can allow women to devote more time to market work by reducing the time they must spend gathering firewood for cooking. Electrification also potentially makes workers more productive on the job, although this turned out not to happen in the South African case. Thus, we assume that the infrastructure program raises $w_t T_t$ in the rural area. Because we are assuming constant returns to scale, changes in T_t and migration responses to infrastructure will not change w_t.

We 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 or costs to the urban area arising from people leaving the urban area.

In the next two sections, we characterize the spatial equilibrium that arises in period 2, after the infrastructure program is implemented. The nature of the post-program equilibrium depends on the form of the market for the local, rival public good (in our case, land).

D. Equilibrium in period 2 with a missing land market

Suppose that, in period 2, land 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 $w_2 T_2 > w_1 T_1$; consumer i chooses to live in the rural area in period 2 if and only if

$$\epsilon_i \geq \bar{U} - (w_2 T_2)^\alpha \left(\frac{A}{N_2}\right)^{1-\alpha} \equiv \bar{\epsilon}_2. \tag{5}$$

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,

$$s\frac{2N_2 - P}{P} = (w_2 T_2)^\alpha \left(\frac{A}{N_2}\right)^{1-\alpha} - \bar{U} = -\bar{\epsilon}_2, \tag{6}$$

where P is the total population in the urban and rural areas. The left-hand side of (6) is strictly increasing in N_2, while the right-hand side is strictly decreasing in N_2 and strictly increasing in $w_2 T_2$. Therefore, the equilibrium population N_2 is strictly increasing in income $w_2 T_2$; more people live in the rural area after the infrastructure is built (or, $\bar{\epsilon}_2 < \bar{\epsilon}_1$).

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 rural income 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 are induced by higher incomes to 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 movers in constructing our welfare bounds.

E. Equilibrium in period 2 with a land market

Suppose alternatively that in period 2, there is a market for land: it can be bought and sold at price $\hat{r}_2$. (Land might be traded for a price, or, if we consider schooling or health services as the local, rival publicly provided good, 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 a market for the local public good. We assume that the people who lived in the rural area in period 1 (when land was rationed) own equal shares of the land endowment. We continue to assume the infrastructure program raises incomes, i.e., $w_2T_2 > w_1T_1$. 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

$$\hat{c}_{2,stayer} + \hat{r}_2\hat{a}_{2,stayer} = w_2T_2 + \hat{r}_2\frac{A}{N_1} \tag{7a}$$

$$\hat{c}_{2,mover} + \hat{r}_2\hat{a}_{2,mover} = w_2T_2. \tag{7b}$$

An equilibrium in period 2 with a land market is a price $\hat{r}_2$, consumption and land 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 land price as given, and (ii) the land market clears. We show in appendix A1 that, in the equilibrium, the indirect utilities of rural stayers and movers are

$$\hat{U}^*_{i2,stayer} = \alpha\left(1 + \frac{1-\alpha}{\alpha}\frac{\hat{N}_2}{N_1}\right)(w_2T_2)^{\alpha}\left(\frac{A}{\hat{N}_2}\right)^{1-\alpha} + \epsilon_i \tag{8a}$$

$$\hat{U}^*_{i2,mover} = \alpha(w_2T_2)^{\alpha}\left(\frac{A}{\hat{N}_2}\right)^{1-\alpha} + \epsilon_i. \tag{8b}$$

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 land on migration depends on whether w_2T_2 is larger than w_1T_1. If $w_2T_2 = w_1T_1$, creating a market does not change incumbents' budget sets, so we have the following result:

PROPOSITION 1 *If $w_2T_2 = w_1T_1$, then $N_2 = N_1$ regardless of whether there is a land market in period 2.*

Proof: See appendix A2. □

This result says that, without the infrastructure program, having a market does not change the equilibrium allocation and thus does not change welfare. Thus, we can analyze how markets change the welfare impact of the program by comparing post-program welfare in the market and no-market cases.

If $w_2T_2 > w_1T_1$, the number of people who move to the rural area depends on whether there is a land market. First, if $w_2T_2 > w_1T_1$, it cannot be an equilibrium for anyone to move out: just as in the no-markets case, because rural incomes in period 2 are larger than they were in period 1, no one who preferred the rural area in period 1 will 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

$$\epsilon_i \geq \bar{U} - \alpha(w_2T_2)^\alpha \left(\frac{A}{\hat{N}_2}\right)^{1-\alpha} \equiv \hat{\bar{\epsilon}}_2. \tag{9}$$

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 a market for land, i.e., $\hat{N}_2 < N_2$.*

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

$$s\frac{2\hat{N}_2 - P}{P} = \alpha(w_2 T_2)^{\alpha}\left(\frac{A}{\hat{N}_2}\right)^{1-\alpha} - \bar{U}. \tag{10}$$

The left-hand sides of (6) and (10) are identical and are both strictly increasing in rural population. Since $\alpha \in (0,1)$, the right-hand side of (10) is strictly less than the right-hand side of (6) for a fixed value of the rural population. Further, the right-hand sides of both equations are strictly decreasing in rural population. Thus, the rural population that solves (6) — the no-markets equilibrium population — is strictly greater than the equilibrium population with a market, which solves (10). □

Proposition 2 is the first central result of the paper. The proposition demonstrates that more people move into the rural area in response to a local infrastructure program when the land market is missing. Put differently: when a market for land exists, the price of land 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 into a rural area after the program, congestion in the local publicly provided good A is taken account of only when that good is priced. In contrast, when anyone in the rural area can access the congestible good, the migration response to the program is higher, which reduces welfare.

Although the migration response is strictly smaller when there is a land market, the existence of a land market does not ensure a socially optimal distribution of people across rural and urban locations. This is because the only way for landlords to collect rent from rural property is for them to remain in rural areas. Hence if the rural area is initially overcrowded compared with the efficient allocation, creating a land market will not induce people to leave the rural area. The implication is that while land markets enable rents to act as a brake on migration, the creation of land markets does not by itself guarantee efficiency.

F. Welfare

To compute the program's welfare impact, we calculate consumers' 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.[12] (Recall that firms earn zero profits in our model, so the program affects welfare only by affecting consumers' welfare.) Specifically, for each person in the 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 land.

No land market

For rural stayers, we must find the k that solves

$$[(1 - k^{stayer})w_2T_2]^{\alpha}\left(\frac{A}{N_2}\right)^{1-\alpha} = (w_1T_1)^{\alpha}\left(\frac{A}{N_1}\right)^{1-\alpha}. \tag{11}$$

Rearranging terms,

$$-\ln(1 - k^{stayer}) = \ln\frac{w_2T_2}{w_1T_1} - \frac{1-\alpha}{\alpha}\ln\frac{N_2}{N_1}. \tag{12}$$

Equation (12) provides a useful decomposition of the program's welfare impact. The first term in the equation is the program's income effect; the second is the congestion effect caused by migration. The argument of our paper is that this congestion effect can be just as important as the income effect when the migration response to the program, $\ln(N_2/N_1)$, is not small and when the preference for the local, rival publicly provided good does not substantially outweigh the preference for the consumption good ($(1-\alpha)/\alpha$ is not too small).[13]

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

$$0 \leq -\ln(1 - k_i^{mover}) < -\ln(1 - k^{stayer}). \tag{13}$$

[12]The use of compensating variation 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 the urban area. The compensating variation allows us to sidestep this issue, but it does have costs. Primarily, it is 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.

[13]Different assumptions about the functional form of congestion in a particular publicly provided good would affect the specific form of equation (12). However, as long as in-migrants create some congestion, the migration response to the initial spatial program will appear as part of the compensating variation.

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

$$CV = \sum_{stayers} k^{stayer} w_2 T_2 + \sum_{movers} k_i^{mover} w_2 T_2. \tag{14}$$

The bounds in (13) then imply

$$N_1 k^{stayer} w_2 T_2 \leq CV < N_2 k^{stayer} w_2 T_2. \tag{15}$$

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. Empirically calculating these bounds does not require any information about who is a mover or stayer. Rather, all we need are estimates 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 (12) is straightforward to estimate from data on the infrastructure program's impact on income and population, and we describe ways to choose sensible values of α for our specific empirical example.

Although our model does not explicitly include moving costs, adding heterogeneous moving costs would not change the calculation of the welfare bounds — only their interpretation. 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 rural land; at the other extreme, movers with no moving cost enjoy the same gain in utility as the stayers do.

With a land market

For rural stayers, we must find the k that solves

$$\alpha \left(1 + \frac{1-\alpha}{\alpha} \frac{\hat{N}_2}{N_1}\right) [(1 - \hat{k}^{stayer}) w_2 T_2]^{\alpha} \left(\frac{A}{\hat{N}_2}\right)^{1-\alpha} = (w_1 T_1)^{\alpha} \left(\frac{A}{N_1}\right)^{1-\alpha}. \tag{16}$$

Rearranging terms,

$$-\ln(1 - \hat{k}^{stayer}) = \ln \frac{w_2 T_2}{w_1 T_1} - \frac{1-\alpha}{\alpha} \ln \frac{\hat{N}_2}{N_1} + \frac{1}{\alpha} \ln \left(\alpha + (1-\alpha)\frac{\hat{N}_2}{N_1}\right). \tag{17}$$

We can now relate the compensating variation with a land market to the compensating variation without a land market:

$$-\ln(1-\hat{k}^{stayer}) = -\ln(1-k^{stayer}) - \frac{(1-\alpha)}{\alpha}\ln\frac{\hat{N}_2}{N_2} + \frac{1}{\alpha}\ln\left(\alpha + (1-\alpha)\frac{\hat{N}_2}{N_1}\right). \quad (18)$$

Thus, a rural stayer's compensating variation with a land market is the compensating variation without the land market, plus the difference in utility between the two states of the world driven by the difference in the migration response to the program, plus a term that accounts for the rents the stayers collect from the movers.

Recall from proposition 2 that $\hat{N}_2 < N_2$. Equation (18) thus implies the following:

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

Proof: Since $\hat{N}_2 < N_2$ and $\alpha \in (0,1)$, the second term in (18) 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 $k^{stayer} < \hat{k}^{stayer}$. □

Proposition 3 is the second main result of the paper. When there is a market for the local, rival publicly provided good, the gain for rural incumbents is larger than when there is no market for this good.

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

$$0 \leq -\ln(1-\hat{k}_i^{mover}) < -\ln(1-\hat{k}^{stayer}). \quad (19)$$

The aggregate value of the compensating variation for consumers thus satisfies

$$N_1\hat{k}^{stayer}w_2T_2 \leq \hat{CV} < \hat{N}_2\hat{k}^{stayer}w_2T_2. \quad (20)$$

Equation (19) is important because it indicates that even if all markets exist, we do not need price data to compute welfare bounds. This is a useful result in settings where population and income can be measured but high-quality land price data are difficult to come by.[14]

Relating welfare bounds with missing land markets to welfare bounds when all markets exist

We have shown that incumbents enjoy higher welfare gains when there is a market for land. What about aggregate welfare gains? The lower bound in the no-markets case (15) is strictly lower than the lower bound in the markets case (20) because $k^{stayer} < \hat{k}^{stayer}$. 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 congestion due to the lack of a land market does not reduce stayers' welfare too much. Alternatively, the upper bound on welfare could be smaller in the no-markets case if there is a small population response and yet congestion greatly reduces stayers' welfare. Which of these outcomes applies will depend on the parameters s and α.

3. Empirical implementation

Our goal is to estimate the effect of an infrastructure program on consumers' welfare. Equation (12), for the case without land markets, and equation (17), for the case with land 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) 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 land prices, regardless of whether there is a market for land. This section describes how we obtain such welfare

[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,

$$\hat{r}_2 = \frac{1-\alpha}{\alpha}\frac{\hat{N}_2 w_2 T_2}{A}.$$

Substituting this result into (17), and assuming that we also observe a period 1 land price $\hat{r}_1$ such that the period 1 population is a market equilibrium, the compensating variation for a rural stayer can be expressed as

$$-\ln(1-\hat{k}^{stayer}) = \frac{1}{\alpha}\ln\frac{w_2T_2}{w_1T_1} - \frac{1-\alpha}{\alpha}\ln\frac{\hat{r}_2}{\hat{r}_1} + \frac{1}{\alpha}\ln\left(\alpha + (1-\alpha)\frac{\hat{r}_2}{\hat{r}_1} - (1-\alpha)\frac{w_2T_2}{w_1T_1}\right).$$

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

$$\ln (w_{jt}T_{jt}) = \beta_{0,j} + \beta_1 t + \beta_2 I_{jt} + u_{jt}^{wT}, \tag{21a}$$

$$\ln N_{jt} = \gamma_{0,j} + \gamma_1 t + \gamma_2 I_{jt} + u_{jt}^{N}. \tag{21b}$$

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 or not they receive the infrastructure program, while the parameters β_2 and γ_2 are the effects of the infrastructure program on income and population, and the residuals u_{jt}^{wT} and u_{jt}^{N} represent all other factors affecting income and population. Thus, in the no-markets case, the compensating variation for a stayer from equation (12) is

$$-\ln (1 - k^{stayer}) = \beta_2 - \frac{1-\alpha}{\alpha}\gamma_2, \tag{22}$$

and in the markets case, from equation (17)),

$$-\ln (1 - \hat{k}^{stayer}) = \beta_2 - \frac{1-\alpha}{\alpha}\gamma_2 + \frac{1}{\alpha}\ln (\alpha + (1-\alpha)\exp (\gamma_2)). \tag{23}$$

We need consistent estimates of β_2 and γ_2 to proceed. This is a challenging empirical problem because 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 (21) 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 (14) and (20) to estimate the total monetary value of the program, we need to know $w_2 T_2$, the post-program income in communities that receive the program. We can estimate $w_2 T_2$ from a regression of $I_{j2} w_{j2} T_{j2}$ on I_{j2}; this regression should be estimated jointly with the system (21) so that standard errors account for the possible covariance between estimates of β_2, γ_2, and $w_2 T_2$.

We also need to know N_1 and N_2 (or $\hat{N}_2$, if there is a land 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

$$N_2 = \sum_{j\,:\,\text{received program}} N_{j2}. \tag{24}$$

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 observed 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

$$N_1(j) = N_{j2} / \exp(\gamma_2). \tag{25}$$

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

$$N_1 = \sum_{j\,:\,\text{received program}} N_1(j) = \sum_j \frac{N_{j2}}{\exp(\gamma_2)} = \frac{N_2}{\exp(\gamma_2)}. \tag{26}$$

Putting together all of our results, the bounds on the compensating variation in the no-markets case are

$$\frac{N_2}{\exp(\gamma_2)}\left[1-\exp\left(-\beta_2+\frac{1-\alpha}{\alpha}\gamma_2\right)\right]w_2T_2 \leq CV < N_2\left[1-\exp\left(-\beta_2+\frac{1-\alpha}{\alpha}\gamma_2\right)\right]w_2T_2. \tag{27}$$

Standard errors for these bounds can be obtained if we have joint estimates of β_2, γ_2, w_2T_2, and N_2. Similar results apply for the markets case, where the bounds can be expressed as

$$\begin{aligned}\frac{\hat{N}_2}{\exp(\gamma_2)}\left[1-\exp\left(-\beta_2+\frac{1-\alpha}{\alpha}\gamma_2-\frac{1}{\alpha}\ln\left[\alpha+(1-\alpha)\exp(\gamma_2)\right]\right)\right]w_2T_2 \leq \hat{CV} \\ < \hat{N}_2\left[1-\exp\left(-\beta_2+\frac{1-\alpha}{\alpha}\gamma_2-\frac{1}{\alpha}\ln\left[\alpha+(1-\alpha)\exp(\gamma_2)\right]\right)\right]w_2T_2. \quad (28)\end{aligned}$$

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 data on population and income is more feasible than collecting good 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, because this parameter strongly affects the welfare calculation.

As $\alpha \to 1$, consumer preferences shift toward the consumption good and away from the local, rival publicly provided good (land). This minimizes the negative impact of migration on welfare through crowding of the publicly provided good and moves the welfare bounds for the markets and no-markets cases toward each other. In the limit, if consumers did not care for land (or schooling or health services) at all, the welfare bounds would be identical — and equal to the program's income effect — regardless of whether there were a market for these goods.

Alternatively, as $\alpha \to 0$, consumer preferences shift toward land 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.

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 three strategies lead us to a similar value for α for the 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, publicly provided goods are more important and a given level of crowding in these goods causes more disutility. Equations (27) and (28) show that, for any given income and population elasticities, the welfare impact of a program is negative when α is sufficiently small. However, in equilibrium in our model, 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

$$\alpha = \frac{\ln(N_2/N_1)}{\ln[(w_2T_2)/(w_1T_1)] + \ln(N_2/N_1)} = \frac{\gamma_2}{\beta_2 + \gamma_2}. \tag{29}$$

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 publicly provided goods were priced, their share of aggregate expenditure would be $1-\alpha$. Many of these goods and services, such as schools and hospitals, are included in measured aggregate expenditure in the national accounts because the government provides them. 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 nonpriced rival and publicly provided goods — 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 service, and defense spending, and related this balance to annual GDP. In the South African case, national accounts data from 1996 to 2002 suggest that the average value of α is 0.93.[15]

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

Because 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. If individuals are indifferent between earning high incomes in high-density areas and low incomes in low-density areas, the relationship between incomes and density tells us the marginal rate of substitution of consumption for local public goods. This is essentially a hedonic approach to valuing these publicly provided goods and services: how much do consumers need to be compensated by 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. We include controls for district fixed effects so that we are studying substitution between relatively similar communities in the same district and are not assuming that people are indifferent between living in two districts that may be quite different. Using the coefficient on the density variable as a proxy for the marginal rate of substitution of consumption for land, we estimate α to be 0.96.[16]

Summary

The three different approaches to choosing a value for α in South Africa produce very similar results: 0.98, 0.93, and 0.96. Since the national accounts method and the hedonics method produce values below 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 publicly provided goods 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.

[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`.

[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 for α using the sample mean values of log earnings and inverse density to proxy for c and a respectively.

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

Another feature of the rural KZN context is that most publicly provided goods 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 goods and services for all residents in a given locality, and access is often determined through queueing.

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

[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.

In this environment, it would be impossible to estimate the value of new infrastructure investments from changes in land prices, because land prices do not exist. The contribution of our paper is that it is at least possible to bound the welfare effects of the electrification program, given the structure of a simple model of location choice.

In our model, A represents schools, clinics, water infrastructure, traditionally held land, and other publicly provided goods. 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 public good 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 these goods implies for migration responses to local programs. Imperfect markets for such publicly provided goods 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 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

$$\Delta y_{jdt} = \nu_1 + \nu_2 \Delta I_{jdt} + \gamma_d X_{jd0} + \lambda_{dt} + \Delta \epsilon_{jdt} \tag{30a}$$

$$\Delta I_{jdt} = \delta_1 + \delta_2 Z_{jd} + \nu_d X_{jd0} + \mu_{dt} + \Delta \omega_{jdt} \tag{30b}$$

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 (30). 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 public goods and services

Table 2 presents our evidence for congestion in local public goods and services. In columns 2 and 4, we see the IV estimates of the impact of electrification on household density and household size, respectively. 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) and the median number of rooms per house for this sample (3 rooms total), this is a large (27%) increase.

The next set of columns show the consequences for schooling. Schools become more 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 local publicly provided goods other than electricity are inelastically supplied.

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 may have negative consequences for (some) incumbents.[20]

[19]The Census data do not contain measures of hours of work, wages, or income. Using a different data set 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.

[20]Recent empirical evidence from the United States (Chetty et al., 2011) suggests that larger class sizes

D. Welfare bounds

In Table 3, we calculate bounds on the compensating variation associated with the program. First, we estimate (21) 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).[21] 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 local publicly provided goods like land or schooling, and 99% from consumption. We use (12) 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. We can monetize this compensating variation by multiplying k by the average monthly earnings in treated areas post-electrification, weighted

(higher STRs) have negative effects on test scores in the short run and negative effects on educational attainment, savings, and home ownership in later life.

[21] 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.

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. In the final two rows of Table 3, 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 ZAR117,456 and ZAR5.8 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, rival publicly provided goods 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 such goods 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 spatial program such as an infrastructure investment 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, congestible publicly provided goods such as land. With missing markets, there is a larger migration response to a spatial program. Each additional mover increases congestion in any inelastically supplied publicly provided goods. This story of the tragedy of the commons has important 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 a local publicly provided good and an assumption about the form of congestion in this publicly provided good, 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 it is possible to estimate welfare gains from a program when land markets are nonexistent as well as when land markets operate but land prices are not well measured. Since these features are 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 enrollment, we show that crowding in schools was one consequence of the large migration response to the program.

One implication of our analysis is that researchers can learn much more about the effects of spatial programs in poor countries by using information about migration, rather than treating migration responses as a nuisance. Researchers conducting randomized controlled trials involving spatial treatments may be particularly well placed to measure migration externalities, if they collect appropriate data on population densities.

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.

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.[22]

[22] More than three-quarters of the urban population in Africa live in slums; future urbanization trends in these areas will continue to put pressure on existing urban areas (Cohen, 2006).

Appendix

A1. Derivation of indirect utilities when there is a land market

There are N_1 stayers and $\hat{N}_2 - N_1$ movers, so market clearing for the local public good (land) requires

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

Maximization by rural stayers implies

$$\hat{c}_{2,stayer} = \alpha \left(w_2 T_2 + \hat{r}_2 \frac{A}{N_1} \right), \quad \hat{a}_{2,stayer} = \frac{1-\alpha}{\hat{r}_2} \left(w_2 T_2 + \hat{r}_2 \frac{A}{N_1} \right), \tag{A2}$$

while maximization by movers to the rural area implies

$$\hat{c}_{2,mover} = \alpha w_2 T_2, \quad \hat{a}_{2,mover} = \frac{1-\alpha}{\hat{r}_2} w_2 T_2. \tag{A3}$$

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

Market clearing for land requires

$$N_1 \frac{1-\alpha}{\hat{r}_2} \left(w_2 T_2 + \hat{r}_2 \frac{A}{N_1} \right) + (\hat{N}_2 - N_1) \frac{1-\alpha}{\hat{r}_2} w_2 T_2 = A \tag{A4}$$

or

$$\hat{r}_2 = \frac{1-\alpha}{\alpha} \frac{\hat{N}_2 w_2 T_2}{A}. \tag{A5}$$

Therefore, the indirect utility of a rural stayer is

$$\begin{aligned} \hat{U}^*_{i2,stayer} &= \max_{\hat{c}_{2,stayer}, \hat{a}_{2,stayer}} \hat{c}^{\alpha}_{2,stayer} \hat{a}^{1-\alpha}_{2,stayer} + \epsilon_i \quad \text{s.t.} \quad \hat{c}_{2,stayer} + \hat{r}_2 \hat{a}_{2,stayer} \leq w_2 T_2 + \hat{r}_2 \frac{A}{N_1} \\ &= \alpha^{\alpha} \left(\frac{1-\alpha}{\hat{r}_2} \right)^{1-\alpha} \left(w_2 T_2 + \hat{r}_2 \frac{A}{N_1} \right) + \epsilon_i \\ &= \alpha \left(1 + \frac{1-\alpha}{\alpha} \frac{\hat{N}_2}{N_1} \right) (w_2 T_2)^{\alpha} \left(\frac{A}{\hat{N}_2} \right)^{1-\alpha} + \epsilon_i \end{aligned} \tag{A6}$$

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

$$\begin{aligned}
\hat{U}^*_{i2,mover} &= \max_{\hat{c}_{2,mover},\hat{a}_{2,mover}} \hat{c}^{\alpha}_{2,mover}\hat{a}^{1-\alpha}_{2,mover} + \epsilon_i \quad \text{s.t.} \quad \hat{c}_{2,mover} + \hat{r}_2\hat{a}_{2,mover} \leq w_2T_2 \\
&= \alpha^{\alpha}\left(\frac{1-\alpha}{\hat{r}_2}\right)^{1-\alpha}(w_2T_2) + \epsilon_i \qquad \text{(A7)} \\
&= \alpha\,(w_2T_2)^{\alpha}\left(\frac{A}{\hat{N}_2}\right)^{1-\alpha} + \epsilon_i.
\end{aligned}$$

A2. Proof of proposition 1

Suppose to the contrary that the rural population either falls or rises. Recall that the wage does not change. Hence, if the rural population falls, then 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. That 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, anyone who preferred the urban area in period 1 must still prefer it in period 2, when wages are no higher than before and in-migrants must pay rent, contradicting the hypothesis that the rural population rises.

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Table 1: Summary statistics

	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

Note: 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 were 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

Note: Each column 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. Not all communities have any schools in the baseline year, and some data on educators are missing for some schools. * indicates p<0.1, ** indicates p<0.05, and *** indicates p<0.01.

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 $\alpha = \gamma_2/(\gamma_2+\beta_2)$	–	0.979
Assumed value of α	1.00	0.99
CV as fraction of income for average rural stayer: *k*	0.080	0.043
	(0.046)	(0.009)
Monetized CV for average rural stayer (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)

Note: Panel A presents program impact estimates from GMM-IV estimation of the system in equation (21). Panel B presents results relevant to the welfare calculations where we ignore migration effects or, equivalently, assume $\alpha = 1$ so that all utility comes from consumption goods (column 1) and where we take into account migration responses to the program under the assumption that $\alpha = 0.99$ (column 2).