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CLIMATE VARIATIONS AND THE POPULATION DISTRIBUTION IN LDC'S

Jennifer Roback

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I. Introduction

The importance of the natural environment has long been recognized
by economists. Ricardo's theory of comparative advantage is implicitly
a theory about location-specific natural attributes. Although Ricardo
does not dwell on the climatic differences between England and Portugal,
it is these differences which make wine relatively inexpensive to produce
in Portugal. Thus, environmental differences, along with technological
differences, play a key role in much of international trade theory.

More recent work has emphasized the fact that consumers may have
preferences about the environment. This line of work has stressed the
mobility of workers to take advantage of more pleasant locations within
a country. This research has shown that both wages and rents must adjust
to clear the labor and land markets.

The observation that nature is important can generate many
insights. If climate influences production, this can explain why some
areas specialize in certain goods. If people have preferences about climate,
this can explain why some regions have lower wages or higher rents than
others. The distribution of location-specific attributes may also provide
insight into the distribution of the population.

As important as this line of thinking is for understanding a modern
economy, it is even more valuable in understanding an under-developed country.
The natural environment is more important in LDC's because these countries
lack the physical capital to cope effectively with their environment.
Differences in rainfall, temperature and terrain may dominate agricultural
output in a country with scant technological knowledge and even less
physical capital with which to implement that knowledge. Differences in

climate are more important to consumers if the available housing provides
little real shelter against the elements. The migration of peoples
and consequent redistribution of the population may be the cheapest means
of coping with the environment in these societies.

Despite the obvious relevance of location specific traits, development
economists have paid them surprisingly little attention. Instead, wage
differences within a country have been regarded as evidence of market
failure. Wage differences enforced by minimum wage laws or other
government interventions certainly do represent an imperfection in the
market. The policy prescription, however, is to remove the intervention,
rather than to assume the governmental restriction as given. If the
wage differentials exist even in the absence of government intervention,
this is not prima facia evidence of market failure. Differences in
naturally occurring amenities or productivity enhancing traits could
support these wage differentials.

Policy makers in LDC's also tend to view migration with alarm.
The large scale movements of people are considered "dislocations" or
"disruptions". The alternative view offered here is that migration is
part of the process of adapting to circumstances. Migration offers
people an opportunity to better themselves individually. The process of
relocating people from unproductive or unpleasant areas to more desirable
places also offers society an inexpensive method of increasing real living
standards.

The theory presented in this paper is generally applicable, both
to developed countries and to LDC's. The model is an extension of previous
efforts in location theory.

One limitation of past work is that the consumers have been assumed

to be homogeneous in tastes and skills. If workers in an economy have
two levels of skill, how will the population of these two groups be
distributed with respect to the location specific traits? If the workers
have different preferences for climate or environment, how will these
preferences be reflected in the wages and rents? This paper attempts to
answer these questions.

The relative population distribution is especially important for
policy in developing countries. Concentrations of certain types of people
in particular areas is not necessarily cause for concern. What appears
to be a lopsided distribution of groups of people may in fact be the
natural outcome of market forces. These market forces, namely, nature,
personal preferences and comparative advantages, are not forces which can
be dissolved at the stroke of an administrative pen. Nor would it be
desirable to eliminate these factors, even if it were possible. The theory
presented here is designed to illustrate the economic effects of these
forces.

II. The Structure of the Model

Imagine a country with some natural feature, n, which varies across
the country. Without loss of generality, define the units of n so that it
is a continuous variable over the interval [0, 1]. We will focus on the
production of a composite commodity, X, whose price will be taken as
numeraire. The country is a small country, so that the price of the
numeraire good is given by world trade.

The production function is constant returns to scale and requires
inputs of land and of two types of labor. The two types can be thought
of as skilled and unskilled, labor and management or simply two distinct
trades. There is no necessary presumption that one type of labor is more

skilled than the other. The only crucial features are that the two types of labor are not perfect substitutes in production and that both types are needed for production. The unit cost function associated with this production function can be written as $C(w, w^*, r, n)$, where w is the wage of the "unskilled" worker, w^* the wage of the "skilled" and r the rent on land.[1]

The zero profit condition for the firm is that costs in all locations be equal to the world prices.

(1) $C(w, w^*, r, n) = 1$

Otherwise, some firms would have an incentive to relocate. Costs may vary across locations because factor prices may vary. The natural attribute affects costs directly by shifting the marginal productivity of each of the factors.

Also, n enters the utility functions of the two types of workers. The workers consume the composite commodity, x, the quantity of natural amenity in the area where they live and work, and some residual land, l, in the same area. The problem for the worker is in two steps: first, to choose the consumption bundle that maximizes his utility subject to his budget constraint in each location and second, to choose the optimal location.[2] The indirect utility function associated with this problem is: $V(w, r, n)$, where w is the wage and r is the price of land.

The location equilibrium of the workers requires that the indirect utility function be equal at all locations. If this were not true, some workers would have an incentive to move to areas where they could enjoy higher utility. This equilibrium condition is:

(2) $\quad V(w, r, n) = k$

An analogous condition can be written for the skilled workers:

(3) $\quad V^*(w^*, r, n) = k^*$

The two types of workers have different utility functions and different wages.

The three equations (1)-(3) contain three unknowns, w, w^* and r, and so can be solved in terms of the parameters. Note that the same price of land, r, appears in all three equations. The owners of land want to rent to the highest bidder; they do not care whether the bidder is a skilled worker, an unskilled worker or a business establishment. In this sense, land is "mobile" between various uses although obviously immobile across physical locations.

A. Factor Price Gradients

The interesting problem is how the factor prices are affected by the naturally occurring amenity. To answer this question, totally differentiate equations (1)-(3) and express in logarithmic terms:

(1') $\quad \theta_w \hat{w} + \theta_w^* \hat{w}^* + \theta_r \hat{r} + \eta \hat{n} = 0$

(2') $\quad \hat{w} - k_\ell \hat{r} + k_n \hat{n} = 0$

(3') $\quad \hat{w}^* - k_\ell^* \hat{r} + k_n^* \hat{n} = 0$

where $\theta_i = C_i i$, or the share of factor price i in total cost, $k_\ell = \dfrac{r\ell}{w}$ and

$k_\ell^* = \dfrac{r\ell^*}{w^*}$, or the budget share of land in each type worker's budget, and

$\hat{x} = \dfrac{dx}{x}$ or the percentage change in the variable x. These relations can be found

by using the fact that C_i is the quantity of the factor whose price is

i needed per unit of output and **Roy's** identity or $V_r/V_w = - \ell$.

The variable k_n is defined as $\dfrac{n}{w} / \dfrac{V_n}{V_w}$. V_n/V_w can be thought

of as the implicit price of n. If n is an amenity, k_n is positive. Thus

k_n is the implicit budget share of n in the consumers budget. The change

in unit costs due to a percentage change in the natural attribute is defined

as η. Specifically, η is the share weighted sum of the effect of n

on the productivity of each factor. $\eta \equiv \theta_w \eta_w + \theta_w^* \eta_w^* + \theta_r \eta_r$, where $\eta_i = \dfrac{n C_{in}}{C_i}$.

If the attribute enhances productivity, its presence reduces unit costs

and $\eta < 0$.

B. Equilibrium

The equilibrium wage and rent gradients can be found by solving

simultaneously for $\hat{w}$, $\hat{w}^*$ and $\hat{r}$ in terms of $\hat{n}$, the percentage change in

the natural attribute. The result is equations (4)

(4) $$\frac{\hat{w}}{\hat{n}} = \frac{1}{\Delta} \left\{ - k_n (\theta_r + \theta_w^* k_\ell^*) + k_\ell (k_n^* \theta_w^* - \eta) \right\}$$

$$\frac{\hat{w}^*}{\hat{n}} = \frac{1}{\Delta} \left\{ - k_n^* (\theta_r + \theta_w k_\ell) + k_\ell^* (k_n \theta_w - \eta) \right\}$$

where $\Delta = \theta_r + k_\ell^* \theta_w^* + k_\ell \theta_w > 0$.

The discussion will focus on the $\hat{w}$ equation, since the $\hat{w}^*$ equation is exactly

analogous.

The first of the two terms in each of the wage equations captures

the effect of consumer preferences on wages. If the "unskilled" workers regard n as an amenity ($k_n > 0$), then the first term in the unskilled wage equation is negative. This is exactly the result that Adam Smith would have predicted when he noticed that the executioner had to be paid a higher wage for his unpleasant job: wages and job-related amenities are negatively related.

The second term of the equation depends on the preferences of the other type of worker and on the productivity characteristics of the natural attribute. If the "skilled" workers enjoy the amenity this tends to raise the wages of the "unskilled". If the attribute increases productivity, wages tend to rise.

The explanation of these two effects can be readily seen with the aid of Figure 1. The downward sloping lines show combinations of w and r will hold costs constant, given the location specific attribute and the wages of the other type of labor. Any change in n or w^* which lowers the costs of production will shift the factor price frontier outward. For example, if n increases productivity, the equality of costs with world price requires that the wage and the rent increase. The upward sloping lines represent the "unskilled" workers' indirect utility function given n. The indifference curves slope upward because workers require higher wages to compensate them for higher rents, other things equal. An increase in n shifts the indifference curve up and to the left because a combination of higher rents and lower wages are required to equalize utility in all locations.

Point A in Figure 1 represents a combination of wages and rents in a region with n_1 of the natural attribute. We want to know how this wage compares with the wage in an area with a greater quantity, n_2, under various

circumstances. The first case is that n is amenable to the unskilled workers, but not to the others and n has no effect on productivity. Point B represents this case: the wages are unambiguously lower than at Point A. This captures the effect of the first term in equation (4).

The second case is that n is amenable to neither group, but it **enhances productivity. Point D represents this case; the wages are higher to offset the cost saving afforded by n. This captures the effect of η in equation (4).**

The third case is that n is amenable to the skilled workers only and has no productivity effects. This situation is exactly like the case where n is productive. If the skilled workers value n, their wages will tend to be lower. Their lower wages reduces unit costs of production, just as a productivity enhancing attribute does. This shifts the cost curve up and to the right, the same way a productive shift in n would. Thus, the point D again is representative of the type of change in factor prices we might observe if the other workers value the natural attribute.

These second and third cases correspond to the terms in the second set of parentheses in the wage equation. If n increases productivity, ($\eta < 0$) the wage rises. If the skilled workers enjoy n, ($k_n > 0$), the wages of the unskilled rise. These two effects offset the negative effect of the attribute on wages which comes about because the workers value n. Point C in Figure 1 illustrates these offsetting effects. Both the indifference curve and the cost curve have been shifted by n and the net effect on wages is ambiguous.

Because of the interaction between the wages of the two types of workers, the reader may wonder how n affects the relative wage of the workers. The relative wage is easily found and is shown in equation (5).

(5) $\quad \dfrac{\hat{w}^*}{\hat{n}} - \dfrac{\hat{w}}{\hat{n}} = \dfrac{1}{\Delta} \left\{ -\theta_r (k_n^* - k_n) - (1 - \theta_r) k_\ell k_\ell^* \left(\dfrac{k_n}{k_\ell^*} - \dfrac{k_n}{k_\ell} \right) + (k_\ell - k_\ell^*) n \right\}$

Not surprisingly, the type with the lower relative preference for n and the higher relative preference for land will have their wages reduced by a greater amount.[3]

This exercise also produces the rent gradient.

(6) $\quad \dfrac{\hat{r}}{\hat{n}} = \dfrac{1}{\Delta} \left\{ k_n \theta_w + k_n^* \theta_w^* - n \right\}$

Rents are higher in high n locations if either type of worker values n. (See points B and D in Figure 1). If the national attribute enhances productivity, this fact also increases rents.

Having solved for the rent gradient, the "real wage" gradient can be found.

$$\dfrac{\hat{w}}{\hat{n}} - \dfrac{\hat{r}}{\hat{n}} = \dfrac{1}{\Delta} \left\{ - k_n (\theta_r + \theta_w^* k_\ell^* + \theta_w) + (k_\ell - 1)(k_n^* \theta_w^* - n) \right\}$$

The real wage is negative as long as the attribute enhances productivity or doesn't diminish productivity greatly. The amenity effects of the natural attribute are unambiguously negative. This is not surprising since the wages and rents must adjust to the climate to keep utility constant in all locations. Measuring the real wage as the change in wages minus the change in rents will produce a lower real wage in high amenity locations because the reduction in disposable income is the implicit payment for the location specific amenity. This result has been found in other work in location theory.

Thus, regional wage differences may be supported by climate. Even

regional differences in wage deflated by the cost of living may persist
in markets where location specific attributes are valued either by
workers or by firms. This result holds in models with non-traded goods
and in models with only one type of worker as well. (See Roback.) The **contributions of the present model are: 1) we can understand the interaction of**
the two types of workers on each others' wages and 2) we can study the
relative distribution of populations.

C. The Population Distribution

The distribution of different types of people across a country
is a matter of great concern to policy makers and we turn now to this
concern. We will confine our attention to the change in population that
results from a change in climate, rather than focusing **on problems of
population size per se.**

The population gradients can be found by using the market clearing
conditions for land and the two types of labor. Market clearing conditions
were conspicuous by their adsence in the previous section. Separating the
problem into the set of the cost function and the equal utility equations
for the factor price gradients and the set of market clearing equations
for the population gradients is the key analytical feature of this model
which renders it tractable.

The labor market clearing[4] conditions in each location follow very
straightforwardly from the production function. C_w is the demand for labor
per unit of output. Therefore, total demand at location n is $X(n)C_w(n)$,
where $X(n)$ is the total output at location n. Labor market clearing requires
that:

(8) $C_w(n)X(n) = h$

$C_w^*(n)X(n) = h^*$

Land market clearing requires that all the land be used, for residences of the two types of workers, or for production. The demand for land in production is $C_r(n)X(n)$: $C_r(n)$ per unit of output, times total output, $X(n)$. The land market clearing condition is:

$$(9) \qquad L(n) = h(n)\,\ell(n) + h^*(n)\,\ell^*(n) + C_r(n)X(n)$$

where $L(n)$ is the total land available with a given amount of the characteristic n.

Examining equations (8) and (9) reveals that a solution to the problem is possible in principle. L(n) is given by nature and is a fundamental parameter of the problem. The worker demand equations from the preceeding section imply solutions for $\ell(n)$ and $\ell^*(n)$. Similarly, $C_r(n)$ is determined by the production demand equation. Thus, we are left with three unknowns, $h(n)$, $h^*(n)$ and $X(n)$ in these three equations.

The simplest solution method is to express (9) in terms of $h(n)$. To do this substitute h/C_w for X (from equation (8)), and hC_w^*/C_w for h^* (also from equation (8)). The result is equation (9'):

$$(9') \qquad L(n) = \frac{h}{C_w}(C_w\ell + C_w^*\ell^* + C_r)$$

We can now easily find the expression for the population gradient of the unskilled workers by differentiating and rearranging equation (9').

$$(10) \qquad \hat{h} = \hat{L} - \left[\hat{\ell}\phi_n + \hat{\ell^*}\phi_n^* + (\hat{C_w^*} - \hat{C_w})\phi_h^* + (\hat{C_r} - \hat{C_w})\phi_x \right]$$

where $\phi_n = \ell h/L$; $\phi_n^* = \ell^* L^*/L$; $\phi_x = C_r X/L$.

The first part of the expression is easily understood: the population h will be higher in regions with larger land masses and in regions where workers each demand relatively little land. The last two terms depend on

relative prices and elasticities of substitution. These expressions are not central to our main purpose here and so their discussion is confined to the Appendix.

The most interesting issue for our purpose is the relative population gradient or, $\hat{h}^* - \hat{h}$. This can be found by rearranging equation (8):

$$(11) \quad \hat{h}^* - \hat{h} = (\hat{C}_w^* - \hat{C}_w) = \theta_r \left[(\hat{w} - \hat{w}^*) \, \sigma_{ww}^* + (\hat{r} - \hat{w}^*) \, \sigma_{wr}^* + (\hat{w} - \hat{r}) \, \sigma_{wr}^* \right] + \hat{n} \, (\eta_w^* - \eta_w)$$

where $\sigma_{ij} = \dfrac{C_{ij}}{C_i C_j}$

The higher the wage of the skilled relative to the unskilled, the lower will be the population of the skilled relative to the unskilled. Similarly, the higher the wage deflated by rental payments, the lower the relative population of that type of worker. All of these effects are stronger, the larger the partial elasticities of substitution in production. If no substitution in production were possible, then relative prices would be irrelevant to the distribution of workers.

The final term describes the direct effect of the environment on production. If n enhances the productivity of h, less h is necessary to produce a unit of output at constant factor prices; this fact is expressed by $\eta_w < 0$. Thus, $\eta_w^* - \eta_w > 0$ means that n increases the productivity of h by more than that of h^*, and the population of h falls relative to that of h^*. The reason for this seemingly paradoxical result is that this productivity effect is a direct demand side effect holding constant factor prices. If factor requirements fall, then demand for that particular

factor falls as well.

The full effect of n on the population gradient includes the direct effect on productivity just discussed and the effect of n on the relative prices as well. Recall from equation (5) that the relative wage of the unskilled are likely to rise, the stronger their taste for land compared to the skilled and the weaker their tastes for the amenity aspect of n compared to the skilled. The rent deflated wage of each type depends only upon whether n is amenable and whether n is productive. If n is both amenable and productive, then $\hat{r} - \hat{w}^* > 0$ and $\hat{w} - \hat{r} < 0$, and the net effect on $\hat{h}^* - \hat{h}$ is ambiguous.

III. Conclusion

What is the implication of all of this analysis for policy making? Stated simply, it is this: Regional wage differences and complex population movements are not sufficient reason for policy makers to discourage migration. The distribution of populations across a country is governed by a complicated set of interacting causes. What appears to be an inexplicable confusion of peoples migrating to and fro, may in fact be the perfectly natural result of reasonable economic behavior.

The model presented in this paper focused on the effects of climate on the relative distribution of two types of people. The results were intuitive and understandable, but ambiguous because of the offsetting interactions of several economic forces. In the real world, location decisions are influenced by many factors not included in this simple model. The living patterns will be that much more unpredictable in the real situations faced by policy makers. But the fact that observers can not immediately explain why people migrate as they do, does not demonstrate that the migration is

not the result of real economic forces. Differences in tastes for climate

alone can produce a complex distribution of populations.

FOOTNOTES

[1]The implicit land and capital ownership assumption is that each
worker owns an equal share of land and of firms in all locations. This
allows us to ignore capital gains from land ownership. Also, unearned
income is independent of location, and so does not appear in the maximization
problem.

[2]People are assumed mobile enough to choose a permanent location
but not mobile enough to work in one region and live in another.

[3]The reader may be surprised to notice that the relative wage of the
two types of labor does not depend on the relative effect of n on the
productivity of each factor. The reason for this is that an increase
in the productivity of one factor decreases the total costs of production.
Decreased costs allows higher prices to be paid to any and all of the
factors. The model does not posses enough structure to assign the factor
specific productivity increases to particular factors of production.
Introducing a second type of output and dropping the requirement that
all factors are required in the production of each of the goods would
illuminate this interesting additional assignment problem.

[4]Readers familiar with the problems of LDC's may balk at
my use of a labor market clearing condition. If the labor market does not
clear in some areas, then an additional wage premium must be paid in those
areas. (See Todaro.) The type of results for population distribution
presented here are affected indirectly through the effect of unemployment
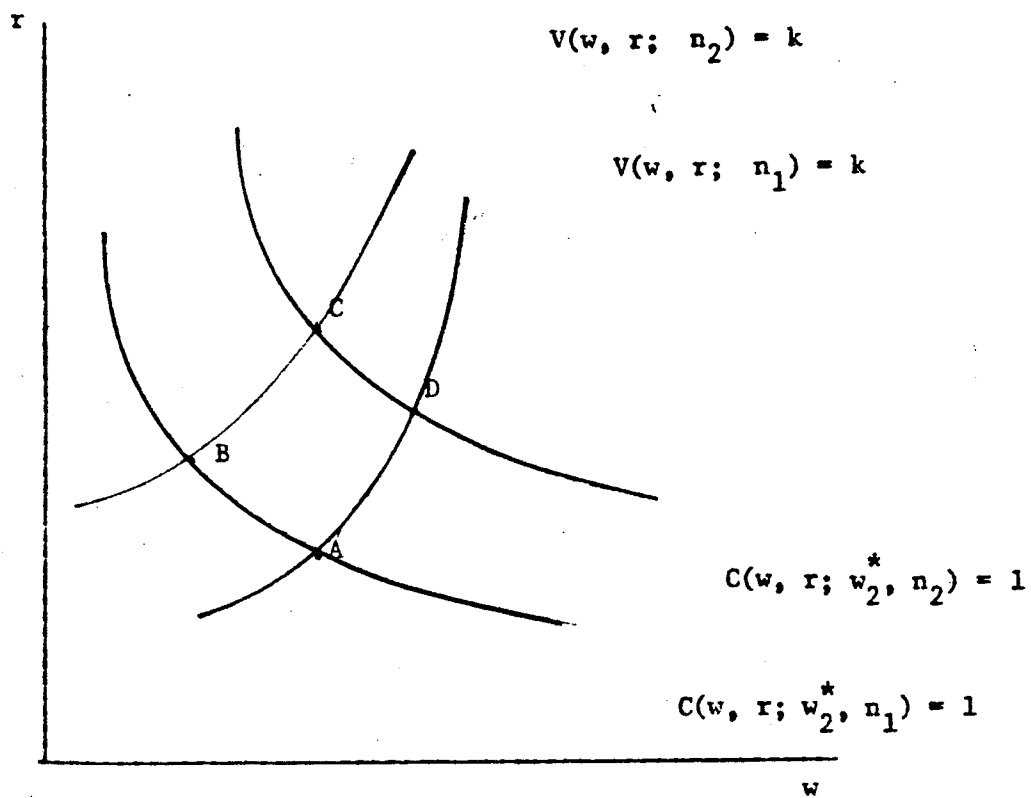on wages.

Figure 1