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Some Methods for Measuring the Geographic Accessibility of Medical Services in Rural Regions

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This paper presents two complementary measures of geographic access to medical care in rural regions that necessitate only modest information inputs on the location of services and client populations. An application for the Abitibi-Temiscamingue region in the Province of Quebec, Canada, is used to illustrate the types of product yielded by the measures. These include mapped patterns of potential accessibility by rural community and a graphic display of the delivery system's potential effectiveness in 'reaching' distant consumers. The relevance of the measures to the planning of medical care provision in rural areas is discussed, as is their extension through disaggregation and improvement of data inputs. Key words: rural medical care; location and distance effects; geographic access measures; Abitibi-Temiscamingue. (Med Care 1988; 26:34–44)

Access to medical care is a concern that has generated considerable interest and research in a number of disciplines and professions over recent decades. In consequence, the associated literature is both substantive and wide-reaching; notable emphases range from the political economy of health service systems[1] to the specification of operational indicators of access to medical care resources.[2] The intent of this paper is to report on a specific geographic response to the challenge of measuring access.

The approach to measuring spatial access presented in this paper is highly general and can be (and has been) applied in different geographic contexts and to various elements of the medical care system.[3] The emphasis here is upon the task of identifying major regularities in spatial access to medical care in rural areas. The very nature of rurality—a dispersed population and a scattered pattern of small service centers—endows considerable importance upon the spatial dimension of access to medical care in rural areas.[4–6] In rural North America, patients are frequently forced to journey considerable distances for medical care,[7] often well beyond reasonable travel limits.[8] Thus, although the geographic perspective is certainly not the only one relevant to the analysis of access to rural medical care, it appears to be of considerable value.[9]

In their review of the literature on medical care delivery Joseph and Phillips[3] suggest a division of research on the spatial dimension of access into two major components: a "revealed accessibility" strategy involving the spatial analysis of patterns of medical

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care utilization and a "potential accessibility" strategy exploring the implications of the geographic displacement of medical care demand and supply patterns. Representative Canadian examples of research on revealed access include Joseph[10] and Thouez,[11] whereas Northcott[12] and Joseph and Bantock[13] speculate on the implications of differentials in the spatial availability of services for consumer access to medical care.

Research on revealed access undoubtedly provides valuable knowledge concerning the role of distance from service facilities in the determination of patterns of medical care utilization. Distance–decay effects (whereby rates of use of a facility decrease with increasing distance from its location) have been detected for various types of medical care and in many countries,[3,4] and have been attributed to the impacts of travel costs and/or distance-sensitive flows of information from service providers to potential clients.[10,14] However, as has been the case in other disciplines,[2] investigations of medical care utilization by geographers have been hamstrung by the difficulty of conceptually and statistically isolating the impact of one particular variable of interest, in this case a spatial one. The roots of this problem lie of course in the complexity of the behavioral processes that serve to translate a perceived need for medical care into use of a particular service facility. This complexity is well illustrated by the utilization models suggested by Gross[15] and Aday and Andersen.[16] The inevitably complex and changing relationship between the impact on the one hand of distance-dependent travel costs and information flows and, on the other, of a host of predisposing, enabling, and need factors,[15] makes the use of distance-decay effects as geographic indicators of access difficult at best.

In comparison with those based upon utilization, potential spatial access indicators are attractive on at least two grounds. First, data needs are modest; information on medical care resources and population by community is sufficient to operationalize simple measures. Moreover, the focus on aggregate supply and potential demand in communities circumvents the problem of confidentiality that inevitably emerges in individual-oriented research. Second, potential access indicators are readily linked to the planning of medical care delivery; almost all governments in advanced industrial societies have tried to define regional minimums or norms for population: physician ratios, hospital beds per 10,000 people, and so on.[17]

Given that measures of potential spatial access are attractive and potentially useful in planning, how should they be structured? The first, and simplest, approach is to gauge regional differentials in medical resource allocation through the use of supply–potential demand ratios like those mentioned above. Canadian examples include Spaulding and Spitzer[18] and Roos et al.,[19] both of which examine the distribution of physicians relative to total population by region. The contribution of work of this type to the debate on geographic access to health care is not in doubt, particularly in the United States where representative works include those of Marden,[20] Joroff and Navarro,[21] and Rushing.[22] Indeed, seminal investigations of rural–urban disparities in access to medical care were based almost exclusively on the generation and manipulation of supply–potential demand ratios (see, for instance, the pioneering work of Mott and Roemer[23]). Unfortunately, despite their appealing simplicity and uncomplicated interpretation, the use of supply–potential demand ratios becomes increasingly problematic as the size of regions decreases because it must be assumed always that neither supply nor potential demand "leaks" across regional boundaries. Obviously, such an assumption becomes increasingly questionable as the regional "net" increases in resolution.[3] Thus, if an investigation is articulated within a framework of small regions a measure that incorporates the potential use of services by "out-of-region" clients (i.e., interaction between supply and demand in different regions) is more appropriate than the simpler, supply–potential demand ratio approach.

The remainder of this paper is devoted to the exposition and demonstration of an interaction-based measure of potential spatial accessibility (how potentially well served are various locales?) and of a related measure of potential spatial effectiveness (how potentially efficient is the medical care system in servicing distant places?). The study area is the Abitibi-Temiscamingue region, situated in the resource–industry hinterland of the Province of Quebec, Canada, and the focus is upon the physician component of medical care in the region.

Methods

Potential Spatial Accessibility

Considering their long history in geography, measures based upon interaction concepts are a surprisingly recent feature in medical care access modelling. Early examples are provided by Guptill[24] and Schultz[25] in the United States and by Knox[26] in the United Kingdom. The accessibility indexes proposed are of varying complexity, but each is characterized by a reliance in the first instance upon a distance-dependent ("gravity") calculation of potential accessibility. In such a calculation it is proposed that potential access is a positive function of the number of physicians within travel range of a community and a negative function of distances from those same physicians. More formally,

(1) $$A_i = \Sigma_j M_j / d_{ij}^b$$

where:

A_i = Potential accessibility of physicians to community i;

M_j = Number of physicians in place j, within travel range of community i;

d_{ij} = Distance between i and j; and

b = Exponent on distance (reflecting its 'frictional effect' on potential interaction between i and j).

Recently, Joseph and Bantock[13] have suggested a modification of this basic formulation to take into account the "relative availability" of doctors, namely, that physicians located in medium-to-heavily populated areas are, because of greater local demands on their services, effectively less available to distant communities than are those located in less populous zones. This relative availability can be gauged for each physician location through a distance-dependent estimation of catchment population (C_j) consistent with equation *1*.

(2) $$C_j = \Sigma_i P_i / d_{ji}^b$$

where:

P_i = Population of place i, within travel range of physician location j.

Combining equation *2* with equation *1* produces an index of potential spatial accessibility that is weighted by an estimate of physician availability to distant places.

(3) $$A_i^* = \Sigma_j (M_j / C_j) / d_{ij}^b$$

The Joseph and Bantock index is dimensionless but internally consistent, with high scores for communities indicating favorable location relative to physicians (and competing populations). The dimensionless nature of the scores necessitates their interpretation relative to mean values for particular experiments, whereas standard deviations provide a useful yardstick for distinguishing between values close to or far from the mean, in either direction.[27] Data inputs are modest, although the specification of travel range and the exponent on distance can be challenging.[3] The latter is particularly important, because it determines the overall relationship between proximity to service locations and potential access. If the exponent is set at 0.0, it follows that all localities would have identical access scores and, as it increases, the "accessibility gap" between proximate (to service locations) and distant places would widen. For both travel range and the exponent on distance, the researcher is reliant on information on travel behavior to guide calibration. For travel range, information of one sort or another is often available on maximum distances traveled to obtain particular medical services within a region. However, the specification of the exponent on distance (with higher values indicating progressively stronger inhibiting effects on travel over given distances) demands comprehensive data on the use of services throughout the region. If such data are unavailable, which is unfortunately the norm, the researcher may be forced to resort to partial data sets (e.g., on the use of a single medical facility) or to more complete data sets for other, but perhaps similar regions.[27] Given these problems of specifying the exponent on distance, it is fortunate that various applications of the Joseph and Bantock index have shown the structure of the (dimensionless) results to be quite robust relative to the specification of the exponent.[28] Readers wishing to pursue these questions further are directed to Joseph and Phillips,[3] who discuss medical care applications, and to Fotheringham[29] and Foot,[30] who consider various types of interaction models and their calibration.

Despite the fact that the Joseph and Bantock index can be disaggregated by population group to reflect different potential incidence of demand for medical care, or refined in other ways,[13,27,28] the approach it represents is clearly only a partial one, both in the broad (access) and narrow (spatial) sense. It has already been acknowledged that spatial proximity is only one among several relevant dimensions of access (albeit an important one in the rural context), and this will not be belabored here. It is also evident, though, that the Joseph and Bantock index does not explicitly tackle the question of overall potential spatial effectiveness within a regional system of communities.

Potential Spatial Effectiveness

The fundamental task of a measure of potential spatial effectiveness is to assess quantitatively the overall degree of spatial separation within a region (made up of several communities within distinct location) between the supply of medical care and potential demand for that care. Consequently, a first step in the development of such a measure is to conceptualize the supply and demand sides of the medical care system. This will vary to some degree between jurisdictions, and in Abitibi-Temiscamingue the demand and supply situations for medical care could be expressed as

$$(4)\quad S_i = (e^{\alpha} d_{ij}{}^{-}\beta)^{X}j(e^{\alpha} d_{ik}{}^{\beta})^{X}{}_{k} \cdots e^{\gamma C}{}_{i}e^{\delta H}{}_{i}$$

$$(5)\quad D_i = (e^{a} d_{ji}{}^{-b})^{Y}j(e^{a} d_{ki}{}^{-b})^{Y}k \cdots e^{cC}{}_{i}e^{dH}{}_{i}$$

where:

S_i = Supply of medical services available to community i;

D_i = Demand on medical services located in community i;

$X_{j,k,} \cdots$ = Supply of physicians at places j, k, . . . ;

$Y_{j,k,} \cdots$ = Demand for medical care in communities j, k, . . . ;

C_i = Dummy variable representing the availability of a clinic in community i;

H_i = Dummy variable representing the availability of a hospital in community i; and

$d_{ij}, d_{ik}, d_i \cdots$ = Distance between places.

The inclusion of clinics and hospitals in the demand and supply equations reflects the importance of capital expenditure on fixed facilities within the Quebec government's rural health care strategy. The use of (simple) dummy variables (rather than supply and distance variables) to represent such facilities stems from a desire in this illustratory analysis to focus on the potential spatial effectiveness of physician location. The nonlinear (exponential) form of the equations is consistent with the empirically verified structure of distance–decay effects in patterns of travel for medical care.[3]

Empirical estimation of the supply equation is relatively straightforward (with data similar to those used in the Joseph and Bantock index), although this simplicity does not extend to the calibration of the demand equation. In the absence of data on actual demands for medical care in individual communities, it is assumed here that potential demand for medical care will be proportional to community populations. This permits attention to be focussed on equation 4 and allows a calibration of the overall relationship between the supply of medical care and the distribution of potential users. This calibration can be accomplished through multiple regression analysis using a logarithmic (linearizing) transformation of the supply equation that isolates the quantity (X_j) and locational (d_{ij}) components of the physician supply available to each community. Namely,

$$(6) \quad \mathrm{Ln}P_i = \alpha\Sigma_j X_j - \beta\Sigma_j d_{ij} + \gamma G_i + \delta H_i$$

where P_i is the population (potential demand for medical care) of community i.

Results

Potential Spatial Accessibility

We applied equation 3 to data for Abitibi-Temiscamingue for 1973 and 1982. The spatial units ("communities") used are municipalities (of which there were 55 in both years), and the information sources were the Medical Association of Quebec (physicians by location and specialization) and the Census of Canada (municipal populations). On the basis of a mix of evidence on travel for medical care in rural Quebec,[11] the travel range parameter (the maximum distance over which a physician contributes to the accessibility of a community) was set at 50 km and the exponent on distance (which governs the potential impact of supply–potential demand distances on access), at 0.5. Potential access to general practitioners and specialists was considered separately.

The index values can be manipulated and presented in a number of ways.[27,28] Here, we elect to present the results in a simple manner, focussing on the distributional (or "equity") aspects of the potential access scores. The patterns of potential access to general practitioner services in 1973 and 1982 are displayed in Figure 1. Map classes are based on the mean and standard deviation for each year, so that a larger number of municipalities in the "moderately good access" and "good access" categories in 1982 versus 1973 indicates a more equitable pattern of potential access. This improvement in the accessibility picture for more isolated municipalities was chiefly the consequence of a marked increase in the number of general practitioners in the region (103 in 1982 versus 45 in 1973, an increase of 126%) rather than a reallocation of existing supply. Indeed, the number of settlements with general practitioners increased by only two between 1973 and 1982 (four obtained a physician and two lost). Nevertheless, the location of additional supply was obviously such as to modify favorably the highly skewed distribution of potential access (with a few municipalities with very high scores and many with very low scores) that existed in 1973.

In the case of specialist physicians (Fig. 2), the relative improvement in the potential access of more isolated communities between 1973 and 1982 appears somewhat less marked than was the case for general practitioners. This stems in no small part from the reduction of the number of settlements with specialist physicians from seven to six over the 9 years in question, notwithstanding a 42% increase in the number of

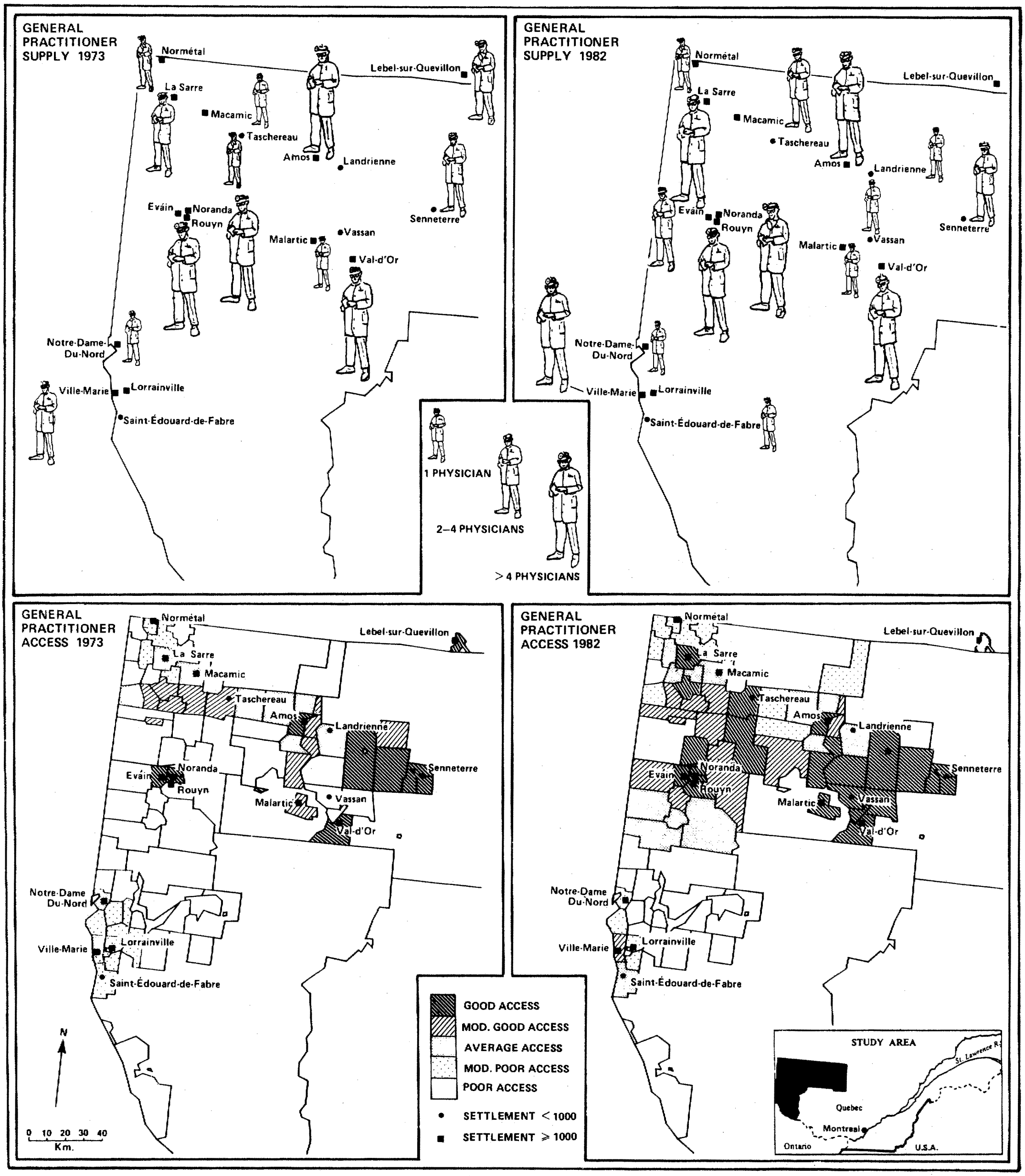

FIG. 1. Supply and potential spatial accessibility of general practitioner services in Abitibi-Temiscamingue, 1973 and 1982.

specialists (from 26 in 1973 to 37 in 1982)! Thus, Abitibi-Temiscamingue provides a good example of the tendency in recent years for higher-order medical services to concentrate into fewer and larger settlements, thereby placing increasing importance on access to primary physicians, both as medical care providers and as referral agents to higher-level care.

This simple example, incorporating as it

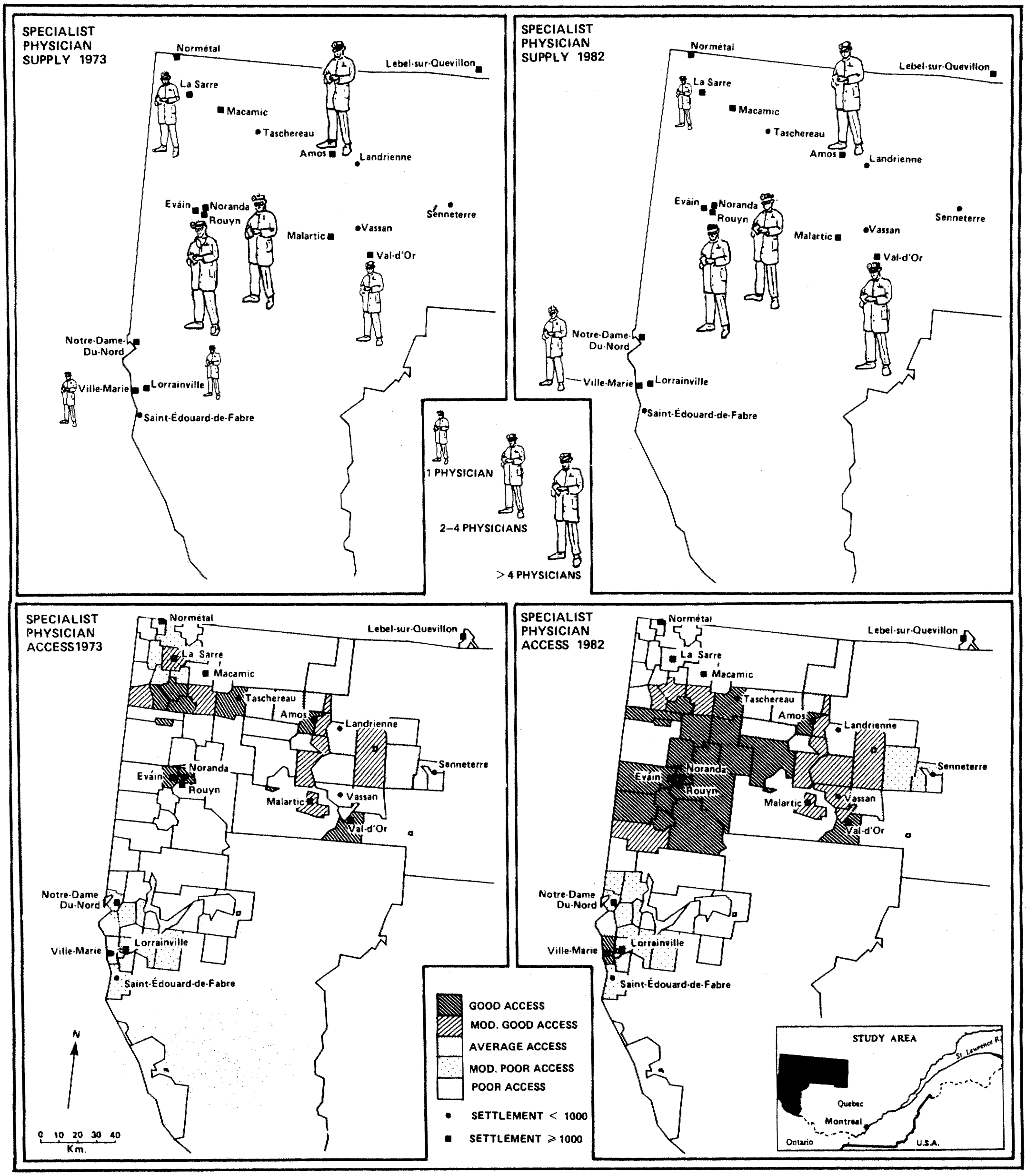

FIG. 2. Supply and potential spatial accessibility of specialist physician services in Abitibi-Temiscamingue, 1973 and 1982.

does temporal and organizational (general practitioner-versus-specialist) dimensions, demonstrates the utility of the Joseph and Bantock index. Low scores are indicative of municipalities where distance may potentially act as a barrier to utilization of medical services and where questions relating to unmet needs for care should be posed. Moreover, the measure provides a simple medium, as shown in Figures 1 and 2, for monitoring the potential impacts of changes in the medical care delivery environment (in

TABLE 1. Calibration of the Potential Spatial Effectiveness Model[a]

	Physical Quantity	Physical Location	Clinics	Hospitals	R^2
Model 1	.089[b]	−.0068			.85
	(.007)[c]	(.0017)			
Model 2	.091	−.0072	2.057		.91
	(.007)	(.006)	(.60)		
Model 3	.089	−.0067		1.95	.89
	(.007)	(.0015)		(.45)	
Model 4	.089	−.0069	.075	1.58	.91
	(.007)	(.0015)	(.076)	(.58)	

[a] See equation 6.
[b] Partial regression coefficients.
[c] Standard error of partial regression coefficients.

the supply of physicians, the location of population, or the effect of distance on demand–supply interaction) on the use of services. Application of the index by Joseph and Bantock[27] in a rural region more continuously settled than Abitibi-Temiscamingue and by Joseph[28] in an urban region has illustrated many of these properties and provides a benchmark for the application reported here.

Potential Spatial Effectiveness

Equation 6 was applied to the Abitibi-Temiscamingue data for 1982. It was found, however, that reliable estimation of the full (four-variable) equation was compromised by the high level of collinearity between the clinic (C) and hospital (H) variables, which is reflected in the high standard errors around their partial regression coefficients (Table 1). As is typical in these cases, removal of one or other of the affected variables has little impact on the explanatory power of the estimating equation (Models 2 and 3). In consequence, we elected to focus on Model 2, primarily because of our belief a priori in the importance of the clinics in the delivery of medical care in the study area but also because the explanatory power of Model 2 (as measured by the Coefficient of Multiple Determination, R^2) is high and identical to that for the four-variable model. In any case, the small increase in R^2 that results from the inclusion of either the clinic or hospital variable indicates that it is the number of physicians within travel range of a community (X_j) and their spatial distribution (d_{ij}) that is of preeminent importance in this matching of potential demand for medical care with its supply through the Abitibi-Temiscamingue region.

The partial regression coefficients for the X_j and d_{ij} variables appear almost unaffected by collinearity problems, thus permitting the use of Model 2 as an estimator of overall potential spatial effectiveness. Simply put, this involves 'plugging in' distance values into the calibrated equation while keeping the remaining variables constant. The results of such an exercise, using distances of 0, 25, 50, 75, and 100 kilometers and percentages to represent the dimensionless numerical results, are graphed in Figure 3. The data indicate that across the region as a whole the potential spatial effectiveness of a unit of supply (in this case, a physician) is 100% at its location, decreases to under 75% at 25 kilometers, and, eventually, to about 62% at 100 kilometers. It is notable that this nonlinear relationship between potential effectiveness and distance is consistent with the form of known geographic regularities, "distance–decay effects," in the utilization of medical care facilities.[3] In regions where the distribution of physicians is less attuned to that of population as it is in Abitibi-Temiscamingue, the distance coefficient in equa-

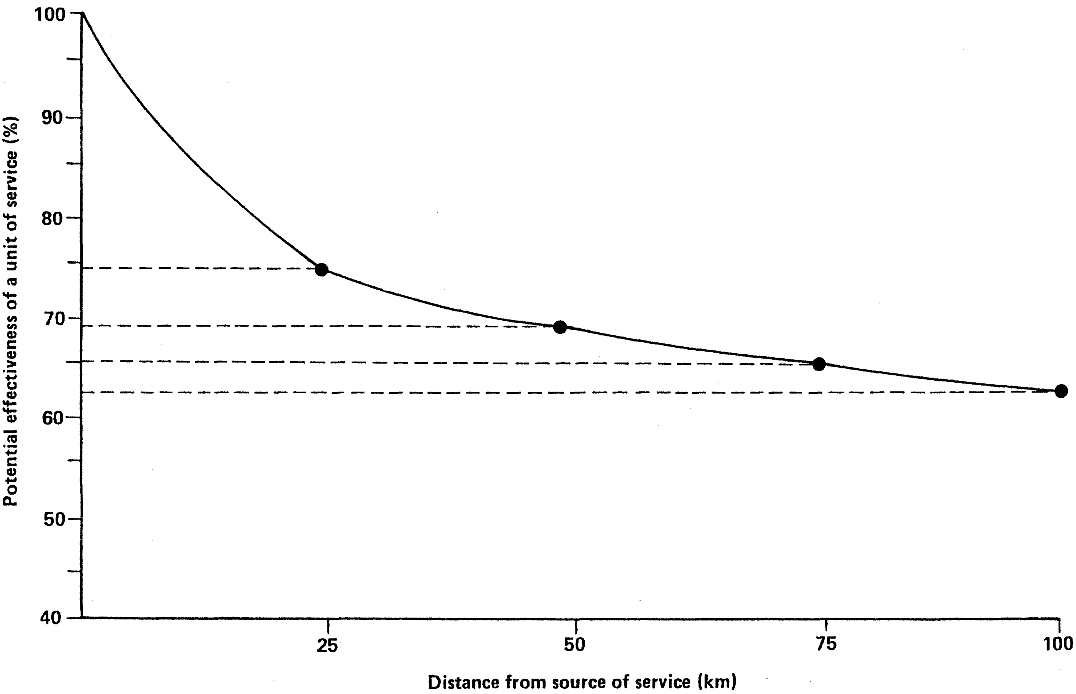

FIG. 3. The potential effectiveness over distance of physician services in Abitibi-Temiscamingue, 1982.

tion *6* will be larger, and the spatial effectiveness curve will be steeper. In this way, the regression-based method described above could be used to examine differences between regions as well as to predict or monitor the impacts over time of developments within them.

Discussion

In this paper we have extended the index of potential spatial access to medical care suggested by Joseph and Bantock[13] by suggesting a complementary regression-based measure of overall potential spatial effectiveness. The potential utility of the resultant package of measures was illustrated using a simple data set for a rural region in Quebec, Canada. The choice of a low-population density region as a test environment stemmed from the demonstrated importance of distance barriers to utilization in such areas.[9] It is freely acknowledged that in regions of high population density (and, consequently, smaller average distances between services and potential clients) various nonspatial (social, economic, organizational) barriers to access would have a higher priority for measurement.

The two measures outlined here examine complementary aspects of the geographic access question: The Joseph and Bantock index calculates the potential spatial access of various communities to the medical care delivery system, whereas the regression-based extension we suggest estimates the overall potential effectiveness of the delivery system in overcoming distance barriers. Both measures are relatively simple but rigorous in structure and modest in their data needs. This is of particular importance, in that all too often it has been difficult to find a happy medium between desired sophistication in measurement and the reality of a limited data base.

The Abitibi-Temiscamingue application outlined is meant to be illustrative rather than definitive. For instance, even though we treat the population (potential demand) component of the measures in the simplest possible way—each individual is assumed to have the same potential need for medical care—it is perfectly feasible given the appropriate data to disaggregate results for specific groups such as the aged, women, or natives. Thus, one might produce maps like those displayed in Figures 1 and 2 for individual age groups. Similarly, the coefficients of equation 6 could be estimated separately for each age group, and individual potential spatial effectiveness curves (like that displayed in Fig. 3) could be plotted. In addition, specific attention might be directed toward the hierarchical structure of medical care delivery. For primary care, the interpretation of distance barriers in relation to the general issue of access is relatively straightforward,[3] whereas for specialized treatment the implications of such barriers for utilization are complicated by the existence of referral systems.[10,31] In western Canada, for instance, the settlement system promotes (and necessitates) the concentration of many specialist physicians in the few large cities, as is reflected in data on surgical procedures and other forms of specialized treatment by region.[32,33] In such situations, distance might represent a "convenience" barrier rather than a deterrent to utilization.[3]

Whatever the level of detail and analytic sophistication deemed appropriate or feasible, it is our contention that in regions where the settlement pattern results in the relative isolation of many communities from sources of medical care, measures such as those suggested here provide a useful means for characterizing potential geographic barriers to access.

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