UNEQUAL ACCESS TO PUBLIC HEALTHCARE FACILITIES: THEORY AND MEASUREMENT REVISITED

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Abstract. Adequate coverage and efficiency of public health services are high priorities for sustainable growth and development. In many countries, public healthcare continues to fall short of demand, and remains unevenly distributed among the population. As in other areas of project appraisal, studies on social equity and access to public utilities are fraught with theoretical and empirical questions. Based on the concepts of marginal disutility with respect to distance, safety thresholds and 'equally distributed equivalent' distance, the paper first reassesses utility theory assumptions supporting the rationale for functional re-specifications. Partly drawing on these theoretical refinements, the analysis formulates a stochastic cost frontier hurdle model with an endogenously determined hospital distance threshold. For illustrative purposes, this model is applied to pooled biennial communal data for Chile. Healthcare accessibility in terms of travel cost/time is proxied by distances of administrative centres from the nearest emergency hospitals over the period 2000-2003.

1 Introduction

In several developing and transition economies, public health expenditures are considered to have tended to favour an inappropriate allocation of medical resources. Resource misallocation appears to be reflected in unequal social and geographical accessibility of healthcare services, and insufficient attention to specific types of ailments, forms of treatment, and measures of a preventive, rather than curative, nature. Shortcomings in health service provision include insufficient stock of facilities and personnel as well as wide disparities between major urban centres and other areas, with referral systems for patients in rural communities being often criticized as ineffective and financially burdensome. Across developing and transition economies,

after accounting for socio-demographic control variables, a higher orientation of public healthcare spending towards primary and preventive care is found to promote equity in health status ([21]). Other interpretations stress problems of inefficacy, relative to the utilization of available resources and a balanced mix of public and private facilities ([14]).

To investigate these problems, attention has increasingly been addressed towards constructing maps of accessibility, quality and optimal location (defined as social equity or fairness, with the two terms used interchangeably) of public healthcare, among other utilities. Healthcare accessibility studies typically aim at estimating excess distances from hospitals within and across target areas ([2], [4]). Relative to both theoretical underpinnings and empirical applications, several questions remain controversial, and deserve further insights. As a step in this direction, theoretical, measurement and estimation problems are reassessed in this analysis.

The paper is organized as follows. Section 2 sets off by examining healthcare service accessibility, through a commonly used functional equation which assumes monotonic strictly concave utility relative to healthcare service complexity weighted against hospital distances. Complementing the analysis, the Appendix puts forward an alternative utility specification, which accounts for increasing marginal disutility beyond a safety threshold, and infers its implications for elasticity of marginal disutility with respect to hospital distance, and social distribution weights for hospital infrastructure investments (see Note 1 in Section 5). By partly drawing on this framework (relative to safety threshold and 'best practice' distances), a stochastic frontier hurdle model is formulated with an endogenously determined distance threshold, beyond which distances from hospitals are influenced by frontier-location factors and inefficiency effects. Results of an application to pooled biennial (2000-03) commune-level data for Chile are presented in section 3. Accessibility is measured in terms of physical distances of communal administrative centres from reference/emergency hospitals. Conclusions are drawn in section 4.

2   Theoretical background and stochastic frontier hurdle model

A utility function for the analysis of healthcare system accessibility should weigh costs associated with distance (as a proxy of travel costs/time), against benefits arising from extent and complexity of medical services offered by healthcare facilities. This can be represented as follows:

$$U_i = U\left(D_{ik}, M_k\right) \tag{1}$$

where D_{ik} represents the distance between a representative demand point i (an individual's or household's place of residence) and a public facility k, and M_k is the 'size' of the facility. In broad terms, the latter attribute can be captured by a composite

index or a set of indicators, which reflect not only hospital capacity, but also variety and quality of the healthcare services provided.

The marginal utility from the size of the facility is generally hypothesized to be decreasing. For disutility related to distance, alternative distance decay functions have been proposed, with some functions accounting for possible non-monotonic declines in marginal utility (a review is provided by Bigman and Deichmann [2]). However, a common argument is that marginal disutility increases monotonically with the rise in distance ([16]). If a single facility is focused on, a utility function which is often adopted in studies based on accessibility indicators is the following ([2]: 189):

$$U_i = M^\gamma/(D_i)^\delta \quad \text{where } \delta > 0 \text{ and } 0 < \gamma < 1 \tag{2}$$

Specification (2) can be questioned on two grounds. First, in contrast with the flexibility of multiplicative utility functions for desirable goods, the marginal decline in utility with respect to distance is bound to be decreasing (inconsistently with the more realistic assumption of increasing marginal disutility), for any positive value of the parameter δ (with $d^2U/dD^2 = M^\gamma\delta[1+\delta]D^{-\delta-2} > 0$). Second, healthcare users can be expected to be indifferent to variations in distance (e.g., passing from 1 to 3 km) up to individual-varying safety distance thresholds z_i, thus implying no change in utility *ceteris paribus* within these limits (see Note 2 in Section 5). An analogous point in project appraisal theory concerns Squire-van der Tak's (henceforth SvdT; [35]) social discount rate, since the latter relies on a marginal utility function with respect to consumption (/income) which does not account for minimum survival (see Note 3 in Section 5). An alternative specification, suited to redress both points, is presented in the Appendix. The remaining part of this section introduces a stochastic frontier hurdle model, aimed at identifying an average safety threshold and hospital location inefficiencies at the level of target areas.

At a more aggregate level, within a target area represented by a commune j, D_j is the average distance for local residents to a main emergency hospital, and M_j the quantity and quality of locally available healthcare facilities. While the true travel/time cost-minimizing frontier is not observed, *best practice* reference distances can be estimated through a stochastic frontier approach, geared to quantify sources of spatial inequality in healthcare access. In a theoretical framework which refers to single facilities, the 'true' frontier is a combination of target area *equally distributed equivalent* (EDE: see the Appendix) distances, given healthcare planners' aversion to access inequality and once control variables are accounted for. In empirical modelling, control variables include proxies for availability and type of local healthcare facilities (in equation (7) in Appendix this is a fixed effect, with no influence on the theoretical EDE distance). The empirical EDE distance adopted here reflects a normative preference in favour of removal of access inequality (the gaps between average and 'best practice' distances) (see Note 4 in Section 5).

Drawing on concepts outlined above and in the Appendix, a stochastic frontier hurdle model with unknown distance-threshold (z) can be formulated. If M_j and control variables, related to the geographical dispersion of hospitals, are included in a vector of variables Z_j, the model applies to panel data as follows (with $r > 0$, $\theta > 0$) (see Note 5 in Section 5):

$$D^* = D(disp, pop, hsavail) \tag{3}$$

$$D_{j[t]} = [\eta_j +]Z'_{j[t]}\beta + v_{j[t]} + u_{j[t]} \tag{4}$$

$$(v \sim N[0, \sigma_v^2]; u \sim N^+[\mu_u, \sigma_u^2] \quad \text{or} \quad u \sim \Gamma[r/\theta, r/\theta^2])$$

or, as an alternative specification,

$$D_{jt} = \alpha_j + Z'_{jt}\beta + v_{jt} = (\alpha + u_j) + Z'_{jt}\beta + v_{jt} \tag{5}$$

D_j^* is a latent variable reflecting the planning authorities' allocation of emergency hospitals within or beyond a national (average) safety threshold vis-à-vis communal centres. The decision process can be captured by a censoring indicator J_j, with $J_j = 0$ if $D_j^* \leq z$, $J_j = 1$ if $D_j^* > z$. Even if not all healthcare centres are fully non-profit, local regulators try to influence hospital construction and upgrading according to a spatial equity criterion, among other social welfare objectives. Once geo-demographic dispersion and size of the local population are accounted for, distances to major hospitals exceeding the threshold limit will be relatively more feasible if other healthcare centres are locally available (*hsavail* in (3); list of variables in Table 1). By contrast, a negative relationship between non-hospital health service availability and distance from main hospital would imply severe cross-commune imbalances in healthcare provision at different levels of healthcare complexity. For areas where the 'hurdle is crossed' (equations (4),(5)), the role of the same benchmark variables, along with other possible determinants, can be investigated.

Similarly to the definition and identification of a poverty line for poverty indices, the choice of a distance threshold is a fundamental and controversial issue. In geographical contexts where a large proportion of the population does not have easy access to transport modes, 5 km is chosen as a representative threshold in a number of health sector studies, with this corresponding to nearly one-hour of travel time on foot (for Niger and Kenya, studies quoted by Bigman and Deichmann [2]: 183; for Madagascar, by the same authors [2]: 196-202). Relative to Costa Rica, Bixby and Güell [5] opt for two criteria of healthcare access inequality: a distance threshold of 4 km and/or, as a proxy of minimum healthcare attention, one hour of available annual medical consultation per hundred residents within a 1 km-ray from the healthcare service.

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Unlike classical data envelopment analysis (where all deviations are attributed to inefficiency), a stochastic approach allows a distinction between a random error v_j and a left-truncated and/or skewed stochastic term u_j as an inefficiency proxy. The first term reflects unsystematic influences and measurement errors (and idiosyncratic -space-time- heterogeneity in a panel in (4), which can be modelled separately with a fixed or random effects term η_j: Farsi *et al.* [12]; Greene [20], and [18]: 11, 13), thus implying in this case that actual distances exceed or fall short of ideal distance yardsticks. Cost inefficiency may be induced by policy-related and budget constraints. In healthcare studies, the stochastic frontier approach is generally applied to provider inefficiency or purchasing agency inefficiency, due to technical problems or suboptimal allocation of resources at a micro- (medical centre, out-contracting agency) or macroeconomic (national healthcare systems) level (see e.g. [32]). In this analysis, the threshold is endogenously determined (as in [38]), and the inefficiency effect concerns distances, namely the spatial distribution of healthcare services (see Note 6 in Section 5).

Equations (4) and (5) rely on different premises concerning inefficiency. If (5) is applied, beyond the safety threshold only one commune would be fully efficient, and OLS or GLS inefficiency estimates for all other communes would be given by the respective gaps vis-à-vis this minimum fixed effect ($u_j = \alpha_j - min(\alpha_j)$: at a cross-country level, an example is given by Evans *et al.* [11]). While specification (5) is unsuitable in this case, a stochastic cost frontier model (4) with a truncated half-normal inefficiency component (with a zero-mean inefficiency term as a nested case) or, alternatively, skewed distributions other than the half-normal (e.g. the exponential distribution) assumes that some communes are basically efficient or near-efficient, and excess distances are measured by the conditional mean of the skewed stochastic term ($E[u_j|v_j + u_j]$). An asymmetry parameter λ ($= \sigma_u/\sigma_v$, i.e. 'signal-to-noise' ratio) reflects the relative importance of the inefficiency component, and parameters are estimated by maximum likelihood.

Relative to excess distances of emergency hospitals, near-constancy in inefficiency scores can be assumed over a medium-term time horizon, with spatial inequality being the consequence of structural deficiencies in the healthcare system. Therefore, the rationale for panel data models can be questioned for hospital distances, particularly in the presence of a short sample period, as the country case examined below. With the process of development, shifts in the marginal utility functions can be associated with more affordable and frequent public transport (including emergency interventions) and infrastructure and service improvements in local clinics, among others, even in the presence of unaltered distances to major hospitals.

3   An illustration

3.1   Chilean case and hypotheses

At a possibly even greater pace than other middle-income economies, Chile is regarded to have been passing through a phase of intense epidemiological transition. Over the last century, the gap in average health status vis-à-vis industrial economies remarkably shrank. While barely exceeding one half of the respective estimate for Sweden in 1910, life expectancy was 76 years in 2000, namely 96% of the corresponding Swedish estimate. Similarly, infant mortality diminished from 120 per thousand live births in 1960, to nearly 9 to 10 per thousand in 2000 ([28]: 9). As in many industrializing economies, infectious diseases have been displaced by illnesses of a chronic type (with cardiovascular problems turning out to affect more than half of the adult population), as most relevant causes of morbidity (see Note 7 in Section 5).

However, the apparent progressive bridging of average health conditions vis-à-vis industrial countries masks the persistence of strong disparities in health status according to socioeconomic and geographical criteria. Among infectious diseases, for instance, a low average nation-wide incidence of tuberculosis coexists with heavy health-status backlogs relative to this disease in a number of poor and remote provinces and communes.

The above transition is reflected in current public health planning targets. The incidence of TBC is expected to drop from 20 cases per hundred thousand individuals in 1999, to 10 cases in 2010, and 5 by 2020. Similarly, relative to 1999 estimates, along with improvements in health and sanitation, education, housing, and other socio-economic conditions, the average infant mortality rate is envisaged to decline by 25% by 2010, to 7.5 per thousand, and maternal mortality by 50%, to 1.2 per 10000 ([27]: 6). Despite substantial financial budget allocations to public healthcare (which accounted for almost 12% of central government expenditures in the late 1990s), this sector is considered to have maintained or even worsened its inefficiencies in service provision, while the private healthcare system has gained increasing importance ([33]). The reduction of health status inequalities and healthcare system inefficiencies are among official policy goals for forthcoming years, including the AUGE (Universal Access with Explicit Guarantees) Plan implemented since mid-2002 ([27]:10, [26]).

In view of particular geographical features of the country, in Chile high dispersion of the population and difficult transport links of some isolated communes with major urban centres represent relevant official criteria for public healthcare investment decisions. However, the effectiveness of these resource-allocation decisions is a controversial issue. On the one hand, isolated communes are offered medical services at a higher level than it would be justified by the number of residents only. On the other, medical emergency treatment and healthcare accessibility remain deficient in

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many of these communes ([29], [8]). Relative to excess distances across communes, following standard theory this analysis assumes increasing marginal disutility beyond an average (individual-varying) distance threshold, vis-à-vis specific healthcare facilities within a commune, thus supporting a stochastic frontier model with threshold-censored untransformed (skewed) distance data.

Beyond the safety distance threshold, excess distances can be hypothesized to depend on socio-demographic factors and local geophysical conditions, in addition to the indicators assumed as a benchmark criterion for the threshold itself (equation (3) vs. (4)). Once the size and population dispersion of communal areas is accounted for, higher urbanization levels can be expected to be associated with closer hospital facilities, due to greater economies of scale of major hospital buildings in towns. With presumably stronger perceptions of the relevance of preventive and curative efforts by residents, relatively higher standards of housing and education can be associated with increased demand for proximity and easier access to medical services, thus implying a possible sample selection bias in related community-level variables ([3], [22]: individuals who care more about their health will often choose areas with a good healthcare system). In terms of healthcare planning objectives, the extent and depth of poverty across target areas, and possibly also gender- and age-related population composition, should in principle affect healthcare investment decisions, with regulators facilitating accessibility to local healthcare for low-income communities (see Note 8 in Section 5). The application which follows is focused on a few key variables, as an illustration of the use of stochastic frontier modelling for healthcare access analysis.

3.2 Dataset, variables and estimation results

Based on a broad statistical database by SUBDERE-SINIM (Secretariat for Regional and Administrative Development-National System of Municipal Indicators; www.sinim.cl), a small subset of variables is chosen here for modelling cross-commune emergency hospital distances in Chile, over the pooled biennial 2000-2003 period. For most indicators in the database, data tend to vary only from 2000-01 to 2002-03, since survey estimates are available on a biennial or triennial basis. Relative to the variables used in the econometric analysis, descriptive statistics are reported in Table 1.

Chilean communes substantially vary in demographic size, with communal population ranging from less than five thousand in some scarcely inhabited areas of Northern and Southern Regions to around 400000 residents for three municipalities in the Metropolitan Region of Santiago (La Florida, Maipú, and Puente Alto). All 341 communes are included in the database (see Note 9 in Section 5). For some variables, missing or unreliable observations affect relatively smaller communes.

Table 1: Variables and descriptive statistics (Chilean communes, 2000-03)

variable	definition	mean	standard deviation	skewness	kurtosis
dist (lndist)	distance of communal administrative centre from the nearest reference or emergency hospital (km)	30.1 (2.6)	38.6 (1.43)	2.78 (-0.43)*	12.99 (2.33)
lnarea	area (km^2)	6.3	1.62	-0.47	3.42
lnpop	population (number of residents)	9.8	1.37	-0.15	3.25
hcpov	headcount poverty index (% below the poverty line)	25.04	10.6	0.33	3.01
hsavail	non-hospital health service availability (weighted average of general urban/rural clinics and rural posts, per 10000 residents: see section 3.2)	1.1	1.14	2.19 *	10.26
disp(j)	degree of geographical dispersion of population in the commune (j = 1, 2, 3, for concentrated, disperse, and very disperse; implicit category j = 0 for highly concentrated population)				
dum(j)ac	accessibility to regional capital (j = m, l, for medium and low degree, respectively; implicit category j = h for high degree of accessibility)				
htype(j)	complexity of hospital service (j = 1 highly equipped hospitals, 2 with specialties, 3 with basic specialties, 4 with general practitioners -for certain emergencies-; 5 non-classified category, i.e. clinics of religious congregations or military personnel; j = 0 commune with no hospital; SINIM)				

Variable names preceded by ln: data in natural logarithms (for lndist: descriptive statistics in parentheses); * zero-bounded variables.

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Time-series inconsistency and extreme outlier observations concern a few remote communes, such as the island of Juan Fernández (with the official urbanization rate 'jumping' from nought in 2000 to 94% in 2004, and the nearest reference hospital being 700 km away). The two most Southern Regions of Aisén and Magallanes have no official statistics of communal areas (Table 1: *lnarea*; relative to the ten communes of Aisén, which is the least populated region -with less than 1% of the total-, no information is available also for hospital distances).

Over the period 2000-2003, the distance of the commune's administrative centre from the nearest emergency hospital reflects near-fixed effects, with rare cases of distance changes due to closure or opening of hospitals during the period analyzed. Commune-level information for distance is rearranged here with leftward censoring at one (by aggregating reported shorter distances together with 1 km distance-length estimates), i.e. at zero for log-transformed data (*lndist*). Relative to a few mainly small communes, cross-year variations in reported distance are likely to be caused by incorrect measurement and imprecise survey responses, or actual changes in local healthcare provision. Hospital distance estimates for these communes are either excluded from the sample or, to the extent possible at this level of analysis, adjusted in accordance with additional specific information (see Note 10 in Section 5). If 'data noise' is regarded as a relevant feature all across the sample, an alternative approach would consist of smoothing the reported distances by averaging (and subsequently log-transforming) the two two-year estimates (*lndistav*). A comparison of the two (two- and four-year) average figures reveals only minor differences, with cross-panel and full-sample correlation coefficients of 0.94 and 0.97, relative to *lndist* in the two sub-periods (2000-01 vs. 2002-03) and *lndist* versus *lndistav* (2000-03), respectively.

Within each commune, the degree of geographical dispersion is measured by the weight of the main centre relative to the population of the three following settlements in terms of demographic size, with a categorical variable reflecting three different degrees of geographical dispersion (Table 1:*disp*, [37]:22). Relative to broad accessibility between a commune and the respective regional capital, communes are distinguished as to whether there is (i) direct access with no apparent difficulties, (ii) regular transport by land facing some functional or climatic difficulties (*dummac*), or (iii) irregular transport, with access combining different transport modes, or in few remote territories, such as Cape Horn, exclusively by sea or by air (*dumlac*). Poverty is defined in terms of household income shortages relative to minimum expenditures for food and non-food basic needs of the household members ([25]). Disparities in extent of poverty across communes appear to be persistent: the headcount indicator (Table 1: *hcpov*) has a cross-panel (2000-01 vs. 2002-03) correlation coefficient of 0.73.

Among indicators of hospital infrastructure standards, based on the official SINIM classification of public hospitals, one has tried to capture here the complexity of hospital services in a commune, if available, with five dummy variables (*htype(n)*: $n = 1, ...5$, with implicit category $n = 0$, for communes with no local hos-

pital services; for larger communes with hospitals of different types, e.g. Valparaíso, the highest available category was chosen). In Chile, type-4 hospitals, together with non-hospital medical facilities (Table 1: *hsavail*), deal with primary care, type-2/3 hospitals also provide secondary care, type-1 hospital services include tertiary care services, while type 5 represents non-classified clinics of religious congregations and military personnel (bip.mideplan.cl, 'normas de clasificación sectorial'). Relative to healthcare services other than hospitals, the variable *hsavail* is obtained as the weighted sum of urban and rural clinical centres and rural medical outposts, per 10000 residents (with weight parameters 1, 1 and 0.2, for the three facilities respectively).
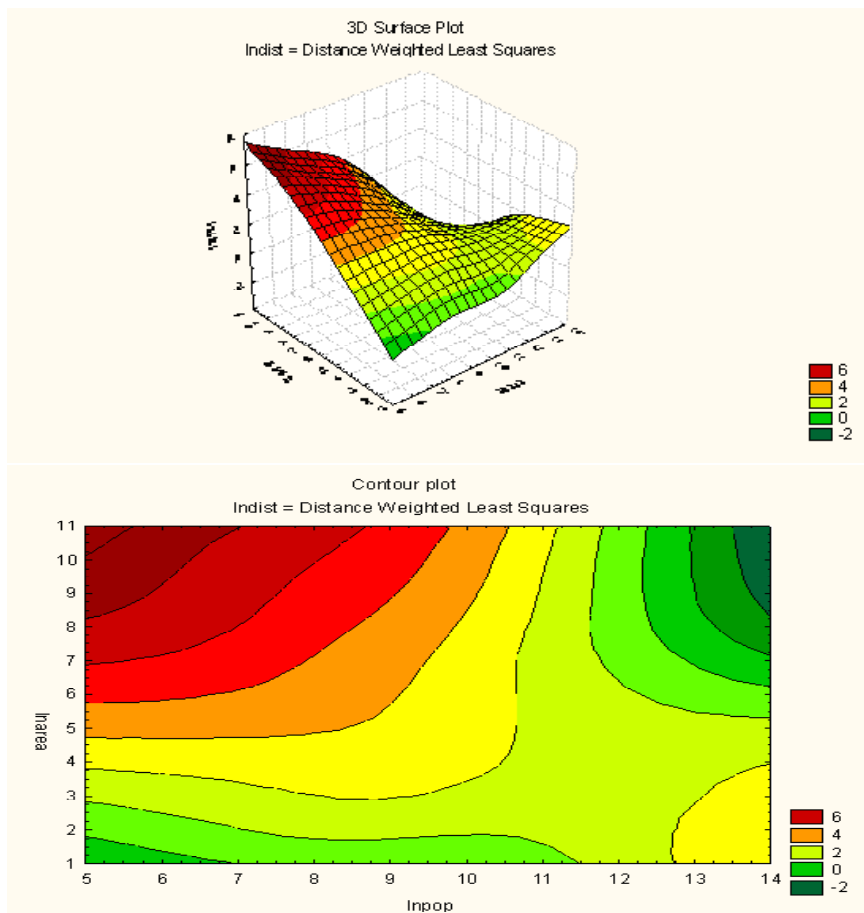
The presence of a safety distance threshold, prior to which otherwise significant socio-demographic factors do not seem to have a substantial relevance in hospital location, is graphically highlighted by scatter plots (and supported by econometric results commented below). At a 3-dimensional level, this pattern is reflected by saddle-shaped cross-commune kernel (distance weighted LS) regression estimates of log-transformed hospital distance vs. area and population (Figure 1: surface and contour plots). For an estimate of the cross-commune hospital distance threshold, a grid search was conducted on binary choice (logit and probit) models, within a range suggested by the above pattern and consistent with previous analyses (from 3 to 7 km). Regression results provide no clear indications, except for marginal support for 5 km. As expected, relatively stronger predictive power is found for observations beyond the respective thresholds (relative to probit, see Table 2). While logit and probit estimates turn out to be basically equivalent in terms of regression diagnostics and predictive power, probit is theoretically more appropriate in this case, by accounting for both sources of uncertainty, relative to the 'imputer' and the public decision-maker respectively ([6]).

Stochastic cost frontier regressions with covariates including those used in probit regressions, and alternative density functions for the inefficiency term, have been applied to 5 km-censored hospital distances. Selected results with half-normal and exponential distribution assumptions are reported in Table 2. Standard stochastic cost frontier models with no hurdle, with the original variable (*dist*) regressed on alternative sets of variables used in the frontier hurdle, do not yield reliable convergence ML estimates. The same occurs for frontier hurdle models if a truncated-normal density is assumed for the inefficiency component. Demographic and geophysical features, partly proxied by dummy variables, have a definite influence on emergency hospital locations. Residents of communes relatively farther away from major hospitals appear to be to some extent 'compensated' on average with greater availability of supplementary non-hospital healthcare. Once population is accounted for, communes with disadvantaged geographical and intra-regional transport conditions face similar hospital distances as communes with easy access to regional administrative centres, while this does not apply to intermediate cases (*dummac*, [3]-[4]).

The complexity of local hospital care services (*htype(n)*) is not found to be a

significant factor of cross-commune disparity in emergency hospital distances, and the simultaneous use of population and rate of urbanization causes multicollinearity. After accounting for other covariates, the extent of poverty is not found to directly concern hospital locations in terms of estimation of a cross-commune travel cost-minimizing frontier, but it does appear to partly explain the heteroscedastic pattern in excess distances measured by the location inefficiency component (Table 2, model [5]) estimated slope parameter in regression of the log-transformed conditional variance of the truncated error $ln(\sigma_u)^2$ on *hcpov* and a constant). However, this result turns out to be sensitive to the explanatory variables used in the cost (distance) equation.

Figure 1: Hospital distances vs. communal area and population (nat. log.; Chilean communes, 2000-2003)

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model	probit					half-N [1]	exp. [2]	half-N [3]	exp. [4]	half-N [5]
dep. variable	dist3	dist4	dist5	dist6	dist7	distcens				
constant						14.3 (1.02)$^\wedge$	-5.14 (-0.5)$^\wedge$	67.9 (4.99)	35.15 (3.88)	1.81 (0.1)$^\wedge$
disp1	0.05 (0.2)$^\wedge$	0.12 (0.4)$^\wedge$	0.19 (0.7)$^\wedge$	0.1 (0.34)$^\wedge$	0.1 (0.34)$^\wedge$					
disp2 (*probit*) dummac (*sfm*)	0.88 (3.83)	1.0 (4.32)	1.1 (4.71)	1.1 (4.67)	1.1 (4.69)			9.71 (3.58)	9.04 (4.52)	
disp3 (*probit*) dumlac (*sfm*)	1.11 (5.81)	1.21 (6.24)	1.32 (6.7)	1.19 (6.07)	1.1 (5.64)			-2.25 (-0.93)$^\wedge$	0.2 (0.1)$^\wedge$	
hsavail	0.53 (4.53)	0.57 (4.96)	0.6 (5.15)	0.67 (5.71)	0.69 (5.97)	1.67 (1.75)"	2.39 (3.15)			1.95 (1.76)"
lnpop	-0.05 (-3.14)	-0.07 (-4.56)	-0.09 (-5.4)	-0.09 (-5.58)	-0.09 (-5.66)	-3.77 (-2.81)	-0.59 (-0.65)$^\wedge$	-7.14 (-4.78)	-3.34 (-3.52)	-2.13 (-1.68)"

Table 2: Maximum –likelihood estimates of stochastic frontier hurdle models

lnarea	2.85 (4.57)			1.98 (3.71)	3.25 (4.77)				
hcpov	0.01 (0.1)$^\wedge$								
λ	[17.5]	9.28	16.54	7.92	20.08				
$\theta(exp.)$ hcpov-*het.* [5]	0.03 (6.13)	0.03 (23.8)		0.04 (24.1)					
χ_2	415.4	586.5	438.4	604.4	444.9	168.03	170.9	168.1	147.4	120.6
Pseudo R^2	0.1	0.12	0.09	0.13	0.1	0.27	0.28	0.29	0.26	0.23
% correct						0.46(-) 0.94(+) 0.82	0.48(-) 0.94(+) 0.83	0.5(-) 0.94(+) 0.84	0.49(-) 0.93(+) 0.84	0,49(-) 0.93(+) 0.84
N	407	473	473	463	463	543	543	543	543	543

Dependent variables: dist*n* (e.g., dist3: 0 $n \leq 3$ km, 1 $n > 3$ km); distcens (=dist - 5 km, excl. negative values). *T*-statistics in parentheses under estimated parameters (level of significance: ' 5%, " 10%, $^\wedge$ more than 10%; in all other cases: 1% or less). Hcpov-het. (model [5]): parameter associated with *hcpov*, as explanatory variable for conditional heteroscedasticity in inefficiency scores (in brackets, asymmetry parameter λ if [5], is applied with no heteroscedasticity modelling). χ^2 likelihood ratio test of fitted versus intercept-only log-likelihood. Pseudo R^2 (McFadden) likelihood ratio index. N sample size.

... Table 2 – Maximum -likelihood estimates of stochastic frontier hurdle models

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Inefficiency scores are highly over-dispersed ($\theta < 1$ in the exponential density), and trace similar patterns in terms of excess hospital-distance ranking of communes, without remarkable changes due to model specification and density assumptions (the correlation coefficients between distance-frontier estimates in the four models [1]-[4] are in the range (0.74, 0.97)). Particularly large spreads between actual and 'best practice' hospital distances concern communes in the geographical extremes, namely the Region of Arica and Iquique in the north, the Regions of Puerto Montt and Punta Arenas in the south, and the Andean communes of Ollagüe and Lonquimay, in Region II and IX, respectively (Figure 2). On the whole, the estimated safety distance threshold and location inefficiency scores are found to be robust to different model specifications (with the inclusion of additional variables), distribution assumptions on the skewed stochastic error component, and sample periods (as indicated by results based on the cross-commune panel extended by one biennium, to cover the period 2000-05: - see Note 8 in Section 5).

Figure 2: Hospital distances: actual vs. fitted stochastic frontier estimates (communes grouped by region)
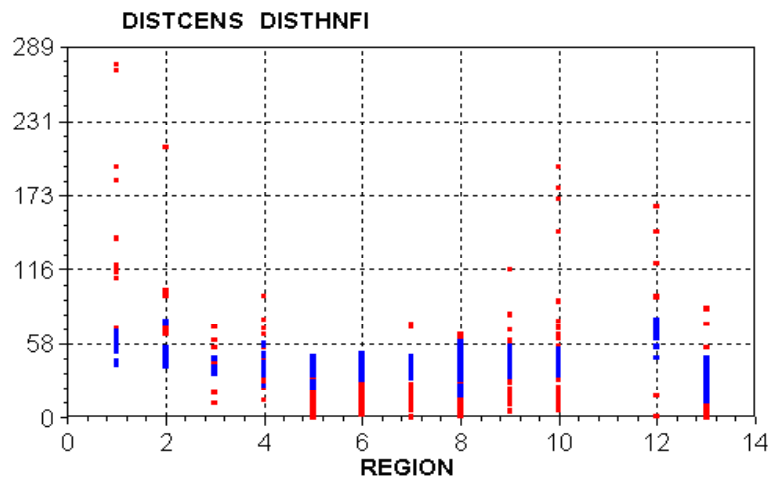
Distcens (red): hospital distances (5 km-threshold censoring); disthnfi (blue): fitted values (model [3]: Table 2). Region (administrative centre): 1 Tarapacá (Iquique); 2 Antofagasta; 3 Atacama (Copiapó); 4 Coquimbo (La Serena); 5 Valparaíso; 6 Libertador Gen. B. O' Higgins (Rancagua); 7 del Maule (Talca); 8 Biobío (Concepción); 9 de la Araucania (Temuco); 10 de los Lagos (P.to Montt); 11 Aisén (Coyhaique; see section 3.2); 12 Magallanes (Punta Arenas); 13 Metropolitana (Santiago).

4 Conclusion

The task of identifying target areas with severe problems of accessibility and insufficient standards of public services is fraught with several theoretical and empirical pitfalls. Similarly to public policy design for poverty alleviation, problems such as failed coverage of poor households in non-target areas and leakages to non-poor in target areas (as considered by Besley and Kanbur [1] can partly be avoided by combining data at different levels of statistical aggregation, such as population census, household and health surveys, and climatic and geo-referenced (e.g., road infrastructure-mapping) information. In this analysis, based on standard assumptions on marginal disutility with respect to distances to public facilities, utility function re-specifications are proposed, with implications for measurement and estimation of spatial inequality in access to healthcare facilities. For illustration purposes, an average safety distance threshold is estimated in a cross-commune application for Chile. This threshold reflects healthcare regulators' views on individual-varying safety distance thresholds z_i, by assuming no change in utility *ceteris paribus* within these limits, and increasing marginal disutility beyond them. As in poverty mapping, estimates of shortfalls in access to public services, including healthcare, at a more disaggregate territorial level are hindered by the frequent lack of sufficient sample size of household surveys.

Besides the hypotheses considered and partly tested in section 3, econometric tests can focus on other issues of concern. For instance, future research could examine to what extent improvements in fiscal instruments at a communal level can contribute to redress market distortions in the spatial allocation of private health-care centres ([34]: 223). Once longer and consistent time series become available, the analysis may examine dynamic effects, which are particularly relevant for public utilities with long time horizons, as typical of healthcare services ([36]). Based on similar theoretical reformulations, the stochastic cost frontier hurdle model could be tailored for a more disaggregate (cross-patient or cross-household) level, so as to include aspects which are not captured by commune-level data (e.g. cross-individual/household testing of the utility specification (6) in Appendix). This would highlight individuals' preferences beyond generally assumed normative criteria, and might include time-varying distance thresholds. Similarly to the debate concerning the difficulties to clearly distinguish between objective and subjective differences in consumption levels ([9], [13]), an individual's shortfall in access would then also become a function of other individuals' changing degrees of access to services, with distance thresholds evolving endogenously with standards of living.

5 Notes

1. The term distribution weight refers to relative values attached to incremental changes in a variable affecting welfare to different population groups. In several developing economies, welfare inequality is believed to arise more out of differences across villages, or across communes within large urban conglomerations, than from differences across individuals within individual villages or communes ([3]: 190).

2. Individual-varying distance thresholds are to some extent highlighted by experiments on consumers' perceptions of waiting time, with the wait regarded as a fixed cost to be borne in order to obtain a service if it is within an expected ('normal') length, but as a loss once this length is exceeded ([30]).

3. Given a survival threshold b and consumption c, $SvdT$ marginal utility can be re-specified as $dU/dc = (c - b)^{-n}$, as proposed by Price and Nair ([31]): 527; $SvdT$ original specification is $dU/dc = c^{-n}$). As a more stable variable across the life cycle, consumption is regarded as a better indicator of living standards than income ([9]: 16).

4. Alternative normative criteria in health system performance assessment are reviewed by Gadikou, Murray and Frenk [37]. The term *best practice* cost (/production) is used by Puig-Junoy and Ortún [32], among others, with this implying a preference for stochastic, rather than deterministic (*true* efficiency), frontier models. Within the stochastic approach, the choice of a probability distribution for the inefficiency term is subject to a degree of contention, with stochastic frontier models not necessarily yielding unequivocal results. In this analysis, location inefficiency estimates are found to be robust to different specifications and distribution assumptions (see section 3.2).

5. In equation (4), removal of the terms in brackets leads to a cross-section specification, and the positive sign superscript for N refers to left-truncation at zero. The gamma density nests the (negative) exponential distribution ($r = 1$). Original contributions have focused on technical and allocation inefficiency within a mostly competitive framework ([19]: 501-505). However, stochastic frontier models are applicable in the presence of a different prevailing objective function, e.g. non-profit nursing homes with objectives implicitly set by regulators ([12]).

6. Hence in this case, sources of distance-related inefficiency are either internal (technical and allocation inefficiency) or external (scale) to individual healthcare facilities. An aspect of the interactions between healthcare efficiency and spatial equity is highlighted by the argument that 'variations in efficiency [of

public services] may lead to unequal quality of services and a consequent perception of unfairness' ([36]: 402).

7. Reductions in proportions of certain illnesses, such as pneumonia and other respiratory diseases, are likely to be partly due to improved codification of causes of death over time ([27]). In the period 2000-03 for Chile as a whole, the most relevant cause of death was represented by cardiovascular illnesses, which accounted for 28% of registered deaths per year. At the health district level, the respective shares ranged from 23% for areas located in the two geographical extremes (Iquique and Antofagasta in the North, and Llanquihue -Puerto Montt- and Aysén in the South) to 32-34% for Valparaíso and Viña del Mar. In Iquique, Antofagasta and Llanquihue, the lower percent estimates are associated with a systematic prevalence of tumors as first cause of death (statistics reported in: deis.minsal.cl/deis/ev).

8. In the late 1990s in Chile, costs of private medical insurances were between 2.5 and 5 times higher for the elderly than for young adult individuals, and access to private healthcare was granted to the elderly only in cases of uninterrupted registrations and preventive care during ten years prior to the 65th year of age ([24]). This age group represents only 7% of beneficiaries of the private health insurance system ([15]: 65). A more in-depth econometric analysis of these issues for Chile, including possible determinants of resource allocation inefficiency ([32]: 20; [10]), is the object of current research by the author.

9. This corresponds to the administrative subdivision during the sample period. Four new communes were established in 2005.

10. For example, the Hospital of Purranque (a commune of 21000 residents in the Region of Puerto Montt), which belonged to the national healthcare service since 1973, was destroyed by fire in 1995. Following various phases of reconstruction, the hospital became again operational in 1998, although the official reopening was in 2003 (www.sso.cl; for this reason, in this analysis missing data for 2000-01 are replaced with the hospital distance registered in 2002-03).

6 Appendix - Safety distance thresholds and marginal disutility with respect to hospital distance

A function which avoids the constraints of equation (2) in section 2, is given by a quadratic polynomial (for simplicity, individual-specific effects other than aspects implicit in the thresholds are ignored):

$$U_i = \zeta M - \xi M^2 - \beta_i \cdot D_i - \theta_i \cdot D_i^2 \tag{6}$$

where $\zeta > 0, \xi > 0, \beta_i \geq 0, \theta_i \geq 0$ ($\beta_i = \theta_i = 0$ if $D_i \leq z_i$ and $\beta_i > 0, \theta_i > 0$ otherwise; if $\xi = \theta_i = 0$ M and (minus) D_i would be perfect substitutes) and $M < \zeta/2\xi$ (positive-value restriction on dU/dM). The safety thresholds z_i can be modelled as a function of characteristics of healthcare users and their place of residence (health status, age, income, transport network, etc.) affecting each person's ability and willingness to travel to the medical facility. In a multiple facility framework, z_{ik} will depend on both individual/household's and hospital's characteristics (cost and quality of services). In a multinomial choice setting, Keane and Moffitt [23] similarly rely on a polynomial equation to model utility by adding a stochastic intercept parameter a_i assumed to depend on partly unobservable socioeconomic characteristics. However, the rationale for the utility function is different, since both good and 'bad' attributes are maximized subject to cost constraints, and the quadratic polynomial form is a second-order Taylor series expansion in these arguments.

A yardstick for measures of distance inequality, which is often preferred to *average* distance (D_A) in welfare economics, is the *equally distributed equivalent* (EDE) distance (D_E), defined as the distance to a public facility that, if all individuals were equally distant from the facility, would give the same level of social welfare as the actual distances of these individuals. Given an additive social welfare function (SWF) and $i = 1, ...N$, equation (6) implies:

$$
\begin{aligned}
N[U(M, D_E)] &= N(\zeta M - \xi M^2 - \beta_E D_E - \theta_E D_E^2) \qquad (7)\\
&= \sum U_i(M, D_i)\\
&= \sum (\zeta M - \xi M^2 - \beta_i D_i - \theta_i D_i^2)
\end{aligned}
$$

From (7) one obtains:

$$D_E = D_A[(\beta + \theta D_A)/(\beta_E + \theta_E D_E)] \qquad (8)$$

For a population evenly distributed over the distance range ($Dmin, Dmax$), the increasing marginal disutility assumption implies that $D_E < D_A$ (as in Bigman and Deichmann [2]: 193; in the presence of a non-uniform distribution with inequality aversion, this inequality holds true once geo-demographic dispersion and similar control variables are accounted for). Hence, on average and ceteris paribus, a higher marginal social value is attached to incremental improvements in accessibility for individuals in more remote places of residence, i.e. farther away from the location of the medical centre. Specification (6) entails that the elasticity of the social marginal disutility ($U_{(-)}$) with respect to distance (beyond the threshold) is not constant, but it increases with distance. This elasticity (η_i) and the distribution weight parameter w (which represents the social value of a unit-reduction of EDE distance relative to the respective social value at the average distance level) are respectively given by (9) and (10):

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$$\begin{aligned}
\eta_i &= (d^2 U_{(-)}/dU^2_{(-)})/(dD/D) &(9)\\
&= (d^2 U_{(-)}/dD^2)/[(dU_{(-)}/dD)/D]\\
&= D_i[2\theta/(\beta + 2\theta D_i)]
\end{aligned}$$

where $0 < \eta_i \leq 1$ (for $\beta \geq 0$ and $\theta > 0$), and

$$\begin{aligned}
w &= (dU_{E(-)}/dD_E)/(dU_{A(-)}/dD_A) &(10)\\
&= (\beta_E + 2\theta_E D_E)/(\beta + 2\theta D_A)
\end{aligned}$$

Beyond the safety threshold, utility with respect to distance is negative and monotonically declining at an increasing rate ($d^2 U/dD^2 = -2\theta < 0$). Likewise, w declines with increasing inequality aversion. In basic project appraisal theory, society's aversion to consumption (/income) inequality is captured by a constant parameter, which is equal (with positive sign) to the elasticity of the social marginal utility (elasticity of marginal utility $-n$ in $SvdT$ formula and notations: see Note 3 in Section 5 and Brent [7]: 62). A less-than-unit value of this parameter implies that social value gains of socially targeted additional consumption (for individuals at, e.g., one-fifth of the average) are less than proportionate relative to gaps in initial consumption levels. Unlike the linearly decreasing analogue in marginal utility (converging to zero), a linearly increasing marginal disutility is theoretically limitless, and the unit upper bound for η_i can only be removed by inserting a cubic term of distance into the polynomial expression (6) ($-\delta_i D_i^3$, with $\delta_i > 0$ beyond the threshold: in the latter case, $\eta_i = [2\theta + 6\delta D_i]/[\beta/D_i + 2\theta + 3\delta D_i]$).

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