Measuring the efficiency of human resources for health for attaining health outcomes across subnational units in Brazil

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Introduction

A number of recent studies have explored the association between the number of health workers in a country and health outcomes, by means of cross-country data (Chen et al., 2004; Anand & Barnighausen, 2004; Anand & Barnighausen, 2006). These studies have shown not only great imbalances in the distribution of health workers across countries, but also a positive association between health worker densities and both population health and levels of intervention coverage. Chen et al. also identified the threshold health worker density at which countries found it difficult to achieve even a minimum acceptable level of coverage of key interventions. This work was further advanced in the *World health report 2006* (WHO, 2006), which estimated minimum desirable levels of coverage of key health interventions.

Although a few studies of the impact of health workers on health outcomes have been undertaken in selected countries (Starfield et al., 2005; Goodman, 2004), there has been little analysis to replicate the cross-country studies focusing on variations in health worker numbers and health outcomes or coverage by geographical area within a country. Health worker numbers are known to be distributed unevenly in low-income and middle-income countries (Gupta et al., 2003a; Gupta et al., 2003b), but the relationship of this maldistribution to health outcomes has not been explored. This is especially important in poor countries with high burdens of disease.

To address the call, the World Health Organization dedicated the *World health report 2006* to human resources for health. The 2006 report draws attention to the importance of health workers in the health systems.

> "Health workers are crucially important for producing good health through the performance of health systems; they constitute a significant share of the labor force and perform key social roles in all societies…. "
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> "Health for All, Primary Health Care and Millennium Development Goals are not achievable without an appropriately prepared, deployed and supported health workforce …."

This paper documents the analytical work done for the *World health report 2006* to produce new evidence on the relationship of human resources with the coverage of key interventions at the subnational level in Brazil. Using stochastic frontier production function models, we explore the efficiency of health workers (aggregated and disaggregated by physicians, nurse professionals and nurse associates) in attaining coverage of antenatal care across municipalities. The analysis will highlight how socioeconomic conditions of the population moderate the ability of health workers to perform their tasks efficiently. We will also underline how various policies designed to achieve more efficient use of resources in disadvantaged municipalities have succeeded in increasing the coverage of antenatal care services. Finally, we examine whether it is possible to determine the optimal skill mix of health workers for each municipality, taking into account their levels of efficiency and wage rates.

In the first part of the paper, we present the background of the different policies in Brazil that have influenced the number and distribution of health workers across municipalities. Then we describe how human resources for health are distributed across municipalities and regions. The third part of the paper is a literature review, with the studies that have analysed the efficiency of health systems since the *World health report 2000*. The fourth part describes the construction of the data for the efficiency analysis at municipality level, followed by the description of the methodology and the results. The final part presents a discussion with policy recommendations that can be extracted from the efficiency analysis.

Specific background of Brazil

The Brazilian Constitution says that "*all people are equal by the law, without any distinction*". In practice, however, there remain major social inequalities. The enormous size of the country and the range of diversities makes it difficult to fully apply the principles established in the Constitution.

Over the last decade, responsibility for the administration and provision of public services in health has been decentralized to the level of the municipality – one level below the states. A series of reforms allowed each municipality to design and develop their local health systems according to their needs, as long as they stayed within a set of federal norms. In addition, states and municipalities could try to look for their own resources – physical, financial and human – to top up those provided by the federal government.

Decentralization has had many benefits (Almeida, 2002; Barros, 2003; Gerschman, 2000; Gerschman, 2001; Viana & Dal Poz, 1998), but development has been heterogeneous across the municipalities for several reasons: differences in geography, wealth, climate and size. Many of the 5507 municipalities (in 2000) are very small, for example, while a few are relatively large. In addition, according to Gerschman (2000; 2001) the implementation of the decentralization process in some municipalities has also been marked by *clientelistics* and *patrimonialists* procedures – in which people in power provide favours to relatives or clients. These behaviours are still endemic in the Brazilian political and institutional culture, and have influenced the results of the decentralization.

In some municipalities, good progress was made through initiatives of the municipal administration, which injected their own resources into the provision of health services, well beyond the minimum set by federal guidelines. In others, municipal administrations did not assume responsibility for many activities, which remained largely in the hands of the federal authorities.

In general, however, health system management has improved with the transfer of federal resources and responsibility to municipalities. Total funding levels increased, which allowed an expansion of services – the most significant being the Health Family Program (PSF) that has to date been implemented in 60% of the municipalities and has been linked to the development of a category of community health workers known as Health Communitarian Agents (Viana & Dal Poz, 1998). Finally, more democratic mechanisms for community participation in decision-making were established.

Accordingly, decisions about the allocation, and to some extent the generation, of financial resources for health are now made at the municipal level. For this reason, our analysis of attainment and efficiency uses the municipality as the unit of analysis.

Distribution of health workers across municipalities and regions in Brazil

Geographical inequalities in the distribution of health workers[1] within countries are usually reflected in urban concentration and rural deficits. Brazil is no exception. Ninety-four per cent of physicians, nurse professionals and nurse associates are concentrated in urban areas. But geographical inequalities are also reflected across municipalities and regions, depicted for municipalities in Figure 1. There are municipalities with fewer than five health workers per 1000 inhabitants, compared to some with more than 35. These inequalities are also found when health workers are disaggregated by physicians, nurse professionals and nurse associates.

Fifty percent of the municipalities with densities below 4.5 workers per 1000 inhabitants are concentrated in the North East region, which has the highest infant mortality rate by region (45 per 1000 live births in 2000 – see Figure 2). A large majority of the municipalities (72%) with densities over 9.8 health workers per 1000 inhabitants are concentrated in the South East and South of the country, where infant mortality rates are less than 19 per 1000 live births.

As a first step to the analysis, we reproduced Chen et al.'s (2004) analysis showing the relationship between total health worker density and coverage with antenatal care services. Figure 3 shows this relationship for the 4282 municipalities in Brazil. The thick line is the predicted line for coverage of antenatal care after fitting a log-linear regression model. The results suggest that a 1% increase in health worker density is associated with a 0.12% increase in the coverage of antenatal care on average. Municipalities with fewer than three health workers per 1000 population do not, in general, achieve a 70% level of coverage.

Figure 3 also shows, however, that there is considerable variation in the level of coverage obtained by municipalities with a given number of health workers. This raises the question of whether they differ in their levels of efficiency, and if so, why.

Background on efficiency

While increasing the number of health workers in a population can contribute to increasing coverage, there is the potential to achieve more by using existing human resources more efficiently. The first study that measured the efficiency of health systems in attaining health outcomes applying production function models was the *World health report 2000* (Evans et al., 2001; Evans et al., 2002; Evans et al., 2003a; Evans et al., 2003b; Tandon et al., 2003). Health system efficiency was defined as goal attainment compared to the maximum that could have been achieved for the observed level of resource use, with goal attainment measured in terms of health alone – as represented by the healthy life expectancy of the population – and in terms of a composite indicator that included health, responsiveness and fairness in financial contributions. Using panel data of 5 years in 191 countries, a stochastic frontier model was applied relating attainment to per capita health expenditure and average years of schooling in the population as inputs. Then a second-stage analysis was implemented to identify characteristics of the environment within which each health system operated that influenced the resulting efficiency (Evans et al., 2003).

In 2004 Greene, using the same data set, suggested that the random effect truncated normal stochastic frontier model was a more appropriate method to analyse efficiency across

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[1] The *World health report 2006* defines health workers as "all paid workers employed in organizations or institutions whose primary intent is to improve health, as well as those whose personal actions are primarily intended to improve health but who work for other types of organizations".

countries (Greene, 2004). This model estimates both efficiency and its determinants in a one-step process that incorporates cross-country heterogeneity into the estimates.

We used Greene's specification in this paper, but for cross-sectional data. The model incorporates into the production function the fact that random shocks outside the control of producers can affect the output and that there is cross-municipality heterogeneity. The data used for this analysis are presented in a later section.

Data description

For the analysis of the *World health report 2006*, a dataset was compiled from three sources of information to analyse the relationship of inputs and outputs at municipality level for the year 2000. The first source was the Census 2000 (IBGE, 2000), which, in a long version questionnaire applied to a representative sample of 11.7% of households, collected detailed information of household characteristics, including factors such as place of residence, religion, schooling, migration and employment. Three indicators were extracted: the number of health workers; the average years of education of adults; and the proportion of the population living in urban areas.

The Census allows 21 categories of health workers to be identified, using the Brazilian classification of occupations (matching the International Standard Classification of Occupations (ISCO) at fourth-digit code level) and the four categories of industry related to the health sector (as per the International Standard Industry Classification, ISIC). The census sought information from all people aged 10 years and over, who, during the last week of the reference month, were employed, and who worked in one of the four health industries. Anyone who responded that they worked in one of the four industries relating to the health sector was counted as a health worker, regardless of occupation. To this we added people who classified themselves as belonging to one of the 21 categories of health workers, even if they worked outside the health sector (e.g. doctors working in mining companies).

For the purpose of our analysis we combined health workers into five categories: physicians; nurse professionals; nurse associates; other health staff; and other support staff.[♣] The construction of the five categories of health workers is described in Table 1. The average years of schooling for the population is defined as the years of formal schooling received, on average, by adults over age 15 (World Bank, 2006). Sample weights were then used to obtain population estimates for the 5507 municipalities. From the total sample, 215 municipalities were excluded from the analysis for not having physicians, nurse professionals and nurse associates.

The second source of information was the Department of Information of the National Health System (DATASUS, 2000) under the Ministry of Health, which produces several databases on health indicators at the municipal level. These included: the proportion of pregnant women covered by antenatal care services; the number of ambulatory units (i.e. health facilities for outpatient care); and public health expenditure per capita. Coverage of antenatal care services is defined as the ratio of the number of live births with seven or more prenatal visits over the total live births. From the 5507 municipalities, 1010 had to be excluded from the analysis for not reporting information on antenatal care coverage. The number of ambulatory units

[♣] Other support staff includes individuals not identified as health workers in the occupation item but who said they worked in the health sector. This category includes administrative and support staff such as secretaries, drivers, etc.

includes all public and private health centres and health posts that provide primary and secondary health care services.

The final source of information was the database compiled and maintained by the Institute of Applied Economic Research (IPEA, 2000), which produces macroeconomic time series of socioeconomic indicators such as population, employment, wages and incomes, production, consumption and sales, etc. From the IPEADATA database we took the information on Gini coefficient, which indicates the distribution of household incomes within each municipality.

Table 2 shows the mean and standard deviation (SD) of the variables used in this analysis. The methodology is presented next.

Methodology

The original version of the stochastic production frontier model was introduced by Aigner, Lovell & Schmidt (1977) and Meeusen & van den Broeck (1977). The production frontier provides the upper boundary of production possibilities, where technical efficiency is defined as the proportion of the maximum possible output that was achieved from a given input vector. Stochastic production frontier models, like deterministic production frontier models, allow technical inefficiency to be estimated but they also incorporate the fact that random shocks outside the control of producers can affect output.

We modeled the coverage of antenatal care c_i as a function of a vector of inputs x_i for the i^{th} municipality $c_i = f(x_i)$. The x_i vector of inputs is composed of total health worker density THW_i, public health expenditure per capita HE_i, and ambulatory units AU_i. Following Kumbhakar and Lovell's (2000) notation the model is:

$$c_i = f(THW_i, HE_i, AU_i; \beta) \cdot \exp\{v_i\} \cdot TE_i \quad (1)$$

where [$f(THW_i, HE_i, AU_i; \beta)*exp(v_i)$] is the stochastic production frontier. The stochastic production frontier consists of two parts: a deterministic part, common to all producers $f\ (THW_i, HE_i, AU_i; \beta)$; and a producer-specific part $exp(v_i)$, which captures the effect of random shocks on each producer. Then technical efficiency (TE) is measured by equation 2.

$$TE_i = \frac{c_i}{f(THW_i, HE_i, AU_i; \beta) \cdot \exp\{v_i\}} \quad (2)$$

This defines technical efficiency as the ratio of observed c_i (output) to maximum feasible output in an environment characterized by $exp(v_i)$ where c_i achieves its maximum feasible value of [$f((THW_i, HE_i, AU_i; \beta)* exp(v_i)$] if, and only if, $TE_i=1$. Otherwise $TE_i<1$ provides a measure of shortfall of observed output from maximum feasible output in an environment characterized by $exp(v_i)$, which is allowed to vary across producers – in this case the municipalities.

We assume that $f\ (THW_i, HE_i, AU_i; \beta)$ takes the log-linear Cobb–Douglas form, which is the most common functional form applied in econometric analysis of efficiency. Then the stochastic production frontier model is:

$$\ln c_i = \beta_0 + \beta_1 \ln THW + \beta_2 \ln AU + \beta_3 \ln HE + v_i - u_i \quad (3)$$

The noise component v_i – random shocks – follows a normal distribution $N(0, \sigma_u^2)$, and u_i is the nonnegative technical inefficiency component of the error term that follows a truncated normal distribution $N^{+}(\mu,\sigma_u^2)$. Then the error term is defined as $\varepsilon_i = v_i - u_i$ [♣]. The noise component v_i is assumed to be distributed independently of u_i.

The normal distribution for the inefficiency component u_i is assumed to be truncated below at zero and it contains an additional parameter μ to be estimated (its mode). The μ of the truncated normal distribution is modelled as a linear function of a set of covariates, in this case average years of schooling of the adult population, the proportion of the population living in urban areas and the Gini coefficient of household income. This model affords the opportunity to avoid an assumption that the data are identically distributed (StataCorp LP, 2006) and provides a more flexible representation of the pattern of efficiency (Kumbhakar & Lovell, 2000).

To explore the impact of health providers, we focus on the contributions of physicians, nurse professionals and nurse associates, who are defined as the health workers who have a direct impact on the coverage of antenatal care through patient contacts. The stochastic production function of coverage of antenatal care with physicians P_i, nurse professionals NP_i and nurse associates NA_i included as separate inputs is measured by equation (4).

$$c_i = f\left(P_i, NP_i, NA_i, HE_i, AU_i; \beta\right) \cdot \exp\{v_i\} \cdot TE_i \quad (4)$$

When including P_i, NP_i and NA_i as inputs in the production function, a zero input problem appears because there are some municipalities with only one or two types of providers. The zero input problem requires a new specification of the log-linear Cobb–Douglas function described in equation 3, because these functional forms are specified only for non-zero inputs.

There are different ways in the literature to treat the zero inputs problem. One possibility is to apply a quadratic production specification instead of the logarithmic specification. This approach, however, affects the global concavity of the production surface: for example, at some point adding more health workers would reduce coverage. Another common solution is the substitution of a small nonzero value (*α)* for zero inputs. The problem is that the results are very sensitive to the value chosen. A different proposal introduced by Moss (2000) applies a bootstrapping technique, in which the estimation is based on random averages from the original sample. But Moss's method cannot be applied in the specific case where the zero input level is a valid approximation of the production process.

Soloaga (2000) proposes the substitution of a small non-zero value with an estimated *α* parameter. The disadvantage of this approach is that the parameters estimated are not stable when the dataset contains a high proportion of zeros. Battese (1997) introduced a variation of the frontier production model where the zero input problem is solved by introducing a dummy variable into the model such that efficient estimators are obtained using the full dataset but no bias is introduced.

Battese's model allows for the Cobb–Douglas functional form to capture the fact that the output is non-zero even when some of the inputs are not used. In Brazil 66% of municipalities did not have physicians and 79% did not have nurse professionals. All had nurse associates. Because of the large scale of inputs lacking, Battese's proposal was considered the most appropriate method to deal with the zero inputs.

Based on the different combinations of health workers involved in providing antenatal care coverage, there are different production functions. The most common case is where the

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♣ *The error term is asymmetric, since ui*≥0 (Kumbhakar & Lovell, 2000).

providers are nurse associates (58%), followed by the combination of physicians and nurse associates (21%), then all three health workers (13%) and finally by nurse professionals and nurse associates (8%).

Battese's modified Cobb–Douglas production frontier incorporates a dummy variable in the model to pool the data such that all the production functions are estimated simultaneously. The parameters are then estimated in the following model:

$$\ln c_i = \beta_0 + (\alpha_1 - \beta_0)D_{Pi} + (\alpha_2 - \beta_0)D_{NPi} + \beta_1 \ln P_i^* + \beta_2 \ln NP_i^* + \beta_3 \ln NA_i + \beta_4 \ln HE_i + \beta_5 \ln AU_i + v_i - u_i \quad (5)$$

where D_p is the dummy of physicians that takes a value of 1 when there are no physicians and zero otherwise and D_{np} is the dummy of nurse professionals that takes a value of 1 when there are no nurse professionals and zero otherwise.

The model implies that when P has a positive value then $P^*=P$, but if P has value zero then $P^*=1$ and when NP has a positive value then $NP^*=NP$, but if NP has value zero then $NP^*=1$.

Then the model specifies that the relationship between the output and the inputs is such that the output elasticity with respect to nurse associates (NA), for example, is the same β_3 for the observations involving positive and zero values of NP and P. It is also specified in such a way that the constant parameters are not necessarily the same for the different production functions, but the variances of the errors are the same.

Finally, we used this production function to identify the isoquants (determined by the marginal rate of technical substitution derived from the production function) for two municipalities with non-zero values of all types of health workers. This can be expressed as:

$$P = \exp\left(\frac{\ln c_0 + ui - \ln \alpha - \beta 2 \ln NP - \beta 3 \ln NA_0 - \beta 3 \ln NA_0 - \beta 4 \ln HE_0}{\beta 1} \right) \quad (6)$$

where c_0 is the level of coverage attained with full efficiency, and the zero sub-indices of NA and HE represent the mean value of these inputs, which are fixed for all combinations of P and NP.

Because each municipality can set salaries according to local needs, wages differ across settings. We used the observed wage rates of the different types of providers in these two municipalities to identify the mix of health workers that would be the most economically efficient – for example, which combination of the technically efficient combinations that could attain a specific level of coverage would minimize cost. (see Annex 1 for details).

The results of all these analyses are presented in the following section.

Results

Two production function models were run. In the first, antenatal care coverage was modeled as a function of the combined density of all types of health workers. In the second, we consider the density of physicians, nurse professionals and nurse associates separately as independent inputs to the attainment of coverage.

Table 3 shows the results for the first model. The number of ambulatory units and the public health expenditure per capita are also included as inputs to the production process. The coefficients are elasticities. All three inputs are statistically significant. A 1% increase in total health worker density is associated with a 0.005% increase in the coverage of antenatal care. The relationship between health expenditure and coverage is also positive, but municipalities with more ambulatory care facilities achieved lower levels of coverage after controlling for other factors. From the inputs defined no multicolinearity was found after applying the VIF test (StataCorp LP, 2006).

All the coefficients of the covariates of inefficiency had the expected signs except for the proportion of the population living in urban areas. Efficiency is higher where educational levels are higher and income inequality is lower. However, efficiency is lower where a high proportion of the population lives in urban areas. It is possible that this could be due to the relatively high correlation between this variable and the average years of education of the population (0.7).

Figure 4 shows the distribution of the estimated levels of technical efficiency attained across the municipalities of Brazil. Consistent with the above findings, municipalities with low education and high inequalities in income – disadvantaged municipalities – have lower levels of efficiency, while those with high education and low inequalities in income – advantaged municipalities – have higher levels. A large majority of the advantaged municipalities (70%) are very efficient, with levels of efficiency over 90%. On the other hand, almost half of the disadvantaged municipalities have relatively low levels of efficiency, defined as efficiency levels below 69%.

That being said, it is possible for disadvantaged municipalities to be very efficient in their use of existing inputs, including health workers. For example, 13% managed to reach efficiency levels of over 90%. In addition, some of the advantaged municipalities had quite low levels of efficiency: as low as 48%.

Table 4 reports the results of the regression in which the densities of physicians, nurse professionals and nurse associates are included separately. The second version excludes education as a covariate of inefficiency. The coefficients of the alphas represent the dummies for zero inputs in Battese's model. Alpha 1 refers to the case where there are no physicians and alpha 2 where there are no nurse professionals. Only the alphas in model 2 have the anticipated negative sign, though neither alpha is significant in either version.

The coefficients of physicians (β_1), nurse professionals (β_2) and nurse associates (β_3) vary in their levels of significance. In model 1 we find that nurse professionals are the only group that has a significant effect on coverage of antenatal care. However in model 2, when average years of education is excluded from the model as a covariate of inefficiency, physicians also have a significant effect on coverage. This result might be explained by the correlation between physicians and average years of education of 0.5.

The coefficients in both models indicate that the elasticity of coverage with respect to a change in the density of nurse professionals is higher than that for physicians. Taking the average of the coefficients of both models in Table 4, a 1% increase in the density of nurse professionals will increase coverage by 0.009%, while a 1% increase in physician density will increase coverage by 0.004%.

Both models suggest a negative association between coverage and the density of nurse associates. This was contrary to our expectations, because this category of health worker is composed largely of primary health workers, specifically trained to deliver basic care interventions such as many undertaken for antenatal care visits. A possible explanation is that municipalities with low levels of coverage had recently hired nurse associates to help them improve coverage – that is, the higher apparent density of this category of worker reflected needs, rather than impact. However, we have no way of testing this hypothesis.

Health expenditure and the covariates of inefficiency are statistically significant with the same signs as in the model presented in Table 3. From the inputs defined, no multicolinearity was found after applying the VIF test (StataCorp LP, 2006).

Figure 5 plots the maximum, minimum and average value of the level of efficiency attained by the municipalities within the states and regions of Brazil. In the x axes are the states grouped by regions and in the y axis is the proportion of efficiency. There is a wide variation in levels of efficiency across municipalities, as suggested by the earlier model, with efficiency varying from 12% to 100%. As expected, municipalities from the better-educated regions of the South East, South and Center West have higher levels of efficiency than municipalities of the less-educated regions North and North East.

Figure 6 plots the density of health professionals across quintiles of technical efficiency, where the first quintile is assigned to municipalities with the lowest level of efficiency and the fifth quintile to municipalities with the highest level of efficiency. It is clear that the mix of health workers differs by levels of efficiency, which raises the question as to the most appropriate mix. We explored this by examining the mix of physicians and nurse professionals in two disadvantaged municipalities with different levels of efficiency. The first is Acopiara, with a level of efficiency of 95%, and the second is Correntina, with a level of 33%.

With a level of efficiency of 95%, Acopiara achieves a 92% coverage of antenatal care with a workforce comprising four times more physicians than nurse professionals. The actual point of production is indicated by the dot in the figures. Correntina, however, attains only 33% coverage of antenatal care, with 24% more nurse professionals than physicians.

The curves labeled as isoquant curves in Figure 7 show the set of all possible combinations of physicians and nurse professionals that could have been used to produce the observed levels of coverage of antenatal care if the municipality had been fully efficient in the technical sense. The actual point at which Acopiara operates is close to the maximum possible isoquant, while Correntina is far from the efficient level of production.

The isocost lines show the relative cost of employing a physician and nurse associate in the two municipalities. The slopes differ because salaries can be set by the municipalities independently, so the relative wages of the two groups of health workers differ by municipality. The point of tangency between a line parallel to the isocost line and the isoquant would be the point at which municipalities could achieve the maximum possible levels of coverage at the lowest salary cost. We have drawn a line from the origin through this point, labeled the cost-minimization line, to show where municipalities should operate for all possible levels of coverage if they wanted to minimize salary costs.

Correntina is producing very low levels of coverage with the resources it has. The other side of the coin is that it could achieve the same level of coverage for a much lower cost – by employing more nurse professionals and fewer physicians, reaching a ratio of 36 nurse professionals to each doctor. Acopiara could also reduce costs for the same level of coverage, but the optimal skill mix would be 18 nurse professionals to each doctor.

Discussion

There are great inequalities in the distribution of health workers across municipalities and states in Brazil. Geographical areas with lower needs have higher numbers of health workers, while those with greater burdens of disease have fewer health workers to service their populations.

We have, for the first time, sought to examine the relationship between the coverage of antenatal care achieved by municipalities in Brazil and the availability of health workers, by means of a production function approach. The specification separated inputs to the production process from the determinants of efficiency. Two primary inputs were examined: labour – represented by total number of health workers available per 1000 population – and capital – represented by the number of ambulatory units. Health expenditure per capita was also incorporated as an input on the assumption that it incorporates other types of inputs to the production process.

The stochastic frontier model was chosen because it has the advantage of incorporating into the production function the fact that random shocks outside the control of producers can affect the output. The Coelli (StataCorp LP, 2006) test showed that the mean level of efficiency varied with changes in a number of our heterogeneity variables, so a half normal or exponential distributional specification of the efficiency component was not appropriate. We therefore used a truncated normal specification.

The overall density of health workers has a statistically significant, positive correlation with the coverage of antenatal care. When health workers are disaggregated by categories, nurse professionals appear to have a greater impact on coverage than physicians. Interestingly, no relationship was found between nurse associates and coverage. This was contrary to our expectations, because this category of health worker is composed largely of primary health workers, specifically trained to deliver basic care interventions such as many of those undertaken for antenatal care visits.

The other important result relates to the factors that determine how well health workers can do their work – that is, the determinants of efficiency. Coverage and efficiency depend not only on the availability of workers and other inputs to the production process, but also on the characteristics of the population with whom they work. Deprived municipalities – those with low levels of education and high income inequality – would face difficulties in achieving the minimum acceptable 70% coverage of antenatal care just by increasing the number of health professionals. Concomitant efforts to increase levels of education and to reduce income inequalities would also be required.

However, some of the deprived municipalities are able to be relatively efficient. It is interesting to note that 80% of the disadvantaged municipalities that achieve relatively high levels of efficiency belong to the state of Ceará. This state began a community health worker programme in 1987 that seems to have been successful in reducing child mortality and that has been adopted by other states.

We found a wide variation in the levels of technical efficiency across municipalities, varying from 12% to 100%. This suggests that most of them could increase their levels of coverage by using their existing resources better. We then explored whether they could reduce costs while attaining the same levels of coverage by considering the relative wages of the different types of health workers, using two of the disadvantaged municipalities as case studies. Both Acopiara and Correntina could maintain existing levels of coverage at lower overall cost if the production process were more intensive in nurse professionals than in physicians. The other side of the coin is that they could attain greater coverage for the same cost by changing the skill mix of workers.

Clearly, increasing the number of health workers is one strategy to achieve the Millennium Development Goals. However, important health gains can be achieved by using the existing human resources more efficiently.

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Annex 1

The Cobb–Douglas Function:

$$c = \alpha P^{B1} NP^{B2} NA^{B3} AU^{B4} HE^{B5} \exp^{-u}$$

De forma in LN:

$$\ln c = \ln \alpha + \beta_1 \ln P + \beta_2 \ln NP + \beta_3 \ln NA + \beta_4 \ln HE - u$$

→ The Marginal Rate of Technical Substitution (MRTS):

$$\frac{dc}{dP} = \alpha\beta 1 P^{B1-1} NP^{B2} NA^{B3} HE^{B4} \exp^{-u}$$

$$= \alpha\beta 1 P^{B1} P^{-1} NP^{B2} NA^{B3} HE^{B4} \exp^{-u} =$$

$$= \frac{\alpha\beta 1 P^{B1} NP^{B2} NA^{B3} HE^{B4} \exp^{-u}}{P} =$$

$$= \frac{\beta 1 c}{P}$$

$$\frac{dc}{dNP} = \alpha\beta 2 P^{B1} NP^{B2-1} NA^{B3} HE^{B4} \exp^{-u}$$

$$= \alpha\beta 2 P^{B1} NP^{B2} NP^{-1} NA^{B3} HE^{B4} \exp^{-u} =$$

$$= \frac{\alpha\beta 2 P^{B1} NP^{B2} NA^{B3} HE^{B4} \exp^{-u}}{NP} =$$

$$= \frac{\beta 2 c}{NP}$$

$$MRTS = \frac{\frac{dc}{dNP}}{\frac{dc}{dP}} = \frac{\frac{\beta 2 c}{NP}}{\frac{\beta 1 c}{P}} = \frac{\beta 2 P}{\beta 1 NP}$$

→ The total cost:

$$\cos t = (salaryP * P) + (salaryNP * NP) + (salaryNA * NA)$$

→ The isocost line:

$$P = \frac{\cos t}{salaryP} * \frac{salaryNP}{salaryP} * NP$$

→ Cost minimization (MRTS=salaries ratio)

$$\frac{\beta 2 P}{\beta 1 NP} = \frac{salaryNP}{salaryP}$$

$$P = \frac{salaryNP}{salaryP} * \frac{\beta 1}{\beta 2} * NP$$