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Equity in regional access to renal dialysis in Brazil

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Abstract. Public healthcare is arguably the most important concern for a region, or national economy. Costs continue to rise, as do expectations for reasonable access to services. Health service facility location is of great importance given its relationship to utilization rates. This paper examines equitable access to renal dialysis in Brazil. System enhancements involving new equipment for different levels of investment are explored. Results show that it is possible to improve the locational efficiency of dialysis equipment. Further, nationwide allocation plans enable shorter average distances to be achieved compared to the state allocation strategy that is traditionally relied on.

JEL classification: R53, I11

Key words: Healthcare policy, location analysis, regional imbalances, dialysis, Brazil

1 Introduction

The costs associated with healthcare are significant, and public healthcare is arguably the single most important concern for a developed or developing region or national economy. In the United States, it is expected that by 2020 taxpayers will cover half of all healthcare spending, reflecting that it can no longer be predominantly funded by individuals or employers. Brazil is different comparatively, because healthcare is a mandated constitutional right that is supposed to be universally accessible to all. In practice, however, the Brazilian health system works as a combination of public and private assistance. The proportional cost burden through taxation reached 46.4 per cent at $490.4 *per capita* in 2012, much higher than many other developing countries, such as China ($180) and India ($20.3) (World Health Organization 2014).

Our focus in this paper is kidney disease, often treated in part by renal dialysis, helping to filter a person's blood through the removal of waste and excess water (National Kidney Foundation 2002). Chronic kidney disease typically is not reversible, but its progression rate and consequences are often treatable. Since the kidney is responsible for regulating a body's salt, potassium and acid content, along with producing hormones that affect the function of other organs, people with chronic kidney disease aresubject to additional risks. These risks associated with chronic kidney disease make its progression rate rather low. A retrospective cohort study found that only 4 per cent of 1076 individuals progressed to end stage kidney disease over a 5.5 year follow-up period whilst 69 per cent had died at the end of follow-up; the cause of death was cardiovascular in 46 per cent of cases (National Collaborating Centre for Chronic Conditions 2008). For example, the cardiovascular death risk for a 20 year-old receiving dialysis is identical to that of an 80 year-old in the general population (Sarnak and Levey 2000). The burden of comorbidities and high mortality are closely related to late diagnosis and treatment. Recent studies show that these effects can be prevented or delayed if the chronic kidney disease is diagnosed and treated early (Bastos et al. 2010). However, due to lack of symptoms in the early stages, the rate of late diagnosis is high. In the United Kingdom in 2005, the mean percentage of patients referred late (less than 90 days before dialysis initiation) was 30 per cent, unchanged from the value in 2000 (National Collaborating Centre for Chronic Conditions 2008).

Brazil is interesting because it has witnessed significant and sustained increases in the number of people requiring dialysis. Between 2000 and 2006, the number of patients in dialysis in Brazil increased 9 per cent per year. A figure that is most likely limited by the inability of the system to comply with the demand for dialysis (Lugon 2009). According to the Brazilian Chronic Dialysis Census (Sesso et al. 2014), the total estimated number of patients on dialysis was 97,586 for 2012. The estimated prevalence rate of chronic kidney disease on maintenance dialysis was 503 patients per million population, which summed up with the rate of patients with functioning renal transplant equals to 700 patients per million population, 13 per cent to 36 per cent lowerthan Argentina and Chile, and 30 per cent to 60 per cent lower than some developed countries in Europe and United States (Sesso et al. 2014). The lower prevalence rate in Brazil is credited to a lower diagnosis rate of chronic kidney disease, lower availability of dialysis treatment and a shorter survival time for patients with diabetes and hypertension, the main causes of chronic kidney disease (Sesso 2006). In 2012 34,366 new patients were estimated to have started dialysis and the annual gross mortality rate was 18.8 per cent (Sesso et al. 2014).

In addition to high mortality rates, patients who require haemodialysis usually must transport themselves to dialysis clinics three times per week. Thus, the location of dialysis machines is crucial given its impact on a patient's travel distance for service utilization. In Brazil, 83.9 per cent of the dialysis patients are funded by the public health system (SUS) (Sesso et al. 2014), making the provision of dialysis equipment mostly an issue of public policy. Current health policy in the country establishes that the healthcare system is to be organized at the regional level, under the co-ordination of the states. An issue is whether this is an effective strategy.

The Brazilian Ministry of Health established in 2002 a minimum standard provision: one dialysis machine should be regionally provided for every 15,000 citizens. This norm had a great impact on the distribution of dialysis equipment across the country. Fernandes et al. (2010) show that between 2004 and 2007 the distance to the nearest dialysis provision centre was less than 50 kilometres for more than 70 per cent of the patients living in the Southeast, South and North regions of Brazil. However, in the Northeast and Centre-West regions almost 40 per cent of the patients resided farther than 50 kilometres from dialysis provision centres. Distance between the nearest centre and one's residence in the Northern region was found by Fernandes et al. (2010) to inhibit use of dialysis services, forcing patients to either move to municipalities closer to provision centres or forgo treatment. Not coincidentally, this region had the highest mortality rate associated with renal problems (Fernandes et al. 2010). Travel times of haemodialysis patients from their residence to a dialysis provision centre was found to reach up to 21 hours per week in some states in Brazil (Ritt et al. 2007). Therefore, inequity in access to dialysis centres has implications not only on welfare but also results in socio-economic inequities due to travel costs and lost hours of work.

The purpose of this paper is twofold. First, we examine the regional distribution of dialysis equipment across municipalities in Brazil in relation to the standard provision norm released by the Ministry of Health. Second, we develop and apply an approach for achieving a more equitable distribution of health services considering investment in new equipment. For this purpose, we compare the results when equipment location decisions are made nationwide against commonly used state-by-state allocations. The results show that the locational efficiency of dialysis equipment can be improved in order to enhance access to provision centres. The findings also suggest that nationwide allocation plans enable shorter average distances to be realized comparedto state-by-state allocation that is traditionally relied on. The identification of allocation methods that improve the equitability of the system are very important in Brazil, especially given the short history of the Brazilian Health System. As a developing country, Brazil is currently undergoing major infrastructure investment, hence the timing is very good for a more efficient allocation policy. This paper contributes to literature showing how location modelling can be used to enhance provision. This finding is especially important for other developing countries that face issues of resource allocation and investment.

The remainder of this paper is divided into four sections. Section 2 reviews the role of accessibility and location in healthcare. Section 3 describes the methodology, data and models used to evaluate the spatial distribution of dialysis equipment in Brazil. Section 4 presents the analysis of the Brazilian healthcare system. The last section offers concluding remarks.

2 Background

The Brazilian 1988 Constitution established the Unified Health System (*Sistema Único de Saúde* – SUS) with the purpose of ensuring equity in healthcare at no cost to the population at the point of delivery. Equity in healthcare is based on the principle of making high quality healthcare accessible to all (Whitehead 1992). Although a mix of public and private providers characterize the Brazilian Health System, 92.4 per cent of the dialysis facilities in Brazil are part of or have agreements with SUS (Sesso et al. 2011), making the provision of dialysis equipment mostly an issue of public healthcare policy.

The traditional view in economic theory is that there is a trade-off between equality and efficiency (see, for example, Okun 1975). The debate on the equality versus efficiency trade-off is very relevant to the discussion of locational strategies in allocating public goods (Smith 1977). In the specific case of the allocation of health facilities, the trade-off translates in balancing efficiency of public spending on health and equality of access. From a social justice point of view, access to treatment should be available within a reasonable distance for all individuals, regardless of population's characteristics and geographic location. This approach leads to a more decentralized provision system, with a higher number of facilities of smaller size (Morrill and Symons 1977). Depending on the economies of scale, this dispersion can imply severe reductions on efficiency. As DeVerteuil (2000, p. 53) puts it, the "equitable pattern would reduce aggregate travel costs but necessarily raise operating costs". On the other hand, an efficient use of public resources may imply the concentration of provision at a minimum number of facilities, resulting in very unequal travel times and costs. The balance between efficiency and equality in this context is reflected as a Pareto equilibrium depending on how much efficiency society would be willing to forgo to achieve more equity, or distributional equity. In this paper, we focus on equality in access to facilities, that is, a balanced distribution of facilities across the territory.

Accessibility is more than the existence or availability of resources at any given time (Aday and Andersen 1974). It is related to the capacity of individuals to take advantage of services provided. Even when a service is available, several factors can constrainaccess to health services, such as insurance, language and culture, spatial location, level of education, knowledge of health conditions and health treatments, socio-economic status, transport costs, among others (Donabedian 1973). Specifically regarding geographic accessibility, the spatial structure of health services is strongly linked to utilization rates, since potential patients may forgo care in case where the service is not easily accessible (Higgs 2009). Therefore, not only must the service be available, but the patient must be able to reach the service, or be reached by it. Hence, availability of the service is important, but the spatial pattern of its provision is also critical.

Dialysis treatment is a complex health service. Nonetheless, due to the high frequency of utilization, a decentralized network of distribution of such demands can optimize the system of provision integrated with provision of other health services, in a pattern similar to the proposed by the central place theory (Christäller 1966; Berry and Horton 1970; Berry and Parr 1988). In this system of provision, the areas of influence of centres of different sizes overlap according to the complexity (hierarchy) of the services supplied, building up urban networks of supply of complementary and interdependent services (Regales 1992). The distribution of central places and their areas of influence is not static, and investment and economic development may optimize the spatial distribution in the supply of services (Ullman 1941).

Given the link between location of services and health outcomes, service facility location is a great concern in planning, both for public and private sectors (Massam 1980; Church and Murray 2009). This is especially true in the developing world where resource constraints are severe. The use of location analysis in planning health services is very important to ensure that resources are allocated in the best way possible, but also in assessing efficiencies in an existing system (Rushton 1984; Kumar 2004; Yao and Murray 2014). In the absence of formal analysis and analytical tools, locational decisions are more subject to local politics and their results can very often be far from optimal (Rahman and Smith 2000).

Location models can help inform decisions, and have been widely used in healthcare (see Cromley and McLafferty 2012; Murray and Grubesic 2015). These models involve simultaneously selecting a set of locations for facilities (i.e. hospital, clinics, etc.) in order to optimize access, equity, costs, accessibility, and ultimately the provision of critical services. The application of location models to improve access to healthcare is not new. Several studies have examined how strategic location of health facilities is crucial to improve access to them (e.g., Mehretu et al. 1983; Rushton 1984). Recent applications in the developing world include the use of GIS and optimization models to evaluate the locational effectiveness of clinics providing sexual and reproductive health services in Mozambique (Yao and Murray 2014), to improve physical access to health facilities in Burkina Faso (Cocking et al. 2012), and to increase the locational efficiency of health services in India through the application of location-allocation models (Kumar 2004). There are also studies specifically addressing the provision of dialysis machines. Eben-Chaime and Pliskin (1992) examine dialysis facilities location taking into account patient travel times and demonstrate the potential to decrease travel times of patients to a dialysis centre, and reduce the imbalances in the provision of dialysis services.

In Brazil, concerns regarding the spatial distribution of health services have drawn a lot of attention from researchers (e.g., Botega et al. 2006; Gasparini and Ramos 2004; Oliveira 2004; Oliveira et al. 2004; Simões et al. 2005). Oliveira et al. (2004) map the provision network of health services based on the origin and destination of the patients and show that nearly 20 per cent of patients have had to travel more than 60 km in order to receive common hospital services. Oliveira (2004) and Botega et al. (2006) analyse hospitalization in the state of Minas Gerais, showing the negative relationship between distance and hospitalization and how health services tend to be spatially concentrated.

3 Methodology

3.1 Data

The DATASUS-Ministry of Health data on the availability of dialysis equipment across Brazilian municipalities in 2010 was used in our analysis. Demographic Census 2010 (IBGE)

Table 1. Dialysis machines in Brazilian municipalities by regions in 2010, per 1,000,000 capita

Region	Obs.	Mean	Std. dev.	Min.[a]	Max.
North	449	43.68	55.72	36.02	229.08
Northeast	1,793	71.81	109.55	7.23	1,048.39
Southeast	1,668	118.42	110.50	4.97	1,301.10
South	1,188	97.78	121.04	12.26	1,051.25
Mid-West	466	102.93	102.18	55.42	723.87
Brazil	5,564	95.13	110.54	4.97	1,301.10

Note: [a]Minimum considering only municipalities with at least one dialysis machine.

for each municipality was utilized for population information. The distribution of dialysis machines across municipalities in Brazil is very concentrated. For the 5,564 Brazilian municipalities, 385 maintained a total of 18,147 machines, amounting to an average of 95 machines for each million people (Table 1). However, these machines were not evenly distributed across regions. The municipalities of São Paulo and Rio de Janeiro together had 15.1 per cent of all dialysis equipment, respectively with 1,685 and 1,053 machines. Given that both municipalities are located in the Southeast, this region had the highest concentration with 118.4 machines per million people. In contrast, only 43.7 machines per million people were available in northern Brazil, nearly a third of the Southeast. Among the municipalities with at least one dialysis machine available, equipment per million people ranged from 5 machines to 1,301, suggesting a highly varied distribution.

The Ministério da Saúde (2002) released the norm called “Portaria Ministerial n. 1101” establishing general guidelines regarding the provision of health equipment based on population.[1] Among other factors, these guidelines were defined based on a study of the national rate of utilization of the system and international parameters. Specifically for dialysis equipment, this norm stipulates that 6 patients could be assigned to each dialysis machine for it to be considered at its full potential. Given the share of the population that is expected to need dialysis, the norm establishes that there should be 1 machine for every 15,000 inhabitants (Ministry of Health 2002, p. 7).[2] This effectively sets 15,000 people as the capacity for each dialysis machine. Since in 2010 there was a total of 18,147 dialysis machines available in Brazil, this would be enough to serve 272 million people, 42.7 per cent more than the total Brazilian population in 2010. Therefore, it would be expected that every region in Brazil should have at least 66.7 machines available per million people. As Table 1 shows, this is not currently the case in the North and it is very close to the number of dialysis machines available in the Northeast, whereas in the Southeast the number of dialysis machines *per capita* is 78 per cent higher than stipulated by the guideline.

[1] There are several different ways to estimate health need, which may include age and gender structure, mortality ratio, morbidity, among others. However, the policy bill formulated by the Ministry of Health to establish the standard provision does not consider any adjustments to need, only population size. Since one of our objectives is to evaluate compliance with the current norm, we also base our calculations on population only. Nonetheless, the methodology we propose in this paper can be used with adjusted demand considering population weighted by age or gender, or any other measure of need for a given type of equipment.

[2] The Ministry of Health considers an homogenous number of population per machine across the country. As shown by Lugon (2009) and Sesso et al. (2014), the prevalence of chronic kidney disease is heterogeneous across Brazilian regions. However, according to the authors, this variation is more related to regional disparities in the provision of health service than actual differences in prevalence. This is a common issue in Latin America, “where the prevalence rate varies enormously among countries; this is basically associated with the different health coverage and gross national income (GNI)” (Cusumano and Gonzalez Bedat 2008, p. 595). Given that using current data on prevalence rate to allocate equipment may actually reinforce the regional imbalances in the provision of health service, we follow the approach used by the Ministry of Health and consider total population.

3.2 Evaluation of spatial distribution of dialysis machines

The intent of this study is to evaluate the spatial distribution of dialysis machines in Brazil and identify opportunities for system enhancement that minimizes distance between patients and provision centres. To support this evaluation, location analysis, optimization methods, and geographic information systems (GIS) are used to manage, manipulate and visualize data, summarize system efficiency, and derive results.

GIS has been increasingly significant for location analysis not only for providing access to needed input data and visual exploration, but also for its capacity to manage, manipulate, and analyse spatial data (Murray 2010). Specifically for this work, we rely on GIS for representing spatial data and displaying results, and performing spatial operations, such as deriving distance, and spatial relationship specification. These are required inputs to our analysis. Municipalities that have dialysis equipment and expected demand for treatment are represented in this study by points defined by the coordinates of the main district of each municipality.

The assessment of system access initially focuses on the distance between population and provision centres. Since our spatial units of analysis are municipalities, provision centres are considered here as municipalities that provide dialysis machines. The purpose of the model presented in this paper (see Equation A1 in the Appendix) is that it can be used to help establish an overall measure of system access to dialysis machines by the population. Once people are allocated to the nearest centre of provision we can evaluate the distance between them and assess inequalities in the spatial distribution of dialysis machines. Since states co-ordinate the health system within their borders, we initially consider the municipalities in each state separately.[3]

3.3 Service location planning for improving access

Analysis can also be undertaken to assess whether locational improvements are possible that enhance access and accessibility to health services. Improvements can be made to the configuration of a health system through expansion or relocation of facilities, personnel and/or equipment. As we have already shown, there is currently a surplus of dialysis equipment in Brazil. This surplus would enable service to an additional 40 per cent of the population. This makes relocation of equipment seem an appealing choice. However, relocation of an existing system, even partially, to improve efficiency could be politically and economically contentious in the context of developing nations (Rahman and Smith 2000). In Brazil, the mixed funding and provision of health services between municipal, state and federal levels creates several political barriers to relocating equipment. As a result, we only consider expansion of the amount of equipment. Hence, municipalities that are not currently provision centres can receivemachines and become provision centres, but existing centres cannot be relocated or have their number of machines decreased (see Equation A5 in the Appendix).

To control for different budget levels, we consider pre-specified amounts of new equipment to be added to the system. More specifically, we consider the budget cap to vary from 1 per cent to 20 per cent for equipment in each state.[4] When selecting possible sites for new dialysis machines, we consider the possibility of economies of scale. Increasing returns to scale in the provision of dialysis equipment may occur in numerous ways, such as increased coordination

[3] The Federal District was considered here as part of the state of Goiás given its exceptional level of integration with its hinterland.

[4] It is not expected thatall states, if deciding independently the allocation of investment in dialysis machines, would decide for the same level of investment. The equal investment rate serves as a benchmark for spatially uneven investment, showing how the effects of equal investment across states can be less efficient than if allocated unevenly focusing on decreasing the national imbalances on provision.

of activities, the sharing of specialized personnel, and volume discounts for purchases (Ozgen 2006). However, the high share of municipalities in Brazil with very few dialysis machines suggests that the degree of economies of scale in the sector is low. In fact, Dor et al. (1992) and Hirth et al. (1999) show that there is no evidence of increasing returns to scale based on facility size in the provision of dialysis services. Instead of economies of scale, Dor et al. (1992) identify economies of scope, although of limited degree. Economies of scope exist when the average cost of a given good or service is decreased as a result of provision combined with a different type of good or service. The existence of economies of scope provides an explanation for the fact that all dialysis equipment available in Brazil is located in municipalities with hospital services. Given the lack of information on the cost function of dialysis equipment, this complementarity is accounted for when selecting the municipalities that should receive priority in the allocation of dialysis equipment, and therefore consider only municipalities that have at least one hospital bed as potential dialysis machines sites.[5] We also assume a linear cost function in the provision of equipment, i.e. constant returns to scale.

4 Results

4.1 Evaluation of actual provision of dialysis machines in 2010

The methods above allow us to evaluate the locational efficiency of the spatial distribution of dialysis equipment. The integer linear programming (ILP) optimization problems were solved using commercial software, Gurobi (Gurobi Optimization, Houston, TX, USA), integrated with Python. Figure 1 shows the actual availability of dialysis equipment and the theoretical allocation of demand for service in Brazil.[6] Each municipality has its expected service demand allocated to the nearest provision centre, within capacity limits, in such a way that average distance to a provision centre is as low as possible. The results are shown for the entire country, but as already noted, this is done by considering the municipalities in each state independently from other states in accordance with Brazilian legislation.

Figure 1 shows that municipalities that do not have their population fully served are concentrated in the North and Northeast regions. In the states of Acre and Amapá, where no municipality has enough equipment to attend to expected demand, only 32.7 per cent and 38.1 per cent of the population is actually capable of being served, respectively. On the other hand, the state of Rio de Janeiro, in the Southeast, has enough dialysis equipment to potentially serve more than twice its population.

Figure 1 also shows that not only is the percentage of population served different between states, but among those that have enough equipment to serve all of their population, the average distance to access provision centres is highly uneven.For example, distance in the Mid-West and Northeast are much longer than in the South and Southeast. The average distance between municipality of residence and nearest provision centre in Brazil is 31.9 km for the 95.2 per cent of the Brazilian population that can be served by the dialysis equipment currently available within their states. Given the imbalance in the spatial distribution of equipment, Rio de Janeiro

[5] In 2010, 1,889 Brazilian municipalities did not have hospital services, so the universe of municipalities entitled to receive a dialysis machine is reduced to 3,675. It is worth highlighting that hospital beds are considered in this paper more as a control for scale of health services provision than availability of infrastructure, material and human resources (such as nephrologists and nurses) for new dialysis machines. Given the lack of information on the compound costs of dialysis machines including all these related costs, we consider investment as new pieces of equipment instead of financial resources.

[6] As pointed out by an anonymous reviewer, this figure resembles the patterns shown in the early work on central place theory done by Berry and Horton (1970).

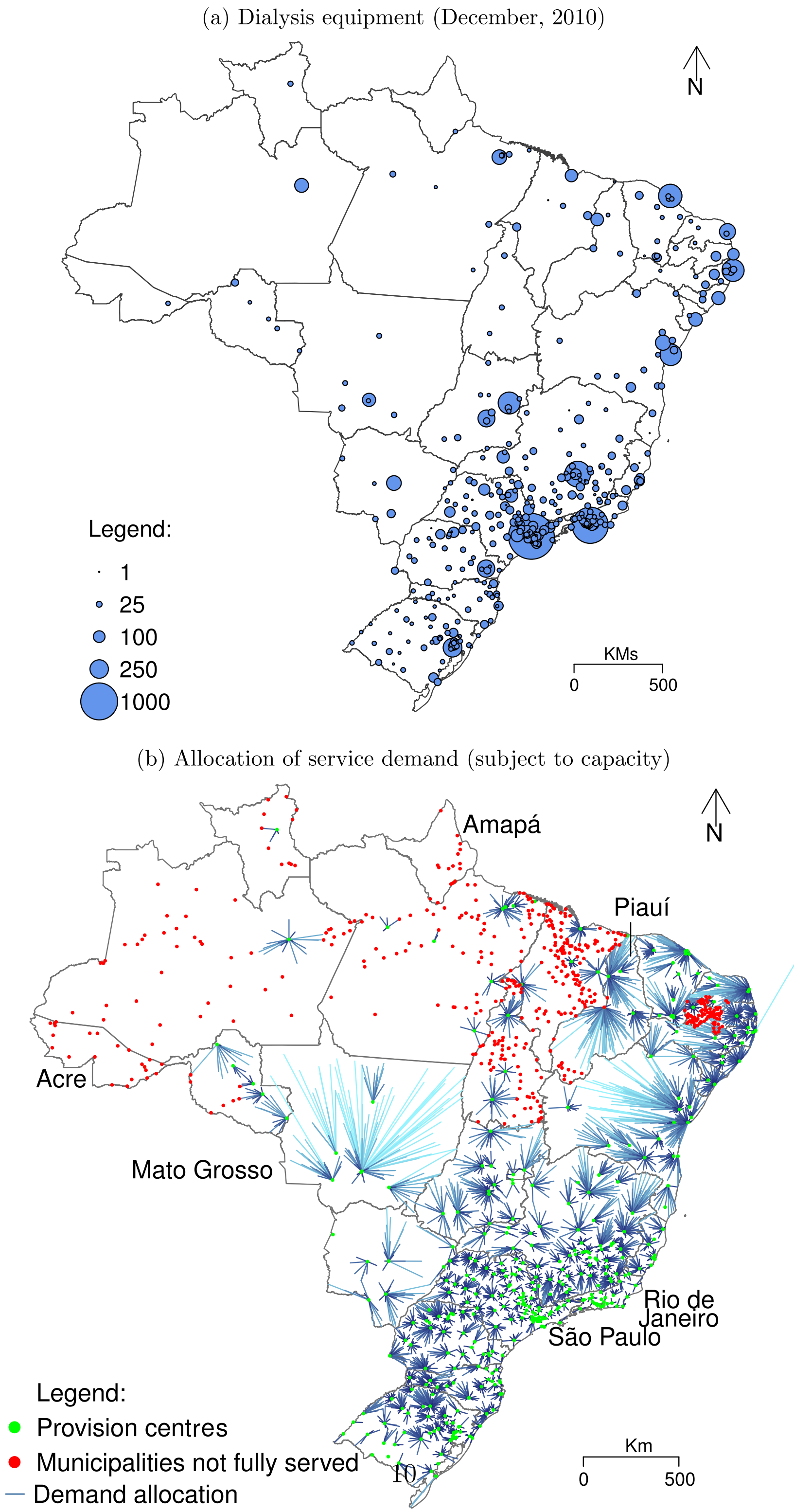


Fig. 1. Location of dialysis and service allocation

and São Paulo are able to enjoy average distances of 2.9 km and 7.7 km, respectively. On the other hand, Mato Grosso and Piauí are subject to average access distances of 165.3 km and 98.3 km, respectively.

4.2 Allocation of dialysis machines when the system is expanded

Given the inequity in the distribution of dialysis equipment, we consider how the system could be expanded with respect to reducing average distance. As Massam (1980, p. 52) describes, “in a planning exercise it is often useful to know the savingsin terms of distance that will occur if we increase the number of supply points”. Figure 2 shows the impact on average distance of a gradual expansion of the system. We consider possible additions of new dialysis equipment ranging from 0 per cent to 20 per cent. The y axis indicates resulting average access distance and the x axis reflects increased investment in new dialysis equipment. The first point of the curve represents equipment level in 2010. Each subsequent point represents an increase of 1 per cent of this amount, up to 20 per cent. The graph can be interpreted as a trade-off curve between average distance and investment in equipment. As Figure 2 shows, the current average distance of 31.9 km can be decreased to 22.2 km with the addition of 5 per cent new equipment (for a total of 19,054 dialysis machines), representing an improvement in the total demand served of 30.4 per cent.

The investment levels considered in this exercise are equal in percentage for all states. However, the impacts of this investment to average distance are uneven across states. Figures 3 reports the impact of gradual expansion of the system for average distance for a set of states in Brazil.

In the state of Bahia, for example, the elasticity of average distance in relation to the amount of new equipment is −6.6 for an investment level of 1 per cent, that is, the 1 per cent investment decreases the average distance 6.6 per cent, shifting it from 94.6 km to 88.2 km. Throughout the investment levels considered, this elasticity remains almost constant, varying within the interval

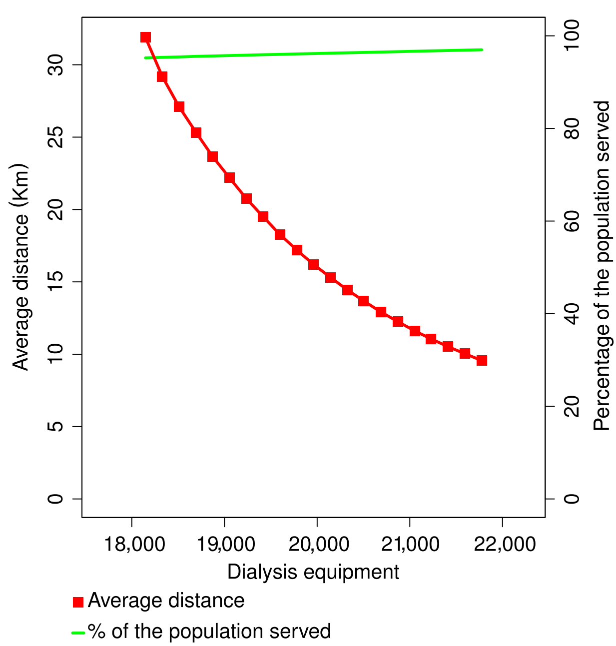


Fig. 2. Average distance between demand for care and provision centres by level of investment

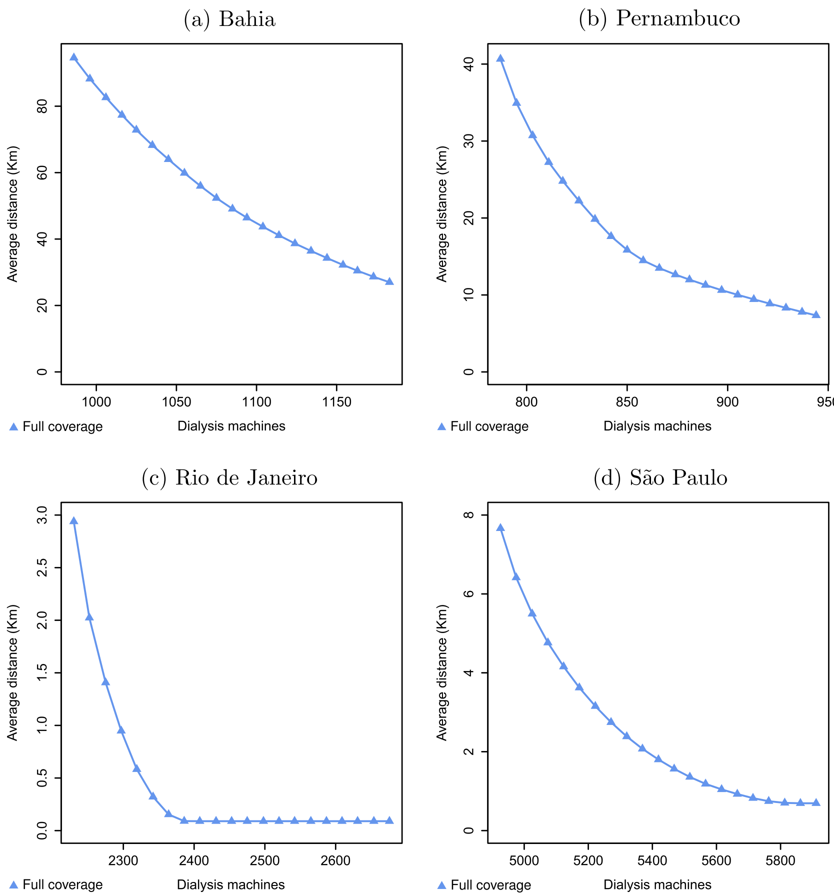


Fig. 3. State based average distance between demand for care and provision centres by investment level

−6.9 and −6.3. Other states, however, show a decreasing impact of investment on average distance. This is the case of Pernambuco, where the elasticity of the distance in relation to the amount of investment per 1 per cent is −13.9. When we consider the impact on average distance when the investment level is increased from 19 per cent to 20 per cent, the elasticity is −7.6, much smaller than what is initially observed.

The results show decreasing returns of investment in new equipment over average distance, but this does vary by state. The state of Rio de Janeiro and São Paulo depict this reality to its extreme. After an investment level of 8 per cent, the elasticityof the distance in relation to the amount of equipment in Rio de Janeiro is zero. Therefore, additional equipment beyond an investment of 8 per cent does not affect average access distance in the state, which would be of 0.09 km at this point. In São Paulo, the elasticity reaches −0.017 when the investment level is increased from 19 per cent to 20 per cent, for which the average distance is 0.69 km. Further decreases in average access distance would not be possible in both states given the distribution of hospital beds, which we consider as fixed and use to control for economies of scope.

When investment in new equipment is considered separately for municipalities in each state, as in the results presented above, some states such as Rio de Janeiro and São Paulo reach a minimal average distance that cannot be further decreased given the distribution hospital beds even with additional equipment, others still do not have sufficient equipment to serve expected demand.

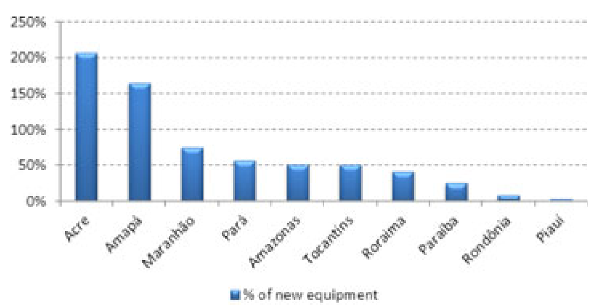
Out of the 26 states in Brazil, eight would not have enough dialysis machines to meet the demand of their population even when we consider an investment level of 20 per cent (namely Acre, Amapá, Amazonas, Maranhão, Pará, Paraíba, Roraima, and Tocantins). Two others, namely Piauí and Rondônia, respectively in the Northeast and North regions of Brazil, only achieve suffcient equipment required to fully serve their population for certain levels of investment. crease in dialysis machines of 5 per cent is required to serve all the population, while in Rondônia the level of investment needed is 9 per cent.

4.3 Nationwide expansion policy

The results shown above indicate that an equal distribution of resources for the expansion of the system reinforces existing inequalities. The average distance in favoured states such as Rio de Janeiro and São Paulo is decreased even further, while deprived states face much greater average access distances or do not even have 100 per cent their population served due to service capacity limitations associated with limited dialysis equipment. A possible approach to promote equity is to consider a nationwide oriented expansion policy, where the municipalities of all states are considered conjointly when locating new equipment.

The minimum investment in dialysis machines required to serve all expected demand in each state of Brazil is reported in Figure 4. As the figure shows, the state of Acre requires the acquisition of more than twice the amount of equipment that was located in the state previously in order for it to be able to attend to the demand of its population fully. Despite the large relative lack of equipment, the amount of equipment required to serve all demand was small: 33 new dialysis machines would have to be added to the 16 it had available in 2010. In the state of Pará this reality was inverted. Pará required a less expressive relative investment in new equipment:

(a) Percentage of new equipment required to serve all demand



(b) Number of new equipment required to serve all demand

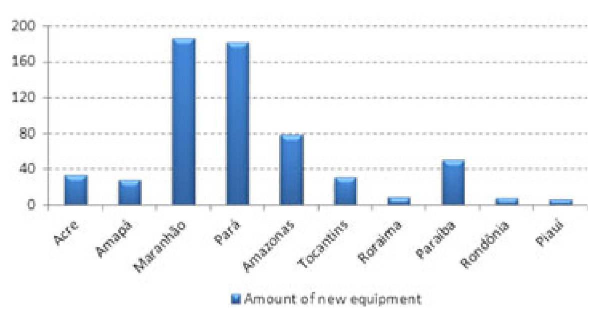


Fig. 4. Investment in dialysis equipment necessary to fulfill expected service demand

Table 2. Comparison of average access distance for nationwide and state-based investment

	Average distance		Population served (%)	
Investment (%)	State-based	National	State-based	National
5	22.19	21.93	95.75	100
10	16.19	12.33	96.17	100
15	12.25	7.7	96.58	100
20	9.56	4.8	96.99	100

56 per cent. However, this amounts to 182 new dialysis machines because nearly 3 million people remained unattended in the state with its 324 dialysis machines.

It is clear that if the allocation of new dialysis machines is based on the ideal of equitable provision with the objective of decreasing average access distance to the equipment, an equal distribution of investment across states is not a good option. To relax the assumption that investment is made independently and equally in each state, we can solve the optimization problem presented in Equations A5, A6, A7, A8, A9, A10 for all Brazilian municipalities conjointly instead of for each state separately. However, in order to consider the border between the states, we assume that population from any given municipality can only be assigned to provision centres within the same state.[7]

Effectively, the optimization problem in this case may be considered as a two-stage problem: *(i)* the federal government decides on the budget allocation across states; and (*ii*). given the budget allocation, state planners independently decide on the location of new investment within their states. In the previous optimization problem, we considered only the second stage of this problem. In this section, stage (*i*) is added and we effectively consider the optimization problem faced by a federal planner in addition to state planners.

When we compare the results considering a nationwide allocation of investments and a state-based allocation, it becomes clear that the nationwide approach yields better results in average access distance. When each state is considered individually, 97 per cent of the population in Brazil is potentially served with an investment of 20 per cent new machines, whereas when a nationwide investment is considered, 100 per cent of the population is potentially served even for just a 5 per cent investment (Table 2).[8]

Regarding the average distance between population and provision centres, the benefits of a nationwide approach increase with the level of investment. For an investment of 5 per cent new dialysis machines, the average access distance is 1.2 per cent shorter under the nationwide approach. This difference is increased to 49.8 per cent when the investment is 20 per cent.

Figures 5 and 6 show the allocation of population according to investment levels when we consider this nationwide oriented policy. Additional 3.4 per cent dialysis machines are required for all states in Brazil to be able toattend their population fully, when these machines are allocated to states that did not have enough machines in 2010 to serve their whole population. Hence, when we consider an investment of 5 per cent, already there is no municipality not fully attended, as reported in Figure 5.

An additional 5 per cent equipment amounts to 907 dialysis machines. More than half of these machines would be located in selected municipalities in the states of Maranhão, Pará

[7] In practice, we modify constraints A6 shown in the Appendix to take into account the state where municipalities are located: $\sum_{j \in S_i} h_{ij} = p_i, \ \forall i$, where S_i is a set containing all municipalities in the same state as i.

[8] Following a suggestion made by one reviewer, we have also considered sequential increments of 1 per cent instead of “all at once” allocations, that is, the result of a 2 per cent increment would consider the result of the previous step: 1 per cent. The difference between this exercise and the one presented on 2 was not much significant.

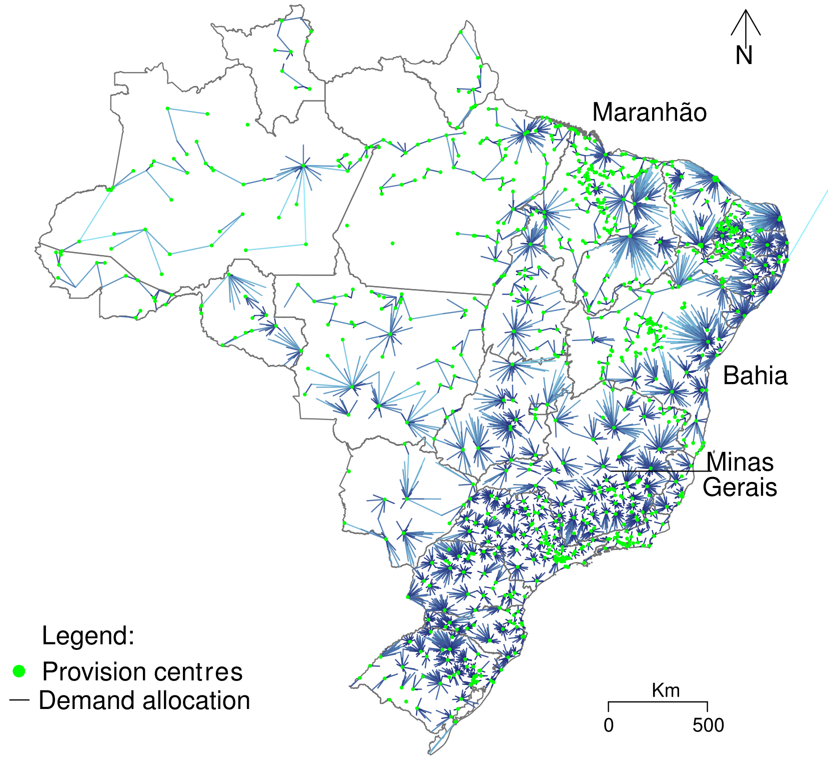


Fig. 5. Theoretical provision network - nationwide oriented investment, 5 per cent new equipment

and Bahia, respectively 21 per cent, 20 per cent and 14 per cent. Therefore, the Northeast region, the poorest region in Brazil, would be a priority. Given the strong link between provision of health equipment and deprivation, it is not surprising that the three prioritized states have income *per capita* lower than Brazilian average. The national income *per capita* in Brazil in 2010 was R$ 767.02, whereas in Maranhão, Pará and Bahia it was respectively R$ 348.72, R$ 429.57 and R$ 481.18. The link between provision of health equipment and deprivation implies that most deprived area tend to have the worst provision network. Hence, these regions tend to be favoured by an allocation rule such as the one adopted in this study, with the objective of improving the regional balance in the provision of any equipment or service.

It is worth highlighting that Bahia currently possesses enough dialysis machines to serve 105.5 per cent of its population. However, the location of these machines is spatially inefficient and concentrated in the coastal region of the state. Investment to create provision centres in western portions of the state would have a great impact on average access distance. When we consider an investment level of 20 per cent, Bahia assumes the first rank of investment receivers, concentrating 13 per cent of the investment. Minas Gerais (10 per cent) and Maranhão (8 per cent) follow.

The levels of expansion of the system considered in this study, while are improvements, still fail to achieve equity across states. For example, if we considering the investment level of 5 per cent in new dialysis machines, the average distance between population and provision centres in Piauí is 61.4 km. On the other hand, in Rio de Janeiro, to where no new machine is allocated at this investment level, the average distance is 2.9 km. Therefore, even after the investment, each inhabitant of Piauí would have to travel in average 20.8 times longer than the inhabitants of Rio de Janeiro to reach a provision centre. To show how the allocation is an improvement, even

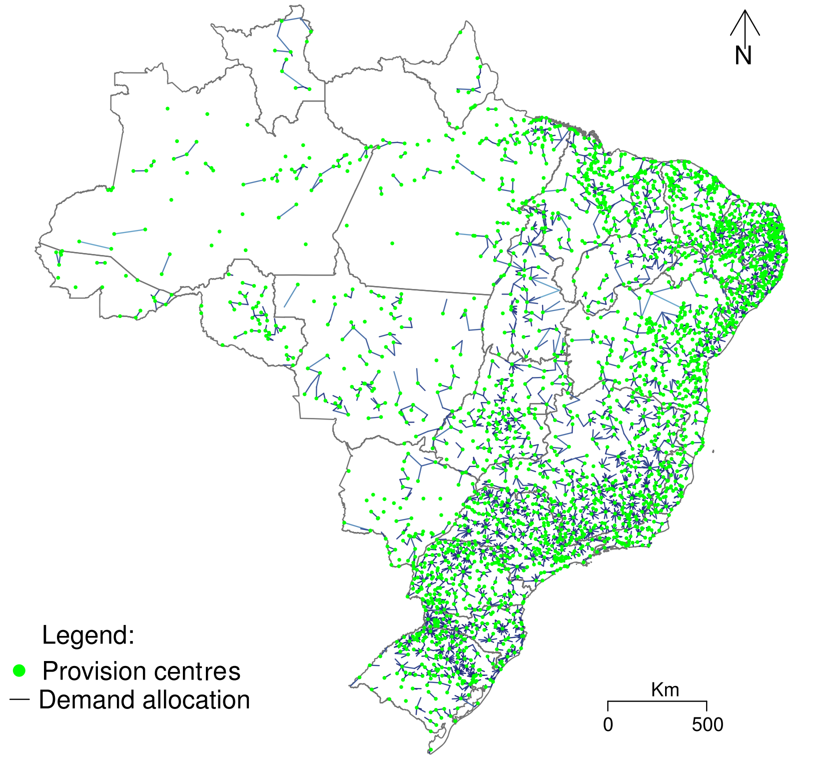


Fig. 6. Theoretical provision network - nationwide oriented investment, 20 per cent new equipment

though it does not provide equity, without the investment each inhabitant of Piauí has to travel an average 57 times longer than the inhabitants of Rio de Janeiro (165.3 km against 2.9 km).

5 Discussion and conclusions

Brazil has witnessed significant and sustained increases in the number of people requiring dialysis. Between 2000 and 2006, the number of patients in dialysis in Brazil increased 9 per cent per year. A figure that is most likely limited by inability of the system to comply with the demand of the population for dialysis (Lugon 2009). The estimated prevalence rate of chronic kidney disease in Brazil is much lower than other countries, such as Chile, Argentina as well as some developed countriesin Europe and United States (Sesso et al. 2014). Among other factors, the lower prevalence rate in Brazil is credited to lower availability of dialysis. In 2012 only, 34,366 new patients are estimated to have started dialysis and the annual gross mortality rate was 18.8 per cent (Sesso et al. 2014).

In addition to the high mortality rate, patients who require haemodialysis usually must transport themselves to dialysis clinics three times per week. The location of dialysis machines is therefore crucial given its impact on a patient's travel distance for service utilization and welfare. Service facility location of clinics is a great concern in this regard. This is especially true in developing countries, where resource constraints are more severe. In this work we proposed the use of optimization models to examine and enhance regional provision of dialysis equipment in Brazil. We examine the allocation of dialysis equipment across Brazilian municipalities and its impact on access. The optimal spatial allocation of new dialysis machines for different levels of investment results in a trade-off between access distance and investment. Our results indicate that improvements to the locational efficiency of dialysis equipment is possible, reducing average distance between the ill and provision centres. Our findings also suggest that a nationwide allocation results in shorter average distances in addition to a greater ratio of population served.

In the past decades, decentralization has been seen as a way to attain greater efficiency and competitiveness (Rodríguez-Pose and Sandall 2008). However, fiscal decentralization is also associated with a significant rise in regional disparities, which the positiveeffects of political decentralization have been unable to compensate (Rodríguez-Pose and Ezcurra 2010). According to the authors, weaker and often times more corrupt institutions, lower access to capital, smaller tax bases, and weaker infrastructural, educational, and technological endowments represent a serious handicap for poorer regions within any given country in order to deliver greater allocative and productive efficiency through decentralization. Therefore, as the positive effects of decentralizationare not disputed, they may be neutralized or overcompensated by its negative effects. As shown by Rodríguez-Pose and Ezcurra (2010, p. 637): “in the developed world political decentralization does not affect the evolution of regional disparities, while fiscal decentralization may contribute to reducing them. In contrast, fiscal decentralization has in the past triggered a significant rise in regional inequalities in the low-income countries”.

In this study, we do not investigate the role of decentralization on inequalities in health in Brazil. But our results do indicate that centralized decisions based on location planning may achieve a more equitable allocation of dialysis equipment. Therefore, although states are in charge of the regionalization of the Brazilian health system, a national coordination when considering investment in new equipment may contribute more to reduce the average travel times between population and provision centres, with potential impact on utilization rates, comorbidities, and prevalence and mortality rates.

Appendix

The models applied in this paper are presented below. Consider the following notation:

i = index of municipalities;
j = index of provision centres (dialysis equipment sites);
d_{ij} = shortest distance between municipality i and dialysis centre j;
p_i = population of municipality i;
c = capacity of equipment;
q_j = amount of equipment in municipality j
h_{ij} = population from municipality i that is served by equipment at centre j.

An allocation taking into account capacity and proximity can be formalized as follows:

$$\text{Minimize} \sum_i \sum_j d_{ij} h_{ij}. \tag{A1}$$

$$\text{Subject to} \sum_j h_{ij} = p_i, \quad \forall i, \tag{A2}$$

$$\sum_i h_{ij} \le q_j c, \quad \forall j, \tag{A3}$$

$$h_{ij} \ge 0, \quad \forall i, j. \tag{A4}$$

This model has an objective A1 to minimize distance weighted by population between dialysis centres and municipalities. Constraints A2 ensures that all population is served by a provision centre. Constraints A3 specifies the capacity limit of each centre based on the amount of equipment at the centre. Constraints A4 imposes non-negative restrictions on decision variable h_{ij}.

One group of constraints in the model deserves attention. As stated above, constraints A2 ensures that all population is served by a provision centre. However, it might be that some regions do not have enough equipment to attend to all of the population, that is, some regions present excess of demand beyond available equipment. In this case, when the amount of equipment is not sufficient for constraints A2 to be met, the model becomes infeasible. Again, allocation in Brazil is done on the basis of regions, so some regions have more demand. To address this issue, constraints A2 and A3 are modified. Instead of requiring that all population be served, all capacity must be exhausted. Algebraically, constraints A2 and A3 are replaced respectively by $\sum_j h_{ij} \leq p_i, \ \forall i$, and $\sum_i h_{ij} = q_j c, \ \forall j$. Thus, the resultant weighted distance is this case refers only to the share of the population that is served. These special cases are highlighted in the results section.

To identify municipalities where new equipment could be located to most increase access by decreasing distance between provision centres and demand, the optimization model presented above can be extended. Consider the following additional notation:

α_j = equipment currently available in municipality j; and
K = additional equipment to be allocated.

This allows for allocation so as not to violate capacity limits, but also simultaneously identifies locations where new equipment should be placed:

$$\text{Minimize} \sum_i \sum_j d_{ij} h_{ij}. \tag{A5}$$

$$\text{Subject to} \sum_j h_{ij} = p_i, \quad \forall i, \tag{A6}$$

$$\sum_i h_{ij} \leq q_j c, \quad \forall j, \tag{A7}$$

$$\sum_j q_j = \sum_j \alpha_j + K, \tag{A8}$$

$$q_j \geq \alpha_j, \quad \forall j, \tag{A9}$$

$$q_j \geq 0, \quad h_{ij} \geq 0, \quad \forall i, j. \tag{A10}$$

This model is similar to A1, A2, A3, A4 except for the addition of constraints A8 and A9 and the non-negative restriction on q_j added to constraint A10. Constraint A8 limits the amount of equipment to the sum initially available and the new investment. Constraint A9 impose a minimum value for the final amount of equipment in each municipality q_j. This minimum value is the amount initially available, α_j, implying no relocation of existing equipment.

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Resumen. El servicio de salud pública es quizá la preocupación más importante para una región, o la economía nacional. Los costos siguen aumentando, al igual que las expectativas de un acceso razonable a estos servicios. La ubicación de un centro de salud es de gran importancia, dada su relación con las tasas de uso. Este artículo explora el acceso equitativo a la diálisis renal en Brasil. Se estudian las mejoras en el sistema que suponen nuevos equipos de diálisis en función de diferentes niveles de inversión. Los resultados muestran que es posible mejorar la eficiencia de la localización de los equipos de diálisis. Además, los planes de asignación a nivel nacional permiten lograr distancias promedio más cortas con respecto a la estrategia de asignación estatal tradicional.

要約: 地域経済または国家経済において、公衆衛生はおそらく最も重要な課題である。サービスが適度に利用しやすいころに対する期待が高まるにつれて、コストも増大する。医療サービス施設の立地は、利用率に関連することを考慮すれと、大きな重要性を持つ。本論文ではブラジルにおける人工透析への公平なアクセスを分析する。様々な投資水準に対する新しい医療機器によるシステム改善を調べる。分析によれば、透析設備の地理的な効率性の向上は可能である。さらに、全国的な配分計画により、従来依拠されてきた州レベルの配分計画よりも、距離の短縮化を実現できる。