NUNO DE MATTOS CAPELETTI

# PERFORMANCE ASSESSMENT OF PRIMARY HEALTH SERVICES IN BRAZIL USING DATA ENVELOPMENT ANALYSIS AND THE QUALITY-ADJUSTED MALMQUIST INDEX

UNIVERSIDADE DO ALGARVE

FACULDADE DE ECONOMIA

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# PERFORMANCE ASSESSMENT OF PRIMARY HEALTH SERVICES IN BRAZIL USING DATA ENVELOPMENT ANALYSIS AND THE QUALITY-ADJUSTED MALMQUIST INDEX

Dissertação de Mestrado em Gestão de Unidades de Saúde

Trabalho efetuado sob orientação de:

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UNIVERSIDADE DO ALGARVE

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This work is dedicated to my family and

my dear wife Lidiane.

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# RESUMO

A Atenção Primária à Saúde (APS) tem um papel central na estruturação de um sistema de saúde por estar projetada para ser a principal porta de entrada do paciente no sistema. No Brasil, o Sistema Único de Saúde (SUS) tem na Estratégia de Saúde da Família (ESF) a base para a promoção de um acesso universal e adaptado às necessidades da população. Tendo em conta o aumento da população idosa e o avanço da tecnologia em saúde, o uso racional dos recursos é cada vez mais premente para a sustentabilidade do sistema. Assim, este estudo teve como objetivo avaliar o desempenho dos serviços de atenção primária prestados pelos municípios do estado brasileiro de Santa Catarina de 2008 a 2014, período com maior disponibilidade de dados referentes à APS. Considerando que os impactos em saúde devem ser considerados na avaliação dos serviços e que estes dados têm sido ainda pouco explorados nas análises de eficiência, optamos por incorporar uma variável relacionada com impactos em saúde para tornar a avaliação de desempenho mais completa.

A aplicação da Análise Envoltória de Dados (DEA), uma técnica não-paramétrica que usa programação linear inicialmente proposta por Charnes, Cooper e Rodes (1978), foi escolhida por lidar satisfatoriamente com múltiplos inputs (recursos) e outputs (resultados) e permitir uma análise comparativa entre as unidades avaliadas. Apesar da crescente avaliação do desempenho da APS, poucos estudos levam em consideração os impactos em saúde nas análises. Com a inclusão de uma variável relacionada à taxa de Internações por Condições Sensíveis à Atenção Primária (ICSAP), torna-se possível valorizar na análise os impactos em saúde gerados pelos serviços. Assim, a análise longitudinal por meio do Índice de Malmquist ajustado para qualidade (Q-MPI) permitiu verificar de forma particular mudanças tanto da produtividade quanto da qualidade dos serviços.

A avaliação do desempenho dos municípios feita por DEA utilizou um modelo orientado para maximização de outputs e com rendimentos constantes à escala. Isso permitiu a análise com foco no que pode ser produzido em termos de serviços com os recursos existentes e verificar sua tendência ao longo do período. Foram incluídas como inputs as variáveis referentes aos profissionais diretamente envolvidos no atendimento da população adscrita. Como outputs foram introduzidos indicadores referentes ao volume dos diferentes tipos de consultas realizadas por tais profissionais, tanto nos centros de

saúde quanto no ambiente domiciliar. Foram utilizados dois modelos de análise com estas variáveis, sendo que em um deles foi incluída uma variável adicional, calculada a partir da taxa de ICSAP padronizada por idade. Isso possibilitou a inclusão de uma variável com representação quantitativa das internações potencialmente evitadas pelos serviços prestados pela APS de cada município. Realizou-se ainda a inclusão de restrições aos pesos por meio da técnica descrita por Podinovski (2004) a fim de garantir que os alvos demonstrados para as unidades consideradas ineficientes sejam atingíveis na realidade. Antes das análises, foram realizados ajustes da base de dados a fim de evitar vieses pela existência de dados atípicos. Como o cálculo das ICSAP prevenidas teve como referência a maior taxa de internações no período, foram identificados e excluídos da análise municípios que em algum momento obtiveram taxas consideradas *outliers* extremos. Outro ajuste realizado foi a identificação de *outliers* em termos de desempenho por meio da análise de super-eficiência proposta por Banker e Chang (2005).

A análise dos 266 municípios incluídos no estudo mostra uma taxa média de desempenho relativo pelo Modelo 1 de 53% a 59%, sendo esta taxa cerca de 10% maior ao se analisar o Modelo 2, o qual inclui a variável das ICSAP prevenidas. Em ambos os casos, no entanto, constata-se uma tendência de queda das taxas de desempenho ao longo dos anos analisados. Foram avaliados também os perfis de pesos atribuídos pelo DEA nos dois modelos com o intuito de identificar características que poderiam ajudar a explicar os resultados encontrados. Percebemos que os municípios considerados eficientes (100% na taxa de desempenho) têm mais peso atribuído às visitas domiciliares e consultas programáticas, enquanto os municípios pior avaliados alocam mais peso às consultas médicas e programáticas. Municípios com menor população comportam-se de forma semelhante aos mais bem avaliados, já os maiores tendem a atribuir peso de forma similar aos com pior avaliação. Em todos os casos, no Modelo 2, ao se incluir uma variável associada aos impactos em saúde, nota-se que o peso atribuído a esta variável costuma ser relativamente alto, em especial para os municípios maiores. Por fim, vê-se que os municípios maiores figuram entre os mais beneficiados com a aplicação do Modelo 2, muito em função das relativamente baixas taxas de ICSAP que apresentam.

Análises de correlação foram feitas com as variáveis disponíveis, tendo-se percebido que a proporção de profissionais de enfermagem em relação a médicos e a taxa de consultas programáticas são indicadores positivamente correlacionados com o desempenho. Por outro lado, percebeu-se que a existência de uma maior dimensão

populacional para cada profissional disponível tem correlação negativa com a taxa de visitas domiciliares, o que pode influenciar no desempenho dos municípios. Por fim, a análise longitudinal por meio do Q-MPI permitiu perceber que, apesar da tendência de queda da produtividade em termos de consultas prestadas, houve uma melhoria sustentada quando se analisa a qualidade, no caso representada pela variável de ICSAP prevenidas.

Os achados da investigação indicam que municípios menores e com maior proporção de enfermeiros em relação a médicos tendem a ser mais bem avaliados, o que pode ser reflexo de uma implantação mais acentuada da ESF, modelo de organização que estimula a prática de ações programáticas e atividades no domicílio, bem como a participação de profissionais não-médicos no atendimento à população. A procura elevada por atendimento em locais maiores, refletida por uma quantidade de profissionais inadequada para o tamanho da população, pode ainda representar uma dificuldade para estes locais obterem resultados melhores em termos de desempenho, uma vez que parecem ter maior propensão a optarem por consultas nos centros de saúde em detrimento da atenção domiciliar. Por outro lado, municípios menores costumam ter maior taxa de ICSAP, que pode ser reflexo do menor grau de qualificação profissional nestes locais além da dificuldade da gestão em fixar tais profissionais, o que compromete a longitudinalidade. Pela análise dinâmica, percebe-se uma tendência geral de diminuição das taxas de ICSAP com consequente aumento das ICSAP prevenidas. Este achado pode ser fruto tanto da expansão da ESF quanto do aumento nos investimentos financeiros na saúde.

A metodologia aplicada e os resultados demonstram a importância da inclusão de variáveis relacionadas com os impactos em saúde nas análises de eficiência, especialmente para tornar mais justa e completa a avaliação e para identificarmos a evolução da qualidade dos serviços ao longo do tempo. Assim, este tipo de análise permite considerar o impacto em saúde gerado aquando da avaliação do desempenho dos serviços, evitando-se análises baseadas unicamente em critérios de atividade. Além disso, este estudo procurou identificar características organizacionais que propiciem melhores resultados. Dessa forma, tais achados podem ser úteis para gestores ao fazerem um planeamento que considere não apenas o volume de atividade, mas também o impacto dos serviços prestados.

**Palavras-chave**

Atenção Primária à Saúde, Análise Envoltória de Dados, Avaliação de Desempenho, Índice de Malmquist ajustado para qualidade

# ABSTRACT

Primary Health Care (PHC) is intended to be the first point of contact, with a continuous, coordinated and comprehensive response to the patients' health needs. Considering the increasing demand for optimising the use of the resources available, it is essential to investigate the health services' performance considering indicators related to outcomes that represent the impact on the population's health. This work examines the performance and the evolution in productivity and quality of the primary care services delivered by the municipalities of the Brazilian state of Santa Catarina from 2008 to 2014. The technique used was the Data Envelopment Analysis (DEA), assuming the CCR model and the orientation to maximise outputs. The study utilises data related to the professionals directly involved in the health care and the services delivered to reflect the standard organisation of a primary care setting. Moreover, aiming at a quality approach, the DEA results are associated with an indicator representing the hospitalisations for ambulatory care sensitive conditions potentially prevented. To perform a longitudinal analysis and observe the changes in quality separately, a Quality-adjusted Malmquist Productivity Index was performed. The results reveal that productivity has deteriorated from 2008 to 2014, while the improvement in the services' quality is observed. Municipalities considered efficient attributed more weight to home visits and programmatic consultations, activities that characterise the model of attention progressively adopted in Brazil. When including a variable related to outcome, we see that bigger municipalities improve their relative performance more significantly. The participation of non-medical professionals, the rate of programmatic consultations, and the adequate sizing of the population for the professionals available were also considered important aspects. Hence, as such findings consider not only the volume of activity but also the impact of the services delivered, they can be useful for managers when structuring the services and planning activities.

**Keywords**

Primary Health Care, Data Envelopment Analysis, Performance Assessment, Quality-adjusted Malmquist Index

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ACSC | Ambulatory Care Sensitive Conditions |
| CRS | Constant Returns to Scale |
| DEA | Data Envelopment Analysis |
| DMU | Decision-Making Unit |
| ESF | Estratégia de Saúde da Família (Family Health Strategy) |
| MPI | Malmquist Productivity Index |
| PHC | Primary Health Care |
| Q-MPI | Quality-adjusted Malmquist Productivity Index |
| SUS | Sistema Único de Saúde (Unified Health System) |
| UNICEF | United Nations Children’s Fund |
| WHO | World Health Organisation |

## 1. INTRODUCTION

The existence of care models based on Primary Health Care (PHC) acting as the first main contact of patients with the health system is well known as an adequate strategy to fulfil the population demands and promote universal access (WHO and UNICEF, 2018). In Brazil, the Unified Health System (Sistema Único de Saúde - SUS) set forth in the Federal Constitution of 1988 is sustained on implementing a PHC based on local management within national guidelines. The decentralisation of resource management allows municipalities to adapt the services provided to their local demands. The activities at this level of care are provided through the Family Health Strategy (Estratégia de Saúde da Família - ESF), which structures the provision of services through health teams allocated to the health centres. These teams are responsible for monitoring the health of the population living in the health centre's catchment area. The municipalities progressively adopted this model, replacing the "traditional" primary care model where there is no clear territorial or population link established (Brasil, 1997).

However, the expansion and consolidation of this type of organisation make it fundamental to ensure that the health system is effective and viable, despite the finite and usually restricted resources, mainly in the public sector (Campos, 2007). This problem is particularly relevant considering that health expenditure is increasing due to the population's ageing and the advancement of health technology. Thus, the judicious use of the existing resources becomes increasingly needed.

In addition, it is fundamental not to compromise the quality of the services provided. As Donabedian (1980) states, health care quality can be evaluated based on structure, process, and outcome indicators. So, to perform an analysis to highlight the impact of the PHC services on the population's health, it is advisable to consider not only the resources used (inputs) and the results reached (outputs) but also the real effects achieved (outcomes). Unfortunately, the unavailability of data about outcomes or the existence of indicators that cover only specific clinical practice situations are often factors that restrict the use of this kind of information. However, in this study, we intend to consider a quality indicator directly related to the outcomes in order to have an accurate situational diagnosis of the PHC system.

The application of methodological instruments evaluating the services' performance contributes to assessing this issue. In this sense, the application of Data Envelopment Analysis (DEA) perfectly fits this task because it deals satisfactorily with multiple inputs and outputs without requiring strong assumptions about the underlying technology that links resources and services. The application of DEA, a non-parametric method that uses linear programming to measure relative efficiency, has been widely used in different contexts, including the Brazilian PHC (Miclos, Calvo and Colussi, 2015a). The crescent employment of this methodology is based on its capacity to evaluate performance in a relative fashion when comparing different units and to estimate targets to be achieved for each unit analysed to reach a best practice status.

This study aims to contribute to the literature by proposing efficiency evaluations with the inclusion of a quality indicator related to health outcomes, allowing us to analyse independently the quality variation of the services provided. The first specific objective of this study is to evaluate the performance of the PHC services provided by the municipalities of the state of Santa Catarina, Brazil. Secondly, it aims to assess the impact on the performance and practice results derived from the inclusion of an outcome variable representing the services' quality. Thirdly, we investigate the trends and patterns of the performance and quality changes from 2008 to 2014. Finally, we seek to identify factors that could explain the results obtained in order to derive lessons for policy.

The remainder of this dissertation is organised as follows. The next section presents a brief literature review about efficiency assessment in PHC. Then, it describes the methodology employed in our study detailing the variables and models used. Afterwards, the main results and a comparative analysis are presented over the analysed period. Later, the results are discussed to compare them with existing knowledge and propose ideas that help explain the information obtained. Finally, we identify the study's limitations and present possible paths for future research in the area.

## 2. PERFORMANCE ASSESSMENT IN PRIMARY HEALTH CARE

A health system oriented towards PHC promotes better health levels, lower costs of services and higher satisfaction of the population attended (Starfield, 1994). So, it is essential to build a qualified PHC to enable a resolutive and economically sustainable health system that, in turn, could induce improvements in the population health status. Since health efficiency can be defined as the ability to generate the largest amount of services with the lowest possible use of resources, it becomes primordial to know the current situation of existing services, which implies the need to find appropriate ways to evaluate the efficiency of the care provided.

The difficulty in assessing PHC performance is justified by the complex and multidimensional nature of the resources and results involved, making difficult the modelling and subsequent analysis of the productive process (Fariñas, Delgado, Moreno and Cepero, 2007). Besides, unlike the hospital context, where the episodes of care are best delimited, the limits of operation of PHC, being a community-integrated health system, are less clear (Amado and Santos, 2009).

Considering the broad resources and results involved in the provision of PHC services, the evaluation of the data collected by applying the DEA becomes a practical choice. The idea to evaluate the efficiency of different units through this non-parametric technique was initially proposed by Charnes, Cooper and Rhodes (1978). Each element in this comparison is represented by a Decision-Making Unit (DMU), which is involved in a transformation process dedicated to generating some products (outputs) from some resources (inputs). In this regard, the DEA's adaptability lies in its potential to measure the efficiency in relative terms rather than absolute ones, which does not demand a theoretical model of an ideal DMU and makes this technique suitable for managers in sharing experiences locally. Unlike analyses based only on regression, DEA aims to estimate the maximum (and not the average) outputs produced from the inputs (Amado and Dyson, 2008; Pelone, Kringos, Romaniello, Archibugi, Salsiri and Ricciardi, 2015). This characteristic is due to the possibility of identifying the optimum weight structure to be applied to input and output data to build a boundary of efficiency that represents the best practices observed among the analysed DMUs (Scaratti and Calvo, 2012).

However, the analysis of a given moment in an isolated manner often does not accurately reflect the performance of a service, being then interesting to get a longitudinal assessment, which also allows the detection of trends in efficiency over time. The Malmquist Productivity Index (MPI), firstly introduced by Caves, Christensen and Diewert (1982), is a valuable index calculated with the DEA efficiency scores that evaluates changes in productivity between different periods. Since productivity represents the ratio of the outputs (products or services) generated to the inputs used (Coelli, Rao, O'Donnell and Battese, 2005), the application of DEA through the MPI also allows the evaluation and comparison of the efficiency at different moments, which broadens the capacity of analysis by providing the measurement of productivity changes. In addition, the inclusion of a quality indicator related to the outcome in the DEA and MPI analysis brings the advantage to assess the evolution of quality separately.

Despite the growing evaluation of PHC performance, there are still few studies taking into account health outcomes. This fact is confirmed by recent reviews showing that, so far, the majority of studies does not include outcomes in PHC performance analysis (Pelone *et al*., 2015; Zakowska and Godycki-Cwirko, 2020). To a large extent, studies most commonly present analyses based on resources used (doctors, nurses, etc.) and activity levels, such as the number of consultations or visits, which lacks information about the outcomes of the care provided. When data about outcomes are unavailable, works often substitute outcome indicators by intermediate proxies expressing disease control or health surveillance, which do not necessarily translate into an improvement in the population health status. The relevance of this distinction relies on the fact that patients are keener to get healthier, expecting that the benefit from diagnosis and treatment justifies their search for care (Amado and Dyson, 2008). Ultimately, the patients' wishes would be better captured by analysing outcomes rather than outputs.

The way quality indicators have been analysed in DEA is also an issue to be highlighted. In this study, we chose to include a variable derived from the outcome as an output through the technique proposed by Färe, Grosskopf and Roos (1995) so that it would allow us to obtain an individualised evaluation of quality evolution throughout the period. In our view, this method has an advantage over that presented by Sherman and Zhu (2006) since it does not imply the exclusion of DMUs that show contrasting efficiency results when comparing quality and productivity.

In particular, in this study we use a variable based on the hospitalisations for ambulatory care sensitive conditions (ACSC) as an indicator of quality related to outcomes. These conditions compound a list, published in 2008 by the Brazilian Ministry of Health, made of specific pathologies organised according to the tenth version of the International Statistical Classification of Diseases and Related Health Problems (ICD-10). Such diseases correspond to the disorders whose hospital admissions are expected to be reduced if adequate and timely health services are promoted by the PHC services. Thus, it would be possible to quantify the potentially preventable hospitalisations and allow an inference of the PHC's resoluteness (Caminal, Mundet, Ponsà, Sánchez and Casanova, 2001; Giuffrida, 1999). Using a customised panel to the Brazilian reality is seen as an advantage because the construction of such a list considers the epidemiological profile, the health systems installed and the local burden of morbidities. Consequently, it gives reliability, validity and representativeness to the findings (Alfradique, Bonolo, Dourado, Lima-Costa, Macinko, Mendonça, Oliveira, Sampaio, Simoni and Turci, 2009; Brasil, 2008).

The hospitalisation rate due to ACSC is a widely used and validated indicator to evaluate the quality of PHC in terms of outcomes. This level of the health system has a role in carrying out activities focused on primary prevention and early disease detection, as well as in monitoring acute episodes and chronic conditions (Cordero, Alonso-Morán, Nuño-Solinis, Orueta and Arce, 2015; Souza and Silva, 2018). Also, according to Alfradique *et al.* (2009), the use of the ACSC hospitalisation variable permits to estimate the impacts of implemented health policies, the resolution and quality of PHC, and helps to investigate inequities in access to health services. Compared to other outcome indicators, the ACSC hospitalisation rate allows earlier detection of health changes. Additionally, it is also less influenced by health actions restricted to some pathologies or groups of patients, whose implementation would not have a broader impact on services' effectiveness (Nedel, Mendonça and Calvo, 2017).

The scenario chosen for this research is the southern Brazilian state of Santa Catarina, known as one of the states with better scores in health performance indicators (Brasil, 2011; Miclos, Calvo and Colussi, 2015b). One reason to undertake a performance analysis in a previously well-evaluated region is to support the results and legitimise the potentials found in the best practice. In addition, this scenario could be more favourable to capture the health impacts of the activities developed in PHC.

Concerning prior research about PHC performance in Santa Catarina, there is still a limited number of works using the DEA technique for this purpose. Previous studies tend to evaluate PHC using perspectives and methods divergent from those applied in our work. Some studies used DEA with different focuses: public expenditure efficiency (Brinckmann, Heinzen, Andrett and Pfitscher, 2019; Mazon, Freitas and Colussi, 2021), use of general rather than ACSC hospitalisations as an outcome (Politelo, Rigo and Hein, 2014) or the evaluation of efficiency analysis for specific health conditions (Rabetti and Freitas, 2011). Additionally, methods other than DEA were applied: classification of municipalities based on score rankings built from variables of ESF coverage, common clinical procedures and ACSC hospitalisations (Henrique and Calvo, 2008) and the use of the Primary Care Assessment Tool (PCATool-Brazil), an evaluation of the PHC based on questionnaires applied to the population attended (Vidal, Tesser, Harzheim and Fontanive, 2018).

Therefore, we are not aware of another study that has evaluated the productivity trend in PHC with the inclusion of a quality indicator and isolating the evolution of this indicator – the existing examples of this approach in the health sector are focused on the hospital setting (Chen, 2006; Karagiannis and Velentzas, 2012; Maniadakis and Thanassoulis, 2000). In this respect, this work contributes to the literature by demonstrating how DEA and the Malmquist Index can be used to holistically evaluate performance in PHC.

# 3. MATERIALS AND METHODS

DEA calculates efficiency by comparing ratios of weighted outputs to weighted inputs for different DMUs. This technique also allows identifying efficient units that serve as a reference to those considered inefficient (benchmarking) and inform the targets needed to reach the efficiency frontier (Amado and Dyson, 2009).

Despite historically limited resources, health care has an increasing demand. So, it is reasonable to conclude that the management of the services should focus on increasing outputs, which means doing more with what they have (Zakowska and Godycki-Cwirko, 2020). Therefore, this study adopted an output-oriented model targeting improved results and outcomes by keeping the existing inputs. About scale assumptions, we chose the constant returns to scale (CRS) because it is most suitable when the aims are to analyse the efficiency in the long term and to measure the evolution in productivity (Thanassoulis, 2001).

This study focuses on analysing the public PHC of the Brazilian state of Santa Catarina. In this work, the DMUs represent the municipalities' health units, each with its set of professionals. Given the limited availability of data specific to primary care, 290 out of 295 municipalities were analysed from 2008 to 2014. For this purpose, state and national databases with open access were consulted: Informatics Department of the Unified Health System (DATASUS), Epidemiological Surveillance of Santa Catarina (DIVE/SC) and Brazilian Institute of Geography and Statistics (IBGE).

## 3.1. Variables used in the study

In order to reflect the daily activities carried out in PHC, this study included variables that could represent the professionals directly involved in patient care and their routine tasks (see Table 3.1). This way, as inputs, the annual mean number of physicians, nurses, and nursing assistants was selected because these are the health workers directly dedicated to the patient's health assistance and have specific functions in the health service.

**Table 3.1** Definition of inputs and outputs.

| Category | Variable | Definition |
|---|---|---|
| Inputs | Physicians | Average annual number of physicians |
| | Nurses | Average annual number of nurses |
| | Nursing Assistants | Average annual number of nursing assistants |
| Outputs | Physician Consultations | Number of spontaneous consultations performed by physicians |
| | Nurse Consultations | Number of spontaneous consultations performed by nurses |
| | Programmatic Consultations | Number of systematic follow-up consultations, including appointments about childcare, prenatal care, screening cervical cancer, sexually transmitted infections, diabetes, hypertension, leprosy and tuberculosis |
| | Nursing Assistant Procedures | Number of procedures performed by nursing assistants, including curatives, inhalations, injections, stitch removal, and oral rehydration therapy |
| | Physician Home Visits | Number of consultations made by physicians at the patient's home |
| | Nurse Home Visits | Number of consultations made by nurses at the patient's home |
| | Nursing Assistant Home Visits | Number of consultations made by nursing assistants at the patient's home |
| | Prevented ACSC Hospitalisations | Number of hospitalisations due to Ambulatory Care Sensitivity Conditions potentially prevented |

Regarding the outputs, given the available data, it was possible to detail the outputs according to the health professionals' different activities. In this respect, the first set of output variables included were the annual amount of spontaneous consultations by physicians and nurses. We also included the number of programmatic consultations, which are usually scheduled and focus on conditions requiring a systematic follow-up. This output comprises appointments about childcare, prenatal care, screening cervical cancer, sexually transmitted infections, diabetes, hypertension, leprosy, and tuberculosis.

Likewise, we added the number of nursing assistants' procedures, including curatives, inhalations, injections, stitch removal, and oral rehydration therapy. Finally, the number of home visits made by each professional category was also included in the analysis, given the importance of these activities to the equity of access in health care.

As referred previously, to include a quality variable in the analysis, we opted to add the ACSC hospitalisation rate as an output. However, as the standard DEA model aims to maximise outputs, we transformed this undesirable outcome in order to estimate the number of hospital admissions prevented by the health actions of each municipality. A method first proposed by Seiford and Zhu (2002), and recently applied by González-de-Julian, Barrachina-Martínez, Vivas-Consuelo, Bonet-Pla and Usó-Talamantes (2021), states the use of a rigidly predefined volume of hospitalisations as reference. Differently, we intend not just to transform this variable to a desirable outcome to fit in the DEA model but also to create an indicator that could represent an absolute number of avoidable hospitalisations. This method allows the creation of a variable that can help understand the magnitude of the impact of health actions.

In this respect, we employed a transformation of the undesirable outcome similar to that used by Santos, Santos, Amado, Rebelo and Mendes (2020), adapted to the present context. In order to estimate the predicted rate of ACSC hospitalisations, it was taken as reference the highest standardised ACSC hospitalisation rate of all analysed periods. To avoid outcome values equal to zero, we added 1 to this value to obtain the predicted rate of ACSC hospitalisation. Afterwards, the standardised value observed in each year and municipality was subtracted from the predicted rate. Finally, the value obtained was multiplied by the respective municipality population divided by 1,000 to estimate the amount of ACSC hospitalisations prevented in a worst-case scenario. Taking as an example the Santa Catarina state's capital, Florianópolis, we find that in 2008 the standardised ACSC hospitalisation rate was 7.17 per 1,000 inhabitants. The reference value used for this process, named here as the predicted rate, was the highest rate observed in the analysed period (48.09 per 1,000 inhabitants) plus 1. This way, to obtain the prevented ACSC hospitalisation rate, we subtracted the Florianópolis rate (7.17) from the reference rate (49.09). Finally, to get the number of prevented ACSC hospitalisations, we multiplied this result (41,92) by the municipality's population of that year (413,037). Then, we divided it by 1,000, resulting in the rounded final value of 17,313. This final

amount was the value included in the DEA Model 2, representing the quality variable for Florianópolis in 2008.

As the output data was represented by the annual quantity of consultations obtained by the sum of monthly values registered by each municipality, it is relevant to mention that data correction was necessary because of abnormally high values found in some output variables. The mensal values at least ten times higher than the other monthly values were interpreted as registration errors and excluded. With the remaining values, a mean monthly value was calculated for that year. Afterwards, the mean value was multiplied by 12 to obtain the annual value. Finally, this corrected value was validated through its comparison to the values from other years to verify if the new data was compatible. This correction technique allowed us to minimise the registration errors that could severely interfere with the data's reliability and, potentially, imply biased performance results. The number of months with excluded data, demanding correction of the annual value, corresponded to only 0,2% of the total output data, which indicates that the original database was not substantially affected.

The variables included in the study had their descriptive and statistical analyses carried out in SPSS version 25.0 (IBM Corp.).

### 3.2. Weight restrictions

The weight restrictions applied to the DEA models are intended to increase the reliability of the performance analysis performed by the DEA technique and reflect the usual work process in the primary care setting more accurately. This way, we avoided an unreasonable weight attribution to the variables, which would be inappropriate (Roll and Golany, 1993). This study introduced weight restrictions to capture the trade-off relationships between inputs and outputs, as proposed by Podinovski (2004). Employing a "trade-off approach", the author presents a method that ensures that the radial target of an inefficient DMU can always be produced and that efficiency maintains its realistic significance as an improvement factor.

Regarding inputs, it was assumed that the activity provided by nursing assistants, in case of need, can be performed by a nurse and that this one's action, in turn, can be performed by a physician. However, the opposite would not be possible. In this respect,

it is reasonable to assume that the weight attributed to one physician should not be lower than the weight attributed to a nurse and that the weight attributed to a nurse should not be lower than the weight attributed to a nurse assistant. This logic is endorsed when we consider the costs related to the work performed by such professionals: it is current practice the payment of higher wages for doctors than for nurses, being the nursing assistants paid less than the nurses. In the efficiency analysis, this assumption means that decreasing one unit of input with less weight while increasing one unit of input with greater weight would not reduce the type and amount of outputs. Furthermore, it was considered that the proportion of weight assumed by each input would correspond to at least 1% of the total weight carried by the inputs. This restriction intends to ensure that no input variable would be ignored in the analysis. In particular, in doing so, we avoid assigning zero values to some inputs, which would not be realistic considering each of these professionals' importance in the health care system.

According to the previous logic, we also considered establishing weight restrictions regarding the output variables, namely the different consultations and services performed. Such an action seeks to attribute greater weight to those activities that are believed to be more resource consuming. In this respect, compared to consultations in health centres, home visits tend to be more costly and require more time, mainly due to the needed displacement to the patients' houses, which extend the average time of the consultations performed. Thus, the weight attributed to medical home visits could not be lower than the weight attributed to the medical consultations (in the health centre). This means that if we were to replace one home visit by a medical consultation, resources are not expected to increase. An identical logic was assumed for the relationship between visits and consultations made by nurses and nursing assistants. Additionally, considering the professionals involved, home visits are subject to the same assumption applied to consultations performed in the health centres. So, medical visits cannot have a lower weight than those done by nurses, and these cannot have a lower weight than those carried out by nursing assistants.

Moreover, we decided to use an identical rationale about the output variables when assigning weights between the different types of consultations performed in the health centres. Such types correspond to the appointments by spontaneous demand carried out by doctors, nurses and nursing assistants, and the programmatic consultations. The later ones are appointments made by doctors or nurses in situations of systematic

monitoring. These were considered the most demanding in terms of resources since they are generally previously scheduled, with a pre-established duration, and require more time. It happens because this kind of consultation is a moment to review and detail a clinical situation, being a space that focuses on health education with behavioural and lifestyle orientations. Thus, the weight of programmatic consultations would have to be greater than or equal to that of physician consultations, which would have a weight higher than or equal to that of nursing consultations, that, in turn, would have a weight equal to or greater than the ones made by nursing assistants. Finally, one last restriction was introduced when considering that the output with the biggest weight should be the home visit made by a physician. This variable, besides the travel costs, involves a more onerous professional. Therefore, a medical home visit's weight was considered greater than or equal to a programmatic consultation.

### 3.3. DEA Models

Two models were drawn up to assess the impact of the inclusion of a quality variable in calculating the performance of the PHC providers. Model 1 considers the above-mentioned inputs and outputs related to the consultations and procedures performed. Model 2 is similar to Model 1 but includes the prevented ACSC hospitalisations as an additional output. The introduction of an additional variable in the DEA model can never lead to a deterioration in the performance score. This aspect can be confirmed from the mathematical formulation (2) presented in the Appendix. The introduction of a new variable will lead to an improvement in the performance score if, in relative terms, a certain municipality shows a relatively better performance in the new variable than in those originally included in the model. In this respect, we consider that the inclusion of this new variable provides a fairer assessment of municipalities because it allows another light into the evaluation of municipalities that do not score so well in terms of the volume of consultations but score better in terms of prevented ACSC hospitalisations. In this respect, the analyses will focus on quantifying the performance improvement due to the introduction of the prevented ACSC hospitalisations. This type of evaluation allows an understanding of why some municipalities improved more than others.

However, it should be noted that, as with any deterministic technique, DEA relies on the assumption that observed deviations (performances away from the border of efficiency) are explained by inefficient behaviour, not considering possible random error (Puig-Junoy, 2000). Also, the achievement of relative efficiencies through the DEA technique is sensitive to the presence of outliers. Thus, besides the correction of the database described above, two other methodologies were used in this work to minimise the impact of potential outliers in the analysis, avoiding the generation of biased results and a consequent loss of reliability and practical relevance.

Firstly, we identified outliers through the super-efficiency analysis, a procedure initially proposed by Banker and Gifford (1988). They established that in super-efficient DMUs, those with efficiency bigger than 100%, there was a greater likelihood of data contamination with random noise or registration errors. The elimination of these outliers would allow obtaining more reliable efficiency results. Later, Banker and Chang (2006) refined this technique by evaluating different super-efficiency thresholds that could be applied. They identified that 120% would be a threshold with ideal performance in tracking outliers, which was therefore used in our study. As only outstanding performance (observed in super-efficient DMUs) can affect the efficiency estimation, removing inefficient outliers (DMUs with performance significantly below the average) is unnecessary. DEA analyses were performed under the CRS assumption and output orientation based on the 290 DMUs that had complete data for the variables in all the years observed. It was noted that 18 DMUs obtained efficiency scores equal to or higher than 120% in at least one of the years. Hence, after eliminating these DMUs, a total of 272 municipalities remained.

Afterwards, we searched for excessively high standardised ACSC hospitalisation rates. When using the highest rate as a reference for calculating the prevented hospital admissions, there is an increased risk of overestimating the obtained values. The reference used could be exceptionally high due to some specific phenomenon that could not truly represent the usual hospitalisation rate. In this respect, we tried to detect the standardised rates considered extreme outliers. These were the values higher than the upper threshold, obtained by the third quartile plus three times the interquartile range. Six municipalities were identified in this situation in at least one of the years and then excluded from the analysis. The final sample of DMUs examined in this work was 266.

The formulations for the DEA models used and the weight restrictions included are presented in the Appendix.

### 3.4. Quality-adjusted MPI

The MPI permits the calculation of efficiency scores in order to detect changes in productivity from one period to another. Färe, Grosskopf, Lindgren and Roos (1992) combined this productivity assessment with the efficiency measurement proposed by Farrell (1957), decomposing the MPI into two components. One component is the Technical Efficiency Change (Catch-up Effect), which measures the changes in the efficiency level of a DMU between two periods, calculating how much it moves away from or towards the efficiency frontier. In turn, the second component is the Technical Change (Frontier Shift Effect) which measures changes in the efficiency frontier, meaning that this component evaluates changes in technology over time.

Including a variable reflecting a health outcome in this study allows the utilisation of an MPI adjusted for quality (Q-MPI). Färe, Grosskopf and Roos (1995) proposed the possibility of incorporating quality indicators (attributes) as outputs in the MPI analysis. This approach allows us to calculate the variation in productivity considering the quality variable and isolate the change in quality throughout the period. In our study, this index decomposition permits a more distinct assessment of the health impact generated by the actions developed by health professionals over the analysed period.

The software used to run the DEA models was the Efficiency Measurement System (EMS) version 1.3, developed by Holger Scheel. In order to conduct the MPI analyses, several DEA models had to be run, evaluating the performance of municipalities at different points in time. The MPI analyses were undertaken using Excel, applying the formulas presented in the Appendix.

# 4. RESULTS

## 4.1. Descriptive statistics of inputs and outputs

Table 4.1 describes the statistics of the input and output variables included in the models. From 2008 to 2014, the mean number of nurses, nursing assistants, spontaneous and programmatic consultations made by physicians and nurses, and prevented ACSC hospitalisations consistently increased. However, the home visits made by physicians, nurses, and nursing assistants, as well as the procedures performed by the last ones, had a general decreasing tendency in the same period. The mean quantity of physicians had a slightly different trend, where it is observed a continuous decrease from 2008 to 2011, with an increase in the following years.

**Table 4.1** Descriptive statistics of inputs and outputs.

| Year | Measure | Physicians | Nurses | Nursing Assistants | Physician Consultations | Nurse Consultations | Programmatic Consultations | Nursing Assistant Procedures | Physician Home Visits | Nurse Home Visits | Nursing Assistant Home Visits | Prevented ACSC Hospitalisations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2008 | Mean | 9.15 | 7.27 | 17.53 | 21,021.44 | 8,523.15 | 9,755.60 | 12,819.79 | 550.94 | 1,079.05 | 1,793.32 | 766.94 |
| | SD | 17.48 | 14.47 | 35.03 | 38,593.78 | 17,921.80 | 18,258.23 | 33,125.24 | 978.89 | 1,670.87 | 3,881.15 | 2,086.74 |
| | Min | 1.00 | 1.00 | 1.00 | 0.00 | 51.00 | 298.00 | 230.00 | 0.00 | 7.00 | 0.00 | 19.01 |
| | Max | 163.00 | 143.58 | 316.08 | 388,021.00 | 179,877.00 | 161,205.00 | 414,967.00 | 9,561.00 | 17,882.00 | 33,631.00 | 21,288.81 |
| 2009 | Mean | 9.05 | 7.53 | 17.67 | 21,120.34 | 8,300.93 | 9,677.33 | 12,077.25 | 483.56 | 1,030.82 | 1,662.10 | 805.66 |
| | SD | 17.57 | 14.66 | 33.65 | 36,499.10 | 16,792.83 | 16,626.31 | 28,265.60 | 809.64 | 1,569.81 | 3,608.48 | 2,117.86 |
| | Min | 1.00 | 1.00 | 1.00 | 0.00 | 24.00 | 297.00 | 192.00 | 0.00 | 24.00 | 0.00 | 14.76 |
| | Max | 168.92 | 148.67 | 283.58 | 291,452.00 | 169,403.00 | 141,875.00 | 276,787.00 | 6,948.00 | 13,515.00 | 327,97.00 | 21,241.79 |
| 2010 | Mean | 8.85 | 7.74 | 17.58 | 21,774.44 | 9,070.56 | 9,718.56 | 12,115.06 | 463.44 | 956.63 | 1,444.31 | 831.10 |
| | SD | 16.97 | 14.78 | 32.97 | 37,655.34 | 17,367.85 | 15,163.06 | 25,220.96 | 720.24 | 1,326.48 | 2,835.54 | 2,174.55 |
| | Min | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 169.00 | 343.00 | 1.00 | 10.00 | 0.00 | 6.40 |
| | Max | 142.58 | 136.17 | 262.67 | 372,227.00 | 161,256.00 | 123,075.00 | 241,177.00 | 5,785.00 | 9,693.00 | 29,848.00 | 21,542.33 |
| 2011 | Mean | 8.70 | 7.71 | 17.75 | 21,908.45 | 9,080.13 | 9,750.32 | 11,311.79 | 448.85 | 936.55 | 1,407.15 | 867.83 |
| | SD | 16.75 | 14.51 | 33.83 | 37,990.25 | 17,886.13 | 15,362.42 | 22,116.62 | 761.94 | 1,385.51 | 2,875.20 | 2,238.44 |
| | Min | 1.00 | 1.00 | 1.00 | 2.00 | 0.00 | 187.00 | 303.00 | 0.00 | 17.00 | 0.00 | 24.13 |
| | Max | 143.00 | 133.00 | 269.33 | 359,319.00 | 171,047.00 | 118,915.00 | 184,763.00 | 5,647.00 | 12,428.00 | 31,270.00 | 21,877.80 |
| 2012 | Mean | 9.03 | 8.11 | 18.52 | 22,537.11 | 9,475.67 | 10,513.03 | 11,272.70 | 452.26 | 887.68 | 1,373.56 | 886.65 |
| | SD | 17.46 | 15.34 | 35.99 | 37,626.47 | 19,770.20 | 16,875.90 | 22,900.68 | 802.51 | 1,231.50 | 2,701.76 | 2,278.99 |
| | Min | 1.00 | 1.00 | 1.00 | 674.00 | 0.00 | 394.00 | 265.00 | 0.00 | 0.00 | 0.00 | 33.91 |
| | Max | 139.58 | 142.67 | 289.75 | 334,192.00 | 181,186.00 | 120,352.00 | 194,554.00 | 6,523.00 | 9,109.00 | 31,311.00 | 21,910.69 |
| 2013 | Mean | 9.30 | 8.49 | 19.00 | 23,166.71 | 9,969.78 | 11,038.85 | 10,764.25 | 424.73 | 802.93 | 1,188.01 | 904.72 |
| | SD | 18.28 | 16.13 | 37.02 | 38,426.823 | 19,528.76 | 17,814.06 | 22,338.32 | 676.65 | 1,153.85 | 2,214.70 | 2,329.94 |
| | Min | 1.00 | 1.00 | 1.00 | 2,120.00 | 0.00 | 329.00 | 252.00 | 0.00 | 0.00 | 0.00 | 51.22 |
| | Max | 147.50 | 144.33 | 313.83 | 358,515.00 | 168,002.00 | 134,586.00 | 198,194.00 | 4,550.00 | 8,865.00 | 23,230.00 | 22,246.98 |
| 2014 | Mean | 9.93 | 9.08 | 19.37 | 25,265.85 | 10,683.32 | 11,380.25 | 11,052.50 | 480.67 | 777.22 | 1,118.82 | 916.21 |
| | SD | 19.01 | 17.67 | 38.00 | 41,489.11 | 21,946.77 | 18,575.77 | 22,566.91 | 679.86 | 1,084.71 | 1,971.65 | 2,374.65 |
| | Min | 1.00 | 1.00 | 1.00 | 1,629.00 | 0.00 | 132.00 | 296.00 | 0.00 | 0.00 | 0.00 | 20.29 |
| | Max | 154.42 | 149.83 | 316.33 | 367,429.00 | 184,315.00 | 140,791.00 | 186,347.00 | 4,708.00 | 7,426.00 | 19,927.00 | 23,051.62 |

### 4.2. DEA results

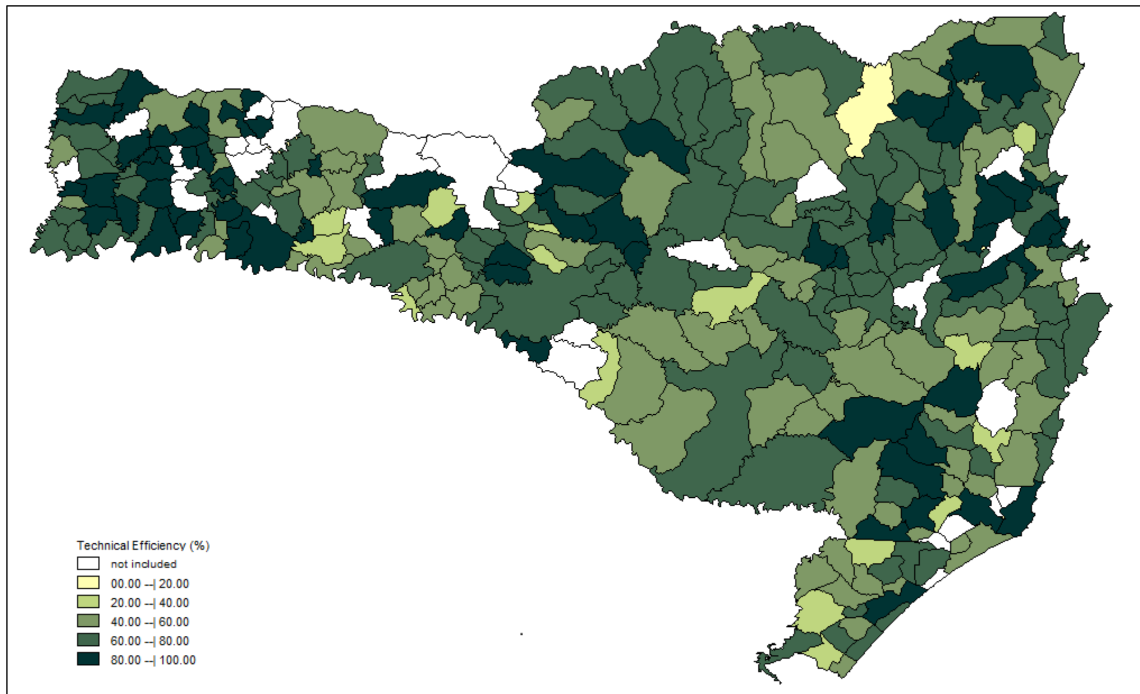
Table 4.2 shows the descriptive statistics of the performance results of 266 municipalities in the Santa Catarina state from 2008 to 2014. It contrasts the two DEA models analysed in this study: Model 1 does not consider outcomes in the analysis, and Model 2 includes the prevented ACSC hospitalisations as an output. Both models show a decreasing trend of the performance scores observed from 2008 to 2014, despite a short period of rising values from 2011 to 2012. However, the mean technical efficiency obtained with the inclusion of the prevented ACSC hospitalisation (Model 2) tends to be higher. While the performance in Model 1 falls from 58.23% to 53.53%, in Model 2, the reduction goes from 68.01% to 62.27%. The annual number of efficient DMUs also varies throughout this period, ranging from 16 to 26 in Model 1. Again, better results are seen in Model 2, where 22 to 35 DMUs operate with performance equal to 100%, which represents an increase of around 3% in the number of DMUs considered efficient. The distribution of performance results among the municipalities obtained in Model 2 is shown in Figure 4.1.

**Table 4.2** Performance results of Primary Health Care in municipalities of Santa Catarina, Brazil, from 2008 to 2014. (Constant Returns to Scale, output-oriented model)

| Year | Model 1 | | Model 2 | |
|---|---|---|---|---|
| | **Mean** | **Number of Municipalities that scored 100%** | **Mean** | **Number of Municipalities that scored 100%** |
| 2008 | 58.23% | 25 (9.40%) | 68.01% | 35 (13.16%) |
| 2009 | 58.03% | 20 (7.52%) | 67.91% | 35 (13.16%) |
| 2010 | 54.46% | 19 (7.14%) | 64.35% | 28 (10.53%) |
| 2011 | 56.12% | 21 (7.89%) | 67.17% | 31 (11.65%) |
| 2012 | 59.05% | 26 (9.77%) | 69.83% | 35 (13.16%) |
| 2013 | 57.08% | 15 (5.64%) | 66.30% | 21 (7.89%) |
| 2014 | 53.53% | 16 (6.02%) | 62.27% | 22 (8.27%) |

Model 1: performance calculated without considering outcomes; Model 2: performance calculated including the prevented ACSC hospitalisation as an output.

**Figure 4.1** Mean performance scores of the municipalities of Santa Catarina, Brazil, obtained in Model 2. (Constant Returns to Scale, output-oriented model)




The DEA technique undertakes a performance analysis by choosing the weight combination of inputs and outputs that put each DMU in its best light. Taking the year 2011 as a reference, Tables 4.3 and 4.4 exhibit output weights profiles for the municipalities, contrasting DMUs with dissonant performance scores and population sizes. It is observed that the municipalities with a performance score of 100%, as well as those with the smallest populations, tend to have more weight attributed to activities related to home visits and programmatic consultations. On the other hand, municipalities with worse evaluation, similarly to those with larger populations, tend to assign more weight to medical and programmatic consultations in both models, with significant emphasis on prevented ACSC hospitalisations in the Model 2 analysis.

**Table 4.3** Mean proportion of weight attributed to each output in 2011 using Model 1. (The gradient in green illustrates the weight levels, where darker colours represent higher values, while lighter colours represent smaller values)

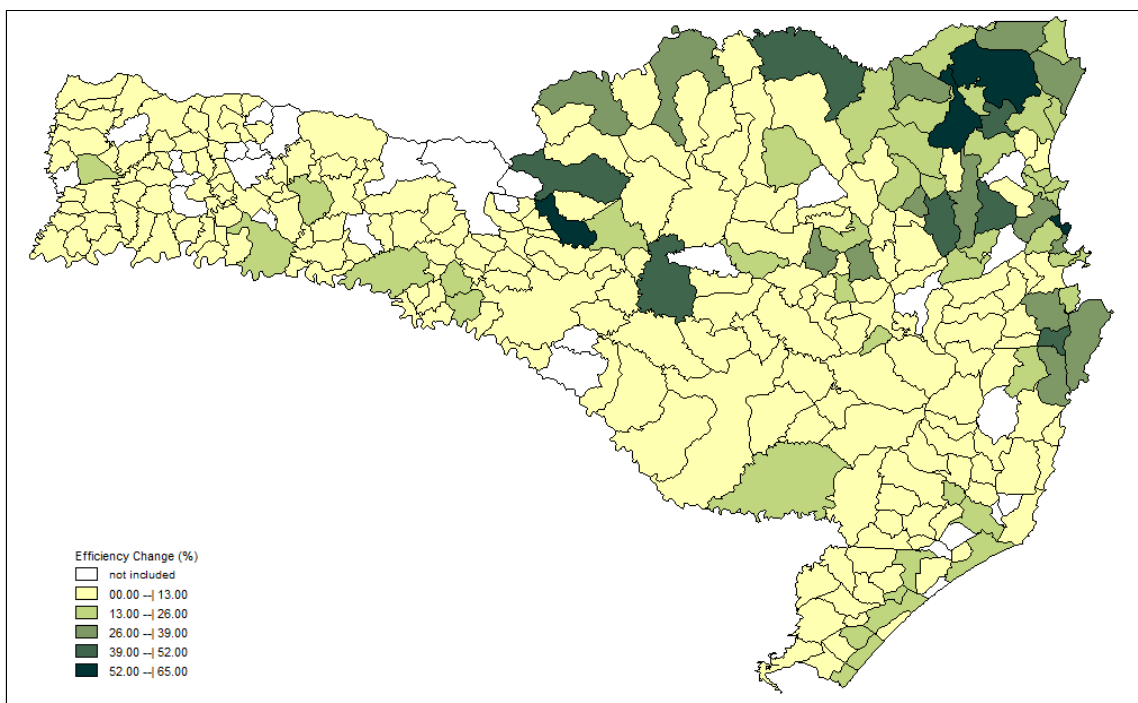
| | Physician Consultations | Nurse Consultations | Programmatic Consultations | Nursing Assistant Procedures | Physician Home Visits | Nurse Home Visits | Nursing Assistant Home Visits |
|---|---|---|---|---|---|---|---|
| **Comparison related to the performance score** | | | | | | | |
| DMUs that scored 100% | 0.1326 | 0.0536 | 0.2214 | 0.0342 | 0.1940 | 0.1905 | 0.1737 |
| DMUs with the smallest scores | 0.3761 | 0.0678 | 0.1661 | 0.0714 | 0.1169 | 0.1562 | 0.0456 |
| **Comparison related to the population's size** | | | | | | | |
| Bigger Municipalities | 0.3389 | 0.0977 | 0.2026 | 0.0596 | 0.1359 | 0.0825 | 0.0828 |
| Smaller Municipalities | 0.1995 | 0.0245 | 0.1923 | 0.0133 | 0.2254 | 0.2523 | 0.0926 |

**Table 4.4** Mean proportion of weight attributed to each output in 2011 using Model 2. (The gradient in green illustrates the weight levels, where darker colours represent higher values, while lighter colours represent smaller values)

| | Physician Consultations | Nurse Consultations | Programmatic Consultations | Nursing Assistant Procedures | Physician Home Visits | Nurse Home Visits | Nursing Assistant Home Visits | Prevented ACSC Hospitalisations |
|---|---|---|---|---|---|---|---|---|
| **Comparison related to the performance score** | | | | | | | | |
| DMUs that scored 100% | 0.0971 | 0.0414 | 0.1750 | 0.0253 | 0.1676 | 0.1428 | 0.1387 | 0.2121 |
| DMUs with the smallest scores | 0.1841 | 0.0330 | 0.1737 | 0.0196 | 0.0457 | 0.1178 | 0.0700 | 0.3561 |
| **Comparison related to the population's size** | | | | | | | | |
| Bigger Municipalities | 0.0804 | 0.0215 | 0.0601 | 0.0138 | 0.0237 | 0.0289 | 0.0308 | 0.7409 |
| Smaller Municipalities | 0.1864 | 0.0359 | 0.1346 | 0.0322 | 0.1607 | 0.1752 | 0.1104 | 0.1646 |

Although the overall difference of the results observed after the inclusion of the prevented ACSC hospitalisations has tended to show a general performance improvement when considering the mean values, it should be noted that the impact on efficiency analysis was different in each municipality. In Figure 4.2, it is possible to see the distribution of DMU's performance scores in Model 2 across the state and the gradient of improvement on efficiency in each municipality. Large municipalities stand out because they have obtained the highest increments in performance.

**Figure 4.2** Absolute change in the mean performance scores when adopting Model 2 instead of Model 1. (Constant Returns to Scale, output-oriented model)




Joinville, the most populous municipality of the state, obtained a mean efficiency in Model 1 of 15,44%, while in Model 2 the mean efficiency was 80,01%, which represents a relative increase in efficiency of 418%. As seen in Table 4.5, other DMUs that also obtained larger increases are Videira, Balneário Camboriú, Jaraguá do Sul and Indaial, all with performance enhancement of at least 50%.

Table 4.6 shows the DMUs that were more frequently evaluated as efficient, detailing for how many municipalities they were reference in each year and their average performance score over the analysed period.

**Table 4.5** Municipalities that most benefited from the inclusion of the outcome variable.

| Municipality | Performance improvement |
|---|---|
| Joinville | 64.58% |
| Videira | 63.03% |
| Balneário Camboriú | 61.98% |
| Jaraguá do Sul | 59.17% |
| Indaial | 51.60% |
| Caçador | 45.74% |
| São José | 43.25% |
| Gaspar | 42.98% |
| Mafra | 40.88% |
| Guaramirim | 40.87% |
| Curitibanos | 40.65% |
| Florianópolis | 39.00% |
| Palhoça | 37.70% |
| Canoinhas | 35.69% |
| Blumenau | 31.82% |
| São Francisco do Sul | 30.38% |

**Table 4.6** Municipalities most frequently assigned as efficient in Model 2. (Constant Returns to Scale, output-oriented model)

| Municipality | Number of DMUs for which the municipality was a benchmark | | | | | | | Number of years that scored 100% | Mean Performance Score |
|---|---|---|---|---|---|---|---|---|---|
| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | | |
| Lindóia do Sul | 178 | 27 | 33 | 23 | 6 | 1 | 1 | 7 | 100.00% |
| Jupiá | 43 | 59 | | 5 | 36 | 1 | 29 | 6 | 99.85% |
| Laurentino | 86 | 105 | 11 | 1 | 0 | | 26 | 6 | 99.43% |
| Coronel Martins | 45 | 121 | 38 | 69 | 7 | 0 | | 6 | 96.51% |
| Sul Brasil | 27 | 6 | | | 0 | 39 | 20 | 5 | 97.95% |
| Serra Alta | | 43 | | 68 | 139 | 71 | 111 | 5 | 97.39% |
| Belmonte | 29 | 0 | | 0 | 22 | 6 | | 5 | 97.31% |
| Águas Frias | 19 | | | 1 | 2 | 13 | 15 | 5 | 96.50% |
| Nova Trento | 7 | 10 | 122 | 120 | 2 | | | 5 | 95.61% |
| Ponte Serrada | 20 | 2 | 16 | 38 | 49 | | | 5 | 93.31% |
| São Joaquim | 19 | 0 | 9 | 1 | 4 | | | 5 | 91.23% |
| Videira | 91 | 73 | 27 | | | | 137 | 4 | 98.18% |
| Indaial | | | 35 | 99 | 132 | 19 | | 4 | 97.75% |
| Siderópolis | 95 | 113 | 103 | | | | 0 | 4 | 95.33% |
| Urussanga | 5 | 13 | | 46 | 3 | | | 4 | 94.36% |
| Bom Jesus | | 43 | 20 | 5 | 1 | | | 4 | 92.58% |
| Itapema | | | 4 | 19 | | 7 | 6 | 4 | 92.06% |
| Anitápolis | 6 | | 2 | 0 | | 1 | | 4 | 89.34% |
| Rio do Oeste | 67 | 27 | 20 | 9 | | | | 4 | 87.15% |
| Timbó Grande | | | | 16 | 54 | 184 | 172 | 4 | 84.25% |
| Fraiburgo | | | | 71 | 17 | 164 | 74 | 4 | 81.27% |

Note that Lindóia do Sul is the only municipality considered efficient in all the years, whereas Jupiá, Laurentino and Coronel Martins are DMUs that were efficient in all but one of the years analysed. In order to identify characteristics about the organisation or work process that could help explain such findings, correlation analyses were performed with existing data.

Table 4.7 presents some of the correlations between the variables considered relevant. Table 4.8 exemplifies with objective data the referred correlations, taking the municipality of Jupiá as a reference and comparing it with three DMUs for which it systematically worked as a benchmark.

**Table 4.7** Relevant correlations between variables. (Spearman correlation. N = 1,862)

| | Performance Model 1 | Performance Model 2 | Nurses / Physicians | % Programmatic Consultations | Population / Health Workers | Home Visits per inhabitant | Standardized ACSC Hospitalization Rate |
|---|---|---|---|---|---|---|---|
| Performance Model 1 | 1.000 | .825** | .234** | .102** | .134** | .462** | .138** |
| Performance Model 2 | | 1.000 | .205** | .120** | .466** | .205** | -.112** |
| Nurses / Physicians | | | 1.000 | -.028 | -.021 | .051* | .024 |
| % Programmatic Consultations | | | | 1.000 | -.028 | .087** | -.015 |
| Population / Health Professionals | | | | | 1.000 | -.438** | -.031 |
| Home visits per inhabitant | | | | | | 1.000 | .054* |
| Standardized ACSC Hospitalization Rate | | | | | | | 1.000 |

** The correlation is significant at level 0.01
* The correlation is significant at level 0.05

**Table 4.8** Values of correlated variables for three DMUs and their benchmark Jupiá in 2011.

| **DMU** | **Performance Model 1** | **Performance Model 2** | **Nurses / Physicians** | **% Programmatic Consultations** | **Population / Health Workers** | **Home Visits per inhabitant** |
|---|---|---|---|---|---|---|
| Jupiá | 100.00% | 100.00% | 1.08 | 21.71% | 427.87 | 0.41 |
| Morro Grande | 65.76% | 65.76% | 0.30 | 33.29% | 283.84 | 0.54 |
| Vargeão | 62.19% | 62.19% | 1.00 | 20.67% | 398.78 | 0.23 |
| Timbé do Sul | 47.76% | 48.22% | 1.00 | 7.45% | 359.47 | 0.26 |

Analysing the indicators available, it is possible to identify a significant positive correlation, although weak, between the nurses-physician ratio and the performance observed for each DMU. This finding shows that having a larger proportion of nurses in relation to doctors can positively influence the performance evaluation.

An indicator of organisation of the activities performed by the health services also proved positively correlated with the municipalities' performance score. We note that the higher the rate of programmatic consultations in relation to the total consultations carried out in the health centres, the better the results in DMU's performance.

Another observation arising from the correlation analysis between the studied variables concerns the effect of potential population demand in the provision of health services. As illustrated in Table 4.8, it was verified that municipalities with more inhabitants by each health professional have a statistically significant tendency to make fewer home visits per inhabitant. Thus, municipalities with a larger population tend to carry out relatively fewer home visits than minor municipalities.

### 4.3. MPI results

The MPI was applied to analyse changes in productivity throughout the 2008-2014 period, and the annual geometric means are presented in Table 4.9. Scores greater than 1 indicate a growth in productivity, values smaller than 1 reveal its deterioration, whereas scores equal to unity demonstrate the conservation of productivity. Decomposing the MPI, we have the catch-up effect, measuring efficiency changes of a DMU from one period to another, and the frontier shift effect that indicates shifts in the efficiency border due to innovation in processes or technology.

**Table 4.9** Results of the Malmquist Productivity Index (Constant Returns to Scale, output-oriented model).

| Period | Model 1 | | | Model 2 | | | |
|---|---|---|---|---|---|---|---|
| | **C** | **F** | **MPI** | **C** | **F** | **Q** | **Q-MPI** |
| 2008 - 2009 | 1.008 | 0.953 | 0.960 | 1.004 | 0.960 | 1.022 | 0.985 |
| 2009 - 2010 | 0.935 | 1.091 | 1.020 | 0.942 | 1.072 | 1.011 | 1.021 |
| 2010 - 2011 | 1.036 | 0.953 | 0.988 | 1.053 | 0.941 | 1.020 | 1.011 |
| 2011 - 2012 | 1.075 | 0.889 | 0.956 | 1.051 | 0.906 | 1.007 | 0.958 |
| 2012 - 2013 | 0.971 | 0.996 | 0.968 | 0.948 | 1.014 | 1.007 | 0.968 |
| 2013 - 2014 | 0.935 | 1.036 | 0.968 | 0.935 | 1.015 | 1.002 | 0.950 |
| 2008 - 2014 | 0.953 | 0.924 | 0.881 | 0.928 | 0.921 | 1.065 | 0.910 |
| Frequency Distribution (2008-2014) | | | | | | | |
| > 1 | 110 (41.35%) | 51 (19.17%) | 96 (35.09%) | 105 (39.47%) | 54 (20.30%) | 202 (75.94%) | 107 (40.23%) |
| = 1 | 5 (1.88%) | 0 (0.00%) | 0 (0.00%) | 8 (3.01%) | 0 (0.00%) | 12 (4,51%) | 0 (0.00%) |
| < 1 | 151 (56.77%) | 215 (80.83%) | 170 (63.91%) | 153 (57.52%) | 212 (79.70%) | 52 (19.55%) | 159 (59.77%) |

Model 1: performance calculated without considering outcomes; Model 2: performance calculated including the prevented ACSC hospitalisation as an output; C: catch-up effect; F: frontier shift effect; MPI: Malmquist Productivity Index; Q: quality change; Q-MPI: quality-adjusted MPI.

Comparing 2008 to 2014, an overall result smaller than the unity was found, indicating a deterioration in the catch-up component and in the frontier shift component in both models analysed. The same findings are present in the Q-MPI values. However, in this case, when the outcome indicator is included, we can observe a smaller depreciation of the productivity index from 2008 to 2014. This effect becomes evident by the increase observed in the number of DMUs that showed progression in performance: 107 municipalities that improved by using Model 2 instead of 96 municipalities with Model 1.

The improvement mentioned above is best visualised with the quality changes index present in Model 2, where the score along the 2008-2014 period (1.065) means an overall improvement in quality of 6.5%. This information means that, even with a tendency to decrease productivity, the services presented an evolution in preventing ACSC hospitalisations.

## 5. DISCUSSION

This study highlights the importance of including a quality indicator based on tangible outcomes for the efficiency calculation and productivity analysis in the PHC context. Also, it shows the relevance of applying an MPI analysis allowing the study of three separate components: efficiency catch-up; frontier shift and quality change. This is advantageous as it pinpoints the causes behind the observed evolution in productivity. This methodology and the results obtained in this study highlight the importance of including both indicators of outputs (activity related) and outcomes of care. With this method, it was also possible to analyse the temporal evolution of performance with the advantage of a decomposition that allows making a distinct evaluation of changes in quality, which unequivocally illustrates the actual impact on the population's health. The inclusion of the quality variable adds value to the analysis by exposing the difference in the efficiency observed, providing a fairer and more comprehensive analysis of the activities developed by each municipality.

According to Salinas-Jiménez and Smith (1996), an indicator of health outcome should ideally be used as a benchmark in evaluating health interventions. Thus, the inclusion of a variable related to outcomes sought to qualify the efficiency analysis since the PHC activity measures should also capture the impact of services provided in patients' health status. The consistent difference observed in the calculation of efficiency by including this type of variable is in accordance with Murillo-Zamorano and Petraglia (2011), confirming that this process provides more reliable efficiency measures by preventing misleading results that could be obtained when considering only activity based criteria in the analysis.

The relevance of including the quality indicator in the analysis is confirmed by the low correlation that was found between the performance results of Model 1 and the hospitalisation rate of each municipality. This weak correlation corroborates the results obtained by Miclos, Calvo and Colussi (2017), who showed that efficiency in health actions (outputs) does not necessarily translate into efficiency in results (outcomes). The lack of significant correlation between performance (based solely on activity indicators) and outcomes may, in part, be explained by the fact that not all consultations contribute equally to improve patients' health. A municipality may be able to use its resources to

maximise the number of consultations, but, pressured by time, the professionals may not have a good performance in terms of preventing hospitalisations.

According to the results, small municipalities predominate among the most efficient DMUs, while larger cities tend to show lower performance scores. However, Souza and Costa (2011) observed that larger municipalities often have lower hospitalisation rates by ACSC. Some explanations for these findings can be found in our study and the literature. We found that the weight profile regarding the outputs show that smaller and best performing municipalities tend to emphasise the execution of programmatic consultations and home visits by doctors and nursing professionals. This finding may be related to the growing implementation of the ESF as a strategy for the organisation of health services, as there is often a more extensive ESF coverage in small municipalities (Henrique and Calvo, 2009). Also, compared to the traditional care model, it is known that the ESF provides greater participation of non-medical professionals in clinical care and gives greater emphasis on programmatic actions, home activities and articulation with the community (Facchini, Piccini, Tomasi, Thumé, Silveira, Siqueira and Rodrigues, 2006; Tomasi, Facchini, Thumé, Piccini, Osorio, Silveira, Siqueira, Teixeira, Dilélio and Maia, 2011). In addition, we see a positive correlation between programmatic consultations and performance. This finding shows that the provision of programmatic consultations can be a suitable strategy to deal with typical clinical situations in primary health care. Such observation becomes even more evident when considering that this type of consultation is performed by both medical and nursing professionals. This sharing of health care among professionals from different areas is consistent with the idea of improving access to PHC services and qualifying the disease management, especially for chronic conditions (Rumball-Smith, Wodchis, Koné, Kenealy, Barnsley and Ashton, 2014).

Despite the diversity of factors that can explain a DMU's performance, another interesting finding was the positive correlation between the nurses per physician ratio and the performance. This proportion indicates that the work team's configuration can influence the performance of the services since a higher relative amount of nursing professionals would be related to better performance results in providing primary health care. Besides the potential to increase patient access to the PHC, the configuration of health teams to prioritise non-physician professionals has been shown to have other advantages like improving health outcomes and patient experience, controlling costs and

even having a positive effect on the care team's work life (Amado and Dyson, 2009; Mitchell, Haag, Klavetter, Beldo, Shah, Baumbach, Sobolik, Rutten and Stroebel, 2019; Norful, Martsolf, de Jacq and Poghosyan, 2017). Consequently, this finding may be useful to health care managers, mainly in regions with a shortage of physicians.

Our study also noted a negative correlation between the number of inhabitants per health professional and the number of home visits per inhabitant. This data can be related to the slower expansion of the ESF in larger cities, which would have delayed the institution of home visits as a current practice. However, this finding could also indicate that a greater demand for health services would lead the professionals to prioritise services carried out in health centres as a strategy to manage the higher demand. As revealed by Conill (2008), the inadequate sizing between population and health teams hinders the establishment of practices such as home visits. Thus, managers should give special attention to the scaling of teams according to the demand so that it will be possible to offer these essential services in a scenario of the growing elderly population and people with chronic and degenerative diseases.

Regarding hospitalisations, the high turnover of professionals in smaller municipalities is due to the local management's difficulty to retain these workers (Kluthcovsky and Kluthcovsky, 2007). This problem undermines the PHC principle of longitudinality by affecting the continuity of care. Consequently, it could lead to the higher use of emergency departments and ACSC hospitalisation rates observed in minor cities (Gill and Mainous, 1998; Rosenblatt, Wright, Baldwin, Chan, Clitherow, Chen and Hart, 2000). In addition, the lower qualification degree of professionals and managers observed in small municipalities (Araújo, Silva, Marcelino, Silva and Brandão, 2016; Viana, Rocha, Elias, Ibañez and Novaes, 2006) can reflect on lower quality of care, with a subsequent increase in the hospitalisations.

The downward trend of efficiency corroborates what was found by Lobo and Araujo (2017), who verified a decrease in the proportion of consultations in a study analysing Brazilian states capitals in a similar period. However, this reduction of performance is not exclusive to the region studied since Gonçalves, Santos, Dias and Ferreira (2012) observed a similar reality in the country's southeastern region.

One of the main advantages of the inclusion of a variable related to outcome in the longitudinal analysis is the productivity index decomposition. This way, it becomes

possible to detect variations in the quality of the services provided, which in the present study is represented by an increase in the prevented ACSC hospitalisations. According to Dourado, Oliveira, Aquino, Bonolo, Lima-Costa, Medina, Mota, Turci and Macinko (2011), the expansion of ESF coverage is one of the factors that led to the decrease observed in ACSC hospitalisation rates. Additionally, Brasil and Costa (2016) found similar findings in Florianópolis, Santa Catarina state's capital, arguing that not just the expansion and consolidation of the ESF but also the increment of financial investments in health can be suggested as causes for this improvement. It is worth noting that the same authors showed that the decreasing tendency of ACSC hospitalisation rate is not just a consequence of a reduction in the hospitalisations by all causes, being even more profound than these last ones. Such a finding is consistent with the current evidence claiming that health systems based on primary health care as the first point of contact, with continuous, coordinated and person-centred actions, lead to improvements in health outcomes (WHO and UNICEF, 2018).

Regarding the applied technique, it is observed that the inclusion of weight restrictions in the analyses provides a reorientation in the emphasis given by a DMU to their different inputs and outputs (Allen, Athanassopoulos, Dyson and Thanassoulis, 1997). This methodology seeks to represent the importance of the complementarity of the various professionals and actions implemented in PHC. Therefore, to improve their performance, inefficient municipalities should re-evaluate their priorities when comparing themselves with their efficient benchmarks. Thus, weight restriction allows municipalities' operation to be seen from the best possible optics but always considering the appropriate relevance given to each resource and service. Otherwise, according to Dyson and Thanassoulis (1988), the absence of weight restrictions could lead to unreal and unfeasible results in practice.

Despite the relevance of the results obtained in the study, some limitations should be considered. First, although the ACSC hospitalisation rate is a comprehensive and suitable indicator to evaluate actions in PHC, it can be influenced by socio-environmental characteristics that were not considered in this work. In addition, the current morbidity prevalence in each place can directly affect the level of hospitalisations, regardless of the quality of primary care services provided. Considering that the disease incidence increases with the patients' age, an attempt to minimise this bias was the age adjustment of the ACSC hospitalisation rate. This approach allowed us to create the variable of

prevented hospitalisations without the influence of the age composition in each municipality. Second, as this variable is related to the local population size, another possible bias would be the tendency to benefit the municipalities with more inhabitants. To mitigate this effect, we used as reference a more ordinary ACSC hospitalisation rate by excluding DMUs with rates considered extreme outliers.

Additionally, the inclusion of the outcome variable as an additional output can artificially increase the number of efficient DMUs. According to Ferrera, Cebada and Zamorano (2014), this occurs by the theoretical loss of the DEA's discriminatory power caused by the increased quantity of outputs maintaining a constant number of observations. However, considering that we have worked with a very large sample, and that we have introduced several weight restrictions, this effect is not expected to be pronounced in this study. Furthermore, this effect did not influence the longitudinal analysis made through the quality-adjusted MPI nor the different impact that the addition of this variable had in the various municipalities.

## 6. CONCLUSIONS

In this study, we analysed the performance of PHC services in 266 municipalities located in the state of Santa Catarina, Brazil, during the period from 2008 to 2014. A representative variable related to outcome based on the age-adjusted ACSC hospitalisation rate was included to obtain inferences about the quality of health actions. The results highlight the importance of incorporating outcome indicators to value the impact generated by the services provided, beyond the evaluation of the volume of activity undertaken. In our view, it promotes a fairer performance analysis, which can later encourage managers to focus on the action planning, considering not just the volume of activity undertaken but also how the services are delivered. Furthermore, using a Spearman correlation analysis, it was possible to identify some of the organisational characteristics of the services and activities performed that provide better health results. Thus, managers can have more information to consider when structuring health teams and planning their actions.

Moreover, a temporal analysis considering an outcome variable allowed the decomposition of the productivity index so that we could individually assess changes in the quality of the services over time. As far as we know, this is the first study focused on PHC to evaluate changes in productivity with the inclusion of a quality index and isolating the evolution of this indicator. As a suggestion for future research in this area, we can point out the inclusion of other health outcomes considered relevant such as indicators of patient satisfaction with the services. Also, additional studies are needed to understand the causes behind the results obtained. In depth studies of the municipalities that consistently appear as best practices should be undertaken to learn about the structures and processes that contribute to their outstanding performance. This would contribute to inform policies and practices with particular attention to what effectively produces improvements in the population’s health.

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# APPENDIX

Consider that there are $n$ DMUs that use $m$ non-negative inputs to produce $s$ non-negative outputs. Consider that $x_{ij}$ and $y_{rj}$ are the observed levels of the $i$th input and the $r$th output at $DMU_j$. Consider that $v_i$ and $u_r$ are the weights given to the $i$th input and the $r$th output, respectively. The relative performance score of $DMU_j$ (with output orientation) can be calculated using model (1), developed by Charnes, Cooper and Rhodes (1978).

$$\text{Min } g_0 = \sum_{i=1}^{m} v_i x_{i0} \tag{1}$$

subject to:

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0; \qquad j = 1, \dots, n.$$

$$\sum_{r=1}^{s} u_r y_{r0} = 1$$

$$u_r, v_i \geq 0; \quad r = 1, \dots, s; \quad i = 1, \dots, m$$

Considering that this model is output oriented, the relative performance score of a particular $DMU_0 = \frac{1}{g_0}$.

Using the duality relations, it is possible to formulate the dual of Linear Programming (1), presented in (2), as developed by Charnes, Cooper and Rhodes (1978). This problem allows the identification of the benchmarks for $DMU_0$ under evaluation ($DMU_j$ is a benchmark for $DMU_0$ if the intensity coefficient $\lambda_j$ is positive).

$$\text{Max } z_0 \tag{2}$$

subject to:

$$\sum_{j=1}^{n} y_{rj} \lambda_j \geq y_{r0} z_o; \qquad r = 1, \dots, s$$

$$\sum_{j=1}^{n} x_{ij} \lambda_j \leq x_{i0} \qquad i = 1, \dots, m$$

$$\lambda_j \geq 0 \qquad j = 1, \dots, n$$

Models (1) and (2) assume Constant Returns to Scale (CRS), meaning that variations in the inputs should lead to proportional variations in the outputs.

Considering that model (2) is the dual of model (1), the optimum solution for these two models is the same. In this respect, the relative performance score of $DMU_0$ can also be calculated through the mathematical inverse of the optimum value for the objective function of (2): $= \frac{1}{z_0}$.

**Weigh restrictions**

We have developed weight restrictions based on feasible production trade-offs, following the approach proposed by Podinovski (2004).

The following trade-offs were defined:

$$P_1 = (1, -1, 0), Q_1 = (0, 0, 0, 0, 0, 0, 0, 0)^T$$

$$P_2 = (0, 1, -1), Q_2 = (0, 0, 0, 0, 0, 0, 0, 0)^T$$

$$P_3 = (0, 0, 0), Q_3 = (-1, 0, 0, 0, 1, 0, 0, 0)^T$$

$$P_4 = (0, 0, 0), Q_4 = (0, -1, 0, 0, 0, 1, 0, 0)^T$$

$$P_5 = (0, 0, 0), Q_5 = (0, 0, 0, -1, 0, 0, 1, 0)^T$$

$$P_6 = (0, 0, 0), Q_6 = (0, 0, 0, 0, 1, -1, 0, 0)^T$$

$$P_7 = (0, 0, 0), Q_7 = (0, 0, 0, 0, 0, 1, -1, 0)^T$$

$$P_8 = (0, 0, 0), Q_8 = (-1, 0, 1, 0, 0, 0, 0, 0)^T$$

$$P_9 = (0, 0, 0), Q_9 = (1, -1, 0, 0, 0, 0, 0, 0)^T$$

$$P_{10} = (0, 0, 0), Q_{10} = (0, 1, 0, -1, 0, 0, 0, 0)^T$$

$$P_{11} = (0, 0, 0), Q_{11} = (0, 0, -1, 0, 1, 0, 0, 0)^T$$

$$P_{12} = (-0.01, -0.01, 0.99), Q_{12} = (0, 0, 0, 0, 0, 0, 0, 0)^T$$

Here, $(P_j, Q_j)$ represent the trade-offs considered feasible, where $j$ is the judgement specifying production trade-offs.

$$Judgment\ 1: v_1 - v_2 \leq 0$$

$$Judgment\ 2: v_2 - v_3 \leq 0$$

$$Judgment\ 3: -u_1 + u_5 \leq 0$$

$$Judgment\ 4: -u_2 + u_6 \leq 0$$

$$Judgment\ 5: -u_4 + u_7 \leq 0$$

$$Judgment\ 6: u_5 - u_6 \leq 0$$

$$Judgment\ 7: u_6 - u_7 \leq 0$$

$$Judgment\ 8: -u_1 + u_3 \leq 0$$

$$Judgment\ 9: u_1 - u_2 \leq 0$$

$$Judgment\ 10: u_2 - u_4 \leq 0$$

$$Judgment\ 11: -u_3 + u_5 \leq 0$$

$$Judgment\ 12: -0.01v_1 - 0.01v_2 + 0.99v_3 \leq 0$$

Where $v_i$ is the weight attached to the input $i$ and $u_r$ is the weight attached to the output $r$.

These 12 weight restrictions were added to model (1). Furthermore, following the explanation of Podinovski (2004), model (2) was modified to account for these 12 trade-offs.

**Malmquist Productivity Index (MPI)**

In order to present the formulas used to calculate the MPI and its components it is important to recall that, as demonstrated by Färe, Grosskopf, Lindgren and Roos (1994), the output distance measure of data point $(x^t, y^t)$, observed for $DMU_0$, with regards to the best practice frontier of period *t*, is the mathematical inverse of the output expansion rate calculated using model (2): $D_0^t(x^t, y^t) = \frac{1}{z_0}$.

In this respect, using data for two periods ($t$ and $t+1$) for a set of DMUs, it is also possible to calculate several other distance measures. For example, it is possible to calculate $D_o^{t+1}(x^{t+1}, y^{t+1})$, which is the distance of data point $(x^{t+1}, y^{t+1})$ observed for $DMU_0$, with regards to the best practice frontier observed in period $t+1$. Furthermore, it is possible to calculate $D_o^t(x^{t+1}, y^{t+1})$, which is the distance of data point $(x^{t+1}, y^{t+1})$ observed for $DMU_0$, with regards to the best practice frontier observed in period *t* and $D_o^{t+1}(x^t, y^t)$ which is the distance of data point $(x^t, y^t)$ observed for $DMU_0$, with regards to the best practice frontier of period $t+1$. Using the approach of super-efficiency, developed by Andersen and Petersen (1993), the two last measures are not required to be bound superiorly by one.

In this regard, following Färe *et al.* (1994), the geometric mean of an output-oriented Malmquist Productivity Index (MPI) is defined as:

$$MPI = \sqrt{\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \times \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)}}$$

The MPI decomposed in technical efficiency change (catch-up effect) and technological change (frontier shift effect), since MPI = C x F

$$C = \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}$$

$$F = \sqrt{\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)} \times \frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})}}$$

**Quality-adjusted MPI (Q-MPI)**

In the calculation of the quality-adjusted MPI (Q-MPI), procedures similar to the previous ones are done, but with the inclusion of quality indicators (attributes).

According to Färe, Grosskopf and Roos (1995), the Q-MPI is defined as follows:

$$Q\text{-}MPI(x^{t+1}, y^{t+1}, a^{t+1}, x^t, y^t, a^t) = \sqrt{\frac{D_o^t(x^{t+1}, y^{t+1}, a^{t+1})}{D_o^t(x^t, y^t, a^t)} \times \frac{D_o^{t+1}(x^{t+1}, y^{t+1}, a^{t+1})}{D_o^{t+1}(x^t, y^t, a^t)}}$$

where: $a^t$ = attribute vector at period $t$ and $a^{t+1}$ = attribute vector at period $t+1$

The Q-MPI can be similarly decomposed in technical efficiency change (catch-up effect) and technological change (frontier shift effect):

$$C = \frac{D_o^{t+1}(x^{t+1}, y^{t+1}, a^{t+1})}{D_o^t(x^t, y^t, a^t)}$$

$$F = \sqrt{\frac{D_o^t(x^t, y^t, a^t)}{D_o^{t+1}(x^t, y^t, a^t)} \times \frac{D_o^t(x^{t+1}, y^{t+1}, a^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1}, a^{t+1})}}$$

Also, with the inclusion of a quality indicator related to outcomes, Q-MPI can generate the Quality Change Index (Q), an additional component defined as:

$$Q\ (x^{t+1}, y^{t+1}, a^{t+1}, x^t, y^t, a^t) = \sqrt{\frac{D_o^t(x^t, y^t, a^{t+1})}{D_o^t(x^t, y^t, a^t)} \times \frac{D_o^{t+1}(x^{t+1}, y^{t+1}, a^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1}, a^t)}}$$