Pinch Analysis as a quantitative decision framework for determining gaps in health care delivery systems

ABSTRACT

With 'good health and well-being' being set as one of the targets of the Sustainable Development Goal (SDG), this paper proposes the application of Pinch Analysis, a quantitative method originally applied to conserve scarce resources in source-demand allocation networks, for identifying gaps in health care service delivery. This method is also found to be useful for health care infrastructure capacity planning and policy testing. The major contribution of this method in this context is identification of marginalized sections and testing specific policies targeted towards them, which will justify release of financial aid and infrastructure development for appropriate sections. We explored this concept for investigating the in-patient health care delivery system in the context of developing nations, where the health care facilities (both public and private) thrive by offering services at drastically different prices. A novel framework is developed in this paper, supported by a case study of Kolkata, India where both the gaps and surplus faced by different sections of population are identified. In order to offset these gaps, we offer recommendations for possible policy implementation. A few hypothetical scenarios are also examined in order to understand the importance of Pinch Analysis for policy testing. We conclude by proving that Pinch Analysis can be a robust integrated decision-making framework for the health care sector, especially in resource-constrained communities.

KEYWORDS

Pinch Analysis; quantitative framework; health care service delivery; decision-making tool; developing countries

1. INTRODUCTION

'Good health and well-being' is set as one of the important targets to achieve the Sustainable Development Goal (SDG) decreed by the United Nations (UN, 2015). Governments all around the world are focusing on issues of social sustainability and innovation within their health care systems. The need of the hour is to construct an innovative assessment system, solutions and strategies towards the realization of sustainable operation of existing health care facilities and sustainable construction of new ones. This becomes imperative because health care systems face increasing demands within constrained resources. Such a sustainable system would entail having an equitable and balanced approach towards managing societal needs, financial constraints, and critical environmental standards. Therefore, the health care sector is in dire need of decision-support frameworks that enable sustainable approaches to development and growth.

Decision making is a critical component of complex cognitive tasks such as public sector planning and problem solving. Decision frameworks are primarily of two types: qualitative, and quantitative. Although policy-makers generally use a wide range of approaches in making decisions about policy and organization of services, they are under increasing pressure to adopt a more systematic approach to utilize the complex conglomeration of publicly available sources of data and evidence (Mays et al, 2005). Questions that have to be addressed by policy-makers have become more complex and are no longer limited to the nature and significance of the problem. The nature of proposed interventions, their differential impact, cost-effectiveness and acceptability (to mention just a few) also need to be answered. This is where quantitative frameworks trump over their qualitative counterparts. Although the data dependencies are larger, implementing a policy without scenario analysis may backfire due to uncertainty of public reaction. Health care service delivery is one of such sectors where there is a demand for developing a quantitative framework. While previous efforts to analyze health facilities, have focused on using simulation (Levine et al, 2013), operations research (Denton, 2013) or management science (Hulshof et al., 2011) to address issues of capacity planning and facility allocation in health care, researchers have addressed only a particular aspect of the problem rather than use an integrated approach. Policy decisions must be guided by a robust integrated decision-making framework, the lack of which is noticeable in the literature.

Health care facilities in resource-constrained societies exhibit a distinct and significant polarity in terms of quality and breadth of services, and the associated expenditure. Public facilities provide services at nominal subsidized rates; however, concerns about quality of infrastructure, training of medical personnel and delays are numerous (Balarajan et al, 2011). On the other hand, private facilities are able to ensure state-of-the-art infrastructure and highly trained personnel, but the expenditure rises quite significantly. Low government subsidies and high levels of competition force private facilities to undertake critical cost reduction measures (such as reduction in the number of beds, cutting staff and merging with other hospitals) drastically without evaluating their impact (Green, 2004). This calls for a comprehensive quantitative framework that allows scenario analysis of different policies.

Despite close proximity of health care facilities, economic accessibility (i.e., affordability) remains severely restricted for the urban poor. In developing countries, public centers are usually "crowded out" and the meagre economic resources of the urban poor restrict their access to the comparatively (and significantly) expensive private facilities (Filmer et al, 2000). To address the needs of the urban poor, the National Urban Health Mission (NUHM) was launched in 2012 in Indian metropolitan cities. NUHM aims to "*address the health concerns of the urban poor through facilitating equitable access to available health facilities by rationalizing and strengthening of the existing capacity of the health delivery for improving the health status of the urban poor…in a manner to ensure that well-identified facilities are set up for each segment of target population…*" (MoHFW, 2012). The additional managerial and financial resources required for these endeavors are to be ensured by NUHM as well.

In the context of developing nations like India, formulating inclusive policies under the purview of NUHM to ensure global "*health for all*" (Goal 3 of the SDGs) while minimizing social seclusion needs a more assiduous approach. It has been pointed out that the unavailability of desired health care facilities due to financial constraints often translated into out-migratory health trips beyond one's neighborhood/district/state (Jana et al, 2014). Reduction of undesired health tours can only be achieved through improved choice sets of facilities in a given region tailor-made to suit all sections of the population. This would also reduce the delay in health care seeking, dependency on others, loss of household savings, and avoidance of health shock.

Recent research efforts have seen the application of integrated planning frameworks for resource-constrained societies with an aim to arrive at sustainable regional development. Considering a brownfield region with rapidly expanding peri-urban areas, Basu, Jana, and Bardhan (2016) proposed a health care facility allocation model keeping national health care policy guidelines and constraints in mind. A more generalizable integrated framework was proposed later by Basu, Aggarwal, and Jana (2017) for determining optimal locations of emergency response facilities with applicability for both greenfield and brownfield urban regions. Although such planning tools have been proposed, there is a need for a tool that can analyze policies and provide sensitivity analysis for scenarios before implementation. For the period 2011-2015, only 4% of the Gross Domestic Product of India has been invested in total health expenditure (1.3% in public health), which is much lower than that made by developed countries like USA and Japan (WorldBank, 2016). Under these financial constraints, it is important to channelize limited public resources so as to meet the demands of the neediest, and encourage private investment to meet the demands of those who can afford state-of-art facilities.

It has been reported that decisions regarding health interventions are often made using heuristic or intuitive approaches, or even for political motives (Baltussen & Niessen, 2006). This marks the need to enable policy-makers to move towards a systematic, transparent and rational approach that results in quantitative results and optimal solutions. With this motivation, we propose the application of Pinch Analysis, a quantitative method to conserve scarce resources in source-demand allocation networks, for identifying gaps in health care service delivery. This method is also found to be useful for health care infrastructure capacity planning and policy testing. The major contribution of this method in this context is identification of marginalized sections and testing specific policies targeted towards them, which will justify release of financial aid and infrastructure development for these people.

Pinch Analysis was originally developed to conserve thermal energy in process industries through Heat Exchanger Networks (HENs) (Hohmann, 1972; Linnhoff, 1982)). Over the years, Pinch Analysis has established itself as a structural tool for analyzing and conserving resources in numerous diversified applications, such as mass exchanger networks (El-Halwagi & Manousiouthakis, 1989), water networks (Wang & Smith, 1994), utility systems (Shenoy, Sinha, & Bandyopadhyay, 1998), distillation columns (Santanu Bandyopadhyay, Malik, & Shenoy, 1999), supply chain management (Singhvi & Shenoy, 2002), hydrogen networks (Alves & Towler, 2002), property integration (Kazantzi & El-Halwagi, 2005), energy sector planning (R. R. Tan & Foo, 2007), batch process scheduling (Gouws, Majozi, Foo, Chen, & Lee, 2010), isolated energy system design (Santanu Bandyopadhyay, 2011), carbon dioxide sequestration (Diamante et al., 2014), project selection problems (Roychaudhuri, Kazantzi, Foo, Tan, & Bandyopadhyay), etc. These numerous applications are united by a common underlying mathematical structure (S. Bandyopadhyay, 2015). Fundamentals and history of Pinch Analysis and its various applications can be found in the handbook by Klemeš (2013). Various non-conventional applications of Pinch Analysis are summarized by R. Tan, Bandyopadhyay, Foo, and Ng (2015). To the best of our knowledge, this is the first time Pinch Analysis is being used in the field of health care systems.

Individuals with greatest need for health care have the greatest difficulty in gaining access to health services and are least likely to have their health needs met (Evans, Hall, & Warford, 1981). While our proposed framework is applicable in developed nations as well, this paper focuses on developing nations because the need for identifying marginalized sections is stronger there. Policies tailor-made to suit the needs of different sections of the society will enable countries to achieve "*health for all*", especially since developing countries actively engage in medical pluralism (Jana & Basu, 2017). This reinforces our motivation to focus exclusively on establishing Pinch Analysis as an important tool for policy-makers in developing nations. While Pinch Analysis aims to contribute to the literature in this regard, there are additional advantages as well. High health care expenses are pushing marginalized sections in developing nations below the poverty line. In such a situation, provision of health insurance becomes an extremely important policy decision (Ellis, Moneer, & Gupta, 2000). Identifying these marginalized sections and setting a cutoff for the poverty line becomes essential. Contrary to previous quantitative and qualitative efforts (simulation/OR/MS), Pinch Analysis is capable of enabling examination of such questions. Various scenarios can be tested to study the system-wide impact of providing different levels of health insurance to different sections. Finally, it has been widely agreed that capacity planning methods in health care are overly dependent on data, most of which are inaccessible to policy-makers due to informality of the payment system (Green, 2004; Smith-Daniels, Schweikhart, & Smith-Daniels, 1988). Comparatively, Pinch Analysis does not require hard-to-gather data or significant computational efforts, which should aid implementation by planning bodies.

The remainder of the paper is organized as follows. Section 2 identifies the specific research questions that this paper aims to address. The research framework is proposed in Section 3, while introduction to the case study area and data used for exemplifying the framework is provided in Section 4. Ensuing discussion of results are in Section 5, and Section 6 provides results from the scenario analysis that we employ for testing policies. Section 7 outlines the conclusion from this research and provides guidelines for future research efforts.

2. RESEARCH QUESTIONS

We aim to answer the following research questions through the course of this paper.

(a) Can Pinch Analysis be extended to quantify gaps in health care service delivery?
(b) How can we apply Pinch Analysis to identify marginalized sections that face affordability constraints in availing proper health care?
(c) What are the consequences of providing health insurance to these identified sections?
(d) What are the consequences of providing additional facilities (capacity augmentation) for particular sections?

While (a) and (b) are intended to be the major contributions of this paper, the authors wish to demonstrate the applicability of Pinch Analysis for scenario evaluation (a necessary component of decision-making) through (c) and (d) as well. Consideration of these two particular scenarios for testing is driven by the mandate to "*achieve universal health coverage, including financial risk protection, access to quality essential health-care services and access to safe, effective, quality and affordable essential medicines and vaccines for all*" (UN, 2015).

3. PROPOSED FRAMEWORK

This section contains a proposed framework which illustrates how Pinch Analysis may be applied in the context of health care decision-making. This framework helps us answer the specific research questions outlined in the previous section. The authors postulate that the framework can be varied to answer particular research questions of one's choice, but this paper remains unique due to being the first application of Pinch Analysis in this sector. Therefore, readers should note that the following framework is *a* framework, not *the* framework for using Pinch Analysis in this field. This also opens up avenues for future research on this topic.

Pinch Analysis aims to balance demand and supply while minimizing externalities, therefore, we model the study area appropriately. Another clarification must be made at this point. Health care services are broadly classified into two categories: Out-patient and in-patient. Out-patient services do not require the patient to be admitted to the facility or an overnight stay at the facility. An example of out-patient service is a single consultation session with a physician. On the other hand, in-patient services require the patient to be admitted to the facility, following which they might have to stay there for multiple days. An example of in-patient service is a surgery. This paper considers only in-patient services in the modeling framework as reliable data sources for out-patient services could not be found (as they are majorly undocumented and are over-the-counter or directly-to-the-doctor payments in most facilities). Henceforth, whenever a referral is made to a patient, it should be considered as a patient availing of in-patient services only.

3.1 Modeling demand

Depending on the scale of the study area (country, state, city, etc.), the demand nodes can be identified as elements or zones of the study area (states, cities, districts/wards, etc. respectively). We consider our study area to be a city, and accordingly assign municipal wards as demand nodes. We assume that there are i demand nodes in the study area.

Pinch Analysis is usually applied to closed systems with known flows from sources. However, that is rarely the case while considering health care systems. In-migration from surrounding areas (countries, states, rural and/or peri-urban areas) is often witnessed due to availability of better and more affordable health care centers in certain regions. To convert this system into a closed one, the in-migration has to be taken into account as an internal part of the system. Thus, the total number of patients in the ith ward can be expressed as a sum of the number of patients originating from that ward itself and the number of in-migrant patients to that ward.

$$P_i^{TOT} = P_i + P_i^{IN} \tag{1}$$

where

P_i^{TOT}: Total number of patients in the ith ward

P_i: Number of patients originating from the ith ward

P_i^{IN}: Number of patients who have migrated (from outside) into the ith ward

The number of patients originating from a ward can be calculated as a fraction of the total population of that ward. This fraction can be considered as the in-patient generation rate of that ward.

$$P_i = POP_i * \ f_i \tag{2}$$

where

POP_i: Population of the ith ward

f_i: Patient generation rate of the ith ward

If the total number of in-migrant patients into the study area is known, then this number can be attributed to each ward in the proportion of the total number of beds available in the health care facilities present in that ward. This ensures a weighted distribution of the in-migrant patients, keeping true to the psychological drive to seek treatment in a ward with larger availability of beds. Note that we consider number of beds since all the patients in this framework are using in-patient services and require admission to the facility (and therefore, a hospital bed).

$$P_i^{IN} = (365/P_{occ}) * r_{occ} * n_i \tag{3}$$

where

P_{occ}: Average bed occupancy period (expressed in bed-days per patient)

r_{occ}: Average bed occupancy rate (expressed as a fraction)

n_i: Number of (hospital) beds available in the ith ward

Pinch Analysis can account for a single quality index. However, recent works indicate that multiple indices can be combined to form a single index for application of Pinch Analysis (Jia et al, 2016; Patole et al, 2017). In this work, we propose constructing a socio-economic index (SEI) that represents affluence or capability to avail health care. While SEI can be an attribute of any entity (individual, or household, or community, etc.), we construct the SEI for each ward since we consider wards as demand nodes in this paper. The SEI incorporates attributes such as % of population who avail banking facilities [*Bank*], % of population below poverty line [*BPL*], % of population who own a private car [*Car*] and % of households who own the house they are currently living in [*HOwn*]. These attributes are calculated by taking the average value of all surveyed households in a particular ward. A Principal Component Analysis was carried out on these four variables to arrive at a single z-value for each ward, which we call the SEI. After normalization, the SEI can be interpreted as follows: 1 meaning 'most affluent' and 0 meaning 'least affluent'.

As mentioned in earlier sections, health insurance is often ignored in decision-making frameworks. Since one of our research questions hinges on testing the effects of providing health insurance, this should be incorporated in our framework through the SEI. We propose dividing the population into two categories: (a) those who are covered by health insurance support, and (b) those who are not. Since out-of-pocket health care expenditures do not have to be borne by those with insurance, their SEI requires modification; an augmentation, to be more specific. The modified SEI will be referred as α_i henceforth in the paper.

$$\alpha_i = [SEI_i * (1 - r_{ins})] + \left[SEI_i * r_{ins} * \left(\frac{1}{1 - r_{exp}}\right)\right] \tag{4}$$

where

SEI_i: SEI of the ith ward (the z-value obtained earlier)

r_{ins}: Proportion of population covered by health insurance support (expressed as a fraction)

r_{exp}: Proportion of total household expenditure being spent on in-patient services (expressed as a fraction)

3.2 Modeling supply

Keeping true to the context of this paper, health care centers have to be modeled as supply nodes. We assume that there are j supply nodes in the study area. Estimation of the number of beds available to patients is necessary. We work on this using a health care facility based approach, leading to parameters forming a $j \times 1$ matrix, where j is the total number of health care centers in the study area. The capacity of each facility can be expressed as follows:

$$C_j = n_j * (365/P_{occ}) \tag{5}$$

where

C_j: Capacity of the jth facility (in terms of number of beds)

n_j: Number of available (empty) beds in the jth facility

It is noteworthy that the variables have been scaled annually in Eqns. (3) and (5) using 365 days as the scaling factor. This capacity from the supply side is equivalent to the generated patients from the demand side. Similar to the SEI, we propose developing an affordability index for each health care facility which will represent how affordable that facility is. Incorporating parameters such as number of beds and level of service (LOS) for that facility, this index is equivalent to the SEI developed earlier from the demand side. The method for calculating this index, henceforth referred to as β_j, is outlined below.

As an example, let us consider that the ith ward has J health care facilities $H_1, H_2, \dots, H_J$. The numbers of beds in these facilities are $n_1, n_2, \dots, n_J$ respectively. Similarly, the level of service for these facilities are $LOS_1, LOS_2, \dots, LOS_J$ respectively. A quality index can be calculated for each facility incorporating these two parameters, as follows.

$$Q_{ji} = \left(n_j * LOS_j\right) \Big/ \left(\sum_{k=1}^{3} n_k * LOS_k\right) \tag{6}$$

where

Q_{ji}: Quality Index of the jth facility in the ith ward

LOS_j: Level of service of the jth facility

It is noteworthy that $\sum_{j=1}^{J} Q_{ji} = 1$, where J is the number of facilities in the ith ward.

Multiplying the SEI of the ward to which that particular health care facility belongs and the quality index of that facility yields the affordability index. If the jth facility is in the ith ward, then the affordability index can be expressed as follows.

$$\beta_j = Q_{ji} * \alpha_i \tag{7}$$

After normalization, this index can be interpreted as follows: 1 meaning ‘least affordable’ and 0 meaning ‘most affordable’. It is noteworthy that this trend is in contrast to that followed by the SEI. Since we are multiplying the SEI to the quality index, a high value of β_j means that more affluent people can avail of that center’s services, thereby implying that its affordability is low.

3.3 Pinch Analysis formulation

A Pinch Analysis formulation is developed to identify the gap in health care services. The general problem is mathematically defined as follows:

- A set of I wards is given. Each ward is associated with a number of patients looking for in-patient services (P_i^{TOT}) and with a known affluence index (α_i), represented by the modified SEI.

- A set of J health care facilities is also given. Each health care facility can accommodate a maximum number of in-patients (given by the capacity, C_j) with an affordability index β_j.
- Population with a given affluence index can avail any health care facility with a lower affordability index. In other words, a portion of P_i^{TOT} can avail *j*th health care facility if $\alpha_i > \beta_j$.
- The objective is to determine whether there are enough health care facilities to cater to the entire population subject to the affordability constraint.

It is important to note the following equivalents with the Pinch Analysis. Number of patients is equivalent to the heat duty of a process stream in HEN. Similarly, affluence and affordability indices play the role of temperature in HEN. The affordability constraint is equivalent to the second law of thermodynamics, where heat can naturally flow from high temperature to low temperature. The proposed problem can be analyzed using the well-established tools of Pinch Analysis: Composite Curves and Grand Composite Curves.

4. RELEVANT INFORMATION FOR THE CASE STUDY

4.1 Study Area

Kolkata, a 300-year old city, has been dynamically growing over time, with components such as planned city core and satellite townships, defunct industrial estate, scattered squatter settlements and splinters of modern living (Sengupta, 2006). Given the disparity of the quality of health care infrastructure and service delivery in the state of West Bengal, a substantial number of health trips originate from different parts of the state destined to Kolkata. Polarization of health care facilities in the city of Kolkata has substantially increased the magnetic pull of health tourists from not only within the state but beyond its boundaries. The pull factor being strong leaves the natives of Kolkata deprived of the needed facilities across socio-economic groups. In this context, there can be two approaches: (a) the long term approach of improving the health care infrastructure across the state reducing the disparity of service delivery and the demand of traveling beyond one's neighborhood, and (b) to facilitate and provision health care infrastructure in Kolkata to allow the natives to avail desired health care needs. This, however, also depends on the financial capability of the health care seeker. In this paper, we consider the second measure as the research goal assuming the demand to be a summation of the needs of the people of Kolkata and the flow of health tourists from beyond the boundary of the city. The supply side is modeled as the existing health care infrastructure in the city.

4.2 Data

A variety of sources (majorly government reports and government-conducted national surveys) have been used to estimate the values of the parameters mentioned in the framework. A thorough description of all pertinent details can be found in Table 1. It is noteworthy that an extensive survey was conducted in West Bengal in the course of the research carried out by Jana et al. (2014). We utilize the data collected by them in order to obtain values of granular-level parameters such as ward or health care center characteristics.

The basic analysis of the data showed that there are approximately 29,867 beds in the 356 healthcare facilities in Kolkata. While the overall demand was exceeding the supply and was estimated to be 30,908 (approximately). These facilities which houses in patient facilities were spread across the city in 141 administrative units (municipal wards).

Table 1. Data used for applying the framework to the case study area.

Parameter	Notation	Data Source	Value	Remarks
Population of ith ward	POP_i	Census of India 2011	-	-
In-patient generation rate for ith ward	f_i	Social Consumption: Health, National Sample Survey (NSS), 71st Round, 2014 (MoSPI, 2015)	0.051[†]	Assumed to be constant for all wards
Average bed occupancy period	P_{occ}	Social Consumption: Health, National Sample Survey (NSS), 71st Round, 2014 (MoSPI, 2015)	6.22 days/ patient	Assumed to be constant for all types of health care facilities
Average bed occupancy rate	r_{occ}	Health on the March 2013-14, West Bengal Government (DoHS, 2014)	0.904 [Average value obtained for medical college hospitals in West Bengal during 2013]	Assumed to be constant for all types of health care facilities
Number of beds in jth health center	n_j	Jana et al. (2014)	-	-
LOS of jth health center	LOS_j	Jana et al. (2014)	-	-
Components of SEI	1) *Bank* 2) *BPL* 3) *Car* 4) *HOwn*	Jana et al. (2014)	-	-
Proportion of people who are covered under health insurance	r_{ins}	2014-15 Report by Insurance Regulatory and Development Authority of India (IRDAI, 2015)	0.2095	No. of people insured / National population (2011 Census) = 253.5 million / 1210.2 million
Proportion of household expenditure spent on health care (only in-	r_{exp}	Saksena (2011)	0.1155	This paper reports a case study of 3,150 households from the state of West Bengal.

patient facilities)	

† This value was validated by using data from two other sources. The total number of admissions to all types of health care facilities in 2013 is equal to 4,696,394 (DoHS, 2014). The total population of West Bengal is 91,276,115 (Census of India 2011). Thus, the in-patient generation rate can be expressed as: 4,696,394 / 91,276,115 = 0.051.

5. RESULTS AND DISCUSSION

The results of Pinch Analysis can be analyzed by examining the Composite Curves and the Grand Composite Curve. In heat recovery Pinch Analysis, the hot composite and the cold composite curves are apart by the minimum temperature driving force (ΔT_{min}). However, for the present context, the conceptual equivalent of ΔT_{min} is zero. In other words, the composite curves are allowed to touch each other and the point they touch is the Pinch point, the bottleneck of the health service. Figure 1 shows that the health service composite curves and the Pinch point is observed at the affordability index of 0.90. The horizontal distance between the health service composite curves indicates the gap in the health service in the below Pinch region and the surplus in the health service in the above pinch region. The overall gap in the health service is indicated to be 89,207 beds/patient-year at the left-end of the composite curve (see Figure 1). Similarly, the overall surplus in the health service is indicated to be 28,130 beds/patient-year at the right-end of the composite curve (see Figure 1).

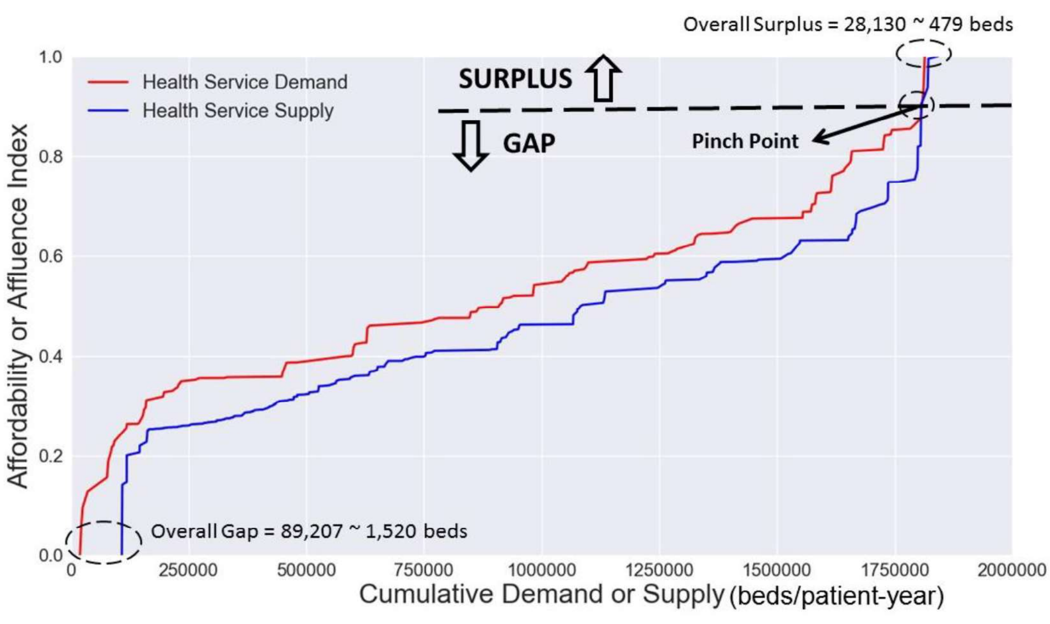

Figure 1. Health service composite curves for base case scenario.

The health service grand composite curve in Figure 2 shows that multiple pockets are created for MIG which can self-balance out among themselves. No external intervention is required for this segment. It may be noted that the horizontal distance between the grand composite curves is minimum (closest) at the affordability index of 0.19, apart from the Pinch point where the gap is equal to zero. This can be interpreted as the population being categorized into three segments: (a) Marginalized or urban poor (UP) with affluence index below 0.19,

(b) Middle income group (MIG) with affluence index between 0.19 and 0.90, and (c) Affluent or high income group (HIG) with affluence index above 0.90.

However, UP can afford to avail of a lesser number of economically accessible facilities than they should, leading to a gap in the health service. On the other hand, HIG faces a surplus in the facilities that they can access on account of their high affluence. It may be noted that groups of a certain affluence have access to all facilities with affordability indices lower than that affluence index. This means that facilities with indices lower than 0.19 face the greatest strain as they can be accessed by both HIG and MIG, who might wish to lower health care expenditure by visiting these facilities. As a result, these facilities cannot cater only to UP, whom they are meant to service as this segment can access only a limited number of facilities.

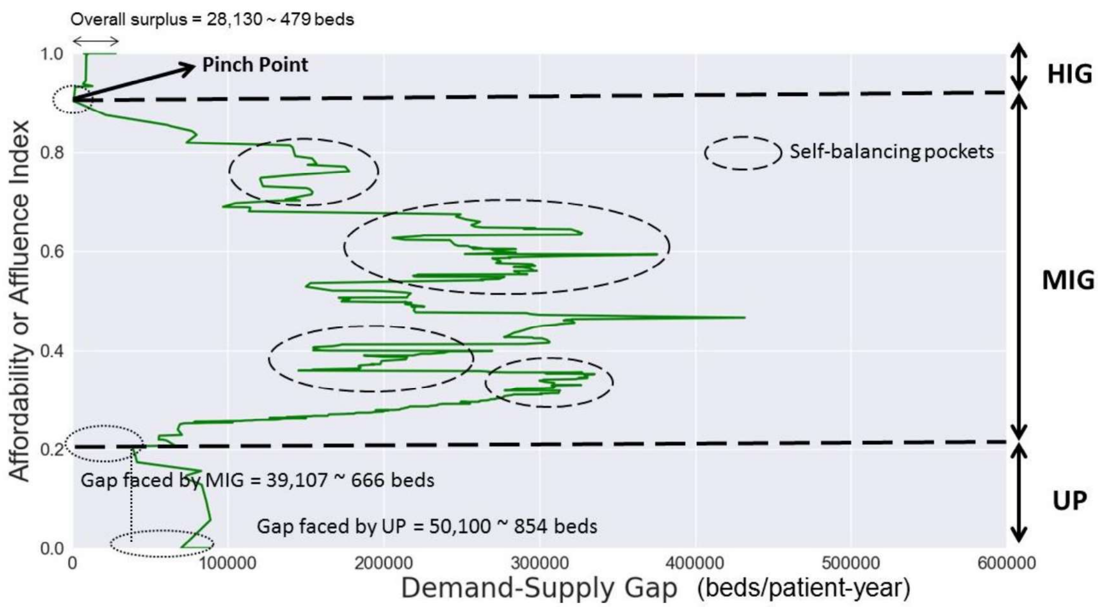

Figure 2. Health service grand composite curve for base case scenario.

Now that the marginalized section has been identified and the gaps in health care service delivery understood, the consequent policy implications of the results are manifold. The gap between demand and supply for MIG was found to be ~ 39,107 beds/patient-year, which can be converted to approximately (39,107/ (365/6.22)) ~ 666 beds. A reactionary policy may be to provide a single multi-specialty hospital with 500 beds (assuming 91 per cent average occupancy rate, as mentioned in Table 1). Multiple facilities may also be provided with the sum of their capacities being 500. It should be noted that this measure is targeted towards MIG only, as UP will not be able to access such a facility. Since MIG has moderate to high levels of affluence, they expect the service quality to be maintained and do not mind paying more for it. This situation is ideal for promoting private investment or public-private partnership (PPP) ventures in health care infrastructure.

The gap experienced by UP is considerably larger and was found to be equal to 50,100 beds/patient-year, which round up to approximately 854 beds using the average bed occupancy period of 6.22 bed-days per patient as stated in previous sections. Assuming the same average occupancy rate, 1000 beds (rounded up to the upper nearest 100 using a ceiling function) need to be provided. NUHM guidelines state that the basic level of health care for UP should be provided through Urban Community Health Care Centers (U-CHCs). Since the capacity of a single U-CHC is 100 beds, a policy solution may be to provide 10 U-CHCs to offset the gap faced by UP. However, it should be kept in mind that since the affordability indices of these U-CHCs are less than 0.19, they can be accessed by both MIG and HIG. Therefore, policy testing becomes essential in order to determine if the gap can be met through 10 facilities or if additional facilities will be required due to down-migratory tendencies of MIG and HIG.

Another important significance of the Pinch point is discussed here. If the Pinch point had been at a point where the indices were equal to a lower value, say 0.80, this would mean that the surplus for people with affluence index higher than 0.80 would be much higher. The implication of this would convey that the people with low affluence have even more difficulty in accessing affordable health care. The Pinch point varies with the study area being considered and appropriate inferences can be drawn according to the explanation provided above.

6. SCENARIO ANALYSIS

In order to determine the feasibility of policies which may lead to improvement of the existing situation, we evaluated some hypothetical scenarios which can be implemented by the government in an effective manner. One important parameter that has been examined through these scenarios is the availability of health insurance, the importance of which has been highlighted throughout this paper.

"*…the burden of dysfunctional health systems is disproportionately felt by the poorest households…They have limited resources to purchase quality services from private providers. Their enrolment in health insurance tends to be marginal. And they are unable to shield themselves from catastrophic health expenditures by drawing on accumulated wealth.*"
- Escobar, Griffin, and Shaw (2011)

In order to counter the above mentioned shortcomings, the Rashtriya Swasthya Bima Yojana was launched by the Ministry of Labor and Employment in 2008, and got transferred to the Ministry of Health and Family Welfare in 2015 (Rumki Basu, 2010). For every household below the poverty line, inpatient medical care insurance of INR 30,000 was provided per family (Devadasan, Seshadri, Trivedi, & Criel, 2013). Hence, we formulated two scenarios examining the effect of availability of health insurance on the gap in in-patient health care delivery.

6.1 Scenario I: Health insurance for urban poor

We explore a scenario where the patients from the first quartile (25 percentile) of wards sorted according to affluence index are provided full health insurance, thereby leading to an increase in their affluence by 13.06%. This situation is important in perspective of providing affordable and efficient health care for UP. We found that the changes in the health service grand composite curve (see Figure 3) are not enough to induce an improvement in reducing the gap faced by different sections of the population. The Pinch point is obtained at 0.90. The increase in affluence is captured in the categorization of UP, which now occurs at an index value of 0.21 instead of the previous value of 0.19. However, the gap faced by UP slightly decreased to 830 beds. The gap of 666 beds experienced by MIG increased to 690. This shows that there would be slight alteration in in-patient health care delivery to the urban poor by providing health insurance to them. However, if the pinch point was lower (say close to 0.1), the discussed policy might have been more beneficial.

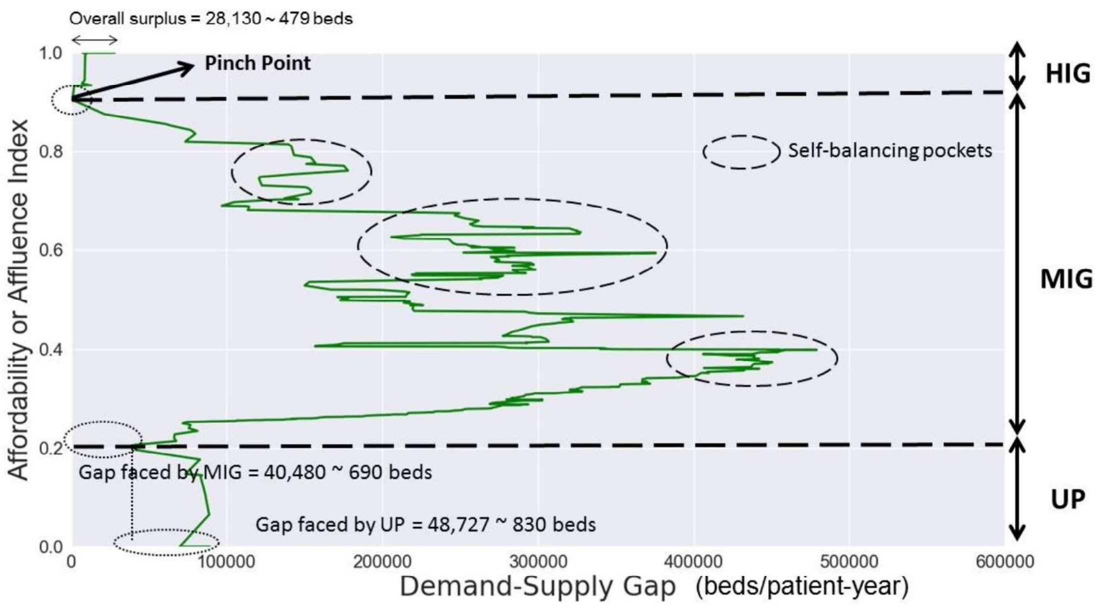

Figure 3. Health service grand composite curve for Scenario I.

6.2 Scenario II: Health insurance for all.

As an extension of this scenario, we examined another situation where full health insurance is provided to the entire population. We found that the changes in the health service grand composite curve (see Figure 3) are not enough to induce an improvement in reducing the gap faced by different sections of the population. The Pinch point is obtained at 0.99, a considerable increase from the 0.90 corresponding to the base case scenario. The increase in affluence did not affect the categorization of UP, for which the index value of 0.2 remained constant with respect to case scenario I. Therefore, the gap faced by UP remained constant at 830 beds, with respect to scenario I. The gap of 690 beds experienced by MIG decreased to 430. This shows that there would be slight alteration for MIG in-patient health care delivery by providing health insurance to all consuming the surplus in HIG.

Although the improvement in the capability and affordability indices of the population might seem desirable, this scenario demonstrates that such an endeavor is not fruitful in isolation.

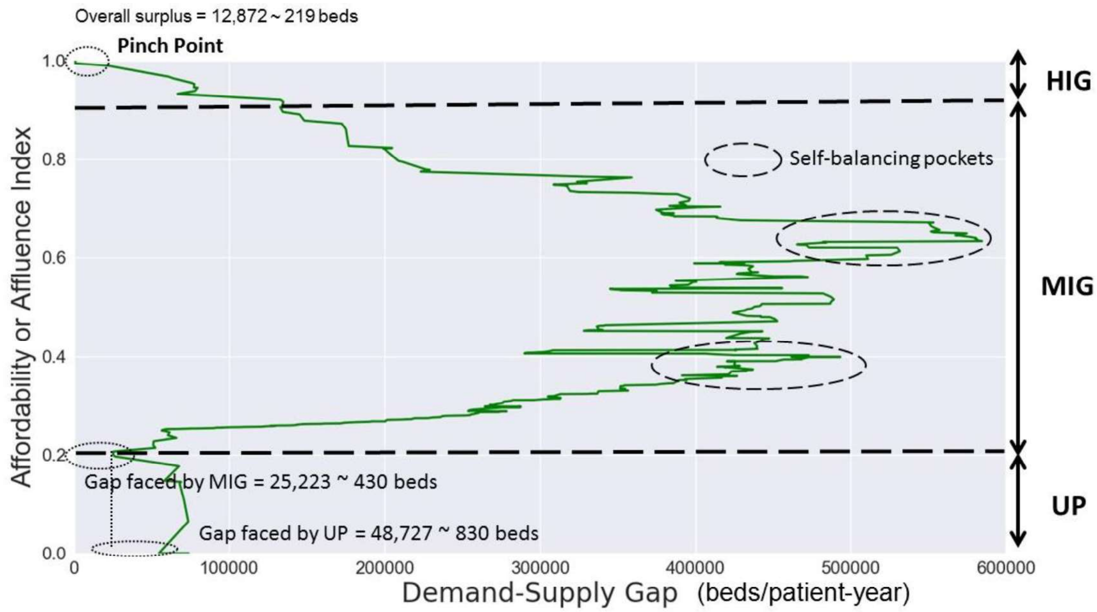

Figure 4. Health service grand composite curve for Scenario II.

6.2 Scenario III: Providing an additional one bed to hospitals with inpatient facilities.

Augmenting one bed to the existing facilities might ensure in reduction of deficit across socio economic status; thereby improving availability of in-patient facilities to all sections. The health service grand composite curve obtained from this scenario is shown in Figure 5. The Pinch point is obtained at 0.90, same as that of the base case scenario.

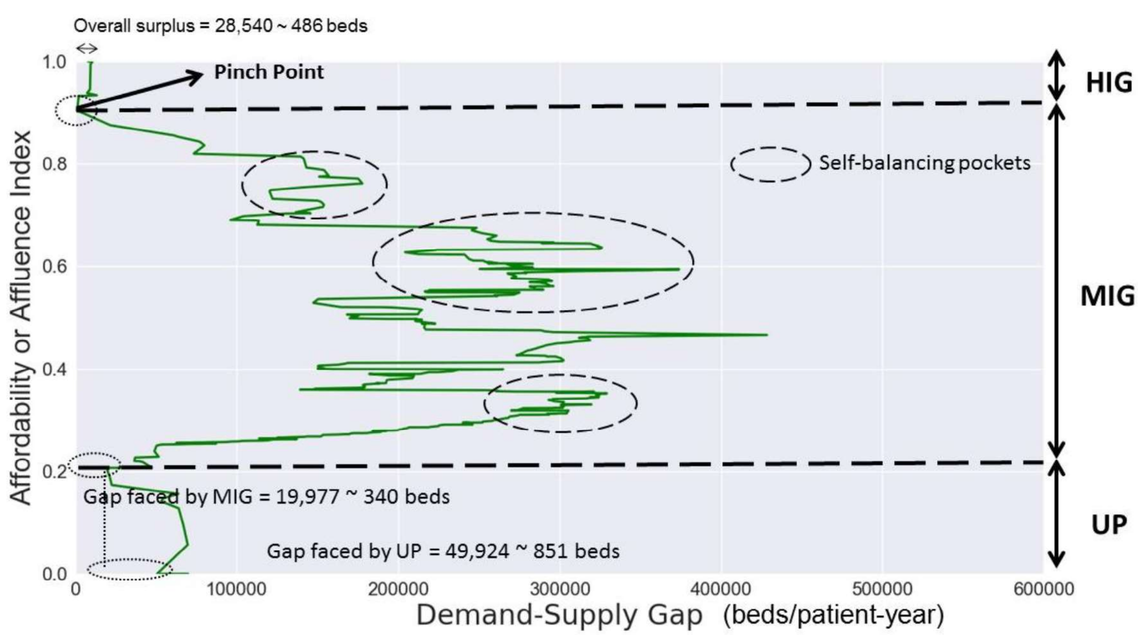

Figure 5. Health service grand composite curve for Scenario III.

It is clear from Figure 5 that the gap faced by MIG has been reduced significantly, for UP a gap of 851 beds remained. An effective strategy to diminish the gap faced by UP might be to set up 10 U-CHCs, as per our earlier recommendations in previous section. However, a scenario analysis would be required before drawing any concrete conclusion.

As a parting note, the thought behind this scenario can be modeled appropriately if the expenses for each bed at a health center are known. This will allow us to categorize availability of beds according to socio-economic strata. A future policy implementation might be to reserve a certain number of beds at each public health facility for a highly subsidized nominal price, along with installation of additional facilities in a targeted manner. While there are several additional scenarios that are interesting to explore, we must limit ourselves to these three for brevity.

7. CONCLUSIONS

Formulation of any health policy requires identification of gaps in equitable access to affordable and effective health care. Keeping with the spirit of providing good health and well-being as per the Sustainable Development Goals, a robust decision framework which can quantify these gaps is proposed by the authors in this paper. The method of *Pinch Analysis* has mainly been applied for optimization of heat and energy systems till date. We explored this concept for investigating the in-patient health care delivery system in the context of developing nations, where the health care facilities (both public and private) thrive by offering services at drastically different prices. This variation in prices has an impact on accessibility by different sections of society, which is primarily governed by disparities. Moreover, polarization of health care facilities in urban areas is observed in resource-constrained communities. In Kolkata, for example, we have two types of demand: (a) people residing in the city of Kolkata itself, and (b) people in-migrating daily for health care needs from adjoining districts as well as states. Therefore, both these demands must be summed up in order to identify the gap. Quantification of this gap is essential in decision making of public health infrastructure financing and to identify the demand of different affordable groups with respect to the different prices of the offered services.

The proposed novel framework is supported by a case study of Kolkata, India where both the gaps and surplus faced by different sections of population are identified. In order to offset these gaps, we offer recommendations for possible policy implementation. A few hypothetical scenarios are also examined in order to understand their importance of *Pinch Analysis* for policy testing. Providing health insurance to the first quartile of population (based on capability indices) did not induce any improvement from the base case scenario. Similar observations were obtained when health insurance was provided to the entire population. However, augmentation of the existing facilities through an increase of one bed, showed that although the gap in MIG segment reduces, without improving the condition of the UP. Therefore, this paper proves that *Pinch Analysis* can be used in the health care sector for: (a) identification and quantification of gaps in health care service delivery, (b) identification of most affected or marginalized sections towards whom future policies should be targeted, and (c) testing of these proposed policies to determine feasibility based on system impacts.

Future research efforts may focus on multi-criteria decision analysis to establish the exact locations and capacities of the new proposed health center(s). Such efforts should aim to keep contextual health care policy constraints in mind, which is found lacking from current frameworks in operations research. Policies also tend to bring about a change in people's health-seeking behavior which can be explored in tandem through feedback loops to arrive at an optimal set of policies. Finally, additional frameworks can be formulated to answer other critical questions pertaining to the health care sector.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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