Estimating spatially specific demand and supply of dental services: a longitudinal comparison in Northern Germany

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Abstract

Objectives: Assessing the spatial distribution of oral morbidity-related demand and the workforce-related supply is relevant for planning dental services. We aimed to establish and validate a model for estimating the spatially specific demand and supply. This model was then applied to compare demand-supply ratios in 2001 and 2011 in the federal state of Mecklenburg–Vorpommern (Northern Germany).
Methods: The spatial units were zip code areas. Demand per area was estimated by linking population-specific oral morbidities to working times via insurance claim data. Estimated demand was validated against the provided demand in 2001 and 2011. Supply was calculated for both years using cohort data from the dentist register. The ratio of demand and supply was geographically mapped and its distribution between areas assessed using the Gini coefficient.
Results: Between 2001 and 2011, a significant decrease of the general population (−7.0 percent), the annual demand (−13.1 percent), and the annual supply (−12.9 percent) was recorded. The estimated demands were nearly (2001: −4 percent) and completely (2011: ±0 percent) congruent with provided demands. The average demand-supply-ratio did not change significantly between 2001 and 2011 ($P > 0.05$), but was increasingly unequally distributed. In both years, few areas were over-serviced, while many were under-serviced.
Conclusions: The established model can be used to estimate spatially specific demand and supply.

Introduction

Dental services planning in Germany aims to secure a "widespread, adequate and accessible" service (1,2). This aim is challenged by a demographically changing and increasingly unequally distributed demand on the one side, and a spatially polarized, more female workforce with reduced clinical working hours on the other side (1,3).

Planning dental services is relevant given that several rural areas in Germany are already under-serviced by general practitioners (4). Such under-servicing mostly affects those with low mobility and high needs (5), and increases the existing unequal distribution of health between populations (6-9). For dentistry, this phenomenon has only been sparsely assessed, with ambiguous results. While some studies could not find an association between service provision and health outcomes (10,11), others confirmed a relationship between supply, demand, and oral health (12-14). Overall there does not seem to be generalized under-servicing in most industrialized countries, but an increasingly unequal distribution of both supply and demand (15,16).

Thus, there is the need to assess how dental workforce quantities and qualities relate to the demand for services in different spatial units. Such a spatially specific demand-supply model could be used to not only assess current service provision, but also to predict future demand-supply ratios in different spatial units. For Germany, there have been attempts to link sociodemography and oral morbidities with reported demand patterns, and to extrapolate these to predict future demand on an average national level (2). Within the present study, we aimed at advancing these efforts to establish and validate a spatially specific demand model. This model was then applied to compare demand with supply of dental services in 2001 and 2011 in Northern Germany via small-area based geographic analyses.

Methods

Study design

This study compared demand and supply of dental services in the Northern German federal state Mecklenburg–Vorpommern, which is characterized by a dynamic and increasingly polarized demographic constitution and an ageing dental workforce. We first calculated local supplies of dental services using the dentist register of the state, accounting for changing workforce characteristics (gender proportion) and working patterns (weekly working hours) in 2001 and 2011. Then, we established a model to estimate the local demand for dental services by linking population and oral morbidity data with the required time for fulfilling the resulting demands using insurance claim data. The constructed model was built on the assumption that the available supply was sufficient, that is, that provided services matched demand, and based on estimates from 1999 and 2000, as all data was available for these years. This demand model was then validated by comparing the predicted demand for dental services with reported services provided in 2001 and 2011. Eventually, demand and supply were compared, and the spatial distribution of the ratio between demand and supply analyzed statistically and geographically.

Supply of dental services

To assess changes in the supply of dental services in different spatial units, we used two datasets. The longitudinal dental workforce register of the dental association of Mecklenburg–Vorpommern was evaluated for data ranging from 2001 until 2011. As maintenance of anonymity of entries was required, only data on zip code level was accessible, with zip code areas (ZCAs) being used as spatial units for subsequent analyses. Only dentists which were clinically active, either as practice owner or employed dentists, were used to calculate the potential supply. Clinical working time was estimated based on repeated cross-sectional data published by Dental Public Services (17). This dataset provided mean weekly clinical working time estimates for the 5 federal states which formerly belonged to the German Democratic Republic (Eastern Germany), including Mecklenburg–Vorpommern. We used data only for these states, as working time differs between the Western and Eastern German States (17). As working time differences between genders have been reported (2), weekly working time was calculated separately for male and female dentists in 2001 and 2011. It should be noted that such differences have been found for different age groups of dentists, too (18). However, no such data was available for Germany, which was why age-dependent working times were not modeled. Given that under the auspices of German healthcare, the role of dental auxiliaries is limited (hygienists or other staff are not allowed to work independently from the dentist, and dental therapists do not even exist), our model did not account for services being provided by other professionals than the dentist. To calculate the annual potential supply, 43 working weeks per year were assumed (2,17).

Demand for dental services

The demand in 2001 and 2011 was estimated based on four datasets. First, oral morbidity [number of decayed, missing, filled teeth, proportion of the population with Periodontal Screening Index (PSI) code >3] in different age groups was estimated for 1999-2001 and 2011 based on extrapolation of repeated cross-sectional data from the German Oral Health Studies (19,20). No separate estimation for different genders was made, as gender differences were assumed to be limited and gender distribution was not expected to change significantly between 2001 and 2011. Second, we defined five dental treatment complexes (conservative/surgical dentistry, prosthetics, periodontology, orthodontics, prophylaxis), and assigned key items of the statutory dental fee catalogue (BEMA) to each of these complexes. Then, the known provided treatments in 1999 and 2000 (2) were transformed into provided treatment time by linking them to national dental working time data for 1999 and 2000 (2,21). Third, provided service quantities (in annual hours) per treatment complex (fee item) were linked to socio-demographic and oral morbidity data as follows: The number of decayed and filled teeth were linked to restorative and surgical treatment quantities, missing teeth to prosthetic treatment quantities, and cases with PSI >3 to periodontal treatment quantities, accounting for the average number of remaining teeth in different ages groups. The demand in these complexes was assumed to decrease in people aged 70 years or older (22). Note that other variables affecting the translation of need into demand (e.g., educational degree, income, and general health) were not introduced in the demand estimation given the lack of spatially specific data for such modeling (23,24). Similarly, as our study investigated services provided under the tenets of the statutory insurance only, individual insurance status as enabler or barrier for demand was not modeled (24). The number of individuals aged 15 years or younger was linked to orthodontic and prophylactic treatment quantities, as only children and adolescents are eligible for such treatments under the German statutory health insurance.

District-specific sociodemography and morbidity data for 2001 and 2011 (25) was then transformed onto each ZCA, and the local demand (in annual hours per ZCA) calculated. The total estimated demand in the federal state was validated against the reported demand in both years (21). Note that for this validation, prosthetic treatment quantities provided in 2011 needed to be calculated using diagnostic related group data, as the latter superseded fee items (26).

Table 1 Sociodemography, Demand and Supply of Dental Services in Mecklenburg–Vorpommern in 2001 and 2011

	2001		2011		Changes 2011 versus 2001
Population	1,759,709		1,634,734		−7.0% ($P<0.001$)
Mean age (years; male/female)	41.2 (39.3/43.1)		45.8 (44.2/47.4)		+11.2% ($P<0.001$)
Demand (annual hours)	Predicted (proportion of overall demand in %)	Reported (deviation from predicted in %)	Predicted (proportion of overall demand in %)	Reported (deviation from predicted in %)	
Conservative-operative	877,610 (50%)	833,838 (−5%)	731,981 (48%)	711,190 (−3%)	−16.6% ($P<0.001$)
Prosthetics	532,140 (30%)	611,581 (+12%)	496,508 (33%)	517,886 (+4%)	−6.7% ($P<0.001$)
Periodontology	104,864 (6%)	105,762 (+1%)	97,787 (6%)	97,778 (±0%)	−6.8% ($P<0.001$)
Orthodontics	168,345 (10%)	196,167 (+15%)	139,252 (9%)	132,669 (−5%)	−17.3% ($P<0.001$)
Prophylaxis	65,367 (4%)	70,396 (+7%)	54,071 (4%)	48,099 (−12%)	−17.3% ($P<0.001$)
Total	1,748,326 (100%)	1,817,747 (+4%)	1,519,598 (100%)	1,507,625 (±0%)	−13.1% ($P<0.001$)
Dentists					
Total (male/female)	1,449 (590/859)		1,312 (525/787)		−9.5% ($P<0.001$)
Age (years – male/female)	45.2 (45.2/45.2)		50.8 (50.6/51.0)		+12.4% ($P<0.001$)
Weekly working hours (male/female)	35.9 (38.8/33.8)		34.5 (37.4/32.5)		−3.9% (n/a)
Supply (annual hours)	2,232,690		1,945,256		−12.9% ($P<0.001$)
Population per dentist	1,435 (1,099/2,116)		1,451 (1,093/2,176)		+1.1% ($P>0.05$)
Ratio demand/supply	105% (65%/142%)		98% (59%/143%)		−6.7% ($P>0.05$)

The ratio of demand per supply indicates the potential over- or under-servicing. If not given otherwise, median and 25th/75th percentiles are given. Differences between 2001 and 2011 were assessed for statistical significance ($P<0.05$/Wilcoxon), with ZCAs or dentists being the units of statistical analysis.

Note also that district level calculations accounted for district mergers between 2001 and 2011.

Analyses

Sociodemographic variables (population density, mean household income, proportion of inhabitants with higher educational degree, proportion of inhabitants in work, mean land prices) were obtained from the state offices for statistics. Sociodemographic variables, supply and demand for dental services were analyzed descriptively, and statistical comparison between 2001 and 2011 performed using Wilcoxon's ranked sum test. Statistical significance was assumed if $P<0.05$. To estimate changes in the spatial distribution of the ratio between demand and supply (<100 percent under-serviced, >100 percent over-serviced), the Gini coefficient was calculated. The Gini coefficient is commonly used to assess income inequality and ranges from 0 (perfect equality) to 100 (complete concentration of income). It is derived from the Lorenz curve, which plots income percentiles per population percentiles (27,28). We fitted the Lorenz curve by plotting all supply per demand percentiles.

Demand-supply ratios were geographically mapped, and assessed for clustering or dispersion of supply and demand. Such patterns have been observed before (29) and are in line with various theories of migration (see below). Global spatial autocorrelation between surrounding ZCAs was assessed using Moran's I (30). Positive autocorrelation (near +1.0) indicates clustering in neighboring areas, negative autocorrelation (near −1.0) indicates spatial outliers (dispersion). Local Indicators of Spatial Autocorrelation (LISA) analysis was performed to measure and display clustering of ZCAs. Autocorrelation means that a value at a certain location is associated (and similar) to a value of spatial neighbors. Global indicators (e.g., Moran's I) are unable to display such localized patterns.

We further assessed if sociodemographic variables had predictive value for the ratio between demand and supply using generalized linear modeling (GLM). Variable choice was guided by data availability and economic theory on migration, with the migrating individual being regarded as an investor in his/her own value (31). In this theory, individuals (dentists) migrate according to the value of the opportunities at different destinations (higher income in affluent or densely populated areas, greater amenities in urban areas, with better availability of schools or medical services, etc.) after subtracting the costs of moving (investment in future practice, loss of secure income at present destination, associated social costs), thus maximizing their financial, social and political net benefits. Previous studies (32,33) had built on a range of variables, with some of them being available for the present evaluation, that is, population density and land price as proxies for urbanization and the associated amenities, annual household income and the proportions of

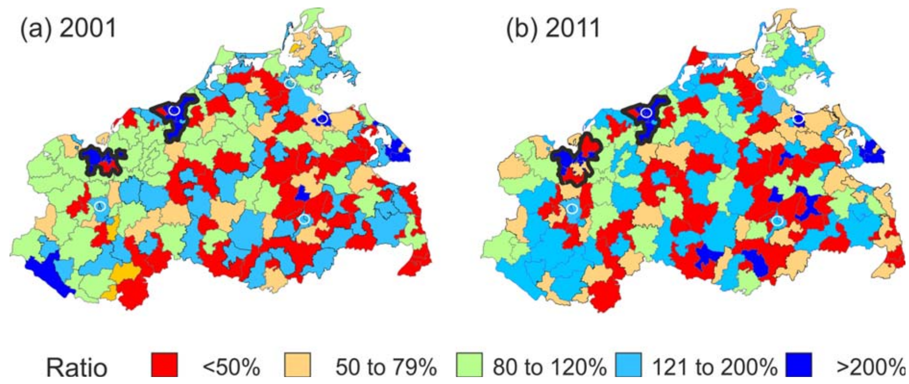

Figure 1 Ratio of demand and supply in 2001 (a) and 2011 (b) in different spatial units (ZCAs). Under-serviced areas (supply less than 50% or between 50 and 79% of the demand) are indicated by red and orange, respectively, while over-serviced areas are indicated by turquoise and blue (supply 21% or more above demand). Areas where demand and service seem to match are shown in green. The five biggest cities (>50,000 inhabitants) are shown by white circles. Areas with spatial clustering (high–high, i.e., blue–blue, and low-high, i.e., blue-red,) are highlighted by an accented border.

the population in work and with higher education degree (as measures for potential dentist income). The employed predictors were available on the district level only, and were distributed to all ZCAs in each district.

GLM was performed using the abovementioned parameters as independent variables, and the demand-supply ratio in different spatial units as the dependent variable. Variables were simultaneously entered, and those with a variable inflation factor >5 removed to reduce multicollinearity. Variables not significantly contributing to the model ($P > 0.1$) were then excluded stepwise (backwards selection). Statistical and spatial analyses were performed using SPSS 20 (IBM, Armonk, NY, USA) and ArcGis 10.2 (Esri, Redlands, CA, USA), respectively.

Results

Between 2001 and 2011, there was a significant decrease of the statewide population (−7.0 percent, $P < 0.001$) and the demand of dental services (−13.1 percent, $P < 0.001$). Nearly 50 percent of the demand was for conservative-surgical services, while that demand for periodontal services and prophylaxis made up 6 percent or less (Table 1). The greatest relative decrease in demand between 2001 and 2011 was found for orthodontic and prophylactic services, the smallest relative decrease for prosthetic and periodontal treatments. Given its absolute share of provided services, the absolute decrease was greatest for combined conservative-surgical services. Overall, the relative share of different treatment complexes per total demand was largely stable in the evaluated decade. Validation of the model found only limited deviation of predicted from reported demands (Table 1).

The number of active dentists decreased (−9.5 percent, $P < 0.001$) and the dental workforce aged between 2001 and 2011. Overall, the supply decreased significantly (−12.9 percent, $P < 0.001$) (Table 1). The average ratio of demand per supply did not change significantly between 2001 and 2011 (−6.7 percent, $P > 0.05$), but was more unequally distributed between ZCAs in 2011 (Gini-coefficient 44.4) than 2001 (41.9).

Table 2 Results of Generalized Liner Modeling

	2001		2011	
	Mean (range)	GLM Mean coefficient (95% CI)	Mean (range)	GLM Mean coefficient (95% CI)
Model fit		X^2=12.49, P=0.029		X^2=10.83, P=0.055
Population density (pop./km^2)	119 (18-1535)	**0.1 (0.0/0.3)**	116 (16-1481)	0.0 (0.0/0.1)
Annual household income (Euro)	13328 (12795-14282)	0.0 (−0.1/0.0)	16373 (15167-17457)	0.0 (0.0/0.0)
Land price (Euro/m^2)	48 (38-84)	0.4 (−0.1/1.4)	44 (31-100)	0.5 (−0.7/1.7)
Proportion in work (%)	42 (39-44)	5.6 (−2.6/14.2)	47 (39-54)	−2.8 (−6.4/0.8)
Proportion with higher education (%)	12 (10-12)	4.6 (−3.5/12.7)	17 (14-25)	1.9 (−2.4/6.2)

Generalized linear modeling (GLM) was performed to assess a potential association between sociodemographic variables of each spatial unit and the ratio between demand and supply. Descriptive values (mean, ranges) are shown for both years. GLM fitted moderately in 2001, with one variable (in bold) showing a significant association. GLM did not find any variable to have significant predictive value in 2011.

Geographic mapping indicated a large variance in the demand-supply ratio with some areas being greatly over-serviced, but many ZCAs being under-serviced. This polarization was increased in 2011 compared with 2001. Significant spatial autocorrelation was observed neither in 2001 nor in 2011 (Moran's $I=0.18$; $Z=1.79$, $P>0.05$ in both years). LISA identified two clusters, one with high–high and one with high-low clustering (Figure 1).

Potential predictors of the demand-supply ratio were submitted to GLM (Table 2). For 2001, only one predictor (population density) showed statistical significance, with an increased ratio (potential over-servicing) in densely versus less densely populated areas. The overall fit of the model was very limited ($P=0.029$). For 2011, no variable showed any statistical significant effect (Table 2).

Discussion

The present study established and validated a model to assess spatially specific demand of dental services. Demand and supply was then estimated for 2001 and 2011 for a Northern German state, indicating an increasingly unequal spatial distribution of the ratio of demand and supply. Our approach seems suitable for assessing spatial patterns in the availability of dental services and identifying spatial areas at risk of over- or under-servicing. This approach could be applied in future studies for predicting small-area demand and supply.

Based on our results, the shrinkage and ageing of the assessed population combined with changes in oral morbidities led to a decrease in the statewide demand in 2011 compared with 2001. The composition of this demand saw limited change, reflecting the limited relative changes in oral morbidity (number of decayed or lost teeth, etc) in the evaluated decade. It is likely that in the future, the demand for certain services will increase (e.g., a greater number of teeth will be retained, potentially increasing the need for periodontal treatment needs), while others will decrease (e.g., tooth replacements). Concurrently, despite shrinking and ageing, the statewide dental workforce seemed sufficient to secure the required supply. More important, there was a severe spatial misdistribution of the ratio between demand and supply. Based on the central place theory, which has been found to apply to medical service supply before (34), such results are not unexpected, as are our findings of certain clustering in or around urban areas. Identifying such spatial inequalities and quantifying these will be helpful for service planners, for example, to tailor interventions to tackle such imbalances.

To our knowledge, this is the first spatial model for estimating both demand and supply for dental services. The used method allows one to estimate demands based on expected or known local demography and morbidity. Therefore, compared with studies calculating dentist-per-population densities, our approach allows more precise and detailed calculations not only of demand quantities, but also qualities. If applied to predict future areas with over- and under-servicing, the availability of sociodemographic variables on zip-code area level might be desirable to increase the precision, as district level data might be too coarse. For detailed service planning, dentist data on a smaller-than-zip-code level might be helpful, allowing an analysis of access (means of transportation), too. Similar studies in general medicine have combined census and morbidity data and simulated the local supply and demand on the individual or household (i.e., micro-) level both statically and dynamically (over time) (35,36).

The constructed model and the underlying data have several limitations. First, our demand model was built on the assumption that in 1999 and 2000, demand and supply quantities were congruent; this assumption is unlikely to hold true, but was required to set a reference standard. In this sense, one should pay more attention to changes in the demand-supply ratio over time or differences between spatial units, than absolute values. It can, however, be expected that demand-supply ratios below 50 percent or above 200 percent indicate under- and over-servicing regardless of the underlying reference.

Second, we used insurance claim data, which does not necessarily reflect demand, as service provision can be assumed to be determined by a great many factors. Moreover, treatment patterns (claimed items) might change with time, which is why the model should be regularly adjusted. Demand itself is likely to be influenced not only be needs (oral morbidities), but also by supply-side factors, which was not accounted for. Moreover, spatially specific enabling and predisposing factors (educational and income factors, insurance status, general health) will affect demand (37). The translation of needs into demand might differ between federal states or different countries (38), as healthcare system-factors will play a role (as will the state- or country-specific proportions of differently insured individuals). Thus, more detailed and small-scaled data regarding oral morbidity and its association with demand are needed.

Third, systematic effects on treatment provision are likely, with macroeconomic and healthcare-specific changes potentially distorting our estimates. One example of such changes are the described introduction of diagnostic related groups in prosthetic dentistry, which was shown to alter service patterns (39). Similarly, a changed provision and consumption of specific treatments might impact on demand (e.g., composite restorations needing renewal earlier or later than amalgams, or repairs being performed more often on composites than amalgams).

Fourth, our demand model was built on claim data of the statutory insurance. This was acceptable for Mecklenburg–Vorpommern given its low proportion of privately (nonstatutory) insured patients (4 percent) (40). Attempts should be made to integrate demands for otherwise reimbursed or privately paid (out-of-pocket) services, as these were shown to differ in different insurance systems (24). Individual differences are likely to be modified by age. Our assumption of age only impacting on demand above a certain threshold is a simplification, while insufficient data is available to model the relationship between age and demand more realistically (23,24).

Fifth, we did not incorporate possible effects of dentists' age on working times, as no data for Germany was available to support such age-dependent supply simulation. Given that, as shown, the workforce is ageing significantly, an age-dependent decrease in the working hours per dentists might well have an impact on our overall estimates. Conversely, future dental services in Germany might be provided by dental auxiliaries to a greater share (as is the case in many other countries). Combined with a greater productivity (e.g., via CAD-CAM assisted prosthetics, rotary endodontics, one-step adhesive systems, etc.), this might increase the supplied services despite a shrinking and ageing workforce of dentists. Last, our supply model accounted for migration of dentists between zip-code areas in the decade, but did not assess any in- or outflow of dentists to or from other federal states or beyond national borders. While such migration of dentists from or to Germany is limited (41), it might be relevant in other countries and should be integrated into the model.

In conclusion, the present study demonstrated how oral morbidity and demographic data can be used to estimate the spatially specific demand for dental services. Using the outlined approach, the local demand can be assessed both quantitatively and qualitatively. Moreover, spatially mapping demand and supply allows to identify areas with current or future over- or under-servicing (42), and to describe or monitor the distribution of demand-supply ratios between spatial units.

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