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# ***Assessing a population's need for healthcare***

## *The role of multimorbidity*

vorgelegt von:

Isabel Desirée Geiger

aus:

Bregenz, Österreich

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| | |
|---|---|
| **First evaluator:** | Prof. Dr. Leonie Sundmacher |
| **Second evaluator:** | Prof. Dr. Eva Grill |
| **Third evaluator:** | Priv. Doz. Dr. Andrea Vodermaier |
| **Fourth evaluator:** | Priv. Doz. Dr. Daniela Koller |

| | |
|---|---|
| **Dean:** | **Prof. Dr. med. Thomas Gudermann** |

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# Table of content

# Abstract (English):

The need for healthcare corresponds to the level of treatable morbidity in a population and is a vital component in healthcare planning to estimate the required number of physicians. As such, the need for healthcare is a complex construct that is ought to be approximated through a robust theoretical concept, considering central indicators. However, a systematic assessment of current methodologies to estimate needs-based supply of physicians using central requirements is missing. In Germany, physician planning follows a supply-based approach using physician-to-population ratios, which are adapted with a demographic factor. In recent years, it was found that multimorbidity (the occurrence of multiple conditions in one individual) is correlated with healthcare utilisation and it has seen a steady increase in prevalence. Thus, multimorbidity as a central driver of need was declared a major challenge for health systems – including Germany – as health systems are centred on single-disease treatment approaches and fragmented in the provision of healthcare. Yet information on the distribution of multimorbid individuals is ambiguous.

This thesis aims to enhance knowledge in both areas: (1) needs-based planning of physicians and (2) necessity to integrate regional multimorbidity in office-based physician planning.

First, a methodological review was conducted to assess current approaches that estimate needs-based supply of physicians through a set of quality criteria while determining the role of multimorbidity. The review highlighted differences in the conceptual frameworks, data bases, modelling approaches and integration of future trends. It was also found that approaches estimating needs-based supply of physicians against quality criteria revealed several weaknesses and methodological gaps, with none of the studies meeting all quality criteria. Importantly, no incorporation of multimorbidity measures in needs-based physician planning was found.

Second, a cross-sectional study was conducted to analyse regional variations of multimorbidity levels in four physician disciplines in Germany: General practitioners (GPs), neurologists, ophthalmologists, and orthopaedic specialists. Bernoulli cluster analysis was applied to detect high-rate and low-rate clusters of multimorbid patients per discipline, with the results tested for robustness through spatial autocorrelation mapping. Additionally, high-rate clusters were compared with the available supply of physicians. The study identified significant variations in the regional distribution of multimorbidity levels. High-rate clusters with varying size and location were predominantly found in central and eastern Germany for all physician groups. The comparison of high-rate clusters with supply demonstrated that almost all high-rate clusters of specialised physicians were met by average supply that exceeded the targeted coverage, but high-rate clusters of GPs were met with average supply below targeted coverage in 5 out of 11 clusters.

To conclude, the methodological weaknesses identified in the systematic review can now be tackled by policymakers and scholars alike to improve future needs-based planning of physicians. Moreover, the variations in regional distribution of multimorbidity clusters highlight the importance of integrating multimorbidity measures when estimating the need for office-based physicians. These findings can be used as an additional resource to reform German physician planning as it will help to direct the planning focus on areas of increased need for healthcare services and care coordination. Given the situation in general practice, improvements in GP care should be targeted most urgently.

# List of figures

# List of tables

# List of abbreviations

ACG – Adjusted Clinical Groups

AVZ – Angepasste Verhältniszahlen

BW – Baden-Württemberg

BY – Bavaria

BE – Berlin

BB – Brandenburg

CL – Cluster

CIRS – Cumulative Illness Rating Scale

DALY – Disability-adjusted life years

EU – European Union

GP – General practitioner

HB – Bremen

HH – Hamburg

HE – Hessen

ICD – International Classification of Diseases

JBI – The Joanna Briggs Institute

KBV – Kassenärztliche Bundesvereinigung

KR – Kreisregionen

NI – Lower Saxony

MB – Mittelbereich

MMAT – Mixed Methods Appraisal Tool

MV – Mecklenburg-Vorpommern

NW – North Rhine-Westphalia

PRISMA – preferred reporting items for systematic reviews and meta-analyses

RP – Rhineland-Palatinate

SL – Saarland

SN – Saxony

ST – Saxony-Anhalt

SH – Schleswig-Holstein

TH – Thuringia

WHO – World Health Organization

# 1. Introduction

## 1.1 Need for healthcare

### 1.1.1 Definition

Need is a complex concept without a uniform definition. In his taxonomy of need, Bradshaw [1] defined four types: the normative, the felt, the expressed and the comparative need.

(I) The *normative need* is the need of an individual as identified by norms laid down by experts and/or administrators. Norms, however, are dependent on the prevailing knowledge and the social values at the time they were laid down, which may be subject to change. An example of normative need in the context of health service planning would be mandatory vaccinations for individuals.

(II) The *felt need*, also referred to as subjective need, is perceived by the individual and thus, limited to their perceptions which are biased as the individual might not know a service exists or might not be willing to express the need truthfully. Thus, overprediction and underprediction of need in a population might be the result. An example of a felt need would be having stomach-ache.

(III) The *expressed need*, equal to the demand, is felt need which is acted upon. Thus, under the expressed need all demanded services are considered. A limitation of the expressed need definition is that it includes the bias of felt need and adds the dependency on existing supply. One example which can be applied for health services planning would be to use waiting lists as proxy for unmet need.

(IV) The *comparative need* is based on characteristics of a population which is receiving certain services and has been used for individual as well as area assessment of need. These services are then compared to the services received by a similar group. If other individuals with resembling characteristics do not receive certain services, then they are assumed to be in need of that service. One example for comparative need is to register risks such as birth trauma of infants who require special care, which are then used to identify infants at risk of special care early.

Bradshaw argues further that the four definitions of need can overlap fully or to only some extent in several variations, with an overlap of all definitions being most reasonable to identify the actual need of a population [1].

After considering the definition of need as a combination of the four types of need, it is vital to distinguish the need for healthcare from the need for health, as the latter entails all shortfalls in health including those that cannot be treated by health services currently available. In turn, the need for healthcare is very specific and refers to a population's capability to profit from healthcare services and interventions [2]. Matthew [3] and Cochrane [4] added to this specification that the healthcare service or intervention needs to be at reasonable costs.

A frequently used definition by Culyer [5] specifies the term ‘reasonable costs’ further as the least amount of resources needed to fulfil an individual’s potential to benefit from healthcare [6]. By doing so, he argues to ensure that need measures are easily interpretable, directly derived from healthcare systems, applicable in the context of horizontal and vertical distribution, person- and services-specific, linked to resources, and are not producing inequitable results [5]. This definition necessitates the accessibility of appropriate treatments and services to improve health outcomes or quality of life [5, 7, 8]. Moreover, Culyer stresses that a treatment should not be classified as appropriate if another identically effective and less resource-intensive treatment is available [5].

Accordingly, the need for healthcare corresponds to treatable morbidity and should be considered a complex construct which cannot be measured directly but must be approximated through a well-grounded theoretical concept, based on central indicators that are related to the need for healthcare [9, 10]. Figure 1 illustrates a systematisation of central indicators that are directly or indirectly related to the need for healthcare for the purpose of this thesis.

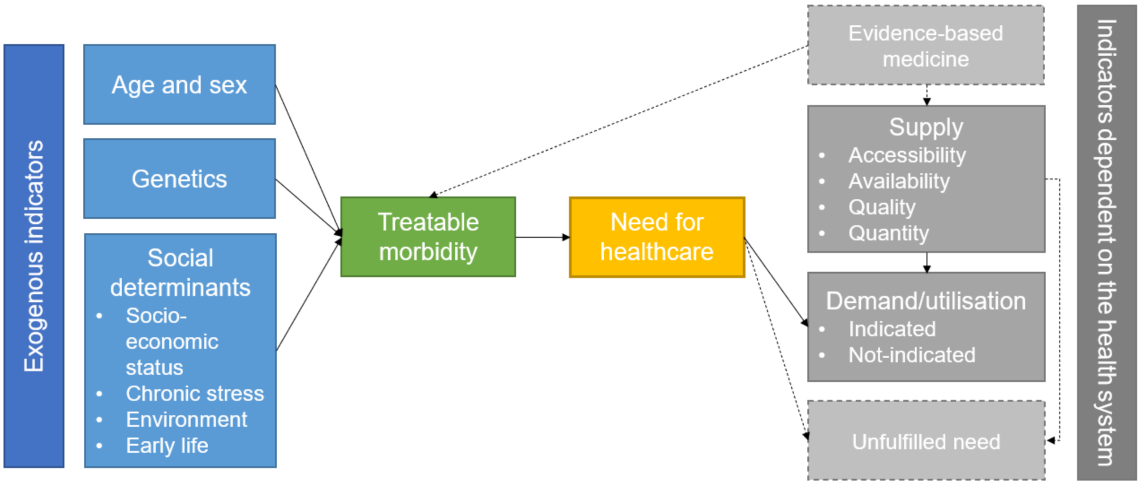


Figure 1 Systematisation of central indicators related to the need for healthcare.

Source: adapted from Sundmacher et al. [10]

### 1.1.2 Indicators related to the need for healthcare

#### 1.1.2.1 Supply-based indicators

The need for healthcare matches morbidity that responds to treatments and healthcare services. Thus, it is influenced by supply dependent factors, including the state of evidence-based medicine. Moreover, treatments and services ought to be cost-effective for a disease to correspond to healthcare needs [6]. Therefore, available supply and related factors which are part of the healthcare system may reflect the need for healthcare if the quantity and quality of healthcare services [11] as well as availability and accessibility of appropriate services over space and time is ensured [6].

However, when relying on supply-dependent factors as the main or only indicators of need, existing inequities in access to care and/or availability of treatments (resulting in unfulfilled need or unindicated demand) are carried forward [12–14]. To account for potential biases in supply-based indicators (e.g. due to variable access to care), indicators such as waiting times or missed appointments can be considered in addition to independent variables related to the need to improve the approximation of the need for healthcare [6].

#### 1.1.2.2 Demand/utilisation-based indicators

The demand for healthcare can be described as the level of utilisation until the conceived marginal benefits of healthcare equal the marginal cost (indirect and direct) of accessing care. Beyond this point, costs offset benefits and an individual will not make use of available healthcare [6]. Thus, demand for healthcare is influenced by healthcare costs to a considerable degree, which are in turn affected by the availability of health insurance, type of health insurance, benefits as well as patient's contributions or out-of-pocket payments [15]. Accordingly, demand-dependent indicators may reflect the need for healthcare if costs do not limit the utilisation of appropriate and cost-effective healthcare services to treat the underlying morbidity.

Nevertheless, relying on utilisation-based indicators to estimate the need for healthcare may lead to overestimation or underestimation of actual need in a population due to patient preferences, availability of care, including affordability of healthcare costs, insurance or time off work, as well as provider incentives such as supply-induced demand [16–19]. Additionally, a recent study found that the availability of health insurances (either private or public) improved access to care but did not promote cost-effective healthcare services [20]. Thus, indicators of healthcare utilisation such as outpatient visits or healthcare expenditure rates reflect the need for healthcare only partially [21]. To account for potential biases from demand-based indicators, which approximate imbalances such as estimates of under detected diseases, uninsurance rates, or uptake rates of routine vaccinations, can be considered conjunct with other factors, including morbidity measures and endogenous indicators [6].

### 1.1.2.3 Exogenous indicators

The need for healthcare correlates with indicators of treatable morbidity independent from the healthcare system, such as demographic variables, individual genetics, and social determinants of health [22–28].

Demographic variables of a person, such as age and sex may significantly influence the likelihood for developing acute and chronic diseases [22–27]. Multimorbidity, for example, appears to be more frequent in women compared to men over all age groups, and both sexes show different disease patterns, with men primarily suffering from several cardiometabolic diseases and women from skeletal and/or mental disorders [29, 30]. Additionally, age and sex may also influence the outcomes and the utilisation of healthcare services [31]. Thus, both indicators are factors to consider when assessing the need for healthcare.

The genetic disposition is known to have an influence on the morbidity of an individual as certain genomes have been associated with specific diseases [28]. Recently, these genetic risk factors were also linked to disability-adjusted life years (DALY) to measure their impact on the quality of life on an individual and population level, which can be used to approximate the need for healthcare [32].

Social determinants of health are social and economic factors that correlate with the need for health services [33]. The socioeconomic status of a person, including education, income, wealth, housing and employment, is associated with the risk of diseases (e.g. obesity) based on factors such as health behaviour (e.g. level of activity) and health literacy [27, 34–37]. Also, chronic stress is known as a risk factor for developing medical conditions, most predominantly cardiometabolic diseases [38]. An individual's health status is also affected by the living and working environment. Regional deprivation (e.g. from air and/or noise pollution) can directly impact health outcomes but also indirectly influences health behaviour such as physical activity levels [27, 39]. Another social determinant which needs to be stressed in this regard are the early life experiences of a person, starting with maternal stress and nutrition during pregnancy, which have a significant influence on the morbidity in later life [40–44]. Maltreatment in childhood (including physical, emotional, sexual abuse, or neglect) was also found to have a significant impact on the development of chronic conditions in adulthood [44]. Additionally, experiencing economic crises in early childhood, like the post-war period in Germany after World War II, was found to be related to an expansion in morbidity in the population when aged 65-71 years [45].

As exogenous factors indirectly approximate the need for healthcare over treatable morbidity, they depend on the accuracy of the relationships between exogenous factors and morbidity levels. Potential inaccuracies due to changes in these relationships may result in over- or underestimations of need. Thus, it is important to regularly reassess established relationships and to combine estimates from exogenous factors with, for instance, other measures of morbidity to ensure that the need for healthcare is accurately predicted [10].

#### 1.1.2.4 Treatable morbidity

Treatable morbidity, including one or several cooccurring diseases directly influences the need for healthcare based on the definition set out in the previous chapter, so it is a central parameter for approximating the need in a population (see Figure 1). Apart from indirectly estimating treatable morbidity by exogenous factors as described above, morbidity levels, morbidity patterns and trends in morbidity can be directly retrieved from incidence and prevalence rates as well as prognoses of diseases from epidemiological studies, medical records, disease registries, or insurance claims data [10, 46, 47].

However, the validity of morbidity estimates may vary depending on the sample size, data collection technique, and data source [46]. As treatable morbidity is amongst other things subject to changes in the current state of evidence-based medicine, it is vital to regularly update estimates to ensure validity and accuracy. Additionally, morbidity measures should be related to exogenous factors, so changes in for instance the demography of a population can be taken into account [10].

## 1.2 Physician planning

### 1.2.1 Overview

Human resources, specifically physicians and their spatial and temporal availability play a central role in meeting the need for healthcare of a population, directly impacting the functionality of healthcare systems. Therefore, the overall objective of physician planning is to guarantee that a sufficient amount of physicians, with an adequate skillset is available to deliver cost-effective health services to the population at the right place and time, making physician planning not only a technical process but also a political topic of interest [48, 49].

Healthcare systems, irrespective of their financing model, experienced difficulties to meet this aim under given resource constraints [4]. In particular, publicly funded healthcare systems seem to struggle with financial sustainability as increased healthcare expenditures are not necessarily linked to increased need, which is why effective planning and management of healthcare resources based on the population’s need is required [50].

There are several studies summarising approaches used for physician planning [47, 49, 51]. The three main approaches described in the literature for healthcare planning are the needs-based approach, the supply-based approach, and the utilisation/demand-based approach [48, 52]. Despite being distinct, the approaches may also overlap to various degrees with no uniform classification. Depending on the indicators used in each method as outlined in the previous chapter, every approach is capable of reflecting the need for healthcare under certain assumptions. A short summary of each method and the hypothesis under which it reflects the need for healthcare, can be found in Table 1. Even though several approaches for physician planning exist, a systematic assessment of the application of each approach is yet missing.

Table 1 Short summary of the three main methods applied in physician planning and hypothesis under which they reflect the need for healthcare of a population.

| **Method** | **Summary** | **Hypothesis** |
|---|---|---|
| Needs-based approach | Needs-based approaches estimate healthcare requirements based on age and sex-specific approximated levels of morbidity in the population, including service norms and trends in morbidity derived from epidemiological, demographic, and sociocultural studies, as well as expert opinions, which are subsequently converted via productivity norms/estimations into workforce requirements. | Needs-based approaches reflect the need of a population, if estimations/predictions of healthcare requirements match actually required healthcare services. |
| Supply-based approach | Supply-based approaches use indicators derived from existing supply to estimate the need for healthcare. In their basic form, supply-based approaches use workforce-to-population ratios (densities) which are set at a proposed threshold as the main indicator to estimate the health workforce needed. More complex approaches try to account for existing imbalances (e.g., limited availability) in various forms. | Supply-based approaches reflect the need of a population, if access to care as well as availability, quality, and quantity of health services are ensured for everyone and remain constant over time. |
| Utilisation/demand-based approach | Utilisation-based approaches use actual or estimated utilisation rates, which are related to demographic characteristics of the population and subsequently converted into workforce requirements based on population projections. Similar to supply-based approaches, complex utilisation-based approaches try to account for imbalances such as unmet need and supply-induced demand. | Utilisation-based approaches reflect the need of a population, if utilised services are indicated, remain constant over time, and are not influenced by subjective needs, limited access, or are induced by supply. |

Regardless of the selected approach, there are four central requirements for physician planning, which should be considered [10]:

(I) A strong conceptual basis is required to approximate the need for healthcare and to define appropriate variables, also considering potential biases of each indicator.

(II) Representative and accurate data sources have to be identified and secured to depict these variables, also considering timeliness and availability of data.

(III) Suitable models need to be selected and tested to estimate the need for healthcare. Subsequently, these estimates have to be linked to service/time requirements of physicians in order to translate them into physician capacities.

(IV) The sustainability of these estimates have to be outlined, including the planning horizon and underlying assumptions regarding future trends and developments [10, 47–49].

Following these requirements can help to improve physician planning by reducing imbalances in current supply estimations.

### 1.2.2 Physician planning in Germany

As healthcare in the European Union (EU) is the responsibility of the member state, every country follows its own approach [53]. Physician planning in Germany started in 1977 and was reformed in the 1990s with the aim to cap the number of office-based physicians by introducing a simple supply-based approach (physician-to-population ratios) with a proposed threshold of the physician density of 1990 [10].

On a national level, the number of physicians needed per discipline and planning level are designated by the self-administered German National Association of Statutory Health Insurance Physicians (*Kassenärztliche Bundesvereinigung*, KBV) [10]. In 2012 and 2015, additional laws were passed as a response to new challenges in physician planning, especially demographic changes. Thus, a so-called demographic factor was introduced to correct the physician-to-population ratios for additional service needs of older adults (65+ years of age compared to 64 years and younger). Moreover, Associations of the Statutory Health Insurance Physicians in each state were given the opportunity to demand regional adaptations of the physician-to-population ratios to so-called ‘adapted physician-to-population ratios’ (*angepasste Verhältniszahlen*, AVZ) based on regional characteristics, specifically morbidity and demography, which go beyond the corrections resulting from the demographic factor but have to be in agreement with relevant state administrative bodies [54].

Since 2019, physician-to-population ratios are adapted with a morbidity factor instead of the demographic factor, which accounts for demographic changes, but also for regional morbidity levels according to two categories, namely increased morbidity and no increased morbidity. An individual is thereby classified under ‘increased morbid’, if the records of the statutory health insurance show at least six diseases out of a list of diseases set by the Federal Insurance Office over a period of two billing quarters. Subsequently, the regional age, gender, and morbidity distribution is compared with the federal level and adapted with a physician-specific requirement factor. No further adaptations to account for potential oversupply or undersupply of services are currently considered. However, the resulting adapted physician-to-population ratios are updated every two years [55].

## 1.3 Multimorbidity

### 1.3.1 Classification

Multimorbidity has been defined in various ways. The World Health Organization (WHO) as the entity responsible for setting international norms and standards, defined multimorbidity as at least two simultaneously occurring chronic health conditions, without further defining the word ‘condition’ and thus leaving room for interpretation [56–58]. As a consequence, over the last decades researchers have employed several definitions of multimorbidity. The most recent systematic literature review found that multimorbidity is most commonly defined as the occurrence of multiple diseases or conditions (threshold typically set at two and above) in one individual [59], with one included study suggesting that the second disease/condition can also be substituted by a biopsychosocial factor or somatic risk factor [58].

Based on their great extent, methods employed to classify multimorbidity are explained separately in the next chapter.

### 1.3.2 Methods to measure multimorbidity

Similar to the variations in definitions, there is no uniform and internationally accepted method to classify multimorbidity to date. Nevertheless, some methods are more frequently applied than others. The four most commonly applied methods to measure multimorbidity in a population are in alphabetical order the Adjusted Clinical Groups (ACG) system, the Charlson co-morbidity Index, the Cumulative Illness Rating Scale (CIRS), and the disease counts approach [59, 60].

The ACG software matches individuals based on their risk score to one of 100 groupings. The risk scores are calculated through age, sex, and diagnosis groups, which are observed over a certain period of time (usually 12 months). The groupings were used amongst others to estimate the morbidity burden in a certain population [61]. The software, which was designed for data from medical records or insurance claims is available for a fee under several licence types, depending on the area of application [60]. The system is continuously evolving and was previously applied, for example, in the field of population profiling, performance analysis and resource allocation [62].

According to the Charlson’s index [63], comorbidities of patients are categorised based on the International Classification of Diseases (ICD) codes, and weights for originally 18 disease categories (chronic and acute) are assigned to each patient, ranging from one to six with six being most severe. If a patient suffers from several diseases, the sum of all weights builds the final score. The Charlson Index was primarily used to assess and predict the effect of comorbidities on mortality [60, 64] but has also been used in its adapted form to predict resource utilisation [65]. Despite the fact that there are variations of the Charlson index, all of them were found to produce similar results [60].

The CIRS is used for measuring chronic comorbidities via 14 categories, rating the person's impairment due to the disease on a scale of 0 (no impairment) to 4 (severe impairment). As the name suggests, the cumulated ratings of the 14 categories are used as final score. CIRS can be recorded during consultations or derived from claims data or medical records. Higher CIRS scores were related to higher mortality and higher healthcare utilisation rates. The CIRS is available in adapted versions which all have been found to obtain similar results [60, 66, 67].

The disease counts approach was most frequently used in the literature to measure multimorbidity. An individual is classified as multimorbid based on simple counts of diseases, disease categories, and/or risk factors from a predefined list. The number of items per list was found to vary between 9 and 40 [60, 68]. Compared to weighted methods, disease counts approaches are applied to detect influences of multimorbidity on multiple health outcomes or for outcomes where no validated measure exists [59, 60].

In general, methods to measure multimorbidity should be chosen according to the objective of the study and based on the validity of the method. Regarding appropriate data sources to measure multimorbidity, no recommendations are found in the literature on preferred data sources. Nevertheless, the selection of the data source is crucial as findings from self-reported surveys may result in different prevalence rates of multimorbidity compared to findings from claims data or medical records (e.g. due to recall biases). Therefore, the selection of the data source has an effect on the outcomes of the study [59].

### 1.3.3 Influence of multimorbidity on healthcare utilisation

Research suggests a strong correlation between multimorbidity and healthcare utilisation of several types [57, 61, 69–73]. The most frequently mentioned uses of healthcare services are summarised below.

Outpatient visits of multimorbid individuals, specifically in older adults, were found to be more than twice as high compared to patients with only one or no chronic condition [69–72, 74]. Additionally, multimorbid patients were found to be frequent emergency department visitors (four or more visits per year), having a significantly increased likelihood when suffering from three to five chronic conditions [72, 75] Moreover, multimorbid patients are associated with higher hospitalisation rates [72].

The occurrence of certain conditions in multimorbid patients were also found to have an influence on the utilisation of health services. Acute coronary syndromes, for example, in multimorbid patients were less often treated with evidence-based treatments and were found to require longer average hospital stays [76]. Moreover, dementia combined with acute myocardial infarction, chronic kidney diseases, heart failure, or rheumatoid arthritis/osteoarthritis had significantly higher risk ratios for annual hospital visits compared to combinations with other chronic diseases such as hypertension or diabetes [77]. Also, Parkinson's disease and cardiac insufficiency were found to be responsible for the largest share of the healthcare costs for multimorbid patients [78]. In general, mental health conditions in multimorbid patients were associated with an increased use of health services and extended consultation lengths [79]. The precise effect of multimorbidity (with or without mental health conditions) on the consultation lengths in terms of additional minutes, however, remains unknown [70, 80, 81].

Another factor that was found commonly present in multimorbid patients was polypharmacy, which leads to more frequent interactions with health services and makes multimorbid patients vulnerable to safety issues [57, 82]. Moreover, the frequent use of potentially inappropriate medications was found to negatively impact the health outcomes of multimorbid patients [83]. Despite the fact that interventions to reduce inappropriate prescribing and healthcare utilisation exist, there is limited evidence on their effect on clinical and patient-related outcomes [84].

Multimorbidity does not only affect older adults. Research on young adults showed that multimorbidity was common in individuals under 30 years of age [85, 86], with increasing rates specifically among women [87, 88]. Being multimorbid as a young adult was found to be related to an increased number of sick days and impaired health-related quality of life, which further increased the economic burden attributed to multimorbidity [88, 89]. No study was found to describe the healthcare utilisation pattern of multimorbid adolescents or children compared to healthy individuals.

One limitation in multimorbidity studies is that they focused mainly on the influence of multimorbidity on healthcare utilisation in general, irrespective of the physician discipline [74, 90, 91]. Thus, it remains uncertain whether utilisation patterns of multimorbid people affect office-based physicians similarly or whether some physicians are more affected than others [92]. This knowledge, however, is critical to distribute healthcare resources efficiently [10].

As definitions and methods to classify multimorbidity vary, the results need to be treated with caution as they might not be directly comparable (or transferable) to other settings [93]. Moreover, since multimorbidity is associated with general indicators of morbidity such as the socio-economic status [94] which in turn influences healthcare utilisation itself, interactions of multimorbidity and other indicators need to be considered [73, 95].

### 1.3.4 Trends in multimorbidity

Multimorbidity was declared a major challenge for national health systems with a steady increase in prevalence over the last decades in varying percentages depending on the underlying population [57, 93, 96–98]. In countries of the EU, for example, average annual percentage change in multimorbidity from 2004 to 2017 found in an ecological survey ranged from 1.0 and 0.9 in France (lowest increase) to 6.9 and 3.3 in Germany (highest increase) for men and women, respectively [98]. Current estimates also suggest that 36% of EU citizens aged ≥65 are suffering from two or more chronic diseases, with women being more frequently affected than men [53]. In general, the multimorbidity burden was also found to expand over time across all age and sex groups, leading to a greater increase of lifetime spent with multimorbidity than the increase of life expectancy [99] with demographic changes in terms of an aging population believed as main drivers for the increase in multimorbidity [57, 100, 101].

Similar to healthcare utilisation, progression of multimorbidity was found to be dependent on health conditions and the socio-economic background of an individual. For morbidity clusters of metabolic and cardiovascular conditions, for instance, factors such as socio-economic status and related physical activity as well as alcohol/tobacco consumption had a significant effect on the progression of multimorbidity [93, 102]. Additionally, clusters of major mental health conditions such as dementia and bipolar or manic mood disorders have significantly increased over time compared to other chronic diseases like cardiac valve diseases or skin ulcer (including decubitus) [100, 103].

The COVID-19 pandemic also increased the number of people suffering from mental health conditions, such as depression, and thus, may have led to an increase in multimorbidity. Additionally, due to long COVID, which affects young and older adults alike (about 10% of people infected with COVID-19 are estimated to suffer from long COVID), further increases in several chronic conditions are expected in the upcoming years [53].

With a rising number of multimorbid individuals and a case-mix towards more severe diseases, healthcare expenditures are expected to increase substantially, putting health systems that are historically centred on single-disease treatment approaches under additional pressure [93, 99, 100]. Specifically, the fragmentation of care and the lack of integrated care approaches pose major challenges to the treatment of multimorbid patients [93].

### 1.3.5 Multimorbidity in Germany

Although international studies defined multimorbidity with at least two diseases/conditions, many studies conducted in Germany set the threshold to three or more chronic diseases. Such studies argue that two chronic diseases were found in almost all older adults, so three chronic diseases would provide a superior depiction of increased disease burden [83, 90, 102, 104–108].

As there is no common definition of multimorbidity in Germany, prevalence rates vary from 17% to 80% [104]. For example, Frank et al. [105] found that between 2007 and 2014 the percentage of multimorbid individuals over at the age of 65 and above increased by 8% (from 68% to 76%) and 9% (from 63% and 72%) for women and men, respectively. In the study, a person was identified as multimorbid if a minimum of three diseases out of a list of 46 chronic conditions were coded in three out of four quarters from claims data from the public health insurance.

In contrast, Souza et al. [98], who used the definition of two or more chronic diseases and classified multimorbidity based on eleven non-communicable diseases that were grouped into five categories, reported an estimated annual average percentage change in multimorbidity from 2004 to 2017 of 6.9% in men and 3.2% in women among people aged 50 and above, starting with multimorbidity levels around 30% for both sexes in 2005 in Germany, with women having slightly higher levels. The data source was obtained by six waves of an ecological study, surveying health, ageing, and retirement across Europe.

No data newer than 2017 and no studies that estimate the multimorbidity burden of people under 50 years across Germany were found.

## 1.4 Aim of the thesis

The aim of this thesis was to systematically assess current approaches that estimate needs-based supply of physicians and to add to the current knowledge where major methodological gaps occur. Furthermore, it intended to test the necessity of integrating regional multimorbidity levels when assessing the need for healthcare, which are hypothesised as proxy for additional healthcare need in a population, in the context of office-based physician planning in Germany. Thus, the following research questions were addressed:

(I) Do previous studies that estimate needs-based supply of physicians follow quality criteria regarding the conceptual basis, data sources, model selection including translation into provider requirements, and sustainability of the results?

(II) Do multimorbidity levels vary regionally and between disciplines exemplified by four office-based physician groups in Germany?

(III) Can the supply of physicians meet the potentially greater need for care and care coordination in areas with significantly higher rates of multimorbid patients exemplified in the case of Germany?

The findings of this thesis can be applied by policymakers and healthcare planners alike to reform current strategies by improving their approaches to estimate needs-based supply of physicians and by strengthening care provision in areas with high multimorbidity levels. The overall objective was to improve the quality of office-based care from both a patient and a provider perspective.

# 2. Material and Methods

## 2.1 Study design

The thesis followed a mixed-method design. First, a systematic, methodological review was performed to evaluate approaches that quantify the need for healthcare in high-resource setting. Second, a cross-sectional study was set up to assess regional variations of multimorbidity levels in selected office-based physicians through cluster analysis in Germany. Additionally, high-rate clusters of multimorbid patients were compared with the current supply of physicians to assess whether the supply could meet potentially greater needs in high-rate areas.

## 2.2 Methodological literature review

As a systematic assessment of approaches to estimate needs-based supply of physicians was yet missing, the main aim of the methodological literature review was to systematically analyse methodologies applied in previous studies that estimated needs-based supply of physicians in high-resource settings. Additionally, the current role of multimorbidity as an emerging driver of healthcare need is determined.

*Disclaimer: Materials and methods from the methodological review have already been published by Geiger et al. ([109]).*

### 2.2.1 Search strategy and study selection

The preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram and the PRISMA 2020 checklist were used to guide the review (see Figure 2) [110, 111]. First, PubMed, ScienceDirect and Web of Science Core Collection as the largest bibliographic databases were searched in April and October 2017 for peer-reviewed articles that fulfil the predefined selection criteria noted in Table 2 using logical combinations of keywords that included ‘workforce planning’, ‘capacity planning’, ‘health human resource’, ‘service requirement*’, ‘physician’, ‘need’, ‘demand’. An update search in all databases was performed in March 2020 (before the outbreak of the COVID-19 pandemic) to ensure that recent literature was included. The results were not restricted by filters and the citation manager software Mendeley was used to collate the literature search results. The full list of keywords used and the respective results per bibliographic database can be found in Appendix A. Next, hand searches on international and national internet sites including amongst others WHO (Regional Office for Europe), were performed to detect additional literature. To complement the results obtained from bibliographic databases and hand searches, author searches and mining of sources from retrieved literature were carried out.

Table 2 Overview of inclusion and exclusion criteria.

| | Criterion | Meaning |
|---|---|---|
| Inclusion | Quantification of need in physician capacities | The need for healthcare had to be quantified and converted into physician capacities. |
| | Date of publication | The search period was restricted to the timeframe between January 1980 and March 2020. |
| | Language restrictions | To prevent errors in translation, language was restricted to English and German. |
| Exclusion | Predicting physicians | Studies were excluded if existing supply was forecasted without using measures relating to healthcare needs. |
| | Hospital care | The studies included were restricted to office-based physician planning due to differences in resource allocation. |
| | Other healthcare professionals | To avoid any biases resulting from estimations of other healthcare professionals, only studies estimating physician supply were included. |
| | Low-resource settings | Due to unique contexts and constraints in data accessibility, only studies in high-resource settings were included. |

Source: adapted from Geiger et al. [109]

Screening of the identified literature was conducted by two independent researchers based on the predefined selection criteria in Table: To be included, a study had to quantify a population's need for healthcare and translate it into physician requirements. Moreover, to avoid any translation biases, studies had to be available either in English or German. All studies that primarily forecasted the supply of physicians based on expected changes in age and gender of the population without including any other indicators of need, were excluded from this review, as they do not assess the need for healthcare. Moreover, studies that focused on workforce planning in hospital care or on healthcare professionals other than office-based physicians were disqualified as they lie outside the scope of this review. Additionally, studies that focused on physician planning in low resource settings were also excluded due to significant differences in healthcare provision and different priorities in healthcare.

After removing duplicates, abstracts were examined by each reviewer, independently. If a study fulfilled all selection criteria mentioned above, full texts were acquired. Both parties settled any disagreements until they reached a consensus. A detailed protocol of the reviewing process can be found in Appendix A.

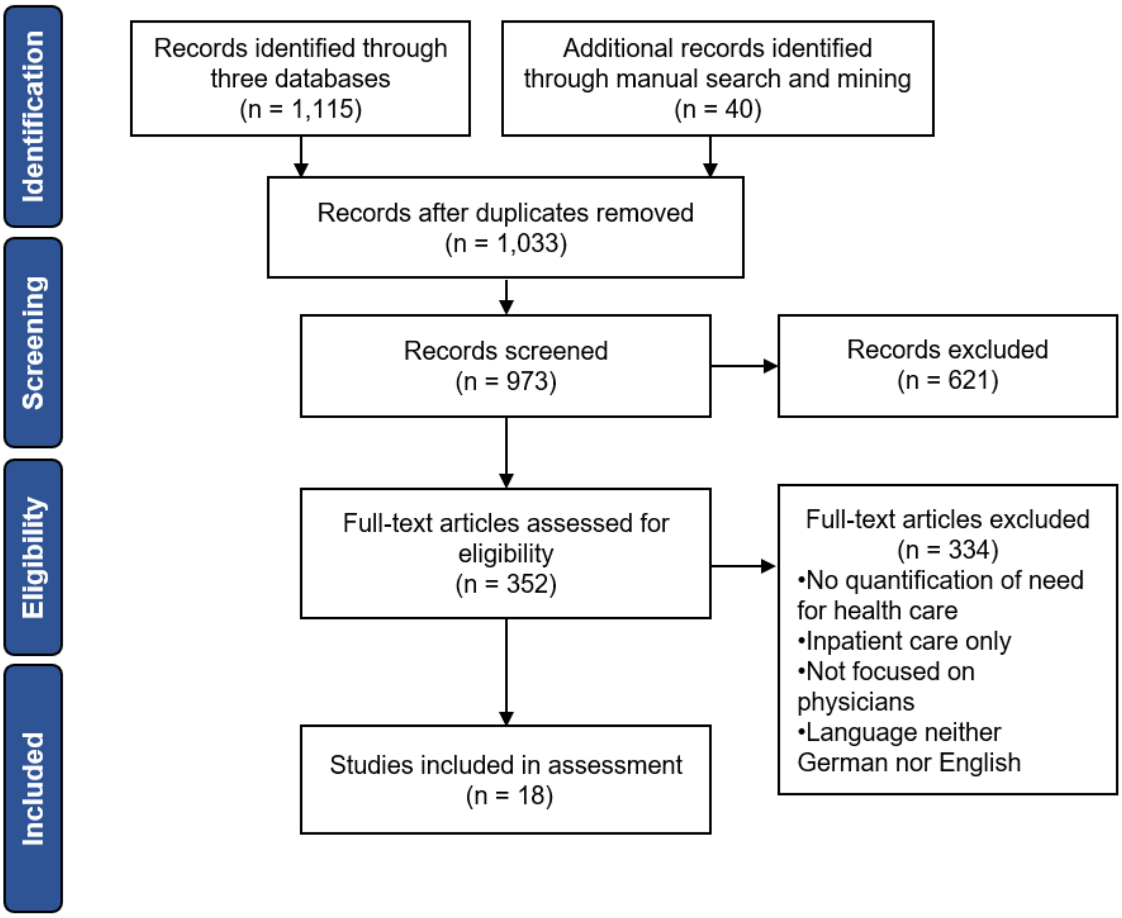


Figure 2 PRISMA flowchart adapted from Moher et al. [111]

Source: Geiger et al. [109]

### 2.2.2 Data collection and synthesis process

For data collection, a matrix with columns representing the four central requirements of physician planning (quality criteria) as defined by Sundmacher et al. [10] was developed. Each requirement was further divided into subcategories, leading to a set of ten criteria which were used to systematically assess each study. An overview of the criteria within the central requirements, including the respective statement to each criterion can be found in Table 3. Also, main characteristics of each study, such as year, planning unit or country of origin were added as columns to the matrix next to the central requirements.

To synthesise the results, the realisation of each criterion is indicated with 1 (the criterion is met) or 0 (the criterion is not or only partially met). Moreover, a short description of how the criterion was presented per study is given in the framework. Each study is thereby represented in a single row. However, if a study applied several approaches, each approach was assessed individually, thus having a separate row.

Table 3 Overview of quality criteria for physician planning.

| Criteria | Statement |
|---|---|
| **1. Conceptual framework** | |
| 1.1 Selection and justification of needs indicators | The selection of indicators is well-founded and, if possible, empirically supported based on the actual context of the study. |
| 1.2 Relationship between supply and need | The conceptual dependency of indicators of need on supply in general regarding unmet need/lack of physicians or overuse/oversupply are explored and, if feasible, accounted for in the analysis. |
| **2. Data basis** | |
| 2.1 External validity | The population for which providers are to be planned and the population from which data are used are identical or representative. |
| 2.2 Internal validity | The observed data accurately measures the indicators of interest. |
| 2.3 Timeliness and availability | The timeliness of data and availability of data sources is reported and considered with respect to the intended planning horizon. |
| **3. Modelling and conversion into physician requirements** | |
| 3.1 Transformation into provider requirements | The estimated need for healthcare is related to some measure of provider productivity to transfer the estimated service requirement to physician capacities. |
| 3.2 Model selection and validation | The statistical model is appropriate and well-founded, and the validity and the robustness of the findings were established. |
| 3.3 Level of analysis | The level of analysis is defined and discussed regarding the potential for ecological errors. |
| **4. Integration of future trends and developments** | |
| 4.1 Projection variables | Projection variables are present that can be modelled according to future changes in the population's need for healthcare. |
| 4.2 Planning horizon | The chosen planning horizon is justified appropriately with respect to future changes. |

Source: adapted from Geiger et al. [109]

### 2.2.3 Risk of bias assessment

When defining the quality criteria based on central requirements, appraisal tools such as the Mixed Methods Appraisal Tool (MMAT) [112] and the appraisal tools of The Joanna Briggs Institute (JBI) [113] were consulted to ensure that the framework is in line with other assessment tools. However, as no appraisal tool to assess the risk of bias at the time of writing was found to be suitable for a methodological assessment of different study types, the development of an own matrix was deemed more suitable to the purpose of our study.

## 2.3 Cross-sectional study

The cross-sectional study was used to provide an overview of variations in multimorbidity across Germany and to examine whether regional multimorbidity levels should be considered for needs-based physician planning.

*Disclaimer: Materials and methods from the cross-sectional study have already been published by Geiger et al. [92].*

### 2.3.1 Study population

Physician planning in Germany is responsible for accommodating the healthcare needs of all individuals under the German statutory health insurance. Thus, the study population for this analysis comprised all publicly insured Germans.

The office-based physician groups under study included general practitioners (GPs), neurologists, ophthalmologists, and orthopaedic specialists. GPs and ophthalmologists were selected based on having the highest outpatient rates and thus treat the highest number of patients per year [91]. Moreover, GPs as central contact points for care coordination, may encounter the highest amount of multimorbid patients of all outpatient physician groups. Neurologists and orthopaedic specialists were included in the study as musculoskeletal disorders and diseases of the nervous system account for the largest percentage of chronic illnesses in Germany, apart from cancer and circulatory diseases [114]. Additionally, disease patterns in combination with dementia, Parkinson's disease or rheumatoid arthritis/osteoarthritis, were found to be associated with a significant increase in healthcare utilisation, which may mostly concern neurologists or orthopaedic specialists, respectively [77, 78].

### 2.3.2 Data source

Claims data from all Germans that were insured under the statutory health insurance over all four quarters of 2015, were made accessible by the KBV for the cross-sectional study to classify multimorbidity levels in the population. In addition to the recorded diseases, the area of residency of an individual and the number of patient visits per physician group were available in the dataset. The dataset was originally used for a report regarding physician planning in Germany [10].

Current numbers of office-based physicians in fulltime equivalents and AVZs per respective planning unit were provided in a survey collected by the KBV in 2016.

### 2.3.3 Measures

#### 2.3.3.1 Multimorbidity

In line with the majority of German studies that examine multimorbidity, individuals suffering from at least three chronic diseases were defined as multimorbid. Following the disease count approach, 40 chronic disease categories as recommended by Barnett et al. [68] were used to classify multimorbidity. The disease count approach was preferred to weighed measures such as the Charlson Co-Morbidity Index, as the purpose was to detect physician-specific variations in multimorbidity levels. Weighted measures were designed for predicting the influence of multimorbidity on particular outcomes such as mortality rather than epidemiological studies (see Chapter 1.3.2.).

One advantage of using the disease categories of Barnett et al. [68] is that they consist of both mental and physical health conditions, and thus represent a great variety of diseases. However, the categories are not linked to the ICD. Thus, ICD-10-GM codes were merged to each category and subsequently validated by two medical specialists. A list of all categories and respective ICD-10-GM codes can be found in Appendix B.

To account for potential errors in coding and to ensure that the coded diseases are manifested in an individual, each category had to be diagnosed in at least two quarters of the year 2015. Finally, the number of multimorbid patients per physician was aggregated to the respective planning unit of each physician discipline, namely the '*Mittelbereich'* (MB) for GPs and the '*Kreisregion*' (KR) for neurologists, ophthalmologist, and orthopaedic specialists.

#### 2.3.3.2 Physician supply

Physician supply per discipline was defined as physician coverage [in percent] per discipline and planning unit: First, the respective AVZ was used to calculate the targeted number of physicians per planning unit. Next, the actual number of physicians available in 2016 were divided by the targeted values and multiplied the results with 100 to receive the physician coverage per physician discipline and planning unit in percent.

Subsequently physician coverage per discipline and planning unit were divided into five levels according to KBV thresholds used for physician planning as outlined in Table 4.

Table 4 Classification for physician coverage

| Level and definition | Percentage physician coverage |
|---|---|
| 1 – shortage | <75% for GPs and <50% for specialists |
| 2 – imminent shortage | 75 to <100 for GPs and 50 to <100% for specialists |
| 3 – target coverage | 100 to <110% for all physicians. |
| 4 – potential excess | 110 to <140% for all physicians |
| 5 – excess | ≥140% for all physicians |

Source: own contribution

### 2.3.4 Statistical methods

#### 2.3.4.1 Descriptive statistics

Multimorbidity levels from claims per physician were descriptively summarised in absolute numbers of multimorbid patients and proportions of multimorbid patients per physician discipline. Moreover, boxplots of multimorbidity shares (in percent) were calculated as measures of dispersion and compared between disciplines. The underlying hypothesis was that substantial variation in multimorbidity shares would support the need to incorporate multimorbidity measures per physician discipline when estimating needs-based physician supply.

#### 2.3.4.2 Bernoulli cluster detection

Spatial scan statistics were selected to measure and test regional variation in multimorbidity between physician disciplines. More specifically, the Bernoulli model was applied to detect high-rate and low-rate clusters of multimorbid patients across Germany.

Based on Kulldorff [115], the spatial point process is expressed as N with N(A) being an arbitrary amount of points in the set $A \subset G$, and with G being the geographical area. When the scanning window moves over the study area, it defines a collection (Ƶ) of zones (Z) in the subset of the geographical area (G). Measures (μ) are only considered so μ(A) is an integer of all subsets ($A \subset G$) with each unit of measure corresponding to a patient who is in one of two states (‘multimorbid’ or ‘not multimorbid’). Patients with multimorbidity are defined as points and the respective area constitutes the point process. Within the zone $Z \subset G$, each patient has the probability (p) of being multimorbid; outside the zone, the probability (q). Importantly, the probability of a patient is independent from all others. The null hypothesis for the Bernoulli cluster detection is $H_0$: $p = q$, and the alternative hypothesis is $H_1$: $p > q$, $Z \in$ Ƶ.

For the likelihood ratio test, $n_Z$ represents the number of multimorbid patients within the zone (Z) and $n_G$ the total number of multimorbid patients [115].

Thus, the likelihood function (1) can be expressed as:

$$L(Z,p,q) = p^{\mathrm{n_Z}}(1-p)^{\mu(Z)-\mathrm{n_Z}} q^{\mathrm{n_G}-\mathrm{n_Z}}(1-q)^{(\mu(G)-\mu(Z))-(\mathrm{n_G}-\mathrm{n_Z})} \qquad (1)$$

To identify the most likely cluster, the zone ($\hat{Z}$) that maximises the likelihood function needed to be found. In summary, the test statistic (2) can be expressed as:

$$\lambda = \frac{sup_{Z\epsilon \mathbb{Z}_{p>q}} L(Z,p,q)}{sup_{p=q} L(Z,p,q)} = \frac{L(\hat{Z})}{L_O} \qquad (2)$$

Thus, the denominator is only dependent on the total number of multimorbid patients and not on their spatial distribution. To detect low-rate areas of multimorbid patients, the direction of the underlying equation can be changed (also compare [115]). Finally, Monte Carlo simulations were used to attain the likelihood ratios and the respective p-values.

The centroids (point processes) in the analysis corresponded to the planning units (MBs for GPs and KRs for all specialised physicians) and patients with and without multimorbidity area aggregated accordingly. As suggested by Kulldorff [116], the maximum size of a spatial cluster was set to 50% of the study population with a circular shaped scanning window. The Bernoulli cluster detection was used to identify high and low rates of multimorbid patients under the premise that the KBV data recorded in 2015 was representative of all publicly insured. High-rate clusters were hypothesised to correspond to a greater need for healthcare and care coordination, whereas low-rate clusters were presumed to indicate no added need for health services. Significant clusters were outlined and compared descriptively and spatially displayed on maps for each physician discipline. For this study, statistical significance was set to a p-value < 0.01. Scanning statistics were executed via SaTScan (version 9.6).

### 2.3.4.3 Robustness test

Spatial autocorrelation mapping of high-rate and low-rate clusters was performed in QGIS (version 3.22.4) to estimate the robustness of the results. According to Anselin [117], the local Moran's I (3) can be expressed as:

$$\mathrm{I_i} = \mathrm{z_i} \textstyle\sum_{j} \mathrm{w_{ij}} \mathrm{z_j} \qquad (3)$$

Where observations $z_i$ and $z_j$ are variations from the mean with the summation over j only comprising neighbouring values $j \epsilon j_i$ [117]. Therefore, spatial autocorrelation is dependent on multimorbidity levels of neighbouring planning units compared to the Bernoulli model, which is dependent only on the total number of multimorbid patients.

#### 2.3.4.4 Comparison of high-rate clusters with current physician supply

In a last step, the high-rate areas, which are hypothesised as pointing to greater health- and integrated care needs, are graphically and descriptively compared with levels of physician coverage to estimate whether the current supply can meet the increased needs in these areas. The underlying assumption was that planning units with a higher probability of multimorbid patients require a great(er) number of physicians to adequately meet their healthcare requirements. As the AVZ, which constitutes the basis of the physician coverage, should comprise need requirements per planning unit and due to the lack of other classifications, level 3 and above as outlined in Chapter 2.3.3 were considered suitable to meet the needs of high-rate areas.

All data in this study were analysed and prepared using CRAN R (version 4.0.3). All maps were produced using QGIS (version 3.22.4).

# 3. Results

## 3.1 Methodologies to estimate needs-based supply of physicians

*Disclaimer: Results from the methodological review have already been published by Geiger et al. ([109]).*

### 3.1.1 Descriptive summary of studies

As noted in Chapter 2.2.1, the review identified 18 studies out of more than 1,000 records when searching for needs-based supply of office-based physicians. Table 5 descriptively summarises the year of publication, the country in which the study was carried out, and the physician discipline that was estimated.

Most studies (n = 12) were published between 2011 and 2017, with the remaining six studies issued between 1995 and 2010. However, there was a gap between 1998 and 2008, where no suitable study was found. Moreover, no suitable study was found between 1980 and 1994.

The country with the highest number of studies identified was Germany (n = 7), followed by the USA (n = 5) and Canada (n = 2). One study each was derived from Australia, Singapore, Spain, and the UK.

The physician disciplines that were estimated in the studies varied extensively, ranging from 1 up to 43. Studies focussing on one physician discipline predominantly assessed eye care professionals, GPs, and mental health professionals, with two studies each. Dental care, oncologists and otolaryngologists were estimated once each.

Most studies (n = 15) estimated needs-based supply of physicians based on a single approach. However, three studies were included that applied two [118], three [119], or four approaches [120]. Thus, the overall number of approaches included in the review exceeds the number of studies (n = 24).

Table 5 Descriptive overview of studies included in the review.

| | **Frequency** | **Reference(s)** |
|---|---|---|
| Year | 1995-2002: n = 3 | [118, 119, 121] |
| | 2003-2010: n = 3 | [122–124] |
| | 2011-2017: n = 12 | [120, 125–135] |
| Country | Australia: n = 1 | [131] |
| | Canada: n = 2 | [124, 129] |
| | Germany: n = 7 | [125–128, 132, 134, 135] |
| | Singapore: n = 1 | [120] |
| | Spain: n = 1 | [122] |
| | UK: n = 1 | [130] |
| | USA: n =5 | [118, 119, 121, 123, 133] |
| Physician discipline | Dentists: n = 1 | [127] |
| | Eye care professionals: n = 2 | [118, 120] |
| | GPs: n = 2 | [130, 131] |
| | Mental health professionals: n = 2 | [123, 126] |
| | Multiple professionals: n = 9 | [121, 122, 124, 125, 128, 132–135] |
| | Oncologists: n = 1 | [129] |
| | Otolaryngologists: n = 1 | [119] |

Source: adapted from Geiger et al. [109]

### 3.1.2 Review against quality criteria

The review against the central requirements, which were used to synthesise the studies and assess the risk of bias, showed that no study was able to meet all appraisal criteria. The study adopting most methodological requirements to estimate needs-based supply was Dall et al. [133]. Apart from the assessment of the accuracy of the data used in the analysis (internal validity) and considerations regarding oversupply/overuse in addition to their consideration of shortages in physicians and underutilisation, all remaining criteria were addressed. An overview of the results per study regarding the assessment against the quality criteria can be found in Appendix C. Moreover, a summary of the findings per criterion can be found in Table 6.

Table 6 Overview of quality criteria to assess methods estimating needs-based supply. Please note that the number of approaches (n = 24) exceeds the number of studies as three studies adopted multiple approaches.

| **1. Conceptual framework** | **Findings** |
|---|---|
| 1.1 Selection and justification of needs indicators<br>• Theoretical rationale<br>• Empirical validation | Theoretical rationale for the indicators<br>• n = 24<br>Empirical validation of indicators<br>• n = 5 |
| 1.2 Relationship between supply and need<br>• Potential influence<br>• Potential unmet need or lack of physicians<br>• Potential overuse or oversupply | Discuss potential influence of supply<br>• n = 9<br>Adjust potential unmet need or lack of physicians<br>• n = 6<br>Adjust potential overuse or oversupply<br>• None |
| **2. Data basis** | **Findings** |
| 2.1 External validity<br>• Representativeness | Representativeness<br>• Population data: n = 2<br>• Representative sample: n = 2<br>• Convenience samples: n = 2<br>• Mixed data: n = 18 |
| 2.2 Internal validity<br>• Accuracy of indicators | Discuss accuracy of indicators<br>• n = 14 |
| 2.3 Timeliness and availability<br>• Survey period | Survey/recording periods (in years)<br>• Ranges between 1-20 years |
| **3. Modelling and conversion into physician requirements** | **Findings** |
| 3.1 Transformation into provider requirements<br>• Methodology | Methodology to translate estimated need into supply<br>• Fulltime equivalents (FTE): n = 14<br>• Physician-to-population ratio adjustment: n = 10 |
| 3.2 Model selection and validation<br>• Type of model<br>• Justification and validation | Type of model<br>• Regression-based: n = 4<br>• Simulations: n = 9<br>• Extrapolations: n = 11<br>Validation of the model<br>• n = 21 |
| 3.3 Level of analysis<br>• Aggregated data<br>• Individual data | Model based on aggregated data<br>• n = 21<br>Model based on individual data<br>• n = 3 |
| **4. Integration of future trends and developments** | **Findings** |
| 4.1 Projection variables<br>• Selection of variables | Variables for projection models<br>• Demographics: n = 13<br>• Utilisation: n = 5<br>• Supply: n = 5<br>• Morbidity: n = 3<br>• Insurance status: n = 2<br>• Health behaviour: n = 1 |
| 4.2 Planning horizon<br>• Length<br>• Validation | Length of need projections<br>• Ranges between 10-31 years, $\bar{x}$ = 17<br>Validation of length<br>• None |

Source: adapted from Geiger et al. [109]

#### 3.1.2.1 Conceptual framework

The assessment of the conceptual framework included the selection and justification of need indicators as well as the consideration of the relationship between supply and need. Criterion 1.1 refers to the foundation of the selected indicators according to the context of the study and their empirical evidence base. Although all studies provided a rationale, the depth of the respective foundation and conceptualisation varied significantly.

Some authors, like Stuckless et al. [129], chose variables following theoretical frameworks of other scholars and which they assume to be the main drivers of need with no empirical verification. Also, Laurence and Karnon [131] (Australia) and the Centre for Workforce Intelligence (CfWI) report (UK) [130] relied on existing conceptual frameworks. Despite being from different counties, both studies applied variables selected by Canadian researchers [136, 137]. In fact, most studies mentioned that the used need indicators were based on prior research (n = 11) [119–122, 126, 127, 129–131, 133, 135].

In contrast, eight authors developed their own framework [118, 120, 123–125, 128, 132, 134]. By way of example, Lee et al. [118] created a step-based conceptual framework, outlining the most important areas regarding the need for eye care professionals and assigning them to corresponding ICD codes. To confirm their approach, an expert panel was invited to assess the conceptual framework.

Five studies [123, 125, 126, 132, 135] presented empirical validation of the indicators used in the analysis by assessing the relationship between morbidity proxies or mortality measures and socioeconomic status or deprivation [125, 126, 135], conducting either factor analyses [125, 132] or regression models [135]. Moreover, prevalence rates of underlying diseases were empirically derived by two studies [123, 126].

As need can be approximated by several indicators, Figure 3 illustrates all indicators applied in the included studies showing their frequency. Six studies employed supply-based indicators such as the number of available physicians [120, 122, 135] and the ability of physicians to deliver necessary services (productivity) [119, 129, 130]. Another six studies used utilisation-based indicators like the number of cases or in-person visits [120, 130, 131, 133, 134], or the frequency of patient referrals [129].

Exogenous determinants as used by almost all studies (n = 17) were the age and sex distribution in the population [118–120, 122–128, 130–135], followed by education and income as part of the social determinants of health, which were applied in eight studies [120, 123, 125, 126, 132, 133]. Other social determinants found in the selected literature were unemployment [125, 126, 132, 135] and environmental factors, such as regional deprivation and place of residency [126, 132, 133, 135] in addition to the risk of passive smoke exposure [124]. Health behaviour such as alcohol intake and obesity levels were included in two studies [124, 133].

Indicators used by more than 80% of studies (n = 14) were measures of treatable morbidity [118–120, 123–128, 131–135], with indicators reaching from incidence and/or prevalence rates [118, 123, 124, 129, 131] over the reliance on long-term care [125, 127] to certain morbidity patterns [119–122, 127, 128, 130, 134, 135]. No study included measures of multimorbidity.

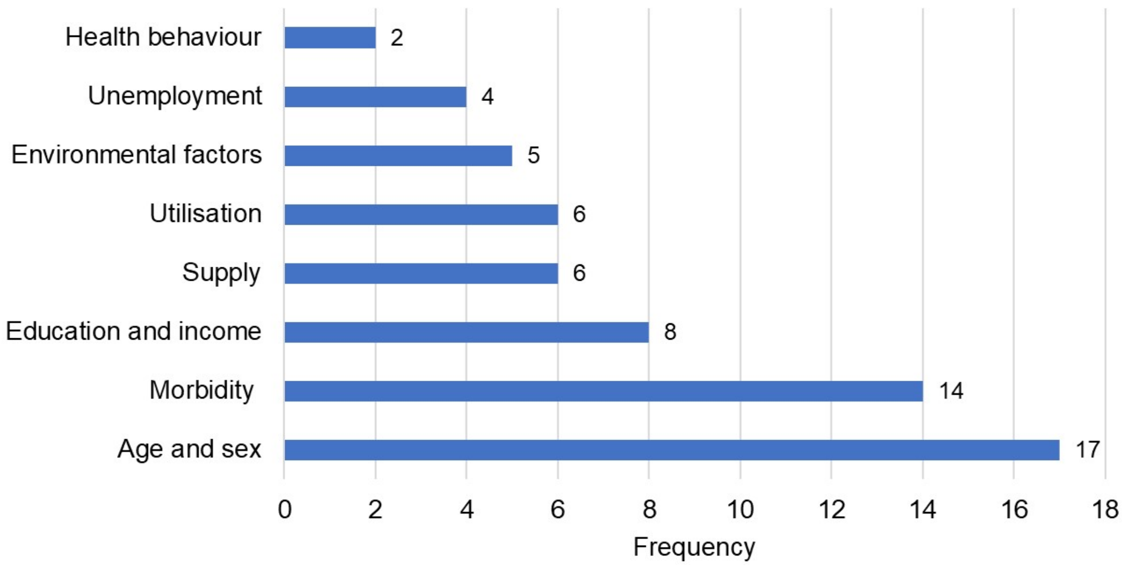


Figure 3 Indicators related to need used in studies estimating needs-based supply of physicians.

Source: adapted from Geiger et al. [109]

Another criterion related to the conceptual framework involves the identification of the relationship between supply and need indicators (Criterion 1.2). Overall, half of the included studies (n = 9) explored the impact of available supply on need indicators [119, 120, 122, 124–126, 130, 133, 134], with two studies excluding indicators based on their assumed dependency on supply [125, 126]. Further three studies highlighted that their results might be biased due to regional differences in the availability of supply which might have affected the number of recorded diseases used in their analysis [134] or may be subject to unequitable access to healthcare services [120, 125].

While one third of these studies theoretically discussed the dependency of need indicators on supply [125, 126, 134], the remaining two thirds tried to account for possible influences of limited access to healthcare services in terms of physician shortages or unmet need [119, 120, 122, 124, 130, 133]. For example, Anderson et al. [119] tried to account for existing inequities in access by including predictions of uninsured individuals in their model. Also, Dall et al. [133] tried to account for barriers to access based on differences in demand patterns of population groups with different socio-economic backgrounds.

Barber and López-Valcárcel [122] tried to account for shortages by looking for available job openings for physicians in Spain, while Singh et al. [124] incorporated the people that were currently not registered at a GP practice in their reference scenario.

Another method was applied by Ansah et al. [120] who incorporated the projected unfulfilled healthcare needs in one of their approaches by looking at waiting lists, i.e. differences between the day of registration and the day of the actual appointment. In contrast, the CfWI [130] consulted an expert panel to provide estimates and accounted for unfulfilled healthcare needs in the population.

None of the included studies assessed and/or corrected their analysis for overuse of healthcare services, including supply-induced demand, oversupply or demand based on the subjective need for health. Also, empirical assessments of the relationship between supply and indicators related to the need for healthcare were not conducted.

#### 3.1.2.2 Assessing the validity of the data basis

To assess the overall validity of the data basis, the external and internal validity of the data was well as the timeliness and availability of the data were examined.

Regarding external validity (Criterion 2.1), it was not feasible to classify the validity of the data sources in the majority of approaches (n = 18) included in the review as several data sources with varying representativeness were used. However, population data, which was assumed as the highest level of validity, was applied in two studies with data originating from statistics offices [125] and the statutory health insurance [128]. Another two studies stated that their data basis was derived from representative samples [126, 133]. The lowest classifiable validity level in terms of representativeness were convenience samples, which were utilised in two approaches [119, 134] with both being derived from claims data.

Internal validity (Criterion 2.2) regarding the quality and accuracy of the data to measure indicators of interest were discussed in 14 approaches within 13 studies [118, 119, 121, 123–126, 128, 130–132, 134], also acknowledging potential biases which may affect the internal validity such as changing insurers when relying on claims data or using non-repeated epidemiological studies [126, 131]. Only one study (CfWI) transparently assessed data quality in combination with limitations of the data and provided confidence ratings per model variable, stating underlying assumptions of each data source [130].

About half of the studies (n = 6) which discussed their internal validity also attempted to account for biases in their datasets [118, 119, 121, 124, 130, 134], most frequently by consulting expert panels [118, 124, 130], retrieving additional information from literature [118, 124], or using an alternative data source [118, 121, 134].

Conclusively, timeliness and availability of the data source (Criterion 2.3) were assessed. Regarding timeliness, all studies provided at least the year of data collection for the primary data source. However, two studies referenced the year of publication of the underlying epidemiological study, instead of the corresponding year of data collection [120, 127].

When comparing the years of data collection with the year for which the physician disciplines were estimated, ranges of one up to 20 years were found, with just two studies discussing the application of several base years, stating the assumption that included measures are unlikely to change over a timeframe of one or two years [134, 135].

Only one study provided detailed information on the availability of data sources, including access and frequency of reporting [131]. The most frequent argument of data application was that the data used was the newest available [125, 131, 133] and that frequency of reporting was routinely [118, 128, 129, 134].

#### 3.1.2.3 Modelling and conversion into physician requirements

Once the approaches for need estimations were identified, transformation of need into provider requirements, model selection and validation as well as considerations regarding the level of analysis were deliberated.

Our results showed that fulltime equivalents (FTE) were most frequently used (n = 14) to convert the population need for healthcare into physician requirements (Criterion 3.1) [118–124, 128–131, 133]. To that end, estimated need measures are related to minutes or visits needed to treat a disease in combination with suggested working hours per year or other productivity measures per physician discipline.

The remaining approaches linked need estimates to measures of physician supply such as physician-to-population ratios which were adjusted by estimates of need instead of directly converting estimates into physician requirements [119, 120, 125–127, 132, 134, 135]. Underlying assumptions and limitations of the conversion method were not discussed in detail, with Konrad et al. [123] pointing to the lack of uniform methods.

The included studies used in 46% of approaches extrapolations [118, 119, 121, 123, 127, 129, 132, 134], 37% simulations [120, 122, 124, 130, 131, 133], and 17% regression models [125, 126, 128, 135]. Five authors from studies using extrapolations [125, 126, 132, 134, 135] provided conceptual rationales. Moreover, authors of system dynamic models highlighted the capability of this type of simulation models to process complex relations over time [120, 122, 130], with one author team of simulation models arguing to use the latest microsimulation approaches [133]. No further rationalisations were provided.

Attempts of model validation (Criterion 3.2) were found in varying depth in almost all approaches [118–120, 123, 126, 129–131, 134], including sensitivity analysis [118–120, 122, 123, 125–134], model fitting [125, 127, 128, 132], cross-validation [120, 121, 133], stakeholder, expert, or literature consultations [119–122, 129], and application of international model validation criteria [133].

The level of analysis (criterion 3.3) was individual data in three approaches [126, 128, 133] with the remaining approaches applying aggregated or in the case of two approaches by Ansah et al. [120] partially disaggregated data. A thorough examination of implications arising from the usage of individual vs aggregated data was not found in any study. However, two studies argued that aggregated data might have concealed correlations due to averaged results [135], highlighting that small-scale models should be preferred over large-scale models [134].

#### 3.1.2.4 Integration of future trends and developments

In the course of integrating future trends and developments, projection variables and planning horizons were assessed.

Our review showed that 12 studies [118–122, 124, 125, 127, 129–131, 133] forecasted needs-based supply of physicians (Criterion 4.1) with projection variables mainly consisting of demographic changes, while holding all other variables constant. Three studies also projected trends in morbidity, either through estimations of future disease prevalence (e.g. from average historical increase rates) [124, 129] or through estimations by expert panels [130]. Variables relating to supply (e.g. consultation rates and staffing ratios) [124, 129, 130, 133] and demand (e.g. utilisation patterns and growth rates) [120–122, 131, 133] were included in eight studies. Additionally, insurance coverage [119, 121] and estimated variations in health risk factors [124] were found in the forecasts of the selected studies.

The planning horizon (Criterion 4.2) ranged from 10 years [129, 131] up to 31 years [121] ($\bar{x}$ = 17 years). The main reason for choosing the respective planning horizon was that population projections, which built the foundation of the projection, were provided in that timeframe [118–120, 122, 125, 127, 130]. No well-grounded validation for the planning horizons was found in the included studies.

## 3.2 Regional variation in multimorbidity in Germany

*Disclaimer: Results from the cross-sectional study have already been published by Geiger et al. [92].*

### 3.2.1 Descriptive summary

In 2015, about 89% of German citizens (~70.8M) were insured under the statutory health insurance, out of which approximately 67.2M were seeing a physician and thus were recorded in the dataset.

Table 7 provides an overview of GPs, neurologists, ophthalmologists, and orthopaedic specialists, including their FTE, average number of cases per year and physician, overall count of patients in the study period, and the number of multimorbid patients as classified using the disease count approach described in chapter 2.3.3. While neurologists were found to have the highest percentage of multimorbid patients (60.1%), ophthalmologists on average faced the highest number of multimorbid patients per year and physician (n = 1,315), with all GPs together seeing the highest absolute amount of multimorbid patients (17.2M) but the lowest proportion (31.5%). Orthopaedic specialists were found to have a lower average number of cases per year (n = 3,824) than ophthalmologists (n = 5,145) and GPs. However, orthopaedic specialists were seeing on average the second highest number of multimorbid patients per year and physician (n = 861) after ophthalmologists.

Table 7 Overview of office-based physician disciplines including fulltime equivalents (FTE), average number of cases per year, patient counts, and multimorbid patients in 2015.

| **Discipline** | **FTE*** | **Ø cases per year** | **Patients** | **Multimorbid patients** |
|---|---|---|---|---|
| GPs | 52,527 | 3,940 | 54,799,570 | 17,239,488 |
| Neurologists | 4,683 | 2,204 | 4,386,298 | 2,637,461 |
| Ophthalmologists | 5,434 | 5,145 | 16,195,148 | 7,145,558 |
| Orthopaedic specialists | 5,483 | 3,824 | 11,659,090 | 4,722,933 |

*FTE were recorded in 2016

Source: adapted from Geiger et al [92]

In order to illustrate overall dispersion, boxplots per physician discipline and planning unit are provided in Figure 4. Neurologists showed the highest median proportion of multimorbid patients (~59%) with an interquartile range (IQR) of ~9.0%, followed by ophthalmologists with a median of 43% and a higher IQR of ~9.5%, orthopaedic specialists with a median of 41% and the highest IQR of ~10.0%, and lastly, GPs with the lowest median (~31%) and lowest IQR (~6.5%).

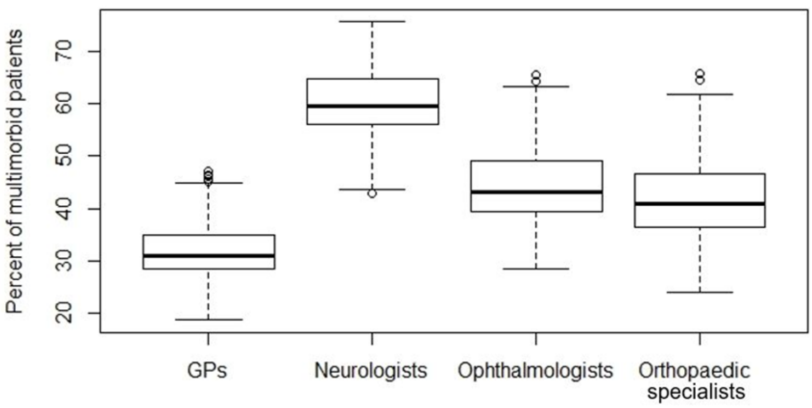


Figure 4 Boxplots of percentages of multimorbid patients seen by GPs, neurologists, ophthalmologists, and orthopaedic specialists in 2015 according to their planning unit.

Source: Geiger et al. [92]

### 3.2.2 Cluster detection and comparison

The Bernoulli spatial scan statistics resulted in eleven high-rate clusters for GPs with relative risks (RR) ranging from 1.04-1.28, eight high-rate clusters for orthopaedic specialists (RR 1.03-1.35), and five high-rate clusters for both neurologists (RR 1.02-1.20) and ophthalmologists (RR 1.04-1.33) as compiled in see Table 8 and Table 10. The clusters are abbreviated as ‘CL’ in combination with Arabic numerals based on the underlying likelihood ratio, starting with number one for the highest likelihood. CL-1 is situated in eastern Germany in all physician disciplines with varying sizes and covering parts of several states, including parts of northern Bavaria (BY), Brandenburg (BB), Saxony (SN), Saxony-Anhalt (ST) and Thuringia (TH). The largest CL-1 was found in orthopaedic specialists with a radius of 177 km compared to neurologists with the smallest radius of 128 km. Other areas of high-rate clusters over all physician disciplines with varying likelihood ratios were found in parts of Mecklenburg-Vorpommern (MV) and North Rhine-Westphalia (NW).

Cluster detection for low-rate clusters resulted in ten clusters for orthopaedic specialists (RR 0.73-0.94) and nine clusters for GPs (RR 0.82-0.93), neurologists (RR 0.83-0.97), and ophthalmologists (RR 0.75-0.94), with the most likely low-rate clusters (CL-2/CL-3) occurring in southern Germany covering Baden-Württemberg and Bavaria. Other low-rate clusters were detected in parts of Bremen (HB), Hamburg (HH), Hessen (HE), Lower Saxony (NI), North Rhine-Westphalia (NW), Rhineland-Palatinate (RP), and Schleswig-Holstein (SH). A comprehensive overview of detected high-rate and low-rate clusters for all physician disciplines per federal state including the areas covered in each state both overall and per individual cluster is presented in Table 9. The corresponding SaTScan scanning results can be found in Appendix D.

Figure 5a maps the regional variation in multimorbidity levels of GPs, and Figure 5b illustrates the detected high- and low-rate clusters of multimorbid patients including the respective areas. As GPs are planned on a separate planning unit (MBs), no direct comparison of the results between GPs and physicians planned on KRs was feasible. However, looking at the results per federal state in Table 9 and comparing Figures 5-8, the Bernoulli model of GPs apparently detected similar areas as for other physician disciplines, though varying in size and location.

Figures 6a/b, 7a/b, and 8a/b provide an overview of regional variation in multimorbidity levels and significant high- and low-rate clusters of multimorbid patients on KR level for neurologists, ophthalmologists, and orthopaedic specialists, respectively. The analysis of high-rate areas in specialised physicians (neurologists, ophthalmologists, orthopaedic specialists) neglecting differences in RR and likelihoods, resulted in 159 KRs found in at least one physician discipline, of which 63 KRs (~40%) were found in all, 35 KRs (~22%) in two and 61 KRs (~38%) in one. In other words, about 62% of high-rate areas were detected for two or more specialists. Neurologists were found to have the highest percentage of overlapping high-rate areas with at least one other discipline (~89%), followed by ophthalmologists and orthopaedic specialists with approximately 78% and 77%, respectively.

When looking at detected low-rate areas, 198 KRs were found in at least one physician discipline, of which 130 KRs (~66%) were overlapping between two or more disciplines. 78 KRs were detected that were present in all specialised physicians. In contrast to high-rate areas, orthopaedic specialists were found to have the highest share of overlapping areas (~93%) with neurologists and/or ophthalmologists, followed by neurologists with about 83% and, ophthalmologists with about 77%.

Table 8 Summary of significant high- and low-rate clusters per physician discipline based on the spatial Bernoulli cluster analysis. '+' denoting high-rate and '-' denoting low-rate clusters and RR abbreviating the relative risk.

| **Physician discipline** | **Clusters +** | **Covered areas +** | **RR range +** | **Clusters -** | **Covered areas -** | **RR range -** |
|---|---|---|---|---|---|---|
| GPs | 11 | 292 MBs | 1.04-1.28 | 9 | 324 MBs | 0.82-0.93 |
| Neurologists | 5 | 97 KRs | 1.02-1.20 | 9 | 146 KRs | 0.83-0.97 |
| Ophthalmologists | 5 | 101 KRs | 1.04-1.33 | 9 | 153 KRs | 0.75-0.94 |
| Orthopaedic specialists | 8 | 122 KRs | 1.03-1.35 | 10 | 107 KR | 0.73-0.94 |

Source: own contribution

As high-rate and low-rate areas were detected within clusters, specialised physicians were also compared on a cluster level. The results showed that most high-rate clusters did not fully match with clusters detected in other disciplines, meaning 100% of high-rate clusters for orthopaedic specialists, 80% (n = 4) of high-rate clusters for neurologists (CL-1, CL-3, CL-5, CL-12) and 80% (n = 4) of high-rate clusters for ophthalmologists (CL-1, CL-2, CL-11, CL-12) did not fully match. Only cluster CL-14 in NW was found to completely overlap in terms of radius and site between neurologists and ophthalmologists with RRs of 1.04 and 1.06, respectively. Identical low-rate clusters in Saarland (SL) were found once in CL-7 for both, ophthalmologists (RR 0.75) and orthopaedic specialists (RR 0.83) also matching with CL-6 for neurologists (RR 0.73). Additional three clusters were identical in two disciplines, with two amongst ophthalmologists (CL-5, RR 0.85 and CL-10, RR 0.88) and orthopaedic specialists (CL-4, RR 0.80 and CL-11, RR 0.88) as well as one between orthopaedic specialists (CL-2) and neurologists (CL-2) with RRs of 0.78 and 0.83, respectively.

A detailed overview of all scanning results of GPs can be found in Appendix E and the comparison between specialised physicians can be found in Appendix F.

### 3.2.3 Robustness test

Figures 5c to 8c provide a visual comparison between the results of the spatial Bernoulli model as represented by blue (low-rate) and yellow (high-rate) circles with corresponding dots and the results obtained by Moran’s I autocorrelation test as represented by filled areas (clusters) or outlined areas (outlier) using the same colour code.

The lowest confirmation rate of high-rate areas was found in GPs, with 146 MBs out of 292 MB detected with Bernoulli confirmed by Moran’s I, equalling 50%, followed by orthopaedic specialists with 72 KRs out of 122 KRs (~59%). Neurologists and ophthalmologists were confirmed in 63 KRs of 97 KRs (~65%) and 71 KRs of 101 KRs (~70%), respectively. The robustness test of low-rate areas delivered less conformities with neurologists being confirmed in 33% of detected low-rate areas, GPs and ophthalmologists in 43%, and orthopaedic specialists in 57%.

When looking at the results reversely, most areas detected through Moran’s I were also identified using the Bernoulli model, with high-rate areas ranging from ~84% (GPs) to ~88% (orthopaedic specialists) and low-rate areas ranging from ~83% (GPs) to ~97% (ophthalmologists). The comparison of the results through spatial autocorrelation within specialised physicians, showed that between ~86% (ophthalmologists) and ~95% of high-rate areas (neurologists), and between 57% (ophthalmologists) and ~74% of low-rate areas (neurologists) were found in all three specialities. A list of the detected areas per physician group and planning unit by Bernoulli and Moran’s I can be found in Appendices E and F.

Table 9 Comparison of significant high-rate and low-rate clusters for GPs, neurologists, ophthalmologists, and orthopaedic specialists on state level with covered areas on planning level (either MBs or KRs) in brackets. '+' denoting high-rate and '-' denoting low-rate clusters.

| **State** | **CLs** | **GPs** (MBs) | **Neurologists** (KRs) | **Ophthalmologists** (KRs) | **Orthopaedic specialists** (KRs) | **Sum** |
|---|---|---|---|---|---|---|
| BW | + | / | / | / | / | / |
| | - | CL-2 (71) | CL-2 (28) | CL-3 (24), CL-8 (9) | CL-2 (28) | 71 MBs, 89 KRs |
| BY | + | CL-5 (12), CL-18 (9) | CL-5 (7) | CL-1 (2) | CL-1 (6), CL-6 (2) | 21 MBs, 17KRs |
| | - | CL-2 (43), CL-8 (72), CL-14 (6) | CL-2 (4), CL-4 (43) | CL-3 (15), CL-4 (36), CL-8 (5), CL-13 (5) | CL-2 (4), CL-5 (16) | 121 MBs, 128 KRs |
| BE | + | / | / | CL-2 (1) | / | 1 KR |
| | - | / | / | / | / | / |
| BB | + | CL-1 (23), CL-3 (13) | CL-1 (9), CL-3 (6) | CL-2 (14) | CL-1 (9), CL-3 (5) | 36 MBs, 43 KRs |
| | - | / | / | / | / | / |
| HB | + | / | / | / | / | / |
| | - | CL-4 (2) | CL-7 (2) | CL-5 (1) | CL-4 (1) | 2 MBs, 4 KRs |
| HH | + | / | / | / | / | / |
| | - | CL-4 (1) | CL-7 (1) | CL-5 (1) | CL-4 (1) | 1 MB, 3 KRs |
| HE | + | CL-5 (24) | CL-5 (4) | / | CL-6 (13) | 24 MBs, 17 KRs |
| | - | CL-6 (16), CL-11 (4) | CL-8 (5), CL-10 (2) | CL-8 (13), CL-9 (2) | CL-9 (4) | 20 MBs, 26 KRs |
| NI | + | CL-5 (1), CL-13 (1) | / | CL-11 (17) | CL-6 (3), CL-14 (1) | 2 MBs, 21 KRs |
| | - | CL-4 (54), CL-7 (2) | CL-7 (22) | CL-5 (4), CL-6 (5) | CL-4 (4), CL-8 (10) | 56 MBs, 45 KRs |
| MV | + | CL-3 (26) | CL-3 (12) | CL-2 (13) | CL-3 (13) | 26 MBs, 38 KRs |
| | - | / | / | / | / | / |
| NW | + | CL-9 (20), CL-15 (38), CL-17 (7) | CL-12 (11), CL-14 (3) | CL-11 (1), CL-12 (1), CL-14 (3) | CL-6 (1), CL-10 (5), CL-13 (5), CL-16 (2), CL-17 (1) | 65 MBs, 33 KRs |
| | - | CL-4 (2), CL-7 (20), CL-11 (16), CL-12 (5), CL-16 (1) | CL-7 (1), CL-9 (7), CL-10 (4) | CL-6 (8), CL-9 (4), CL-10 (1), CL-11 (9), CL-13 (1) | CL-8 (15), CL-11 (1), CL-12 (5), CL-15 (2), CL-18 (1) | 44 MBs, 59 KRs |
| RP | + | CL-10 (5), CL-19 (1), CL-20 (8) | / | / | CL-17 (4) | 14 MBs, 4 KRs |
| | - | CL-6 (6), CL-11 (1) | CL-8 (3), CL-10 (1) | CL-8 (6), CL-9 (1) | CL-9 (1), CL-12 (1) | 7 MBs, 12 KRs |
| SL | + | CL-10 (1), CL-20 (2) | / | / | / | 3 MBs |
| | - | | CL-6 (5) | CL-7 (5) | CL-7 (5) | 15 KRs |
| SN | + | CL-1 (47) | CL-1 (24) | CL-1 (18) | CL-1 (25) | 47 MBs, 67 KRs |
| | - | / | / | / | / | / |
| ST | + | CL-1 (20) | CL-1 (6) | CL-1 (10), CL-2 (2) | CL-1 (8) | 20 MBs, 26 KRs |
| | - | / | / | / | / | / |
| SH | + | / | / | / | / | / |
| | - | CL-4 (16) | CL-7 (8) | CL-5 (8) | CL-4 (8) | 16 MBs, 24 KRs |
| TH | + | CL-1 (17), CL-5 (17) | CL-1 (3), CL-5 (12) | CL-1 (19) | CL-1 (8), CL-6 (11) | 34 MBs, 53 KRs |
| | - | / | / | / | / | / |

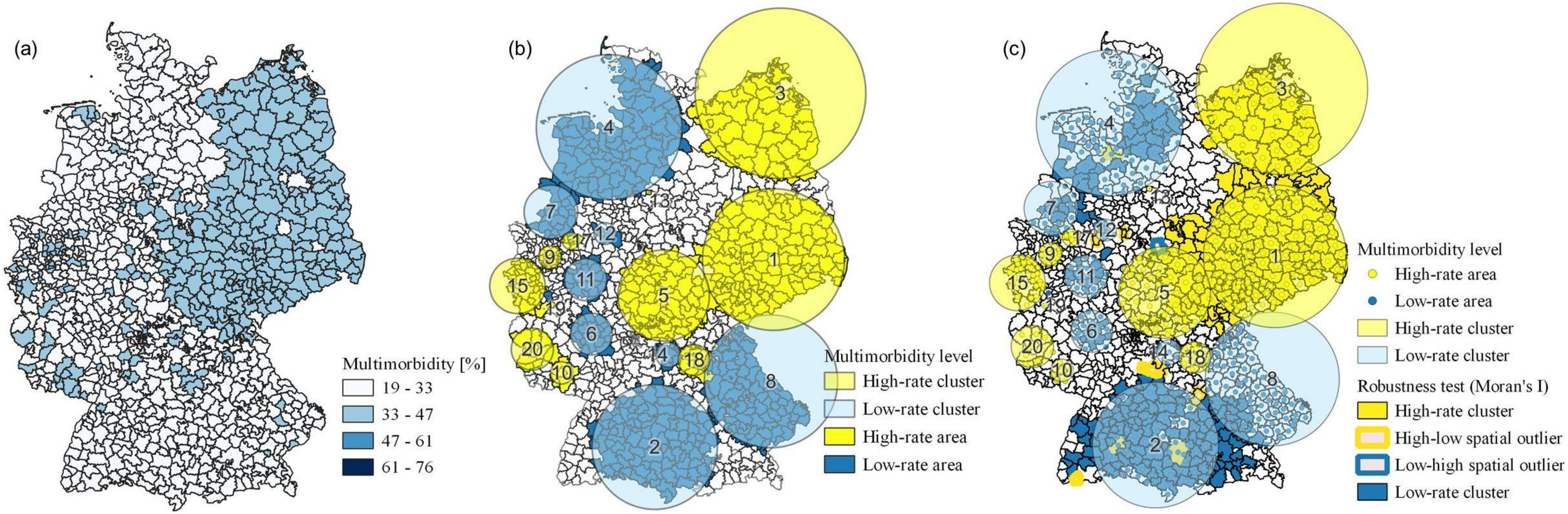


Figure 5 Multimorbidity levels in percentage (a), significant high-rate and low-rate clusters (b) of multimorbid patients numbered consecutively based on the underlying likelihood ratio and comparison of results with Moran's I autocorrelation test (c) for **GPs** in Germany in 2015.

Source: adapted from Geiger et al. [92]

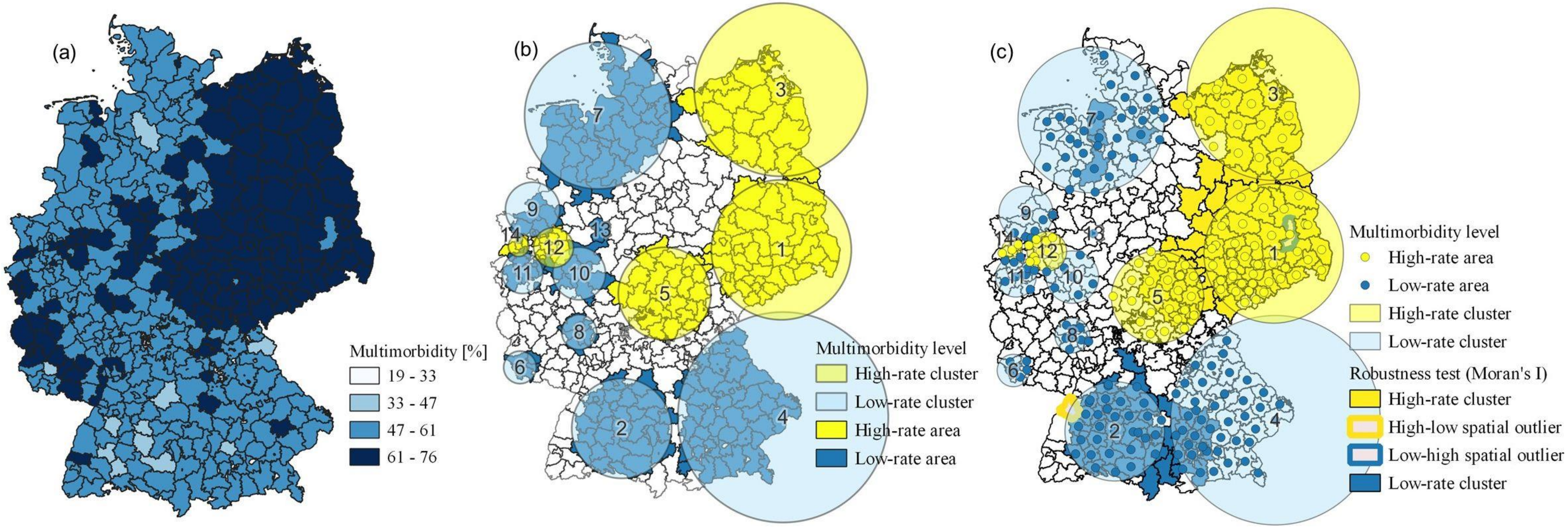


Figure 6 Multimorbidity levels in percentage (a), significant high-rate and low-rate clusters (b) of multimorbid patients numbered consecutively based on the underlying likelihood ratio and comparison of results with Moran’s I autocorrelation test (c) for **neurologists** in Germany in 2015.

Source: adapted from Geiger et al. [92]

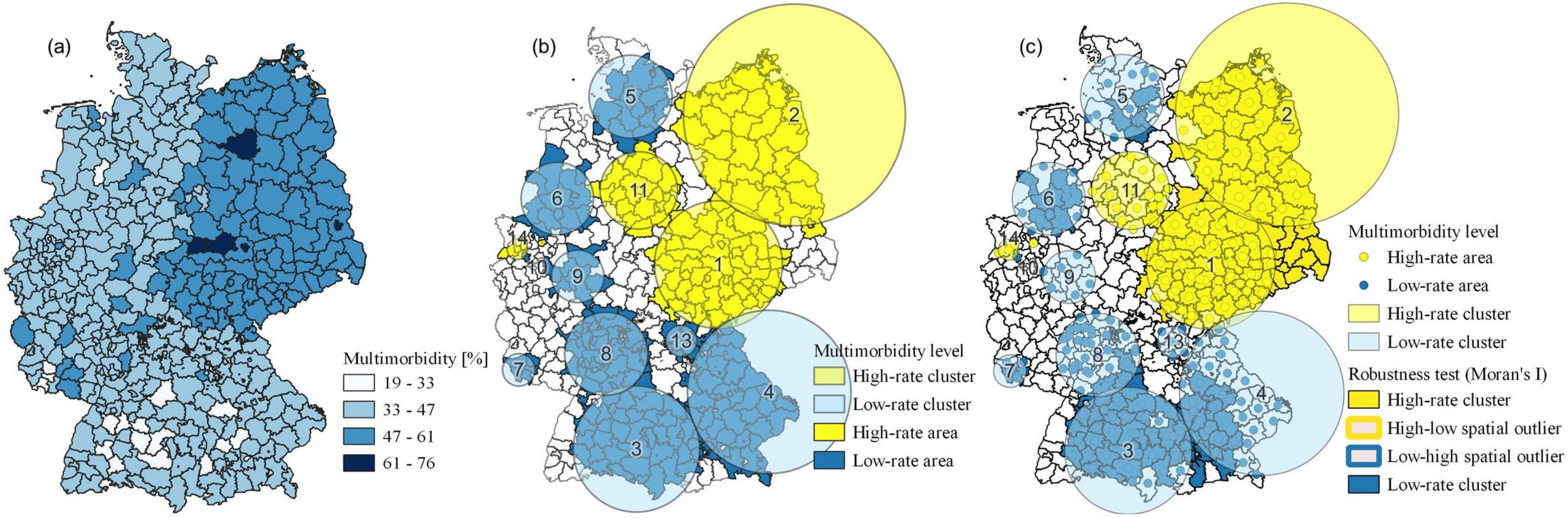


Figure 7 Multimorbidity levels in percentage (a), significant high-rate and low-rate clusters (b) of multimorbid patients numbered consecutively based on the underlying likelihood ratio and comparison of results with Moran's I autocorrelation test (c) for **ophthalmologists** in Germany in 2015.

Source: adapted from Geiger et al. [92]

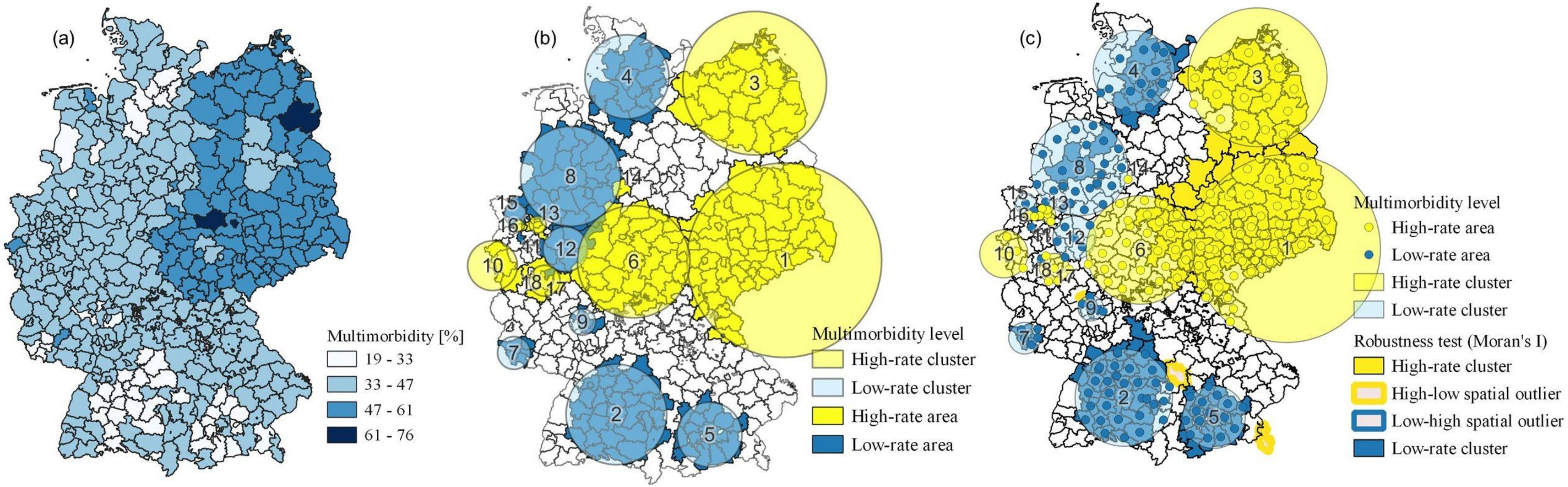


Figure 8 Multimorbidity levels in percentage (a), significant high-rate and low-rate clusters (b) of multimorbid patients numbered consecutively based on the underlying likelihood ratio and comparison of results with Moran’s I autocorrelation test (c) for **orthopaedic specialists** in Germany in 2015.

Source: adapted from Geiger et al. [92]

### 3.2.4 Comparison of high-rate clusters with current physician supply

The comparison of detected high-rate clusters of multimorbid patients with the current supply was drawn at cluster level, meaning that the average supply level of all regions within a cluster was used as a measure of cluster supply (see Table 10). It should be noted that Figures 9 and 10 illustrate high-rate clusters mapped on original levels of physician supply per planning unit to provide a better understanding of the supply distribution within a cluster.

In general, the comparison demonstrated that almost all high-rate clusters were met by average supply that exceeded the targeted coverage as defined in Chapter 2.3.3. GPs were the exception, as five clusters (CL-1, CL-3, CL-13, CL-15, CL-20) were met with average supply below targeted coverage, having supply coverage down to 2 which represents imminent shortage in the case of CL-13. Moreover, CL-19 was met exactly by target supply.

Appendices D and E provide an overview of all results of the cross-sectional study including the average supply level per cluster and physician discipline.

Table 10 Juxtaposition of high-rate clusters of multimorbid patients with average (Ø) physician supply on cluster level per physician discipline.

| **Physician discipline** | **Below targeted coverage** | **Above targeted coverage** |
|---|---|---|
| GPs | CL-1, Ø = 2.87<br>CL-3, Ø = 2.77<br>CL-13 Ø = 2.00<br>CL-15, Ø = 2.92<br>CL-20, Ø = 2.80 | CL-5, Ø = 3.46<br>CL-9, Ø = 3.35<br>CL-10, Ø = 3.33<br>CL-17, Ø = 3.57<br>CL-18, Ø = 3.22<br>CL-19, Ø = 3.00 |
| Neurologists | | CL-1, Ø = 4.51<br>CL-3, Ø = 4.40<br>CL-5, Ø = 4.11<br>CL-12, Ø = 4.60<br>CL-14, Ø = 4.00 |
| Ophthalmologists | | CL-1, Ø = 3.91<br>CL-2, Ø = 4.04<br>CL-11, Ø = 3.77<br>CL-12, Ø = 4.00<br>CL-14, Ø = 4.00 |
| Orthopaedic specialists | | CL-1, Ø = 4.25<br>CL-3, Ø = 4.28<br>CL-6, Ø = 4.33<br>CL-10, Ø = 4.00<br>CL-13, Ø = 4.40<br>CL-14, Ø = 4.00<br>CL-16, Ø = 4.50<br>CL-17, Ø = 4.40 |

Source: own contribution

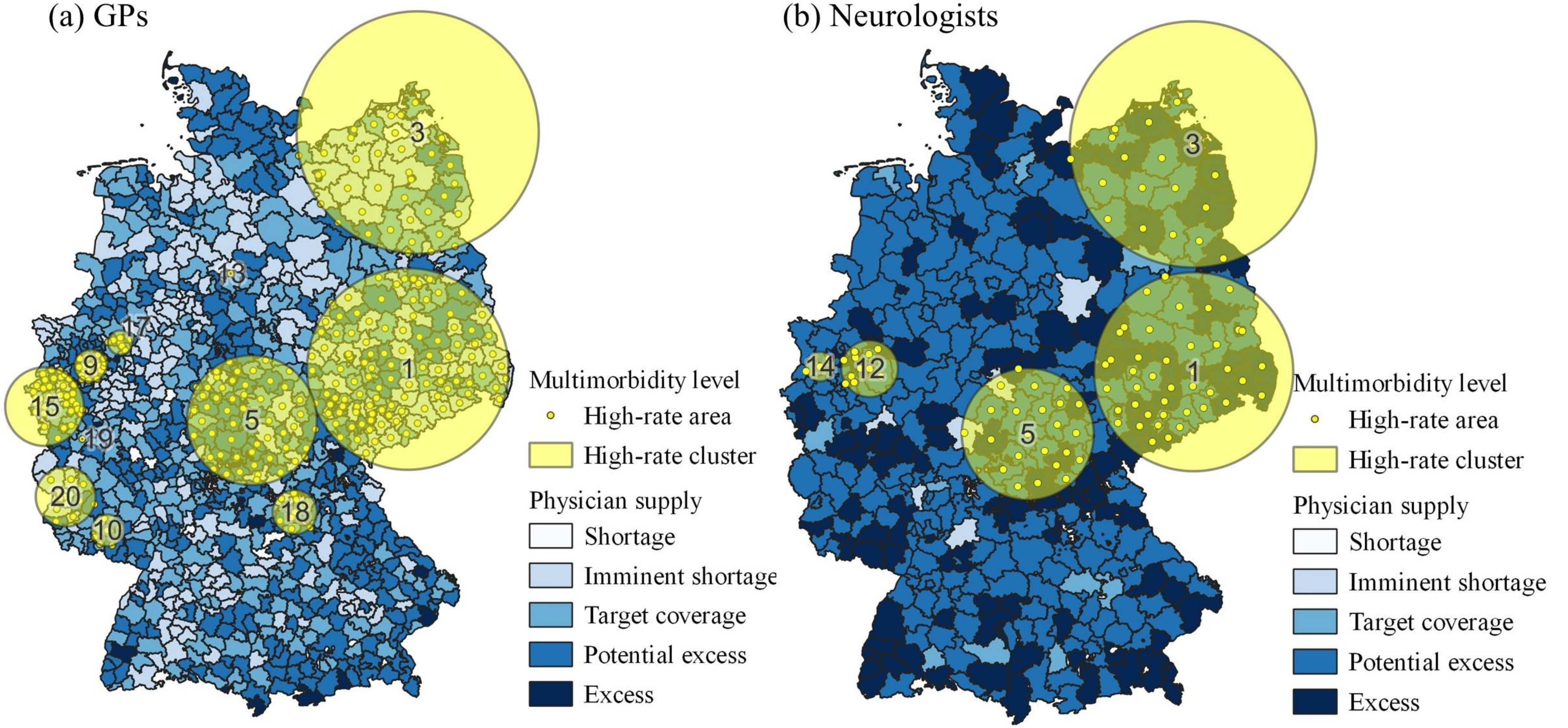


Figure 9 Level of physician supply and significant high-rate clusters of multimorbid patients numbered consecutively based on the underlying likelihood per planning unit for (a) GPs and (b) neurologists in Germany in 2015.

Source: Geiger et al. [92]

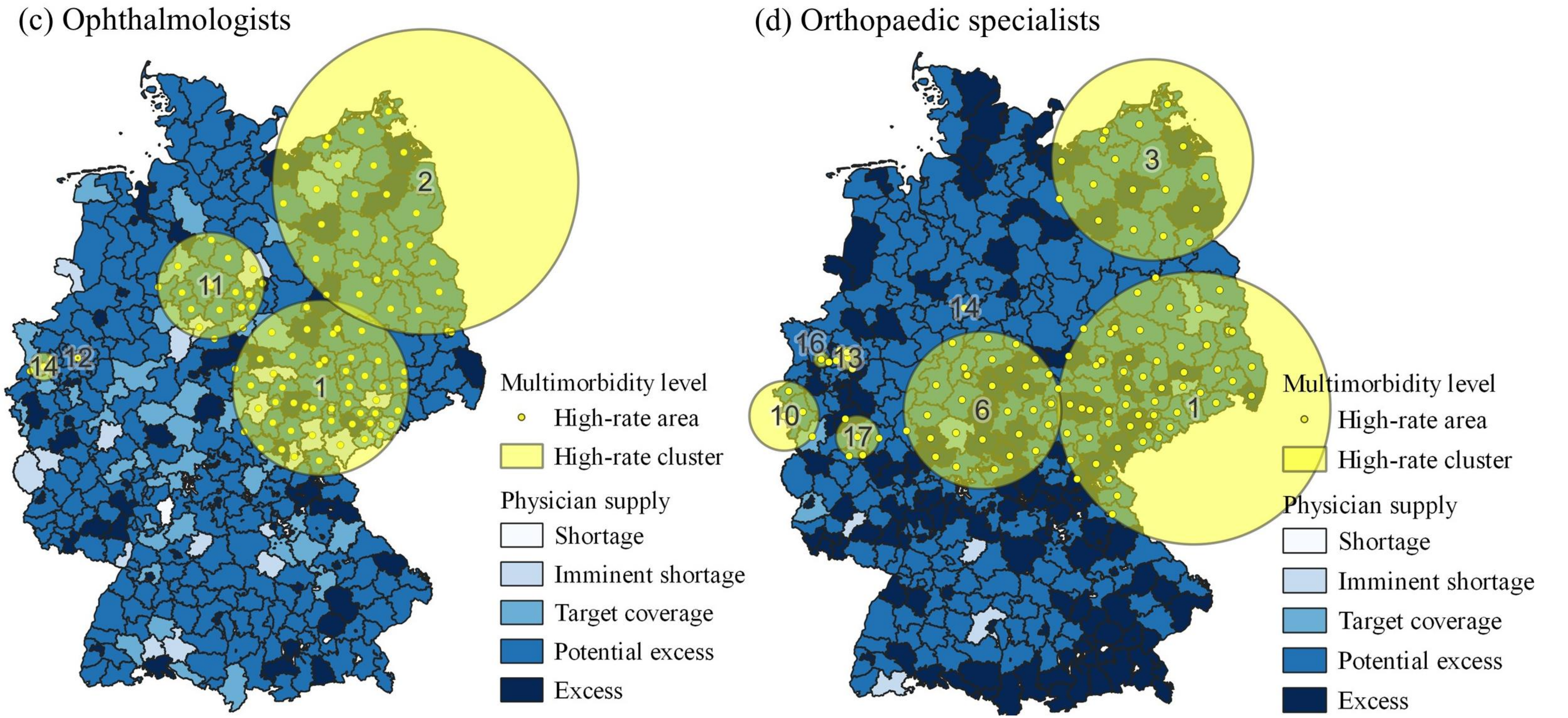


Figure 10 Level of physician supply and significant high-rate clusters of multimorbid patients numbered consecutively based on the underlying likelihood per planning unit for (a) ophthalmologists and (b) orthopaedic specialists in Germany in 2015.

Source: Geiger et al. [92]

# 4. Discussion

Physician planning under consideration of changes in healthcare needs of a population (e.g. the rising number of multimorbid individuals) plays a central role in achieving equitable access to healthcare services. The assessment of approaches estimating needs-based supply of physicians against quality criteria revealed weaknesses and methodological gaps, which should be addressed in future studies. By detecting regional variation in multimorbidity levels within and between office-based physicians, the importance of integrating multimorbidity measures when estimating the need for healthcare was emphasised. Given that almost 50% of the high-rate clusters of multimorbid patients in GPs are met with physician coverage below targeted values, improvements in GP care should be targeted most urgently.

## 4.1 Methodological assessment of studies

The conceptual basis of needs-based physician planning including proxies used to approximate the need for healthcare are governed by underlying assumptions with no uniform standards. Transparently deliberating and reporting these assumptions was missing in the included studies. In particular, when relying on approaches from other scholars [119–122, 126, 127, 129–131, 133, 135], it is important to reflect whether these approaches can be applied in another context or if adaptations are required. For instance, transferability of established approaches especially to other countries may be limited due to differences in healthcare delivery, population structure, and access to care.

When looking at the indicators used to approximate need for healthcare, a comprehensive selection of indicators was revealed. Despite being the most direct measure of need according to the systematisation of healthcare needs in this thesis, four studies did not apply morbidity measures in their analysis, with even fewer studies including social determinants of health. Not drawing from the full range of indicators related to need for healthcare could be a source of biases and thus seems like a passed opportunity as each indicator may add to the validity of the estimates. An example of how several indicators can be integrated when estimating the need for healthcare is provided by Sundmacher et al. [10], who set up several regression-based models to estimate needs-based supply of physicians in Germany.

Indicators related to need can be heavily influenced by physician supply and access to healthcare services (see Chapter 1.1.2). Not reflecting on the effects of supply on need estimations potentially harms the accuracy of the estimates and replicates existing imbalances. With more than every third study (39%) included in the review not discussing these limitations in any of their approaches used to estimate needs-based supply, a major gap was identified. Ways to account for supply dependency in terms of unmet need or lack of physicians provided in the review include waiting lists, unfilled positions, uninsured or unattached individuals, estimates from an expert panel, and accounting for differences in access by socio-economic background (see 3.1.2.1). Apart from unmet healthcare needs, unindicated healthcare utilisation in terms of supply-sensitive care should also be acknowledged when estimating needs-based supply based on utilisation measures [138], which was not considered in any study included in the review. Resources discovering supply-sensitive care are available for several countries [139], with one prominent example being the Dartmouth Atlas of Health Care (USA) [140].

Requirements regarding the data basis were challenging in two ways; firstly, with regards to the assessment of the studies itself as the transparency of reporting internal and external validity as well as timeliness of the data basis was limited, and secondly, concerning the ability of studies to fulfil these areas. Overall, data availability seemed to be the most limiting factor within the requirements for the data basis. Efforts to improve data availability on a national and international level including the provision of funding to develop a sustainable platform that is made accessible to scholars under adherence of the General Data Protection Regulation are needed. For hospital care, international platforms which can be used for research purposes, such as eNewborn [141] in the field of neonatology, already exist. In Germany, endeavours were undertaken to establish a data centre for research purposes but the data is not yet accessible to researchers [142]. As outlined by the European Parliament, there are still several obstacles preventing the establishment of a European-wide data centre, which need to be addressed by all member states [143].

While assessing the translation of estimated healthcare needs to physician requirements, it became clear that more research is needed to find a uniform conversion method. As direct conversions are the preferred option, some measures of productivity must be employed. Productivity measures, however, may vary over time and between physician disciplines as they are dependent on the availability of physicians in general and the way of service provision [130]. Innovative models of service delivery, for example, which aim to reduce physician contacts through integrated care approaches may have an influence on overall productivity measures [144, 145]. Moreover, researchers showed that changes in income can also lead to alterations in productivity, even having a negative effect on productivity if income is set over a certain limit [146]. Therefore, productivity measures need to be carefully selected bearing in mind their limitations and regularly tested for validity.

The selection of a statistical model should be based on the properties of the included variables, considering the level of analysis to avoid ecological fallacy. Moreover, all models need to be validated to ensure accuracy of the findings. Apart from models using system dynamics or extrapolations based on indices, no explanation for model selection was offered. While most studies provided at least one type of model validation, thorough validation processes were also missing, being limited to three studies [118, 120, 133]. Consulting reports for model validation such as provided by Eddy et al. [147] may help to improve future models.

To incorporate future trends and developments is again a very complex task as medical care is a fast-changing area [148]. Nevertheless, it is important to project estimates of needs-based supply of physicians into the future as sustainable provision of physicians relies on forward planning. Projection variables identified in the review mainly consist of demographic changes (age and sex distribution). However, relying on age and sex as main indicators to forecast need bears the risk of overestimation or underestimation as demographic variables alone may be insufficient to accurately predict need for healthcare. For example, since morbidity seems to be expanding in high-resource countries like Germany [105], need projections based on age and sex alone would lead to underestimation of future healthcare needs. Integrating changes and trends in morbidity may improve predictions as they are directly influencing the need for healthcare [10]. The main challenge with morbidity measures also constitutes their reliability over time. Even if historic datasets are used to estimate a trend in morbidity, outcomes should be additionally validated by expert panels as they may be aware of trends in morbidity that are not yet visible [122, 130].

Given the great range in planning horizons (10-31 years) observed in the methodological review, which were mainly justified by the availability of population data, the need for an evidence-based selection process of planning horizons is stressed. In general, short-term estimations for 3-5 years provide more accurate results with less uncertainty [149, 150]. However, adopting a range-based horizon with an increasing number of scenarios and decreasing certainty over time – such as applied by the WHO when estimating scenarios regarding future pandemics and epidemics [149] – may allow for medium-term and long-term physician planning under considerations of certain assumptions. Importantly, short-term scenarios need to be frequently updated to detect relevant developments, changes, or trends in healthcare needs at an early stage.

The outbreak of the COVID-19 pandemic [151] led to sudden changes in healthcare needs across and within countries, which are not covered under the general needs-based physician planning as infectious disease outbreaks in particular are difficult to predict [152]. The knowledge of such events, however, can be used as a resource to complement findings from needs-based physician planning. Canadian researchers, for example, estimated additional service requirements needed in the case of an outbreak of influenza [153] and during the COVID-19 pandemic [154]. However, before integrating these approaches, their accuracy in predicting additional healthcare needs must be tested more extensively.

## 4.2 Regional variation in multimorbidity in Germany

The results from the cross-sectional study in all of Germany illustrate that levels of multimorbid patients vary significantly between areas and affect physician disciplines to a varying degree. These findings in combination with the increased healthcare utilisation of multimorbid patients as outlined in Chapter 1.3.3 promote the integration of regional multimorbidity levels when estimating needs-based supply of physicians. While regional differences in clusters of multimorbid patients between specialised physicians detected by the Bernoulli model were more prominent, results from the spatial autocorrelation test demonstrate more similar patterns between all three specialities, specifically in high-rate areas. Thus, more research is needed to test whether regional multimorbidity levels should be integrated overall or rather stratified by physician discipline. However, if overall levels are used as they might prove more robust over time, ways to account for the different shares of multimorbid patients between physician disciplines should be considered (e.g. by assigning weights).

The most likely high-rate clusters were found in Eastern Germany. i.e. in areas of the former German Democratic Republic. One reason might be that the old-age dependency ratio in East German area states is higher than in West German area states, with a ratio of 40.9 individuals of pensionable age (to 100 individuals in working age) in East German compared to 33.9 in West German area states in 2015 [155]. Moreover, Eastern Germany also seems to have higher levels of deprivation according to the deprivation index of Kroll et al [156]. This, however, does not hold true for other high-rate clusters found, for example, in North Rhine-Westphalia as their old-age dependency ratio was set at 34.0 in 2015 [155] with varying levels of deprivation [156]. In-depth research regarding the underlying reason for high rates in multimorbidity is required in order to efficiently improve care.

Moran’s I was used to validate the findings derived from the Bernoulli model. Although the majority of high-rate areas was confirmed, low-rate areas were only confirmed to a limited extend. One reason for the differences in detected areas may lie in the underlying functions as the Bernoulli model [115] is not influenced by neighbouring areas compared to Moran’s I [117]. Researchers testing several spatial clustering approaches confirmed that clusters identified through different methods are likely to differ as they are looking for different types of clusters [157]. In accordance with the aim of the thesis, the Bernoulli model was deemed most appropriate method for cluster detection as the number of multimorbid patients in neighbouring areas was of low relevance.

According to the data used in the cross-sectional study, Germany seems to be well-equipped regarding the provision of neurologists, ophthalmologist, and orthopaedic specialists. Thus, it is unsurprising that average physician coverage even in high-rate clusters of multimorbid patients is exceeding targeted values. The question remains, however, if physician planning in 2015, which was mainly based on physician-to-population ratios from the 1990s adapted with a demographic factor (see Chapter 1.2.2), sufficiently accounted for healthcare needs based on the underlying morbidity. Thus, it would be essential to repeat the study and test whether the potential excess in specialised physicians, specifically in the identified high-rate areas, remains identical when applying new AVZs as basis, which (since 2019) include measures of morbidity [55]. The integration of morbidity measures might have led to an increased number of targeted physicians, which in turn could lead to a lower level of physician coverage in areas with a greater likelihood of multimorbid patients. Moreover, the morbidity factor itself can be tested against high- and low-rate areas of multimorbid patients to examine whether the estimations of additional care needs are similar.

In contrast to specialised physicians, the physician coverage of GPs varied significantly across Germany. Almost half of the detected high-rate clusters are met with average physician supply below targeted values. Following the above-mentioned hypothesis that physician planning in 2015 might have underestimated the need for healthcare in the population, the suggested shortages in GPs might also be an understatement. Therefore, it is of utmost importance to improve care, specifically in high-rate areas with imminent shortages of GPs.

## 4.3 Strengths and limitations

The assessment of methodologies of studies that quantify needs-based supply was systematically structured and followed clear quality criteria, enabling a coherent and replicable evaluation, which constitutes an advancement to previous studies [49, 158]. While existing appraisal tools failed to grasp the complexity of physician planning, the framework used in the review at hand provides a novel appraisal tool, which encompasses central requirements of needs-based physician planning as defined by Sundmacher et al. [10].

In addition to what has been previously studied, knowledge regarding shortcomings of current studies estimating needs-based supply specifically with regards to the influence of supply on need proxies and in combination with recommendations on how to improve these areas is added. These recommendations can be directly applied by policymakers to improve their current workforce planning.

Given that multimorbidity is found at any age [85, 86], the classification of multimorbidity without age restrictions used in this thesis to assess regional variation of multimorbidity across Germany can be seen as central advancement, providing an overview of multimorbidity burden per physician discipline and planning unit. Other studies conducted in Germany predominantly focussed on older adults [83, 90, 102, 104–108], which limits the explanatory power of the research as trends in multimorbidity in younger age categories would be missed. An important area for future research are age-specific prevalence rates of multimorbid patients and their development over time. Interaction terms between multimorbidity and age could be used to analyse their influence on need for healthcare and to test whether interaction terms or age and multimorbidity as separate variables are better predictors of healthcare needs under consideration of other variables such as sex [29].

One limitation in the methodological review was the language restriction. Despite including two languages, studies in other languages might have been missed. As workforce planning is a national task, it is reasonable to assume that many countries provide their approaches to estimate need in a population in their national languages and thus were not included in this study. Future studies should be conducted in a large (multinational) team or cooperative research project with a great variety in native languages and ideally also knowledge of various country-specific workforce planning approaches to ensure that as many studies as possible can be considered whilst nevertheless avoiding translation errors.

Moreover, as the aim of the review was to assess models for needs-based supply of physicians, no recommendations regarding supply side modelling were provided. Further research is needed to evaluate whether approaches for supply-side modelling are adequate. Similar to needs-based models, supply-side models also need to take changing productivity of physicians and other factors such as demographic changes and shifting expectations of the health workforce into account to achieve a sustainable provision of physicians [130, 159]. With regards to the COVID-19 pandemic and the considerable potential of similar outbreaks [149], improved preparedness plans including a diverse portfolio of measures to quickly increase available physician capacities in order to meet changing healthcare needs, are needed [152, 160].

The cross-sectional study was based on claims data of the German statutory health insurance. Despite being combined data of all statutory health insurance providers (>100 in Germany), differences in access to care might have influenced the results. For example, uninsured people would not be visible in the data. Based on limitations in data availability, no cross-validation was feasible as only data from a European-wide survey of people aged 50 and above (including 20 disease categories) on low resolution (national level) would have been available [161].

Previous studies showed that age and socio-economic status may correlate with the number of multimorbid patients [162, 163]. Nevertheless, neither variable was used to adjust the results from the cross-sectional study, with the main reason being data restrictions and uncertainties regarding the actual influence of age and socio-economic status on multimorbidity, which can be primarily attributed to differences in definitions of multimorbidity. Sundmacher et al. [10] also found that adding multimorbidity to the analysis when estimating need for healthcare (including variables regarding age and socio-economic status) increases the explanatory power. More research is needed to clarify the underlying relationship between these variables.

Another limitation lies in the timeliness of the data used to identify multimorbidity, specifically as the estimates are pre-dating the onset of the COVID-19 pandemic [151]. Although German estimations of changes in multimorbidity over time are limited to people above 50 years of age [98] or 65 years of age [105], and vary between 1% and

7% increase per year [98, 105], there is reason to assume that the number of multimorbid patients has increased since 2015. Thus, it will be important to update the estimates of this thesis once the consequences from the COVID-19 pandemic are fully unfold, particularly including chronic or secondary conditions such as (or associated with) long COVID.

## 4.4 Role of multimorbidity in future

In order to integrate multimorbidity measures sustainably when assessing the need for healthcare in a population, additional research is needed to understand the influence of multimorbidity on healthcare needs, starting with agreeing on a common definition for multimorbidity with regards to the need for healthcare and including an evidence-based threshold of the minimum number of diseases required to be classified as multimorbid. Moreover, a core set of healthcare conditions with international consent would ease the comparability of findings between studies. Research showed that even within one country such as Germany detected prevalence rates of individuals suffering from multimorbidity may vary significantly [104].

Despite the above-mentioned limitations, multimorbidity measures are important proxies of the need for healthcare and should be considered for future estimations of needs-based supply of physicians. This is particularly important with regards to the increase in mental health conditions related to the COVID-19 pandemic [53, 160], as these conditions combined with other diseases were found to be associated with increased healthcare utilisation and consultation lengths [79].

Researchers found that multimorbid patients require continuous care initiatives as they suffer disproportionally from the fragmentation of care, leaving them vulnerable to adverse effects from inadequate medication, which in turn impacts their quality of life [70, 164] Moreover, challenges arising from multimorbid patients like uncertainties in evidence of treatments, interactions between medications, and undefined responsibilities put an additional burden on the attending physicians [165]. Therefore, policymakers are demanded to strengthen integrated care specifically in areas with high rates of multimorbid individuals, which would support patients and physicians alike. Moreover, these areas are also well-suited to test innovative, integrated care approaches in order to improve the health outcomes for multimorbid patients and relief burden from physicians [166].

In order to decrease the burden of multimorbidity on healthcare systems in general, initiatives decelerating the development and progression of chronic noncommunicable diseases, which account for more than half of the global burden are needed. As shown by the global Burden of Diseases, Injuries, and Risk Factors Study [167], many of the illnesses causing the majority of DALYs concern conditions that may be preventable, such as mental health conditions, low back pain, diabetes, ischaemic heart disease, and stroke with attributed risk factors including (among others) smoking, unhealthy diet including alcohol consumption, air pollution and bullying. These factors in addition to the socio-economic status and the physical activity level were also linked to accelerated progression of multimorbidity [93, 102]. Initiatives promoting physical activity, which was found to improve outcomes of multimorbid patients and does not require many resources [168], can help to lower the burden of multimorbidity. However, more research is needed on how to implement preventive measures and policies sustainably [169] to decrease the number of chronic diseases and thus the number of multimorbidity in the population.

# 5. Conclusion

The methodological review identified weaknesses in almost all central areas in current approaches for workforce planning. These weaknesses can now be tackled by policymakers and scholars alike to improve future needs-based planning of physicians. Despite the fact that the level of multimorbid individuals is constantly rising and associated with increased healthcare needs, its integration into needs-based physician planning is yet missing. Significant differences in regional multimorbidity levels across Germany underline the importance of integrating multimorbidity measures in needs-based physician planning. For an effective integration, empirical studies defining a core set of diseases to classify multimorbidity and information on their influence on healthcare utilisation and consultation lengths are needed. Moreover, data availability must be expanded in order to allow for appropriate estimations of the need for healthcare and to account for potential influences of supply on indicators used to approximate need.

In the meantime, findings from the cross-sectional study, pointing to high-rate clusters of multimorbid individuals predominantly in the central and eastern parts of Germany, can be used as additional resource to reform German physician planning and to strengthen areas with an increased need for healthcare services and care coordination.

The results of the thesis underline that estimating needs-based supply of physicians is a complex task which requires deliberate decision-making under consideration of certain limitations with regards to the conceptual basis, data sources, model selection including translation into provider requirements, and sustainability of the estimates.

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# Appendix A: Review protocol

1. Search history
    a. Electronic database

| Database, provider | | Web of Science Core Collection, Thomson Reuters | | Update |
|---|---|---|---|---|
| Search date (dd/mm/yyyy) | | 05/04/2017 | | 09/03/2020 |
| Period or update status | | 1963-05/04/2017 | | 05/04/2017-09/03/2020 |
| # | Search | | Results | Results |
| 1 | TOPIC: ("workforce planning") | | 680 | / |
| 2 | TOPIC: ("capacity planning") | | 2,024 | / |
| 3 | TOPIC: ("human resource*") | | 27,379 | / |
| 4 | TOPIC: ("planning") | | 343,331 | / |
| 5 | TOPIC: ("service requirement*") | | 2,857 | / |
| 6 | TOPIC: ("health") | | 1,545,733 | / |
| 7 | TOPIC: ("physician*") | | 252,153 | / |
| 8 | #7 AND #6 | | 80,602 | / |
| 9 | #8 AND #5 | | 8 | / |
| 10 | #8 AND #1 | | 66 | / |
| 11 | #8 AND #2 | | 7 | / |
| 12 | #8 AND #4 AND #3 | | 70 | / |
| 14 | #13 OR #12 OR #11 OR #10 OR #9 | | **132** | **91** |

Source: Geiger et al. [109]

| Database, provider | | PubMed, U.S. National Library of Medicine | | Update |
|---|---|---|---|---|
| Search date (dd/mm/yyyy) | | 16/05/2017 | | 09/03/2020 |
| Period or update status | | 1980-16/05/2017 | | 16/05/2017-09/03/2020 |
| # | Search | | Results | Results |
| 1 | TOPIC: ("need") | | 391,069 | / |
| 2 | TOPIC: ("capacity planning") | | 83 | / |
| 3 | TOPIC: ("health human resource") | | 104 | / |
| 4 | TOPIC: ("demand") | | 67427 | / |
| 5 | TOPIC: ("healthcare") | | 166,724 | / |
| 6 | TOPIC: ("workforce planning") | | 511 | / |
| 7 | TOPIC: ("forecast") / ("projection") | | 4,400 / 48,535 | / |
| 8 | #6 AND #5 | | 85 | / |
| 9 | #6 AND #5 AND #1 | | 25 | / |
| 10 | #6 AND #5 AND #4 | | 24 | / |
| 11 | #6 AND #5 AND #7 | | 2 | / |
| 12 | #6 AND #3 | | 4 | / |
| 13 | #6 AND #7 | | 8 | / |
| 14 | #3 AND #1 | | 25 | / |
| 15 | #3 AND #4 | | 13 | / |
| 16 | #9 OR #10 OR #11 OR #12 #13 OR #14 OR #15 | | **186** | **3** |

Source: Geiger et al. [109]

| Database, provider | | Science Direct, Elsevier | Update |
|---|---|---|---|
| Search date (dd/mm/yyyy) | | 20/09/2017 | 09/03/2020 |
| Period or update status | | 1980-20/09/2017 | 20/09/2017-09/03/2020 |
| # | Search | Results | Results |
| 1 | TOPIC: ("need") | 6,016,181 | / |
| 2 | TOPIC: ("capacity planning") | 5,326 | / |
| 3 | TOPIC: ("health human resource") | 403 | / |
| 4 | TOPIC: ("demand") | 1,537,913 | / |
| 5 | TOPIC: ("healthcare") | 392,618 | / |
| 6 | TOPIC: ("workforce planning") | 1,344 | / |
| 7 | TOPIC: ("forecast") / ("projection") | 244,797 / 698,167 | / |
| 8 | #6 AND #3 | 26 | / |
| 9 | #6 AND #5 AND #4 AND #1 | 298 | / |
| 10 | #6 AND #7 AND #5 AND #4 AND #1 | 65 | / |
| 11 | #6 AND #7 AND #3 | 10 | / |
| 12 | #2 AND 5 AND #7 | 117 | / |
| 13 | #8 OR #9 OR #10 OR #11 OR #12 | **516** | **187** |

Source: Geiger et al. [109]

Summary of search history

| Database, provider | Search date (dd/mm/yyyy) | Period or update status | Results | Update |
|---|---|---|---|---|
| Web of Science Core Collection, Thomson Reuters | 04/04/2017 | 1963 – 05/04/2017 | 132 | 91 |
| PubMed, U/S/ National Library of Medicine | 16/05/2017 | 1980 – 16/05/2017 | 186 | 3 |
| Science Direct, Elsevier | 16/05/2017 | 1980 – 20/09/2017 | 516 | 187 |
| Overall including duplicats | | | 834 | 281 |
| Overall no duplicats | | | **790** | **203** |

Source: Geiger et al. [109]

b. List of websites included in the identification process [109]

i. International

- GHWA http://www/who/int/workforcealliance/
  - NOW transitioned into: http://www/who/int/hrh/network/en/
- WHO Health Workforce http://www/who/int/hrh/resources/en/
- OECD http://www/oecd/org/
- World Bank http://www/worldbank/org/
- Andean network of Observatories for human resources for health http://www/observatoriorh/org/andino/?q=taxonomy/term/23
- European Observatory on Health Systems and Policies http://www/euro/who/int/en/about-us/partners/observatory
- WHO EURO Health Evidence Network (HEN)
- http://www/euro/who/int/en/data-and-evidence/evidence-informed-policy-making/health-evidence-network-hen
- The Health Systems and Policy Monitor
- http://www/hspm/org/mainpage/aspx
- European Commission on Public Health, health workforce http://ec/europa/eu/health/workforce/policy/index_en/htm
- Joint Action on Health Workforce Planning and Forecasting http://www/euhwforce/eu/
- HRH Global Resource Centre http://www/hrhresourcecenter/org/
- KIT http://www/kit/nl/kit/en/
- Health Cluster EU http://healthclusternet/eu
- WHO Collaborating Centers focusing on HRH
  - University of Western Cape http://www/uwc/ac/za/Faculties/CHS/soph/Pages/WHO-Collaborating-Center-/aspx
  - University of Illinois at Rockford http://ncrhp/uic/edu/index/cfm?id=1031&b=1003&page=World%20Health%20Organization%20%28WHO%29%20Collaborating%20Centre
  - McMaster University http://nursing/mcmaster/ca/WHO_collaborating_centre/html

- WHO Collaborating Center on Health Workforce Policy and Planning - http://whoccworkforce/ihmt/unl/pt/

ii. Country specific

- Canada
  - Health Canada (human resources strategy) http://www/hc-sc/gc/ca/hcs-sss/hhr-rhs/strateg/index-eng/php
  - CHHRN http://www/hhr-rhs/ca/
- Netherlands
  - NIVEL http://www/nivel/nl/en
  - Advisory Committee on Medical Manpower Planning http://www/capaciteitsorgaan/nl/Publicaties/tabid/68/language/en-US/Default/aspx
- Austria
  - Gesundheitsportal https://www/gesundheit/gv/at/Portal/Node/ghp/public
  - Hauptverband der österreichischen Sozialversicherungsträger http://www/hauptverband/at/portal27/hvbportal/content?contentid=10007/752050&viewmode=content
- Sweden
  - Ministry of Health and Social Affairs http://www/government/se/sb/d/2061
  - National Board of Health and Welfare http://www/socialstyrelsen/se/english
- UK
  - Centre for Workforce Intelligence http://www/cfwi/org/uk/
  - Department of Health https://www/gov/uk/government/publications?departments[]=department-of-health
  - Health Education England https://hee/nhs/uk/
- Germany
  - IGES Institut GmbH https://www/iges/com/
  - Zentralinstitut für die kassenärztliche Versorgung http://www/zi/de/
  - GKV Spitzenverband https://www/gkv-spitzenverband/de/
  - Wissenschaftliches Institut für Gesundheitsökonomie und Gesundheitssystemforschung http://www/wig2/de/

# Appendix B: Multimorbidity categories according to Barnett et al. [68]

| Disease categories | ICD-10-GM codes | | |
|---|---|---|---|
| | 1-digit code | 3-digit code | 4/5-digit code |
| Hypertension | | I10 - I11 | |
| | | O11 | |
| Depression | | F33 | F41.2 |
| | | F32 | F20.4 |
| | | F34 | |
| Painful condition | | M54 | F62.80 |
| | | N23 | F45.40 |
| | | R51, R52 | H57.1 |
| | | R10 | K14.6 |
| | | | K08.88 |
| | | | M25.5 |
| | | | M79.6 |
| | | | N64.4 |
| | | | H92.0 |
| | | | R10.2 |
| | | | R07.0, R07.1 |
| Asthma (currently treated) | | J45, J46 | |
| Coronary heart disease | | I20 - I25 | |
| Treated dyspepsia | | K29 - K31 | F45.31 |
| | | | R10.1 |
| Diabetes | | E10 - E14 | |
| Thyroid disorders | | E00 - E07 | |
| Rheumatoid arthritis, other inflammatory polyarthropathies & systematic connective tissue disorders | | M05 - M14 | |
| | | M20 - M25 | |
| Hearing loss | | H90 | H83.3 |
| | | H93 | H91.0, H91.2, H91.3, H91.9 |
| Chronic obstructive pulmonary disease | | J44 | |
| Anxiety & other neurotic, stress related & somatoform disorders | | F40 - F48 | |
| Irritable bowel syndrome | | K58 | |
| New diagnosis of cancer in last 5a | C, D (48) | | |
| Alcohol problems | | F10 | |
| Other psychoactive substance misuse | | F11 - F19 | |
| Treated constipation | | | K59.0 |
| Stroke & transient ischaemic attack | | I60 - I62 | |
| | | I63 | |
| | | I65 - I67 | |
| | | G45, G46 | |
| Chronic kidney disease | | N18 | |
| Diverticular disease of intestine | | K57 | |
| Atrial fibrillation | | I47 - I49 | |
| Peripheral vascular disease | | I70 - I89 | |
| Heart failure | | I50 | |
| Prostate disorders | | N40 - N42 | |
| Glaucoma | | H40 | |
| Epilepsy (currently treated) | | G40, G41 | |
| Dementia | | F00 - F03 | |
| Schizophrenia (and related non-organic psychosis) or bipolar disorder | | F20, F21, F25 | F23.3 |
| | | | F20.4 |
| Psoriasis or eczema | | L40 | |
| | | L20, L21 | |
| Inflammatory bowel disease | | K50 - K52 | |
| Migraine | | G43, G44 | |
| Blindness & low vision | | H53, H54 | |
| Chronic sinusitis | | J32 | |
| Learning disability | | F80, F81, F83, F84 | |
| Anorexia or bulimia | | F50 | |
| Bronchiectasis | | J47 | Q33.4 |
| | | A15, A16 | |
| Parkinson's disease | | G20, G22 | |
| | | G21 | |
| Multiple sclerosis | | G35 | R63.0 |
| Viral Hepatitis | | B15 - B19 | |
| Chronic liver disease | | K70-77 | |

Source: Geiger et al. [92]

# Appendix C: Overview of assessment against the quality criteria

| ID | First author | Year | Country | Physician group |
|---|---|---|---|---|
| 1 | Albrecht, M | 2012 | Germany | outpatient care physicians |
| 2 | Ansah, J | 2017 | Singapore | eyecare workforce |
| 3 | Anderson, G | 1997 | USA | otolaryngologist |
| 4 | Barber, P | 2010 | Spain | medical specialists |
| 5 | Greenberg, L | 1997 | USA | primary care physicians |
| 6 | Jäger, R | 2016 | Germany | dentists |
| 7 | Konrad, T | 2009 | USA | mental health professionals |
| 8 | Lee, P | 1995 | USA | eyecare workforce |
| 9 | von Stillfried, D | 2011 | Germany | office-based physicians |
| 10 | CfWI | 2014 | UK | general practitioner |
| 11 | Stuckless, T | 2012 | Canada | oncologists |
| 12 | Singh, D | 2010 | Canada | primary care physicians |
| 13 | Laurence, C | 2016 | Australia | general practitioner |
| 14 | Albrecht, M | 2016 | Germany | psychotherapists |
| 15 | Ozegowski, S | 2012 | Germany | office-based physicians |
| 16 | Kopetsch, T | 2016 | Germany | office-based physicians |
| 17 | Czaja, M | 2012 | Germany | psychotherapists and GPs |
| 18 | Dall, T | 2015 | USA | physician workforce (primary care, medical specialties, surgical specialties and "other" specialties) |

Source: Geiger et al. [109]

| | Conceptional framework | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1.1 Rationale of indicators of need and empirical justification | Description | 1.2 Influence of supply on need | Description | 1.2.1 Accounting for potential unmet need or lack of physicians | Description | 1.2.2 Accounting for potential overuse or oversupply |
| **ID** | 0/ 1 | | 0/ 1 | | 0/1 | | 0/1 |
| 1 | 1 | individual framework and factor analysis | 1 | target variables that are statistically independent from supply | 0 | | 0 |
| 2 | 1 | prior research | 0 | supply based model, unequal distribution of healthcare workforce | 0 | | 0 |
| | 1 | prior research | 0 | | 0 | | 0 |
| | 1 | prior research | 0 | | 0 | | 0 |
| | 1 | individual framework | 1 | | 1 | unmet care needs (waitlists) | 0 |
| 3 | 1 | prior research | 1 | | 1 | adjusted for uninsured | 0 |
| | 1 | prior research | 0 | | 0 | | 0 |
| | 1 | prior research | 0 | | 0 | | 0 |
| 4 | 1 | prior research | 1 | supply based model | 1 | positions unfilled | 0 |
| 5 | 1 | prior research | 0 | highlight the effects of under- and oversupply in introduction (lacking access to services and supply induced demand) | 0 | | 0 |
| 6 | 1 | prior research | 0 | try to establish association between need/demand and access using the Gini coefficient and regression models | 0 | | 0 |
| 7 | 1 | individual framework and regression model (logit) to estimate prevalence | 0 | | 0 | | 0 |
| 8 | 1 | individual framework | | | 0 | | 0 |
| | 1 | individual framework | | | 0 | | 0 |
| 9 | 1 | individual framework | 0 | | 0 | | 0 |
| 10 | 1 | prior research | 1 | qualitative discussion of unmet need | 1 | panel estimates unmet | 0 |
| 11 | 1 | prior research | 0 | | 0 | no | 0 |
| 12 | 1 | individual framework | 1 | acknowledge importance of needs-based models instead of utilisation/pop-physician-ratio | 1 | limited access, different estimates on physician shortages (people unattached to GP) | 0 |
| 13 | 1 | prior research | 0 | | 0 | | 0 |
| 14 | 1 | (update of) prior research and individual data analysis to estimate prevalence | 1 | measure morbidity via epidemiological study to get data independent of supply (find more need for older people than utilisation data suggested) | 0 | | 0 |
| 15 | 1 | individual framework | 1 | utilisation is influenced by e.g. supply-induced demand; however assumption that over and under supply cancel each other out throughout Germany, additionally argue only publicly funded utilisation for less influence | 0 | | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 16 | 1 | prior research and regression model (GIMD ~ morbidity, utilisation, mortality) | 0 | | 0 | | 0 |
| 17 | 1 | individual framework and factor analysis | 0 | mention that demand might be supply-driven, neglect potential oversupply or undersupply | 0 | | 0 |
| 18 | 1 | (update of) prior research | 1 | assumption supply and demand roughly in equilibrium (conservative), however no systematic study to quantify current shortfalls/excess of supply, thus demand projections are extrapolated from 2014 -> take imbalance (shortfalls or excess) into the future | 1 | account for shortages in GPs and psychiatrists; include utilization equity scenario to account for underutilisation (inadequate access) | 0 |

Source: Geiger et al. [109]

| | Validity of data basis | | | | | |
|---|---|---|---|---|---|---|
| | 2.1 External validity | Description | 2.2 Internal validity | Description | 2.3 Timeliness and availability | Description |
| **ID** | 0/ 1 | | 0/ 1 | | 0/ 1 | |
| 1 | 1 | population data | 1 | discuss potential limitations | 1 | 2007/8, latest data available |
| 2 | 0 | mixed data (population data - statistics, data from medical council, limitations not discussed) | 0 | unclear | 1 | 2012, further years not mentioned just referenced, assumed numbers to remain constant, not further disclosed |
| | 0 | mixed data (population data - statistics, SEED study limitations not discussed, ministry of health) | 0 | unclear | 1 | 2012, further years not mentioned just referenced, assumed numbers to remain constant to remain constant, not further disclosed |
| | 0 | mixed data (population data - statistics, SEED study limitations not discussed, ministry of health) | 0 | unclear | 1 | 2012, further years not mentioned just referenced, assumed numbers to remain constant to remain constant, not further disclosed |
| | 0 | mixed data (population data - statistics, SEED study limitations not discussed, literature, expert opinions) | 0 | unclear | 1 | 2012, further years not mentioned just referenced, assumed numbers to remain constant to remain constant, not further disclosed |
| 3 | 0 | convenience sample (three largest HMOs, use adjustments to make extrapolations possible | 1 | try to enhance (based on limitations adjustments were applied; sensitivity analysis of adjustments) | 1 | 1992-4, not further disclosed |
| | 0 | mixed data (numbers from Bureau of Health Professionals) | 0 | unclear (final estimations given from external source (not further discussed)) | 1 | 1993, not further disclosed |
| | 0 | mixed data (estimates of Delphi panel, utilisation data) | 1 | discuss potential limitations (acknowledge that only limited to people that have access to care and office-based care, subject to bias) | 1 | 1992, 1994, not further disclosed |
| 4 | 0 | mixed data (population data, data of Health Ministry on physicians, estimation of private doctors, data from autonomous community health service and internet searches) | 0 | unclear, no discussion | 1 | 1990-2008, not further disclosed |
| 5 | 0 | mixed data (population and survey data (representativeness not discussed)) | 1 | try to enhance (use additional dataset to adjust unsystematically reported data) | 1 | 1980, 1985, 1989, not further disclosed |
| 6 | 0 | mixed data (population data, insurance claims data, cross-sectional data) | 0 | used repeated cross-sectional data (not discussed further) | 1 | 2011, 2014, year of cross-sectional study not mentioned just referenced, not further disclosed |
| 7 | 0 | mixed data (population data, survey (nationally representative), survey data adjusted for utilisation estimates) | 1 | discuss potential limitation and try to enhance (sampling error, repeated replications utilisation based on self-reported data) | 1 | 2001, 1990, 2003, 1993, 2006, not further disclosed |

| | | | | | | |
|---|---|---|---|---|---|---|
| 8 | 0 | mixed data (epidemiological data, smaller studies, population data, current utilisation rescaled), state non representative sample | 1 | try to enhance indicator validity (validate with utilisation numbers, advisory panel, adjust incidents rates downward based on experts/literature, check for response bias) | 1 | 1989-1991, 1993, state survey is periodically conducted |
| | 0 | mixed data (epidemiological data, smaller studies (scientific literature), population data (census), current utilisation rescaled), state non representative sample | 1 | try to enhance indicator validity (validate with utilisation numbers, advisory panel, adjust incidents rates downward based on experts/literature and check for response bias) | 1 | 1989-1991, 1993, state survey is periodically conducted |
| 9 | 1 | population data (all publicly ensured patients) | 1 | discuss (potential limitation if patients change insurance) | 1 | 2008, routinely collected data |
| 10 | 0 | mixed data (national statistics, literature, NHS data) | 1 | try to enhance (used Delphi panel exercise to estimate uncertain/poor quality data and state limitations of approach, data confidence rating, validation approaches, state assumptions) | 1 | 2012, 2011, 2010, updated in march 2013, not further disclosed |
| 11 | 0 | mixed data (various datasets, e.g. cancer registries and survey (complete response rates), validity of data checked when possible, claim robust dataset) | 0 | unclear, no discussion | 1 | 1989–2009, state possibility to recalculate annually (collected annually) |
| 12 | 0 | mixed data (literature reviews, statistic bureau, survey - low response rate) | 1 | try to enhance (weighted variables based on expert opinion, complementary literature) | 1 | 2001-2005, 2008, not further disclosed |
| 13 | 0 | mixed data (bureau of statistics, claims data, acknowledge limitation based on sample size and selection bias) | 1 | discuss (unrepeated cross-sectional data, use reference group of experts for additional info on trends) | 1 | 2003, 2004, 2007, detailed description and scope of dataset, latest data available |
| 14 | 1 | representative sample (survey data (country-wide, stratified, representative sample), but limitations) | 1 | discuss (using prevalence data from surveys is more precise than claims data) | 1 | 2004, 2014, latest data available |
| 15 | 0 | convenience sample (claims data from one sickness fund, not validated if representative) | 1 | discuss and try to enhance (excluded utilisation data outside home area, discuss accuracy of claims data) | 1 | 2007, 2008, discuss transferability |
| 16 | 0 | mixed data (public health insurance claims, national statistics, GIMD) | 0 | unclear, no discussion | 1 | 2006, 2008, 2010, mention potential to update, discuss transferability |
| 17 | 0 | mixed data (insurance claims data (KV Berlin), indices, national statistics) | 1 | discuss potential limitations (morbidity index with diseases corresponding to physicians) | 1 | 2007, 2007, 2010, not further disclosed |
| 18 | 1 | representative sample (i.e. derived through matching and re-sampling) | 0 | unclear, state that some data based on telephone interviews | 1 | 2004, 2008-2013; numbers assumed to remain constant, latest data available |

Source: Geiger et al. [109]

## Appendix C: Overview of assessment against the quality criteria

| | Modelling | | | | | | | Integration of future trends and developments | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3.1 Conversion into FTE | Description | 3.2 Model (description) | Validation | Description | 3.3 Level of analysis | Description | 4.1 Projection variable | Description | 4.2 Planning horizon |
| **ID** | 0/ 1 | | | 0/ 1 | | 0/ 1 | | 0/ 1 | | |
| 1 | 0 | (adaptation/adjustment of) physician-population ratio | regression analysis and adjustments | 1 | used $R^2$ | 0 | aggregated | 1 | population projection (change size and age) | 2010-2025 (15a) |
| 2 | 0 | physician-population ratio | System Dynamics | 1 | compare results with historical data, stakeholder validation, sensitivity analysis of outcome parameter (sensitivity bounds) | 0 | aggregated | 1 | population projection (change size and age) | 2010-2040 (30a) |
| | 1 | FTE - average demand for eye service divided per average patient visit per ophthalmologist | System Dynamics | 1 | compare results with historical data, stakeholder validation, sensitivity analysis of outcome parameter (sensitivity bounds) | 0 | aggregated | 1 | population projection (change size and age) | 2010-2040 (30a) |
| | 1 | FTE - expected patient visits divided by average patient visit per ophthalmologist (including uptake rate) | System Dynamics | 1 | compare results with historical data, stakeholder validation, sensitivity analysis of outcome parameter (sensitivity bounds) | 0 | aggregated (partially) | 1 | population projection (change size and age) | 2010-2040 (30a) |
| | 1 | FTE - expected patient visits divided by average patient visit per ophthalmologist (changes in uptake rates among different populations included) | System Dynamics | 1 | compare results with historical data, stakeholder validation, sensitivity analysis of outcome parameter (sensitivity bounds) | 0 | aggregated (partially) | 1 | population projection (change size and aging, use of service), differences in disease treatment duration | 2010-2040 (30a) |
| 3 | 0 | (adaptation/adjustment of) physician-population ratio | descriptive analyses and extrapolations | 1 | sensitivity analyses | 0 | aggregated | 1 | population projection | 1994-2010 (16a) |
| | 1 | FTE - physician productivity over minutes required for service, then dividing required total patient-care minutes by average number of minutes worked per physician | Delphi survey, descriptive analyses and extrapolations | 0 | | 0 | aggregated | 1 | population projection, based on demographics, insurance coverage projections | 1994-2010 (16a) |
| | 0 | visits per population (translation not explained) | descriptive analyses and extrapolations | 1 | suggest that other method (Delphi panel) not suitable | 0 | aggregated | | new estimations of physician Delphi panel | 1994-2010 (16a) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 0 | adjusted ratios to FTE | System Dynamics, Delphi survey | 1 | argue method is frequently used and adapted for planning purposes | 0 | aggregated | 1 | population growth, four potential variations in demand - demographics and Delphi panel (growth-rate of demand) | 2008-2025 (17a) |
| 5 | 1 | FTE - through translation of minutes (total number of minutes devoted by physicians divided by total number of physicians) | extrapolations | 1 | highlight advantages to simpler approaches, cross-validation | 0 | aggregated | 1 | six different scenarios, change in demographics, insurance status, utilisation pattern | 1989-2020 (31a) |
| 6 | 0 | no direct translation: comparison of relative regional need (in terms of morbidity estimated in demand-time) and relative physician supply | extrapolations | 1 | mention in discussion: established model (model fit estimate using $R^2$) | 0 | aggregated | 1 | population growth scenarios, morbidity based on age, changing pattern per scenario | 2011-2030 (19a) |
| 7 | 1 | FTE - conversion of minutes of services needed, yearly hours of direct patient contact | adjusted extrapolation model | 1 | replications + CI for prevalence, acceptable fit, might be subject to prediction error and sampling error | 0 | aggregated | 0 | | |
| 8 | 1 | FTE - based on work time (minutes) associated with disease divided by patient care minutes available per FTE, conversion factor | adjusted extrapolation model | 1 | sensitivity analysis | 0 | aggregated | 1 | population projections (demographic changes) | 1994-2010 (16a) |
| | 1 | FTE - based on work time (minutes) associated with disease divided by patient care minutes available per FTE, conversion factor | adjusted extrapolation models, bootstrapped data | 1 | sensitivity analysis | 0 | aggregated | | population projections (demographic changes) | 1994-2010 (16a) |
| 9 | 1 | FTE - averaged need (in points) of a region divided by average number of points a physician group performs | linear regression analysis, descriptive analyses | 1 | more variation explained after adding morbidity ($R^2$) | 1 | individual | 0 | projection (in 5a intervals) mentioned in discussion | |
| 10 | 1 | FTE - staffing patterns are used to convert to FTE: national volume of services divided by number of physicians | System Dynamics | 1 | sensitivity analyses | 0 | aggregated | 1 | population growth and changing composition, increased morbidity, increased workload, increased consultations per age and gender | 2013-2030 (17a) |
| 11 | 1 | FTE - estimated demand in patient referrals is divided by the amount of new patients seen per FTE | forward calculation (prediction) model | 1 | expert panel and literature review, predictive validation, sensitivity analysis | 0 | aggregated | 1 | incident growth annually recalculated, ratio of new cases per FTE, 5a baseline data | 2010-2020 (10a) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 1 | FTE - based on work time associated with disease (survey data), variance is converted by average number of hours work per year per speciality | simulation model (state transition cohort model, different base cases) | 0 | | 0 | aggregated | 1 | change in demographics, increase in disease prevalence, health risk factors based on gender, productivity | 2008-2030 (22a) |
| 13 | 1 | FTE - Estimated number of consultations per year (+ average length by gender/age) were translated into FTE with 40 hour working week and 44-week working year (allow for CME, holiday etc) | simulation model (two sub-modules) | 1 | sensitivity analyses, predictive validity | 0 | aggregated | 1 | three scenarios change in demographics and different utilisation rates or increasing prevalence | 2003-2013 to compare with real numbers (10a) |
| 14 | 0 | (adaptation/adjustment of) physician-population ratio | regression analysis for prevalence predictions, small area estimations | 1 | sensitivity analyses, variation coefficient, area under the curve | 1 | individual | 0 | mentioned possibility in discussion | |
| 15 | 0 | no direct translation: comparison of relative regional need (in terms of expected physician contacts) and relative physician supply | extrapolations model | 1 | rationalise usage of concentration index in context, sensitivity analyses | 0 | aggregated | 0 | | |
| 16 | 0 | (adaptation/adjustment of) physician-population ratio | regression based linear additive model | 0 | | 0 | aggregated | 0 | | |
| 17 | 0 | (adaptation/adjustment of) physician-population ratio | linear additive model using weighting | 1 | weight both indices equally | 0 | aggregated | 0 | | |
| 18 | 1 | FTE - demand for physicians is linked to demand for healthcare services, accounting for portion of time that physicians spend providing care in different delivery settings. FTE is the average weekly patient care hours (per specialty) 35.3 hours up to 54.3 hours | microsimulation of individual utilisation and regression models, model calibration | 1 | full validation based on ISPOR guidelines | 1 | individual | 1 | demographics (age, gender, race/ethnicity), utilisation pattern - extrapolated, staffing | 2014-2025 (11a) |

Source: Geiger et al. [109]

# Appendix D: SaTScan scanning results from the Bernoulli purely spatial analysis [92]

"General information:
Data Checking
-------------
Temporal Data Check: Check to ensure that all cases and controls are within the specified temporal study period.
Geographical Data Check: Check to ensure that all observations (cases, controls and populations) are within the specified geographical area.

Spatial Neighbours
-----------------
Use Non-Euclidian Neighbours file: No
Use Meta Locations File: No
Multiple Coordinates Type: Allow only one set of coordinates per location ID.

Spatial Window
--------------
Maximum Spatial Cluster Size 50 percent of population at risk
Window Shape: Circular
Isotonic Scan: No

Inference
---------
P-Value Reporting: Standard Monte Carlo
Report Gumbel Based P-Values: No
Number of Replications: 999
Adjusting for More Likely Clusters: No

Spatial Output
--------------
Report Hierarchical Clusters: Yes
Criteria for Reporting Secondary Clusters: No Geographical Overlap
Report Gini Optimized Cluster Collection: No
Restrict Reporting to Smaller Clusters: Yes
Reported Clusters: Only clusters smaller than 10 percent of population at risk reported.

**1. GPs**

SUMMARY OF DATA

Study period: 2015/1/1 to 2015/12/31
Number of locations: 959
Total population: 54,799,570
Total number of cases: 17,239,488
Percent cases in area: 31.5

CLUSTERS DETECTED

1. Location IDs included.: 3400200, 3400196, 3400407, 3400207, 3400201, 3400206, 3400194, 1204120, 3400164, 3400202, 3400409, 1204070, 3400321, 3400198, 3400204, 1503070, 3400208, 3400165, 3400203, 3400193, 1204080, 1204110, 3400166, 1603000, 3400167, 3400209, 3400190, 1503010, 3400178, 1503020, 3400172, 3400189, 3400188, 1603100, 1205080, 3400192, 3400171, 1504020, 1504030, 3400168, 1204100, 3400177, 3500161, 3500159, 1503060, 3400173, 3400191, 1204040, 3400176, 3400199, 3600522, 3400169, 3400197, 3400187, 1503040, 1504040, 3600526, 1205070, 1204020, 1602600, 3400170, 1204090, 3400408, 1205110, 1602900, 1504010, 1204050, 1205050, 1602700, 3400186, 1503030, 3600527, 1503050, 3400174, 1603500, 1602500, 1204010, 1602000, 3600524, 1205120, 1504060, 1502020, 1205130, 3400181, 3400179, 1204060, 3400185, 1205040, 1205100, 1603400, 3600528, 1204030, 1204130, 1502050, 1203040, 3400182, 3400180, 1505050, 1505060, 1600200, 1603200, 1205030, 3400184, 1505040, 1601900, 3400183, 3500162
Coordinates / radius..: (51.319400 N, 13.053642 E) / 131.52 km
Population............: 5428136
Number of cases.......: 2117537
Expected cases........: 1709101.26
Observed / expected...: 1.24
Relative risk.........: 1.27
Percent cases in area.: 39.0
Log likelihood ratio..: 76489.133840
Monte Carlo rank......: 1/1000
P-value...............: 0.001

2. Location IDs included.: 811050, 811020, 915030, 811040, 915020, 811030, 2900144, 811060, 811010, 812080, 915040, 915010, 2900145, 810060, 812040, 915050, 812020, 801140, 810030, 812030, 803040, 812010, 2900143, 812070, 915060, 801130, 2900352, 801100, 2900391, 810020, 916030, 916010, 801120, 812090, 2900123, 812060, 916020, 916050, 810080, 803030, 812050, 801090, 2900343, 916060, 810050, 810010, 803020, 801070, 2900142, 916070, 2900371, 809060, 2900309, 2900373, 2900122, 801060, 810040, 809090, 810070, 801080, 801110, 909050, 2900303, 803010, 808040, 916040, 917010, 801150, 809080, 801030, 914050, 909040, 2900302, 2900310, 916080, 806070, 801040, 809070, 802090, 801050, 808020, 917020, 914080, 2900124, 806050, 910030, 806040, 801010, 801020, 914030, 2900152, 910040, 917080, 802050, 808050, 2900132, 808010, 802080, 917040, 806060

Coordinates / radius..: (48.212343 N, 9.925358 E) / 115.75 km
Population............: 5329548
Number of cases.......: 1404320
Expected cases........: 1678059.87
Observed / expected...: 0.84
Relative risk.........: 0.82
Percent cases in area.: 26.3
Log likelihood ratio..: 37164.729538
Monte Carlo rank......: 1/1000
P-value...............: 0.001

3. Location IDs included.: 3300503, 3300501, 3300511, 3300502, 3300505, 3300520, 3300509, 3300510, 3300506, 3300514, 3300516, 1302050, 1303070, 3300513, 1303080, 3300517, 3300515, 3300518, 1302040, 3300507, 1202010, 1202020, 1201080, 1301060, 1202030, 3300508, 1201010, 1201040, 3300155, 1202040, 3300519, 1201050, 1201060, 1202050, 1203060, 1201030, 3300512, 1201070, 3300504

Coordinates / radius..: (54.088914 N, 13.414215 E) / 157.82 km
Population............: 1665881
Number of cases.......: 656200
Expected cases........: 524518.79
Observed / expected...: 1.25
Relative risk.........: 1.26
Percent cases in area.: 39.4
Log likelihood ratio..: 23961.215522
Monte Carlo rank......: 1/1000
P-value...............: 0.001

4. Location IDs included.: 2400001, 339010, 2300429, 2300434, 2300087, 2300107, 2300112, 333020, 314020, 319010, 2300108, 2300100, 2300103, 2400000, 2300105, 321010, 2300099, 319020, 329010, 2300086, 2300115, 2300090, 104030, 2300085, 321020, 2300111, 330020, 2300101, 104020, 331010, 319030, 104040, 2300442, 323020, 2100083, 104010, 330010, 2300102, 338010, 315010, 105070, 331020, 2300096, 2200000, 307020, 325010, 332010, 320010, 2300437, 307030, 103020, 103040, 320030, 338020, 2300113, 2100080, 337010, 2300441, 2100084, 320020, 105050, 332020, 101120, 504010, 306010, 101110, 337020, 504020, 2300004, 103010, 2300114, 2300432, 2100082, 306030, 101090

Coordinates / radius..: (53.542867 N, 8.576513 E) / 134.61 km
Population............: 5401922
Number of cases.......: 1531117
Expected cases........: 1700847.53
Observed / expected...: 0.90
Relative risk.........: 0.89
Percent cases in area.: 28.3
Log likelihood ratio..: 13948.338567
Monte Carlo rank......: 1/1000
P-value...............: 0.001

5. Location IDs included.: 1600900, 601200, 1601100, 601210, 1600800, 1601000, 2900372, 601190, 601180, 601220, 601170, 2900346, 3600523, 1601200, 601130, 903020, 601150, 602080, 2900345, 1601800, 1600500, 1601300, 2600270, 601120, 903030, 1600400, 603060, 2600272, 1601500, 1600600, 602070, 601050, 3600521, 903040, 2600271, 2900148, 601100, 2600274, 603090, 602060, 2900127, 2900304, 2900149, 904020, 602120, 2600273, 1602300, 1600700, 1600300, 603070, 2300095, 1602200, 904010, 601090

Coordinates / radius..: (50.745283 N, 10.128848 E) / 84.64 km
Population............: 2197553
Number of cases.......: 773317
Expected cases........: 691920.87
Observed / expected...: 1.12
Relative risk.........: 1.12
Percent cases in area.: 35.2
Log likelihood ratio..: 7143.345783
Monte Carlo rank......: 1/1000
P-value...............: 0.001

6. Location IDs included.: 603130, 603110, 603160, 603170, 603140, 603100, 603120, 703030, 603190, 603260, 703020, 603150, 603200, 603180, 703010, 603250, 603020, 701110, 2700116, 703050, 602150, 603270
Coordinates / radius..: (50.079149 N, 8.260376 E) / 38.74 km
Population............: 1974684
Number of cases.......: 550963
Expected cases........: 621748.41
Observed / expected...: 0.89
Relative risk.........: 0.88
Percent cases in area.: 27.9
Log likelihood ratio..: 6231.632185
Monte Carlo rank......: 1/1000
P-value...............: 0.001

7. Location IDs included.: 503060, 503050, 503120, 503040, 503110, 503130, 503070, 503140, 503170, 503010, 503080, 503160, 503090, 503150, 503100, 503230, 2300438, 503180, 503240, 332030, 503020, 503270
Coordinates / radius..: (52.093125 N, 7.058568 E) / 49.60 km
Population............: 1137345
Number of cases.......: 319570
Expected cases........: 358104.10
Observed / expected...: 0.89
Relative risk.........: 0.89
Percent cases in area.: 28.1
Log likelihood ratio..: 3153.444098
Monte Carlo rank......: 1/1000
P-value...............: 0.001

8. Location IDs included.: 911050, 911060, 2900350, 912010, 2900386, 2900401, 2900406, 2900377, 912090, 2900383, 2900351, 2900400, 2900392, 2900397, 2900394, 2900375, 911030, 912100, 2900362, 906070, 2900379, 2900384, 2900357, 2900141, 2900398, 2900385, 2900344, 2900341, 912050, 912060, 2900396, 906020, 913030, 2900367, 2900128, 2900353, 911070, 911090, 2900380, 906010, 2900359, 906040, 911080, 2900368, 2900356, 2900361, 2900146, 2900129, 2900370, 912080, 913080, 2900358, 913010, 911010, 2900402, 907060, 2900393, 913070, 905040, 905080, 2900136, 914010, 2900399, 2900138, 918010, 907050, 2900342, 2900348, 2900135, 2900130, 918020, 2900137
Coordinates / radius..: (49.285830 N, 12.880936 E) / 123.30 km
Population............: 2243965
Number of cases.......: 659238
Expected cases........: 706534.14
Observed / expected...: 0.93
Relative risk.........: 0.93
Percent cases in area.: 29.4
Log likelihood ratio..: 2438.324057
Monte Carlo rank......: 1/1000
P-value...............: 0.001

9. Location IDs included.: 501430, 501400, 505360, 501420, 501440, 505340, 501390, 501160, 501410, 505350, 501380, 501170, 501370, 505390, 505320, 505330, 501460, 505370, 501450, 501360
Coordinates / radius..: (51.337479 N, 7.088029 E) / 21.23 km
Population............: 1573763
Number of cases.......: 533963
Expected cases........: 495514.54
Observed / expected...: 1.08
Relative risk.........: 1.08
Percent cases in area.: 33.9
Log likelihood ratio..: 2212.714316
Monte Carlo rank......: 1/1000
P-value...............: 0.001

10. Location IDs included.: 705030, 705020, 705040, 1000080, 705050, 705060
Coordinates / radius..: (49.413043 N, 7.526107 E) / 20.80 km
Population............: 340205
Number of cases.......: 125115
Expected cases........: 107116.84
Observed / expected...: 1.17
Relative risk.........: 1.17
Percent cases in area.: 36.8
Log likelihood ratio..: 2161.111783
Monte Carlo rank......: 1/1000
P-value...............: 0.001

11. Location IDs included.: 505160, 505170, 505130, 505190, 505200, 505150, 505140, 505180, 701010, 602020, 505120, 505230, 505210, 502300, 602010, 502330, 505090, 505240, 602090, 601070, 505070
Coordinates / radius..: (50.984411 N, 8.061247 E) / 38.92 km
Population............: 754396
Number of cases.......: 212675
Expected cases........: 237528.90
Observed / expected...: 0.90
Relative risk.........: 0.89
Percent cases in area.: 28.2
Log likelihood ratio..: 1962.870483
Monte Carlo rank......: 1/1000
P-value...............: 0.001

12. Location IDs included.: 504220, 504210, 505020, 504230, 504200
Coordinates / radius..: (51.765423 N, 8.540728 E) / 20.21 km
Population............: 266785
Number of cases.......: 70591
Expected cases........: 83999.84
Observed / expected...: 0.84
Relative risk.........: 0.84
Percent cases in area.: 26.5
Log likelihood ratio..: 1620.065221
Monte Carlo rank......: 1/1000
P-value...............: 0.001

13. Location IDs included.: 306050
Coordinates / radius..: (52.465977 N, 9.704680 E) / 0 km
Population............: 37589
Number of cases.......: 15180
Expected cases........: 11835.26
Observed / expected...: 1.28
Relative risk.........: 1.28
Percent cases in area.: 40.4
Log likelihood ratio..: 661.230403
Monte Carlo rank......: 1/1000
P-value...............: 0.001

14. Location IDs included.: 902050, 2900389, 903070, 2900403, 2900313, 2900404
Coordinates / radius..: (49.753176 N, 10.256027 E) / 22.89 km
Population............: 227996
Number of cases.......: 64713
Expected cases........: 71786.75
Observed / expected...: 0.90
Relative risk.........: 0.90
Percent cases in area.: 28.4
Log likelihood ratio..: 520.489293
Monte Carlo rank......: 1/1000
P-value...............: 0.001

15. Location IDs included.: 502120, 502080, 502110, 502220, 502070, 502100, 502230, 502130, 502060, 502180, 502050, 502030, 502140, 502240, 502020, 502170, 502040, 502160, 502010, 502190, 501320, 502380, 502260, 501260, 502150, 502390, 501250, 502200, 502400, 501270, 502250, 501330, 502420, 501230, 501290, 501280, 502410, 501240
Coordinates / radius..: (50.828460 N, 6.269418 E) / 51.32 km
Population............: 1742905
Number of cases.......: 568218
Expected cases........: 548770.54
Observed / expected...: 1.04
Relative risk.........: 1.04
Percent cases in area.: 32.6
Log likelihood ratio..: 516.342800
Monte Carlo rank......: 1/1000
P-value...............: 0.001

16. Location IDs included.: 502430
Coordinates / radius..: (50.688724 N, 7.095696 E) / 0 km
Population............: 199568
Number of cases.......: 56252
Expected cases........: 62835.92
Observed / expected...: 0.90
Relative risk.........: 0.89
Percent cases in area.: 28.2
Log likelihood ratio..: 515.520854
Monte Carlo rank......: 1/1000
P-value...............: 0.001

17. Location IDs included.: 505430, 505420, 505460, 505450, 505400, 505440, 503290
Coordinates / radius..: (51.622922 N, 7.629610 E) / 15.89 km
Population............: 374967
Number of cases.......: 126716
Expected cases........: 118062.00
Observed / expected...: 1.07
Relative risk.........: 1.07
Percent cases in area.: 33.8
Log likelihood ratio..: 460.306138
Monte Carlo rank......: 1/1000
P-value...............: 0.001

18. Location IDs included.: 907010, 907020, 2900364, 904060, 907030, 2900378, 2900347, 2900349, 907040
Coordinates / radius..: (49.666190 N, 10.914525 E) / 28.93 km
Population............: 927128
Number of cases.......: 304870
Expected cases........: 291915.24
Observed / expected...: 1.04
Relative risk.........: 1.05
Percent cases in area.: 32.9
Log likelihood ratio..: 423.526710
Monte Carlo rank......: 1/1000
P-value...............: 0.001

19. Location IDs included.: 701050
Coordinates / radius..: (50.471370 N, 6.999173 E) / 0 km
Population............: 63772
Number of cases.......: 22953
Expected cases........: 20079.23
Observed / expected...: 1.14
Relative risk.........: 1.14
Percent cases in area.: 36.0
Log likelihood ratio..: 293.484437
Monte Carlo rank......: 1/1000
P-value...............: 0.001

20. Location IDs included.: 2700283, 2700281, 702080, 2700282, 702050, 1000010, 702060, 702040, 1000020, 703080
Coordinates / radius..: (49.786803 N, 6.746398 E) / 39.02 km
Population............: 377791
Number of cases.......: 125826
Expected cases........: 118951.16
Observed / expected...: 1.06
Relative risk.........: 1.06
Percent cases in area.: 33.3
Log likelihood ratio..: 289.077760
Monte Carlo rank......: 1/1000
P-value...............: 0.001

**2. Ophthalmologists**

SUMMARY OF DATA

Study period: 2015/1/1 to 2015/12/31
Number of locations: 385
Total population: 16,195,148
Total number of cases: 7,145,558
Percent cases in area: 44.1

CLUSTERS DETECTED

1. Location IDs included.: 150840, 160740, 150880, 160520, 160530, 150020, 340061, 340021, 160710, 160770, 160760, 160680, 150870, 340033, 340035, 340024, 160510, 340039, 160750, 160650, 160730, 350017, 340027, 160700, 150890, 340019, 340083, 340028, 350018, 340081, 340036, 160670, 160620, 340038, 160640, 150910, 160720, 94750, 94760, 150850, 340023, 340026, 340037, 150030, 340022, 160690, 340082, 160610, 160660
Coordinates / radius..: (51.147303 N, 11.883881 E) / 117.24 km
Population............: 1556108
Number of cases.......: 883094
Expected cases........: 686579.75
Observed / expected...: 1.29
Relative risk.........: 1.33
Percent cases in area.: 56.8
Log likelihood ratio..: 55229.122868
Monte Carlo rank......: 1/1000
P-value...............: 0.001

2. Location IDs included.: 130620, 120730, 130590, 130550, 130520, 120600, 120650, 130560, 130610, 120640, 130570, 120680, 130530, 310016, 130510, 130030, 120630, 130600, 120540, 120670, 120700, 120610, 120690, 120720, 150900, 130580, 130540, 150860, 120520, 120710
  Coordinates / radius..: (53.574148 N, 14.069925 E) / 203.26 km
  Population............: 1604093
  Number of cases.......: 845977
  Expected cases........: 707751.50
  Observed / expected...: 1.20
  Relative risk.........: 1.22
  Percent cases in area.: 52.7
  Log likelihood ratio..: 26608.229601
  Monte Carlo rank......: 1/1000
  P-value...............: 0.001

3. Location IDs included.: 84260, 84360, 84250, 84210, 97750, 84370, 84150, 97780, 84350, 97740, 97760, 81170, 84170, 81160, 81350, 97800, 84160, 83350, 83270, 97770, 97720, 97730, 81110, 97610, 91810, 81150, 81360, 81190, 83250, 97710, 91900, 83260, 97790, 81180, 82370, 82350, 91790, 91880, 81270
  Coordinates / radius..: (48.107673 N, 9.774403 E) / 115.62 km
  Population............: 1532075
  Number of cases.......: 546811
  Expected cases........: 675976.01
  Observed / expected...: 0.81
  Relative risk.........: 0.79
  Percent cases in area.: 35.7
  Log likelihood ratio..: 24803.581092
  Monte Carlo rank......: 1/1000
  P-value...............: 0.001

4. Location IDs included.: 92760, 92710, 92720, 93720, 92780, 92750, 92790, 92770, 93750, 93620, 93760, 92740, 92730, 91710, 91830, 93740, 93710, 93730, 91770, 93770, 91780, 91860, 91760, 91610, 91890, 95740, 91750, 94790, 91850, 91870, 95760, 94720, 91720, 91740, 91620, 91840
  Coordinates / radius..: (49.022814 N, 13.099907 E) / 149.87 km
  Population............: 1180312
  Number of cases.......: 455320
  Expected cases........: 520772.54
  Observed / expected...: 0.87
  Relative risk.........: 0.87
  Percent cases in area.: 38.6
  Log likelihood ratio..: 8020.783563
  Monte Carlo rank......: 1/1000
  P-value...............: 0.001

5. Location IDs included.: 10610, 10560, 10510, 33590, 10600, 10580, 20000, 33520, 10620, 10020, 10570, 33530, 40120, 33570
  Coordinates / radius..: (53.924334 N, 9.514041 E) / 76.12 km
  Population............: 897025
  Number of cases.......: 340739
  Expected cases........: 395781.78
  Observed / expected...: 0.86
  Relative risk.........: 0.85
  Percent cases in area.: 38.0
  Log likelihood ratio..: 7337.090564
  Monte Carlo rank......: 1/1000
  P-value...............: 0.001

6. Location IDs included.: 55660, 55150, 34040, 34590, 55580, 55700, 34560, 55540, 34540, 57540, 59150, 34600, 55620
  Coordinates / radius..: (52.211514 N, 7.579225 E) / 66.45 km
  Population............: 761920
  Number of cases.......: 286515
  Expected cases........: 336171.30
  Observed / expected...: 0.85
  Relative risk.........: 0.85
  Percent cases in area.: 37.6
  Log likelihood ratio..: 6975.807202
  Monte Carlo rank......: 1/1000
  P-value...............: 0.001

7. Location IDs included.: 100440, 100420, 100410, 100430, 100460
Coordinates / radius..: (49.355298 N, 6.775427 E) / 29.75 km
Population............: 161830
Number of cases.......: 54027
Expected cases........: 71401.99
Observed / expected...: 0.76
Relative risk.........: 0.75
Percent cases in area.: 33.4
Log likelihood ratio..: 3919.720863
Monte Carlo rank......: 1/1000
P-value...............: 0.001

8. Location IDs included.: 64370, 96760, 64310, 64320, 82250, 64110, 82210, 82260, 82220, 96710, 64380, 64330, 73140, 64130, 73380, 81280, 64120, 81250, 73310, 81210, 96770, 64360, 73150, 81260, 64350, 73320, 64140, 96790, 96630, 73390, 82150, 64340, 64400
Coordinates / radius..: (49.671448 N, 8.979515 E) / 76.11 km
Population............: 1581231
Number of cases.......: 656609
Expected cases........: 697664.42
Observed / expected...: 0.94
Relative risk.........: 0.94
Percent cases in area.: 41.5
Log likelihood ratio..: 2405.610518
Monte Carlo rank......: 1/1000
P-value...............: 0.001

9. Location IDs included.: 59700, 59660, 65320, 71320, 65340, 59580, 53740
Coordinates / radius..: (50.937659 N, 8.194734 E) / 48.15 km
Population............: 282308
Number of cases.......: 113798
Expected cases........: 124558.81
Observed / expected...: 0.91
Relative risk.........: 0.91
Percent cases in area.: 40.3
Log likelihood ratio..: 852.522449
Monte Carlo rank......: 1/1000
P-value...............: 0.001

10. Location IDs included.: 51110
Coordinates / radius..: (51.235418 N, 6.810261 E) / 0 km
Population............: 105254
Number of cases.......: 40695
Expected cases........: 46439.75
Observed / expected...: 0.88
Relative risk.........: 0.88
Percent cases in area.: 38.7
Log likelihood ratio..: 646.961954
Monte Carlo rank......: 1/1000
P-value...............: 0.001

11. Location IDs included.: 32411, 32412, 31570, 32540, 32570, 32520, 33510, 31020, 32560, 31010, 32550, 31510, 33580, 31580, 31030, 57700, 31530, 31550
Coordinates / radius..: (52.379486 N, 9.769642 E) / 70.98 km
Population............: 790463
Number of cases.......: 362014
Expected cases........: 348764.92
Observed / expected...: 1.04
Relative risk.........: 1.04
Percent cases in area.: 45.8
Log likelihood ratio..: 472.367233
Monte Carlo rank......: 1/1000
P-value...............: 0.001

12. Location IDs included.: 59110
Coordinates / radius..: (51.469928 N, 7.224923 E) / 0 km
Population............: 82982
Number of cases.......: 40225
Expected cases........: 36612.99
Observed / expected...: 1.10
Relative risk.........: 1.10
Percent cases in area.: 48.5
Log likelihood ratio..: 318.710764
Monte Carlo rank......: 1/1000
P-value...............: 0.001

13. Location IDs included.: 94710, 95720, 96740, 94740, 94780
Coordinates / radius..: (49.894622 N, 10.893297 E) / 28.70 km
Population............: 117407
Number of cases.......: 47664
Expected cases........: 51801.85
Observed / expected...: 0.92
Relative risk.........: 0.92
Percent cases in area.: 40.6
Log likelihood ratio..: 299.837851
Monte Carlo rank......: 1/1000
P-value...............: 0.001

14. Location IDs included.: 51140, 51120, 51660
Coordinates / radius..: (51.345236 N, 6.579665 E) / 18.94 km
Population............: 183259
Number of cases.......: 85623
Expected cases........: 80856.80
Observed / expected...: 1.06
Relative risk.........: 1.06
Percent cases in area.: 46.7
Log likelihood ratio..: 253.351019
Monte Carlo rank......: 1/1000
P-value...............: 0.001

**3. Orthopaedic specialist**

SUMMARY OF DATA

Study period.......................: 2015/1/1 to 2015/12/31
Number of locations................: 385
Total population...................: 11,659,090
Total number of cases..............: 4,722,933
Percent cases in area..............: 40.5

CLUSTERS DETECTED

1. Location IDs included.: 340032, 340020, 340037, 340031, 340022, 340026, 340082, 340081, 340027, 340019, 340029, 340023, 340042, 340028, 340024, 340043, 340035, 340036, 340038, 120620, 120660, 340039, 160770, 340061, 340041, 340021, 340033, 160520, 120520, 340083, 120710, 160760, 150910, 150840, 120610, 120720, 150020, 160740, 150880, 160750, 94790, 160530, 350017, 350018, 94750, 93770, 120670, 160710, 120690, 160730, 94760, 93740, 150870, 150890, 120540, 94770
Coordinates / radius..: (50.890262 N, 13.650447 E) / 176.50 km
Population............: 1138830
Number of cases.......: 600906
Expected cases........: 461324.02
Observed / expected...: 1.30
Relative risk.........: 1.35
Percent cases in area.: 52.8
Log likelihood ratio..: 38598.865331
Monte Carlo rank......: 1/1000
P-value...............: 0.001

2. Location IDs included.: 84150, 81160, 84160, 84250, 84170, 81170, 84370, 84210, 81110, 81150, 84260, 81190, 97750, 83270, 82350, 81180, 83250, 81350, 82370, 82310, 84360, 82360, 81360, 84350, 97740, 83350, 83260, 81210, 97780, 81250, 97730, 81270
Coordinates / radius..: (48.406387 N, 9.365822 E) / 91.13 km
Population............: 1062119
Number of cases.......: 344208
Expected cases........: 430249.47
Observed / expected...: 0.80
Relative risk.........: 0.78
Percent cases in area.: 32.4
Log likelihood ratio..: 16297.499237
Monte Carlo rank......: 1/1000
P-value...............: 0.001

3. Location IDs included.: 130520, 130550, 130590, 130560, 130530, 130570, 130510, 130030, 130620, 130610, 130600, 120730, 120680, 120650, 120700, 120600, 130580, 130540
   Coordinates / radius..: (53.797036 N, 13.041971 E) / 130.09 km
   Population............: 322937
   Number of cases.......: 174974
   Expected cases........: 130817.24
   Observed / expected...: 1.34
   Relative risk.........: 1.35
   Percent cases in area.: 54.2
   Log likelihood ratio..: 12604.469461
   Monte Carlo rank......: 1/1000
   P-value...............: 0.001

4. Location IDs included.: 10610, 10560, 10510, 33590, 10600, 10580, 20000, 33520, 10620, 10020, 10570, 33530, 40120, 33570
   Coordinates / radius..: (53.924334 N, 9.514041 E) / 76.12 km
   Population............: 630204
   Number of cases.......: 205382
   Expected cases........: 255286.78
   Observed / expected...: 0.80
   Relative risk.........: 0.80
   Percent cases in area.: 32.6
   Log likelihood ratio..: 8881.998704
   Monte Carlo rank......: 1/1000
   P-value...............: 0.001

5. Location IDs included.: 91840, 91620, 91750, 91880, 91790, 91740, 91770, 91820, 91730, 91780, 91870, 91810, 91900, 91830, 91860, 97710
   Coordinates / radius..: (48.077661 N, 11.646389 E) / 58.65 km
   Population............: 569294
   Number of cases.......: 189205
   Expected cases........: 230612.99
   Observed / expected...: 0.82
   Relative risk.........: 0.81
   Percent cases in area.: 33.2
   Log likelihood ratio..: 6716.969712
   Monte Carlo rank......: 1/1000
   P-value...............: 0.001

6. Location IDs included.: 66320, 66340, 160630, 66360, 66310, 65350, 66110, 160660, 66330, 160610, 160640, 160670, 31520, 66350, 96730, 65340, 65310, 96720, 64350, 64400, 160690, 160700, 160510, 31550, 160620, 57620, 31560, 160650, 65320, 160680
   Coordinates / radius..: (50.906127 N, 9.752800 E) / 101.88 km
   Population............: 623733
   Number of cases.......: 285133
   Expected cases........: 252665.47
   Observed / expected...: 1.13
   Relative risk.........: 1.14
   Percent cases in area.: 45.7
   Log likelihood ratio..: 3664.122625
   Monte Carlo rank......: 1/1000
   P-value...............: 0.001

7. Location IDs included.: 100440, 100420, 100410, 100430, 100460
   Coordinates / radius..: (49.355298 N, 6.775427 E) / 29.75 km
   Population............: 138825
   Number of cases.......: 41446
   Expected cases........: 56236.06
   Observed / expected...: 0.74
   Relative risk.........: 0.73
   Percent cases in area.: 29.9
   Log likelihood ratio..: 3433.147290
   Monte Carlo rank......: 1/1000
   P-value...............: 0.001

8. Location IDs included.: 34040, 34590, 55660, 57580, 57540, 34600, 57110, 55700, 55150, 57700, 55580, 34540, 32510, 59150, 57660, 34530, 34560, 32570, 59740, 32560, 34580, 57740, 59780, 55540, 55620
   Coordinates / radius..: (52.277683 N, 8.047039 E) / 90.64 km
   Population............: 1113903
   Number of cases.......: 416396
   Expected cases........: 451226.44
   Observed / expected...: 0.92
   Relative risk.........: 0.92
   Percent cases in area.: 37.4
   Log likelihood ratio..: 2518.484320
   Monte Carlo rank......: 1/1000
   P-value...............: 0.001

9. Location IDs included.: 64330, 64110, 73150, 64360, 64320
Coordinates / radius..: (49.904380 N, 8.470254 E) / 23.90 km
Population............: 139233
Number of cases.......: 47073
Expected cases........: 56401.33
Observed / expected...: 0.83
Relative risk.........: 0.83
Percent cases in area.: 33.8
Log likelihood ratio..: 1340.113758
Monte Carlo rank......: 1/1000
P-value...............: 0.001

10. Location IDs included.: 53341, 53342, 53580, 53700, 53660
Coordinates / radius..: (50.759551 N, 6.109727 E) / 45.08 km
Population............: 194072
Number of cases.......: 87073
Expected cases........: 78615.84
Observed / expected...: 1.11
Relative risk.........: 1.11
Percent cases in area.: 44.9
Log likelihood ratio..: 769.947620
Monte Carlo rank......: 1/1000
P-value...............: 0.001

11. Location IDs included.: 51110
Coordinates / radius..: (51.235418 N, 6.810261 E) / 0 km
Population............: 114573
Number of cases.......: 41097
Expected cases........: 46411.91
Observed / expected...: 0.89
Relative risk.........: 0.88
Percent cases in area.: 35.9
Log likelihood ratio..: 523.760529
Monte Carlo rank......: 1/1000
P-value...............: 0.001

12. Location IDs included.: 59660, 59700, 59620, 53740, 59580, 71320
Coordinates / radius..: (51.086125 N, 7.976392 E) / 40.68 km
Population............: 226743
Number of cases.......: 86407
Expected cases........: 91850.40
Observed / expected...: 0.94
Relative risk.........: 0.94
Percent cases in area.: 38.1
Log likelihood ratio..: 278.341399
Monte Carlo rank......: 1/1000
P-value...............: 0.001

13. Location IDs included.: 59110, 59160, 55130, 51130, 59540
Coordinates / radius..: (51.469928 N, 7.224923 E) / 15.31 km
Population............: 292449
Number of cases.......: 123359
Expected cases........: 118466.98
Observed / expected...: 1.04
Relative risk.........: 1.04
Percent cases in area.: 42.2
Log likelihood ratio..: 173.443781
Monte Carlo rank......: 1/1000
P-value...............: 0.001

14. Location IDs included.: 32520
Coordinates / radius..: (52.095088 N, 9.389877 E) / 0 km
Population............: 18239
Number of cases.......: 8530
Expected cases........: 7388.36
Observed / expected...: 1.15
Relative risk.........: 1.15
Percent cases in area.: 46.8
Log likelihood ratio..: 146.495503
Monte Carlo rank......: 1/1000
P-value...............: 0.001

15. Location IDs included.: 51700, 51190
Coordinates / radius..: (51.626927 N, 6.618260 E) / 20.24 km
Population............: 85248
Number of cases.......: 32292
Expected cases........: 34532.77
Observed / expected...: 0.94
Relative risk.........: 0.93
Percent cases in area.: 37.9
Log likelihood ratio..: 124.013962
Monte Carlo rank......: 1/1000
P-value...............: 0.001

16. Location IDs included.: 51120, 51170
Coordinates / radius..: (51.439558 N, 6.734696 E) / 10.36 km
Population............: 103466
Number of cases.......: 44183
Expected cases........: 41912.62
Observed / expected...: 1.05
Relative risk.........: 1.05
Percent cases in area.: 42.7
Log likelihood ratio..: 103.732396
Monte Carlo rank......: 1/1000
P-value...............: 0.001

17. Location IDs included.: 71380, 71110, 71370, 53820, 71430
Coordinates / radius..: (50.557667 N, 7.469048 E) / 28.00 km
Population............: 192062
Number of cases.......: 80337
Expected cases........: 77801.62
Observed / expected...: 1.03
Relative risk.........: 1.03
Percent cases in area.: 41.8
Log likelihood ratio..: 70.372784
Monte Carlo rank......: 1/1000
P-value...............: 0.001

18. Location IDs included.: 53140
Coordinates / radius..: (50.705774 N, 7.109870 E) / 0 km
Population............: 49345
Number of cases.......: 18739
Expected cases........: 19988.97
Observed / expected...: 0.94
Relative risk.........: 0.94
Percent cases in area.: 38.0
Log likelihood ratio..: 66.443825
Monte Carlo rank......: 1/1000
P-value...............: 0.001

### 4. Neurologists

SUMMARY OF DATA

Study period: 2015/1/1 to 2015/12/31
Number of locations: 385
Total population: 4,386,298
Total number of cases: 2,637,461
Percent cases in area: 60.1

CLUSTERS DETECTED

1. Location IDs included.: 340082, 340022, 120620, 340020, 340081, 340036, 340029, 120660, 340032, 340037, 340035, 340027, 340031, 340042, 340019, 340026, 340033, 340061, 340021, 150910, 120520, 340024, 120710, 340028, 120610, 120720, 160770, 340041, 340023, 340043, 340039, 340038, 350018, 150020, 350017, 160520, 150840, 150880, 120670, 160760, 120690, 120540
Coordinates / radius..: (51.311954 N, 13.494769 E) / 127.88 km
Population............: 437064
Number of cases.......: 305521
Expected cases........: 262804.59
Observed / expected...: 1.16
Relative risk.........: 1.18
Percent cases in area.: 69.9
Log likelihood ratio..: 9983.240277
Monte Carlo rank......: 1/1000
P-value...............: 0.001

2. Location IDs included.: 84150, 81160, 84160, 84250, 84170, 81170, 84370, 84210, 81110, 81150, 84260, 81190, 97750, 83270, 82350, 81180, 83250, 81350, 82370, 82310, 84360, 82360, 81360, 84350, 97740, 83350, 83260, 81210, 97780, 81250, 97730, 81270
Coordinates / radius..: (48.406387 N, 9.365822 E) / 91.13 km
Population............: 392866
Number of cases.......: 198564
Expected cases........: 236228.54
Observed / expected...: 0.84
Relative risk.........: 0.83
Percent cases in area.: 50.5
Log likelihood ratio..: 8122.802459
Monte Carlo rank......: 1/1000
P-value...............: 0.001

3. Location IDs included.: 130590, 130520, 130620, 130610, 130550, 130570, 120730, 130560, 130530, 130030, 130510, 120650, 120600, 120680, 130600, 120700, 120640, 130580
Coordinates / radius..: (53.940993 N, 13.662774 E) / 157.99 km
Population............: 175232
Number of cases.......: 125088
Expected cases........: 105366.20
Observed / expected...: 1.19
Relative risk.........: 1.20
Percent cases in area.: 71.4
Log likelihood ratio..: 5022.797305
Monte Carlo rank......: 1/1000
P-value...............: 0.001

4. Location IDs included.: 92750, 92720, 92710, 92770, 92760, 92790, 91710, 92780, 91830, 92740, 93720, 91890, 91720, 93620, 91770, 93750, 92730, 91870, 91780, 91750, 93760, 91860, 91840, 91620, 91610, 91820, 91740, 93730, 91760, 93710, 93740, 91850, 91790, 91880, 91730, 97710, 93770, 95740, 95760, 97610, 95770, 91810, 91900
Coordinates / radius..: (48.559606 N, 13.368473 E) / 192.15 km
Population............: 424221
Number of cases.......: 236621
Expected cases........: 255082.15
Observed / expected...: 0.93
Relative risk.........: 0.92
Percent cases in area.: 55.8
Log likelihood ratio..: 1837.135196
Monte Carlo rank......: 1/1000
P-value...............: 0.001

5. Location IDs included.: 160660, 96730, 160690, 160630, 160670, 160700, 66310, 94730, 160720, 96720, 66320, 160510, 160730, 160640, 96740, 96780, 66360, 94760, 94780, 160710, 160680, 65350, 160610
Coordinates / radius..: (50.629134 N, 10.427062 E) / 84.72 km
Population............: 141416
Number of cases.......: 94606
Expected cases........: 85032.80
Observed / expected...: 1.11
Relative risk.........: 1.12
Percent cases in area.: 66.9
Log likelihood ratio..: 1427.789132
Monte Carlo rank......: 1/1000
P-value...............: 0.001

6. Location IDs included.: 100440, 100420, 100410, 100430, 100460
Coordinates / radius..: (49.355298 N, 6.775427 E) / 29.75 km
Population............: 61262
Number of cases.......: 30707
Expected cases........: 36836.56
Observed / expected...: 0.83
Relative risk.........: 0.83
Percent cases in area.: 50.1
Log likelihood ratio..: 1270.805666
Monte Carlo rank......: 1/1000
P-value...............: 0.001

7. Location IDs included.: 40120, 33520, 34610, 33560, 34550, 40110, 34030, 34510, 33590, 34620, 33570, 34580, 10510, 33610, 10610, 10560, 34570, 34520, 34530, 32510, 20000, 33530, 34600, 33580, 32560, 10600, 10580, 10620, 34540, 10540, 33550, 57700, 10530, 34590
Coordinates / radius..: (53.542867 N, 8.576513 E) / 133.89 km
Population............: 392262
Number of cases.......: 223428
Expected cases........: 235865.35
Observed / expected...: 0.95
Relative risk.........: 0.94
Percent cases in area.: 57.0
Log likelihood ratio..: 896.607212
Monte Carlo rank......: 1/1000
P-value...............: 0.001

8. Location IDs included.: 73150, 64140, 73390, 64330, 64360, 64390, 73310, 64110
Coordinates / radius..: (49.974177 N, 8.241514 E) / 31.98 km
Population............: 71887
Number of cases.......: 39273
Expected cases........: 43225.33
Observed / expected...: 0.91
Relative risk.........: 0.91
Percent cases in area.: 54.6
Log likelihood ratio..: 454.795093
Monte Carlo rank......: 1/1000
P-value...............: 0.001

9. Location IDs included.: 55540, 55580, 55620, 51700, 55120, 55130, 55150
Coordinates / radius..: (51.961076 N, 6.899097 E) / 49.62 km
Population............: 95062
Number of cases.......: 53214
Expected cases........: 57160.35
Observed / expected...: 0.93
Relative risk.........: 0.93
Percent cases in area.: 56.0
Log likelihood ratio..: 345.714083
Monte Carlo rank......: 1/1000
P-value...............: 0.001

10. Location IDs included.: 59700, 59660, 65320, 71320, 65340, 59580, 53740
Coordinates / radius..: (50.937659 N, 8.194734 E) / 48.15 km
Population............: 74261
Number of cases.......: 41353
Expected cases........: 44652.80
Observed / expected...: 0.93
Relative risk.........: 0.92
Percent cases in area.: 55.7
Log likelihood ratio..: 307.718816
Monte Carlo rank......: 1/1000
P-value...............: 0.001

11. Location IDs included.: 53620, 53150, 53580, 53160, 51620, 53140, 53780, 51160, 51110
Coordinates / radius..: (50.904871 N, 6.716684 E) / 37.31 km
Population............: 205435
Number of cases.......: 120299
Expected cases........: 123527.13
Observed / expected...: 0.97
Relative risk.........: 0.97
Percent cases in area.: 58.6
Log likelihood ratio..: 110.545535
Monte Carlo rank......: 1/1000
P-value...............: 0.001

12. Location IDs included.: 59140, 59540, 59620, 59130, 59110, 51240, 51200, 59780, 59160, 51130, 51220
Coordinates / radius..: (51.348029 N, 7.497563 E) / 36.41 km
Population............: 201707
Number of cases.......: 124156
Expected cases........: 121285.50
Observed / expected...: 1.02
Relative risk.........: 1.02
Percent cases in area.: 61.6
Log likelihood ratio..: 89.658819
Monte Carlo rank......: 1/1000
P-value...............: 0.001

13. Location IDs included.: 57740
Coordinates / radius..: (51.664034 N, 8.719670 E) / 0 km
Population............: 17805
Number of cases.......: 10003
Expected cases........: 10706.07
Observed / expected...: 0.93
Relative risk.........: 0.93
Percent cases in area.: 56.2
Log likelihood ratio..: 57.563240
Monte Carlo rank......: 1/1000
P-value...............: 0.001

14. Location IDs included.: 51140, 51120, 51660
Coordinates / radius..: (51.345236 N, 6.579665 E) / 18.94 km
Population............: 47701
Number of cases.......: 29723
Expected cases........: 28682.39
Observed / expected...: 1.04
Relative risk.........: 1.04
Percent cases in area.: 62.3
Log likelihood ratio..: 48.175398
Monte Carlo rank......: 1/1000
P-value...............: 0.001“

# Appendix E: Bernoulli model and Moran’s I results of GPs

| State | Region (MB) | Cluster GP | Low rate | High rate | Average cluster supply | Moran's I p-value | Moran's I q-value |
|---|---|---|---|---|---|---|---|
| Brandenburg | 1203040 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1204010 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1204020 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1204030 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1204040 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1204050 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1204060 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1204070 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Brandenburg | 1204080 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1204090 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1204100 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1204110 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1204120 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1204130 | 1 | | 1 | 2.87 | 0.048 | 1 |
| Brandenburg | 1205030 | 1 | | 1 | 2.87 | 0.026 | 1 |
| Brandenburg | 1205040 | 1 | | 1 | 2.87 | | |
| Brandenburg | 1205050 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1205070 | 1 | | 1 | 2.87 | 0.01 | 1 |
| Brandenburg | 1205080 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Brandenburg | 1205100 | 1 | | 1 | 2.87 | | |
| Brandenburg | 1205110 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Brandenburg | 1205120 | 1 | | 1 | 2.87 | 0.016 | 1 |
| Brandenburg | 1205130 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1502020 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1502050 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1503010 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1503020 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1503030 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1503040 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1503050 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1503060 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1503070 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Saxony-Anhalt | 1504010 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1504020 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1504030 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Saxony-Anhalt | 1504040 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1504060 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1505040 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 1505050 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Saxony-Anhalt | 1505060 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Thuringia | 1600200 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Thuringia | 1601900 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Thuringia | 1602000 | 1 | | 1 | 2.87 | 0.008 | 1 |
| Thuringia | 1602500 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Thuringia | 1602600 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Thuringia | 1602700 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Thuringia | 1602900 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Thuringia | 1603000 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Thuringia | 1603100 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Thuringia | 1603200 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Thuringia | 1603400 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Thuringia | 1603500 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony | 3400164 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Saxony | 3400165 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony | 3400166 | 1 | | 1 | 2.87 | 0.01 | 1 |
| Saxony | 3400167 | 1 | | 1 | 2.87 | 0.01 | 1 |
| Saxony | 3400168 | 1 | | 1 | 2.87 | 0.04 | 1 |
| Saxony | 3400169 | 1 | | 1 | 2.87 | 0.044 | 1 |
| Saxony | 3400170 | 1 | | 1 | 2.87 | | |
| Saxony | 3400171 | 1 | | 1 | 2.87 | 0.012 | 1 |
| Saxony | 3400172 | 1 | | 1 | 2.87 | 0.024 | 1 |
| Saxony | 3400173 | 1 | | 1 | 2.87 | 0.006 | 1 |
| Saxony | 3400174 | 1 | | 1 | 2.87 | | |

| State | Region (MB) | Cluster GP | Low rate | High rate | Average cluster supply | Moran's I p-value | Moran's I q-value |
|---|---|---|---|---|---|---|---|
| Saxony | 3400176 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony | 3400177 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Saxony | 3400178 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Saxony | 3400179 | 1 | | 1 | 2.87 | 0.006 | 1 |
| Saxony | 3400180 | 1 | | 1 | 2.87 | | |
| Saxony | 3400181 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony | 3400182 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Saxony | 3400183 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony | 3400184 | 1 | | 1 | 2.87 | 0.006 | 1 |
| Saxony | 3400185 | 1 | | 1 | 2.87 | 0.014 | 1 |
| Saxony | 3400186 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony | 3400187 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony | 3400188 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Saxony | 3400189 | 1 | | 1 | 2.87 | 0.016 | 1 |
| Saxony | 3400190 | 1 | | 1 | 2.87 | 0.01 | 1 |
| Saxony | 3400191 | 1 | | 1 | 2.87 | 0.044 | 1 |
| Saxony | 3400192 | 1 | | 1 | 2.87 | | |
| Saxony | 3400193 | 1 | | 1 | 2.87 | 0.032 | 1 |
| Saxony | 3400194 | 1 | | 1 | 2.87 | 0.006 | 1 |
| Saxony | 3400196 | 1 | | 1 | 2.87 | 0.006 | 1 |
| Saxony | 3400197 | 1 | | 1 | 2.87 | 0.022 | 1 |
| Saxony | 3400198 | 1 | | 1 | 2.87 | 0.032 | 1 |
| Saxony | 3400199 | 1 | | 1 | 2.87 | 0.008 | 1 |
| Saxony | 3400200 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Saxony | 3400201 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony | 3400202 | 1 | | 1 | 2.87 | 0.008 | 1 |
| Saxony | 3400203 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony | 3400204 | 1 | | 1 | 2.87 | 0.022 | 1 |
| Saxony | 3400206 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Saxony | 3400207 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony | 3400208 | 1 | | 1 | 2.87 | 0.006 | 1 |
| Saxony | 3400209 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony | 3400321 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Saxony | 3400407 | 1 | | 1 | 2.87 | 0.012 | 1 |
| Saxony | 3400408 | 1 | | 1 | 2.87 | 0.006 | 1 |
| Saxony | 3400409 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 3500159 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Saxony-Anhalt | 3500161 | 1 | | 1 | 2.87 | | |
| Saxony-Anhalt | 3500162 | 1 | | 1 | 2.87 | 0.018 | 1 |
| Thuringia | 3600522 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Thuringia | 3600524 | 1 | | 1 | 2.87 | 0.008 | 1 |
| Thuringia | 3600526 | 1 | | 1 | 2.87 | 0.002 | 1 |
| Thuringia | 3600527 | 1 | | 1 | 2.87 | 0.004 | 1 |
| Thuringia | 3600528 | 1 | | 1 | 2.87 | 0.006 | 1 |
| Baden-Württemberg | 801010 | 2 | 1 | | 3.07 | | |
| Baden-Württemberg | 801020 | 2 | 1 | | 3.07 | 0.02 | 3 |
| Baden-Württemberg | 801030 | 2 | 1 | | 3.07 | 0.004 | 3 |
| Baden-Württemberg | 801040 | 2 | 1 | | 3.07 | 0.008 | 3 |
| Baden-Württemberg | 801050 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 801060 | 2 | 1 | | 3.07 | 0.012 | 3 |
| Baden-Württemberg | 801070 | 2 | 1 | | 3.07 | 0.008 | 3 |
| Baden-Württemberg | 801080 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 801090 | 2 | 1 | | 3.07 | 0.018 | 3 |
| Baden-Württemberg | 801100 | 2 | 1 | | 3.07 | 0.006 | 3 |
| Baden-Württemberg | 801110 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 801120 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 801130 | 2 | 1 | | 3.07 | 0.006 | 3 |
| Baden-Württemberg | 801140 | 2 | 1 | | 3.07 | 0.006 | 3 |
| Baden-Württemberg | 801150 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 802050 | 2 | 1 | | 3.07 | 0.01 | 3 |
| Baden-Württemberg | 802080 | 2 | 1 | | 3.07 | 0.006 | 3 |
| Baden-Württemberg | 802090 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 803010 | 2 | 1 | | 3.07 | 0.004 | 3 |
| Baden-Württemberg | 803020 | 2 | 1 | | 3.07 | 0.01 | 3 |
| Baden-Württemberg | 803030 | 2 | 1 | | 3.07 | 0.006 | 3 |
| Baden-Württemberg | 803040 | 2 | 1 | | 3.07 | 0.01 | 3 |
| Baden-Württemberg | 806040 | 2 | 1 | | 3.07 | 0.018 | 3 |
| Baden-Württemberg | 806050 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 806060 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 806070 | 2 | 1 | | 3.07 | 0.002 | 3 |

| State | Region (MB) | Cluster GP | Low rate | High rate | Average cluster supply | Moran's I p-value | Moran's I q-value |
|---|---|---|---|---|---|---|---|
| Baden-Württemberg | 808010 | 2 | 1 | | 3.07 | 0.044 | 3 |
| Baden-Württemberg | 808020 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 808040 | 2 | 1 | | 3.07 | 0.014 | 3 |
| Baden-Württemberg | 808050 | 2 | 1 | | 3.07 | 0.006 | 3 |
| Baden-Württemberg | 809060 | 2 | 1 | | 3.07 | 0.018 | 3 |
| Baden-Württemberg | 809070 | 2 | 1 | | 3.07 | 0.032 | 3 |
| Baden-Württemberg | 809080 | 2 | 1 | | 3.07 | 0.038 | 3 |
| Baden-Württemberg | 809090 | 2 | 1 | | 3.07 | | |
| Baden-Württemberg | 810010 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 810020 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 810030 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 810040 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 810050 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 810060 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 810070 | 2 | 1 | | 3.07 | 0.004 | 3 |
| Baden-Württemberg | 810080 | 2 | 1 | | 3.07 | 0.006 | 4 |
| Baden-Württemberg | 811010 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 811020 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 811030 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 811040 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 811050 | 2 | 1 | | 3.07 | 0.008 | 3 |
| Baden-Württemberg | 811060 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 812010 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Baden-Württemberg | 812020 | 2 | 1 | | 3.07 | 0.006 | 3 |
| Baden-Württemberg | 812030 | 2 | 1 | | 3.07 | 0.02 | 3 |
| Baden-Württemberg | 812040 | 2 | 1 | | 3.07 | 0.004 | 3 |
| Baden-Württemberg | 812050 | 2 | 1 | | 3.07 | | |
| Baden-Württemberg | 812060 | 2 | 1 | | 3.07 | | |
| Baden-Württemberg | 812070 | 2 | 1 | | 3.07 | 0.018 | 3 |
| Baden-Württemberg | 812080 | 2 | 1 | | 3.07 | 0.012 | 3 |
| Baden-Württemberg | 812090 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Bavaria | 909040 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Bavaria | 909050 | 2 | 1 | | 3.07 | 0.01 | 3 |
| Bavaria | 910030 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Bavaria | 910040 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Bavaria | 914030 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Bavaria | 914050 | 2 | 1 | | 3.07 | 0.004 | 3 |
| Bavaria | 914080 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Bavaria | 915010 | 2 | 1 | | 3.07 | 0.004 | 3 |
| Bavaria | 915020 | 2 | 1 | | 3.07 | | |
| Bavaria | 915030 | 2 | 1 | | 3.07 | 0.006 | 3 |
| Bavaria | 915040 | 2 | 1 | | 3.07 | | |
| Bavaria | 915050 | 2 | 1 | | 3.07 | 0.006 | 4 |
| Bavaria | 915060 | 2 | 1 | | 3.07 | | |
| Bavaria | 916010 | 2 | 1 | | 3.07 | 0.004 | 3 |
| Bavaria | 916020 | 2 | 1 | | 3.07 | 0.024 | 3 |
| Bavaria | 916030 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Bavaria | 916040 | 2 | 1 | | 3.07 | 0.008 | 3 |
| Bavaria | 916050 | 2 | 1 | | 3.07 | 0.042 | 3 |
| Bavaria | 916060 | 2 | 1 | | 3.07 | 0.032 | 3 |
| Bavaria | 916070 | 2 | 1 | | 3.07 | 0.038 | 3 |
| Bavaria | 916080 | 2 | 1 | | 3.07 | | |
| Bavaria | 917010 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Bavaria | 917020 | 2 | 1 | | 3.07 | 0.004 | 3 |
| Bavaria | 917040 | 2 | 1 | | 3.07 | 0.012 | 3 |
| Bavaria | 917080 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Bavaria | 2900122 | 2 | 1 | | 3.07 | 0.004 | 3 |
| Bavaria | 2900123 | 2 | 1 | | 3.07 | | |
| Bavaria | 2900124 | 2 | 1 | | 3.07 | 0.008 | 3 |
| Bavaria | 2900132 | 2 | 1 | | 3.07 | | |
| Bavaria | 2900142 | 2 | 1 | | 3.07 | 0.01 | 3 |
| Bavaria | 2900143 | 2 | 1 | | 3.07 | | |
| Bavaria | 2900144 | 2 | 1 | | 3.07 | 0.004 | 3 |
| Bavaria | 2900145 | 2 | 1 | | 3.07 | 0.016 | 3 |
| Bavaria | 2900152 | 2 | 1 | | 3.07 | | |
| Bavaria | 2900302 | 2 | 1 | | 3.07 | | |
| Bavaria | 2900303 | 2 | 1 | | 3.07 | 0.024 | 3 |
| Bavaria | 2900309 | 2 | 1 | | 3.07 | 0.022 | 3 |
| Bavaria | 2900310 | 2 | 1 | | 3.07 | 0.046 | 3 |
| Bavaria | 2900343 | 2 | 1 | | 3.07 | 0.014 | 3 |

## Appendix E: Bernoulli model and Moran's I results of GPs

| State | Region (MB) | Cluster GP | Low rate | High rate | Average cluster supply | Moran's I p-value | Moran's I q-value |
|---|---|---|---|---|---|---|---|
| Bavaria | 2900352 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Bavaria | 2900371 | 2 | 1 | | 3.07 | 0.016 | 3 |
| Bavaria | 2900373 | 2 | 1 | | 3.07 | 0.002 | 3 |
| Bavaria | 2900391 | 2 | 1 | | 3.07 | 0.036 | 3 |
| Brandenburg | 1201010 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Brandenburg | 1201030 | 3 | | 1 | 2.77 | | |
| Brandenburg | 1201040 | 3 | | 1 | 2.77 | 0.026 | 1 |
| Brandenburg | 1201050 | 3 | | 1 | 2.77 | 0.006 | 1 |
| Brandenburg | 1201060 | 3 | | 1 | 2.77 | 0.016 | 1 |
| Brandenburg | 1201070 | 3 | | 1 | 2.77 | | |
| Brandenburg | 1201080 | 3 | | 1 | 2.77 | 0.01 | 1 |
| Brandenburg | 1202010 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Brandenburg | 1202020 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Brandenburg | 1202030 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Brandenburg | 1202040 | 3 | | 1 | 2.77 | 0.004 | 1 |
| Brandenburg | 1202050 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Brandenburg | 1203060 | 3 | | 1 | 2.77 | 0.004 | 1 |
| Mecklenburg-Western Pomerania | 1301060 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Mecklenburg-Western Pomerania | 1302040 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Mecklenburg-Western Pomerania | 1302050 | 3 | | 1 | 2.77 | 0.004 | 1 |
| Mecklenburg-Western Pomerania | 1303070 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Mecklenburg-Western Pomerania | 1303080 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Mecklenburg-Western Pomerania | 3300155 | 3 | | 1 | 2.77 | 0.004 | 1 |
| Mecklenburg-Western Pomerania | 3300501 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Mecklenburg-Western Pomerania | 3300502 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Mecklenburg-Western Pomerania | 3300503 | 3 | | 1 | 2.77 | | |
| Mecklenburg-Western Pomerania | 3300504 | 3 | | 1 | 2.77 | | |
| Mecklenburg-Western Pomerania | 3300505 | 3 | | 1 | 2.77 | | |
| Mecklenburg-Western Pomerania | 3300506 | 3 | | 1 | 2.77 | 0.006 | 1 |
| Mecklenburg-Western Pomerania | 3300507 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Mecklenburg-Western Pomerania | 3300508 | 3 | | 1 | 2.77 | 0.014 | 1 |
| Mecklenburg-Western Pomerania | 3300509 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Mecklenburg-Western Pomerania | 3300510 | 3 | | 1 | 2.77 | | |
| Mecklenburg-Western Pomerania | 3300511 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Mecklenburg-Western Pomerania | 3300512 | 3 | | 1 | 2.77 | 0.012 | 1 |
| Mecklenburg-Western Pomerania | 3300513 | 3 | | 1 | 2.77 | | |
| Mecklenburg-Western Pomerania | 3300514 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Mecklenburg-Western Pomerania | 3300515 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Mecklenburg-Western Pomerania | 3300516 | 3 | | 1 | 2.77 | 0.002 | 1 |
| Mecklenburg-Western Pomerania | 3300517 | 3 | | 1 | 2.77 | | |
| Mecklenburg-Western Pomerania | 3300518 | 3 | | 1 | 2.77 | 0.004 | 1 |
| Mecklenburg-Western Pomerania | 3300519 | 3 | | 1 | 2.77 | | |
| Mecklenburg-Western Pomerania | 3300520 | 3 | | 1 | 2.77 | | |
| Schleswig-Holstein | 101090 | 4 | 1 | | 2.97 | | |
| Schleswig-Holstein | 101110 | 4 | 1 | | 2.97 | | |
| Schleswig-Holstein | 101120 | 4 | 1 | | 2.97 | | |
| Schleswig-Holstein | 103010 | 4 | 1 | | 2.97 | | |
| Schleswig-Holstein | 103020 | 4 | 1 | | 2.97 | 0.048 | 3 |
| Schleswig-Holstein | 103040 | 4 | 1 | | 2.97 | | |
| Schleswig-Holstein | 104010 | 4 | 1 | | 2.97 | | |
| Schleswig-Holstein | 104020 | 4 | 1 | | 2.97 | | |
| Schleswig-Holstein | 104030 | 4 | 1 | | 2.97 | | |
| Schleswig-Holstein | 104040 | 4 | 1 | | 2.97 | 0.046 | 3 |
| Schleswig-Holstein | 105050 | 4 | 1 | | 2.97 | | |
| Schleswig-Holstein | 105070 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 306010 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 306030 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 307020 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 307030 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 314020 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 315010 | 4 | 1 | | 2.97 | 0.002 | 3 |
| Lower Saxony | 319010 | 4 | 1 | | 2.97 | 0.016 | 3 |
| Lower Saxony | 319020 | 4 | 1 | | 2.97 | 0.02 | 3 |
| Lower Saxony | 319030 | 4 | 1 | | 2.97 | 0.022 | 3 |
| Lower Saxony | 320010 | 4 | 1 | | 2.97 | 0.03 | 3 |
| Lower Saxony | 320020 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 320030 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 321010 | 4 | 1 | | 2.97 | 0.028 | 3 |
| Lower Saxony | 321020 | 4 | 1 | | 2.97 | 0.002 | 3 |
| Lower Saxony | 323020 | 4 | 1 | | 2.97 | | |

| State | Region (MB) | Cluster GP | Low rate | High rate | Average cluster supply | Moran's I p-value | Moran's I q-value |
|---|---|---|---|---|---|---|---|
| Lower Saxony | 325010 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 329010 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 330010 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 330020 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 331010 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 331020 | 4 | 1 | | 2.97 | 0.012 | 3 |
| Lower Saxony | 332010 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 332020 | 4 | 1 | | 2.97 | 0.048 | 3 |
| Lower Saxony | 333020 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 337010 | 4 | 1 | | 2.97 | 0.018 | 3 |
| Lower Saxony | 337020 | 4 | 1 | | 2.97 | 0.038 | 3 |
| Lower Saxony | 338010 | 4 | 1 | | 2.97 | 0.018 | 3 |
| Lower Saxony | 338020 | 4 | 1 | | 2.97 | 0.014 | 3 |
| Lower Saxony | 339010 | 4 | 1 | | 2.97 | | |
| Nordrhein-Westfalen | 504010 | 4 | 1 | | 2.97 | | |
| Nordrhein-Westfalen | 504020 | 4 | 1 | | 2.97 | | |
| Schleswig-Holstein | 2100080 | 4 | 1 | | 2.97 | | |
| Schleswig-Holstein | 2100082 | 4 | 1 | | 2.97 | | |
| Schleswig-Holstein | 2100083 | 4 | 1 | | 2.97 | 0.014 | 3 |
| Schleswig-Holstein | 2100084 | 4 | 1 | | 2.97 | 0.028 | 3 |
| Hamburg | 2200000 | 4 | 1 | | 2.97 | 0.014 | 3 |
| Lower Saxony | 2300004 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300085 | 4 | 1 | | 2.97 | 0.018 | 3 |
| Lower Saxony | 2300086 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300087 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300090 | 4 | 1 | | 2.97 | 0.034 | 4 |
| Lower Saxony | 2300096 | 4 | 1 | | 2.97 | 0.024 | 3 |
| Lower Saxony | 2300099 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300100 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300101 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300102 | 4 | 1 | | 2.97 | 0.028 | 3 |
| Lower Saxony | 2300103 | 4 | 1 | | 2.97 | 0.02 | 3 |
| Lower Saxony | 2300105 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300107 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300108 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300111 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300112 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300113 | 4 | 1 | | 2.97 | 0.008 | 3 |
| Lower Saxony | 2300114 | 4 | 1 | | 2.97 | 0.02 | 3 |
| Lower Saxony | 2300115 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300429 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300432 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300434 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300437 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300441 | 4 | 1 | | 2.97 | | |
| Lower Saxony | 2300442 | 4 | 1 | | 2.97 | 0.042 | 3 |
| Bremen | 2400000 | 4 | 1 | | 2.97 | | |
| Bremen | 2400001 | 4 | 1 | | 2.97 | | |
| Hessen | 601050 | 5 | | 1 | 3.46 | | |
| Hessen | 601090 | 5 | | 1 | 3.46 | | |
| Hessen | 601100 | 5 | | 1 | 3.46 | | |
| Hessen | 601120 | 5 | | 1 | 3.46 | | |
| Hessen | 601130 | 5 | | 1 | 3.46 | | |
| Hessen | 601150 | 5 | | 1 | 3.46 | | |
| Hessen | 601170 | 5 | | 1 | 3.46 | | |
| Hessen | 601180 | 5 | | 1 | 3.46 | | |
| Hessen | 601190 | 5 | | 1 | 3.46 | | |
| Hessen | 601200 | 5 | | 1 | 3.46 | | |
| Hessen | 601210 | 5 | | 1 | 3.46 | | |
| Hessen | 601220 | 5 | | 1 | 3.46 | | |
| Hessen | 602060 | 5 | | 1 | 3.46 | | |
| Hessen | 602070 | 5 | | 1 | 3.46 | | |
| Hessen | 602080 | 5 | | 1 | 3.46 | | |
| Hessen | 602120 | 5 | | 1 | 3.46 | | |
| Hessen | 603060 | 5 | | 1 | 3.46 | | |
| Hessen | 603070 | 5 | | 1 | 3.46 | | |
| Hessen | 603090 | 5 | | 1 | 3.46 | | |
| Bavaria | 903020 | 5 | | 1 | 3.46 | | |
| Bavaria | 903030 | 5 | | 1 | 3.46 | | |
| Bavaria | 903040 | 5 | | 1 | 3.46 | | |

| State | Region (MB) | Cluster GP | Low rate | High rate | Average cluster supply | Moran's I p-value | Moran's I q-value |
|---|---|---|---|---|---|---|---|
| Bavaria | 904010 | 5 | | 1 | 3.46 | | |
| Bavaria | 904020 | 5 | | 1 | 3.46 | | |
| Thuringia | 1600300 | 5 | | 1 | 3.46 | 0.002 | 1 |
| Thuringia | 1600400 | 5 | | 1 | 3.46 | 0.012 | 1 |
| Thuringia | 1600500 | 5 | | 1 | 3.46 | 0.004 | 1 |
| Thuringia | 1600600 | 5 | | 1 | 3.46 | 0.044 | 1 |
| Thuringia | 1600700 | 5 | | 1 | 3.46 | 0.014 | 1 |
| Thuringia | 1600800 | 5 | | 1 | 3.46 | 0.008 | 1 |
| Thuringia | 1600900 | 5 | | 1 | 3.46 | | |
| Thuringia | 1601000 | 5 | | 1 | 3.46 | 0.026 | 1 |
| Thuringia | 1601100 | 5 | | 1 | 3.46 | 0.004 | 1 |
| Thuringia | 1601200 | 5 | | 1 | 3.46 | 0.002 | 1 |
| Thuringia | 1601300 | 5 | | 1 | 3.46 | 0.002 | 1 |
| Thuringia | 1601500 | 5 | | 1 | 3.46 | 0.004 | 1 |
| Thuringia | 1601800 | 5 | | 1 | 3.46 | 0.004 | 1 |
| Thuringia | 1602200 | 5 | | 1 | 3.46 | 0.002 | 1 |
| Thuringia | 1602300 | 5 | | 1 | 3.46 | 0.006 | 1 |
| Lower Saxony | 2300095 | 5 | | 1 | 3.46 | | |
| Hessen | 2600270 | 5 | | 1 | 3.46 | | |
| Hessen | 2600271 | 5 | | 1 | 3.46 | | |
| Hessen | 2600272 | 5 | | 1 | 3.46 | | |
| Hessen | 2600273 | 5 | | 1 | 3.46 | | |
| Hessen | 2600274 | 5 | | 1 | 3.46 | | |
| Bavaria | 2900127 | 5 | | 1 | 3.46 | | |
| Bavaria | 2900148 | 5 | | 1 | 3.46 | | |
| Bavaria | 2900149 | 5 | | 1 | 3.46 | | |
| Bavaria | 2900304 | 5 | | 1 | 3.46 | | |
| Bavaria | 2900345 | 5 | | 1 | 3.46 | | |
| Bavaria | 2900346 | 5 | | 1 | 3.46 | | |
| Bavaria | 2900372 | 5 | | 1 | 3.46 | | |
| Thuringia | 3600521 | 5 | | 1 | 3.46 | 0.032 | 1 |
| Thuringia | 3600523 | 5 | | 1 | 3.46 | 0.002 | 1 |
| Hessen | 602150 | 6 | 1 | | 3.32 | | |
| Hessen | 603020 | 6 | 1 | | 3.32 | | |
| Hessen | 603100 | 6 | 1 | | 3.32 | | |
| Hessen | 603110 | 6 | 1 | | 3.32 | | |
| Hessen | 603120 | 6 | 1 | | 3.32 | | |
| Hessen | 603130 | 6 | 1 | | 3.32 | | |
| Hessen | 603140 | 6 | 1 | | 3.32 | | |
| Hessen | 603150 | 6 | 1 | | 3.32 | | |
| Hessen | 603160 | 6 | 1 | | 3.32 | | |
| Hessen | 603170 | 6 | 1 | | 3.32 | | |
| Hessen | 603180 | 6 | 1 | | 3.32 | | |
| Hessen | 603190 | 6 | 1 | | 3.32 | | |
| Hessen | 603200 | 6 | 1 | | 3.32 | | |
| Hessen | 603250 | 6 | 1 | | 3.32 | | |
| Hessen | 603260 | 6 | 1 | | 3.32 | 0.032 | 3 |
| Hessen | 603270 | 6 | 1 | | 3.32 | | |
| Rhineland-Palatinate | 701110 | 6 | 1 | | 3.32 | | |
| Rhineland-Palatinate | 703010 | 6 | 1 | | 3.32 | | |
| Rhineland-Palatinate | 703020 | 6 | 1 | | 3.32 | 0.038 | 3 |
| Rhineland-Palatinate | 703030 | 6 | 1 | | 3.32 | 0.046 | 3 |
| Rhineland-Palatinate | 703050 | 6 | 1 | | 3.32 | | |
| Rhineland-Palatinate | 2700116 | 6 | 1 | | 3.32 | | |
| Lower Saxony | 332030 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503010 | 7 | 1 | | 3.18 | 0.046 | 3 |
| Nordrhein-Westfalen | 503020 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503040 | 7 | 1 | | 3.18 | 0.034 | 3 |
| Nordrhein-Westfalen | 503050 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503060 | 7 | 1 | | 3.18 | 0.05 | 3 |
| Nordrhein-Westfalen | 503070 | 7 | 1 | | 3.18 | 0.008 | 3 |
| Nordrhein-Westfalen | 503080 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503090 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503100 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503110 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503120 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503130 | 7 | 1 | | 3.18 | 0.014 | 3 |
| Nordrhein-Westfalen | 503140 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503150 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503160 | 7 | 1 | | 3.18 | | |

| State | Region (MB) | Cluster GP | Low rate | High rate | Average cluster supply | Moran's I p-value | Moran's I q-value |
|---|---|---|---|---|---|---|---|
| Nordrhein-Westfalen | 503170 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503180 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503230 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503240 | 7 | 1 | | 3.18 | | |
| Nordrhein-Westfalen | 503270 | 7 | 1 | | 3.18 | | |
| Lower Saxony | 2300438 | 7 | 1 | | 3.18 | | |
| Bavaria | 905040 | 8 | 1 | | 3.40 | | |
| Bavaria | 905080 | 8 | 1 | | 3.40 | | |
| Bavaria | 906010 | 8 | 1 | | 3.40 | | |
| Bavaria | 906020 | 8 | 1 | | 3.40 | | |
| Bavaria | 906040 | 8 | 1 | | 3.40 | | |
| Bavaria | 906070 | 8 | 1 | | 3.40 | | |
| Bavaria | 907050 | 8 | 1 | | 3.40 | | |
| Bavaria | 907060 | 8 | 1 | | 3.40 | | |
| Bavaria | 911010 | 8 | 1 | | 3.40 | | |
| Bavaria | 911030 | 8 | 1 | | 3.40 | | |
| Bavaria | 911050 | 8 | 1 | | 3.40 | | |
| Bavaria | 911060 | 8 | 1 | | 3.40 | | |
| Bavaria | 911070 | 8 | 1 | | 3.40 | 0.014 | 3 |
| Bavaria | 911080 | 8 | 1 | | 3.40 | 0.022 | 3 |
| Bavaria | 911090 | 8 | 1 | | 3.40 | | |
| Bavaria | 912010 | 8 | 1 | | 3.40 | | |
| Bavaria | 912050 | 8 | 1 | | 3.40 | | |
| Bavaria | 912060 | 8 | 1 | | 3.40 | | |
| Bavaria | 912080 | 8 | 1 | | 3.40 | | |
| Bavaria | 912090 | 8 | 1 | | 3.40 | | |
| Bavaria | 912100 | 8 | 1 | | 3.40 | | |
| Bavaria | 913010 | 8 | 1 | | 3.40 | 0.002 | 3 |
| Bavaria | 913030 | 8 | 1 | | 3.40 | | |
| Bavaria | 913070 | 8 | 1 | | 3.40 | | |
| Bavaria | 913080 | 8 | 1 | | 3.40 | | |
| Bavaria | 914010 | 8 | 1 | | 3.40 | 0.004 | 3 |
| Bavaria | 918010 | 8 | 1 | | 3.40 | 0.004 | 3 |
| Bavaria | 918020 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900128 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900129 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900130 | 8 | 1 | | 3.40 | 0.002 | 3 |
| Bavaria | 2900135 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900136 | 8 | 1 | | 3.40 | 0.002 | 3 |
| Bavaria | 2900137 | 8 | 1 | | 3.40 | 0.006 | 3 |
| Bavaria | 2900138 | 8 | 1 | | 3.40 | 0.002 | 3 |
| Bavaria | 2900141 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900146 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900341 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900342 | 8 | 1 | | 3.40 | 0.004 | 3 |
| Bavaria | 2900344 | 8 | 1 | | 3.40 | 0.032 | 3 |
| Bavaria | 2900348 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900350 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900351 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900353 | 8 | 1 | | 3.40 | 0.036 | 3 |
| Bavaria | 2900356 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900357 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900358 | 8 | 1 | | 3.40 | 0.016 | 3 |
| Bavaria | 2900359 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900361 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900362 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900367 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900368 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900370 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900375 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900377 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900379 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900380 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900383 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900384 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900385 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900386 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900392 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900393 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900394 | 8 | 1 | | 3.40 | | |

| State | Region (MB) | Cluster GP | Low rate | High rate | Average cluster supply | Moran's I p-value | Moran's I q-value |
|---|---|---|---|---|---|---|---|
| Bavaria | 2900396 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900397 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900398 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900399 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900400 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900401 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900402 | 8 | 1 | | 3.40 | | |
| Bavaria | 2900406 | 8 | 1 | | 3.40 | | |
| Nordrhein-Westfalen | 501160 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 501170 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 501360 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 501370 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 501380 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 501390 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 501400 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 501410 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 501420 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 501430 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 501440 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 501450 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 501460 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 505320 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 505330 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 505340 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 505350 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 505360 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 505370 | 9 | | 1 | 3.35 | | |
| Nordrhein-Westfalen | 505390 | 9 | | 1 | 3.35 | | |
| Rhineland-Palatinate | 705020 | 10 | | 1 | 3.33 | | |
| Rhineland-Palatinate | 705030 | 10 | | 1 | 3.33 | 0.028 | 1 |
| Rhineland-Palatinate | 705040 | 10 | | 1 | 3.33 | | |
| Rhineland-Palatinate | 705050 | 10 | | 1 | 3.33 | | |
| Rhineland-Palatinate | 705060 | 10 | | 1 | 3.33 | | |
| Saarland | 1000080 | 10 | | 1 | 3.33 | | |
| Nordrhein-Westfalen | 502300 | 11 | 1 | | 2.48 | 0.038 | 3 |
| Nordrhein-Westfalen | 502330 | 11 | 1 | | 2.48 | | |
| Nordrhein-Westfalen | 505070 | 11 | 1 | | 2.48 | | |
| Nordrhein-Westfalen | 505090 | 11 | 1 | | 2.48 | | |
| Nordrhein-Westfalen | 505120 | 11 | 1 | | 2.48 | 0.01 | 3 |
| Nordrhein-Westfalen | 505130 | 11 | 1 | | 2.48 | | |
| Nordrhein-Westfalen | 505140 | 11 | 1 | | 2.48 | 0.006 | 3 |
| Nordrhein-Westfalen | 505150 | 11 | 1 | | 2.48 | | |
| Nordrhein-Westfalen | 505160 | 11 | 1 | | 2.48 | 0.01 | 3 |
| Nordrhein-Westfalen | 505170 | 11 | 1 | | 2.48 | 0.016 | 3 |
| Nordrhein-Westfalen | 505180 | 11 | 1 | | 2.48 | | |
| Nordrhein-Westfalen | 505190 | 11 | 1 | | 2.48 | 0.006 | 3 |
| Nordrhein-Westfalen | 505200 | 11 | 1 | | 2.48 | | |
| Nordrhein-Westfalen | 505210 | 11 | 1 | | 2.48 | | |
| Nordrhein-Westfalen | 505230 | 11 | 1 | | 2.48 | | |
| Nordrhein-Westfalen | 505240 | 11 | 1 | | 2.48 | | |
| Hessen | 601070 | 11 | 1 | | 2.48 | | |
| Hessen | 602010 | 11 | 1 | | 2.48 | | |
| Hessen | 602020 | 11 | 1 | | 2.48 | | |
| Hessen | 602090 | 11 | 1 | | 2.48 | | |
| Rhineland-Palatinate | 701010 | 11 | 1 | | 2.48 | | |
| Nordrhein-Westfalen | 504200 | 12 | 1 | | 2.40 | | |
| Nordrhein-Westfalen | 504210 | 12 | 1 | | 2.40 | | |
| Nordrhein-Westfalen | 504220 | 12 | 1 | | 2.40 | | |
| Nordrhein-Westfalen | 504230 | 12 | 1 | | 2.40 | | |
| Nordrhein-Westfalen | 505020 | 12 | 1 | | 2.40 | | |
| Lower Saxony | 306050 | 13 | | 1 | 2.00 | | |
| Bavaria | 902050 | 14 | 1 | | 4.00 | | |
| Bavaria | 903070 | 14 | 1 | | 4.00 | | |
| Bavaria | 2900313 | 14 | 1 | | 4.00 | | |
| Bavaria | 2900389 | 14 | 1 | | 4.00 | | |
| Bavaria | 2900403 | 14 | 1 | | 4.00 | | |
| Bavaria | 2900404 | 14 | 1 | | 4.00 | | |
| Nordrhein-Westfalen | 501230 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 501240 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 501250 | 15 | | 1 | 2.92 | | |

| State | Region (MB) | Cluster GP | Low rate | High rate | Average cluster supply | Moran's I p-value | Moran's I q-value |
|---|---|---|---|---|---|---|---|
| Nordrhein-Westfalen | 501260 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 501270 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 501280 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 501290 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 501320 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 501330 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502010 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502020 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502030 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502040 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502050 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502060 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502070 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502080 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502100 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502110 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502120 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502130 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502140 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502150 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502160 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502170 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502180 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502190 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502200 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502220 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502230 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502240 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502250 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502260 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502380 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502390 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502400 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502410 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502420 | 15 | | 1 | 2.92 | | |
| Nordrhein-Westfalen | 502430 | 16 | 1 | | 4.00 | | |
| Nordrhein-Westfalen | 503290 | 17 | | 1 | 3.57 | | |
| Nordrhein-Westfalen | 505400 | 17 | | 1 | 3.57 | | |
| Nordrhein-Westfalen | 505420 | 17 | | 1 | 3.57 | | |
| Nordrhein-Westfalen | 505430 | 17 | | 1 | 3.57 | | |
| Nordrhein-Westfalen | 505440 | 17 | | 1 | 3.57 | | |
| Nordrhein-Westfalen | 505450 | 17 | | 1 | 3.57 | | |
| Nordrhein-Westfalen | 505460 | 17 | | 1 | 3.57 | | |
| Bavaria | 904060 | 18 | | 1 | 3.22 | | |
| Bavaria | 907010 | 18 | | 1 | 3.22 | | |
| Bavaria | 907020 | 18 | | 1 | 3.22 | | |
| Bavaria | 907030 | 18 | | 1 | 3.22 | | |
| Bavaria | 907040 | 18 | | 1 | 3.22 | | |
| Bavaria | 2900347 | 18 | | 1 | 3.22 | | |
| Bavaria | 2900349 | 18 | | 1 | 3.22 | | |
| Bavaria | 2900364 | 18 | | 1 | 3.22 | | |
| Bavaria | 2900378 | 18 | | 1 | 3.22 | | |
| Rhineland-Palatinate | 701050 | 19 | | 1 | 3.00 | | |
| Rhineland-Palatinate | 702040 | 20 | | 1 | 2.80 | | |
| Rhineland-Palatinate | 702050 | 20 | | 1 | 2.80 | | |
| Rhineland-Palatinate | 702060 | 20 | | 1 | 2.80 | | |
| Rhineland-Palatinate | 702080 | 20 | | 1 | 2.80 | | |
| Rhineland-Palatinate | 703080 | 20 | | 1 | 2.80 | | |
| Saarland | 1000010 | 20 | | 1 | 2.80 | | |
| Saarland | 1000020 | 20 | | 1 | 2.80 | | |
| Rhineland-Palatinate | 2700281 | 20 | | 1 | 2.80 | | |
| Rhineland-Palatinate | 2700282 | 20 | | 1 | 2.80 | | |
| Rhineland-Palatinate | 2700283 | 20 | | 1 | 2.80 | | |
| Lower Saxony | 301110 | | | | | 0.002 | 1 |
| Nordrhein-Westfalen | 503030 | | | | | 0.016 | 3 |
| Nordrhein-Westfalen | 503190 | | | | | 0.034 | 3 |
| Nordrhein-Westfalen | 504190 | | | | | 0.026 | 3 |
| Nordrhein-Westfalen | 504270 | | | | | 0.044 | 4 |
| Nordrhein-Westfalen | 505010 | | | | | 0.012 | 4 |
| Nordrhein-Westfalen | 505050 | | | | | 0.02 | 3 |

| State | Region (MB) | Cluster GP | Low rate | High rate | Average cluster supply | Moran's I p-value | Moran's I q-value |
|---|---|---|---|---|---|---|---|
| Baden-Württemberg | 802030 | | | | | 0.03 | 4 |
| Baden-Württemberg | 802040 | | | | | 0.002 | 3 |
| Baden-Württemberg | 802070 | | | | | 0.008 | 3 |
| Baden-Württemberg | 806010 | | | | | 0.04 | 3 |
| Baden-Württemberg | 807010 | | | | | 0.018 | 3 |
| Baden-Württemberg | 807020 | | | | | 0.02 | 3 |
| Baden-Württemberg | 807030 | | | | | 0.026 | 3 |
| Baden-Württemberg | 807050 | | | | | 0.016 | 3 |
| Baden-Württemberg | 807080 | | | | | 0.04 | 3 |
| Baden-Württemberg | 807100 | | | | | 0.042 | 3 |
| Baden-Württemberg | 807110 | | | | | 0.038 | 3 |
| Baden-Württemberg | 808030 | | | | | 0.004 | 3 |
| Baden-Württemberg | 809020 | | | | | 0.01 | 3 |
| Baden-Württemberg | 809030 | | | | | 0.036 | 4 |
| Bavaria | 908070 | | | | | 0.022 | 4 |
| Bavaria | 910010 | | | | | 0.05 | 3 |
| Bavaria | 910050 | | | | | 0.002 | 3 |
| Bavaria | 914060 | | | | | 0.002 | 3 |
| Bavaria | 914090 | | | | | 0.026 | 3 |
| Bavaria | 917030 | | | | | 0.032 | 3 |
| Bavaria | 917050 | | | | | 0.004 | 3 |
| Bavaria | 918120 | | | | | 0.004 | 3 |
| Berlin | 1100000 | | | | | 0.002 | 1 |
| Brandenburg | 1203010 | | | | | 0.002 | 1 |
| Brandenburg | 1203020 | | | | | 0.002 | 1 |
| Brandenburg | 1203030 | | | | | 0.002 | 1 |
| Brandenburg | 1203050 | | | | | 0.006 | 1 |
| Brandenburg | 1203070 | | | | | 0.01 | 1 |
| Brandenburg | 1203080 | | | | | 0.022 | 1 |
| Brandenburg | 1205010 | | | | | 0.038 | 1 |
| Brandenburg | 1205020 | | | | | 0.002 | 1 |
| Saxony-Anhalt | 1501010 | | | | | 0.008 | 1 |
| Saxony-Anhalt | 1501040 | | | | | 0.018 | 1 |
| Saxony-Anhalt | 1502060 | | | | | 0.004 | 1 |
| Saxony-Anhalt | 1505010 | | | | | 0.008 | 1 |
| Saxony-Anhalt | 1505020 | | | | | 0.006 | 1 |
| Saxony-Anhalt | 1505030 | | | | | 0.002 | 1 |
| Thuringia | 1600100 | | | | | 0.002 | 1 |
| Thuringia | 1603300 | | | | | 0.01 | 1 |
| Lower Saxony | 2300094 | | | | | 0.044 | 2 |
| Lower Saxony | 2300433 | | | | | 0.03 | 1 |
| Lower Saxony | 2300435 | | | | | 0.018 | 1 |
| Lower Saxony | 2300439 | | | | | 0.034 | 1 |
| Bavaria | 2900131 | | | | | 0.002 | 3 |
| Bavaria | 2900140 | | | | | 0.014 | 1 |
| Bavaria | 2900305 | | | | | 0.028 | 3 |
| Bavaria | 2900306 | | | | | 0.004 | 1 |
| Bavaria | 2900308 | | | | | 0.042 | 3 |
| Bavaria | 2900355 | | | | | 0.002 | 3 |
| Bavaria | 2900363 | | | | | 0.018 | 1 |
| Bavaria | 2900365 | | | | | 0.02 | 1 |
| Bavaria | 2900376 | | | | | 0.006 | 1 |
| Bavaria | 2900381 | | | | | 0.034 | 3 |
| Saxony-Anhalt | 3500160 | | | | | 0.006 | 1 |
| Thuringia | 3600525 | | | | | 0.002 | 1 |

Source: Geiger et al. [92]

# Appendix F: Bernoulli model and Moran’s I results of specialised physicians

| State | KR | Cluster ophthalmologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster neurologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster orthopaedics | Low rate | High rate | Average cluster supply | Moran's I q-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BY | 94760 | 1 | | 1 | 3.91 | 1 | 5 | | 1 | 4.11 | 1 | 1 | | 1 | 4.25 | 1 |
| BY | 94750 | 1 | | 1 | 3.91 | | | | | | | 1 | | 1 | 4.25 | 1 |
| SN | 340019 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340021 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340022 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340023 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | | 1 | | 1 | 4.25 | |
| SN | 340024 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340026 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340027 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340028 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340033 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340035 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340036 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340037 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340038 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | | 1 | | 1 | 4.25 | 1 |
| SN | 340039 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340061 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340081 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340082 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340083 | 1 | | 1 | 3.91 | 1 | | | | | 1 | 1 | | 1 | 4.25 | |
| ST | 150020 | 1 | | 1 | 3.91 | | 1 | | 1 | 4.51 | | 1 | | 1 | 4.25 | 1 |
| ST | 150840 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| ST | 150880 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| ST | 150910 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| ST | 350017 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| ST | 350018 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | | 1 | | 1 | 4.25 | 1 |
| ST | 150870 | 1 | | 1 | 3.91 | 1 | | | | | 1 | 1 | | 1 | 4.25 | 1 |
| ST | 150890 | 1 | | 1 | 3.91 | 1 | | | | | 1 | 1 | | 1 | 4.25 | 1 |
| ST | 150030 | 1 | | 1 | 3.91 | 1 | | | | | | | | | | 1 |
| ST | 150850 | 1 | | 1 | 3.91 | 1 | | | | | | | | | | 1 |
| TH | 160520 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| TH | 160760 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| TH | 160770 | 1 | | 1 | 3.91 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| TH | 160710 | 1 | | 1 | 3.91 | 1 | 5 | | 1 | 4.11 | 1 | 1 | | 1 | 4.25 | 1 |
| TH | 160730 | 1 | | 1 | 3.91 | 1 | 5 | | 1 | 4.11 | 1 | 1 | | 1 | 4.25 | 1 |
| TH | 160530 | 1 | | 1 | 3.91 | | | | | | | 1 | | 1 | 4.25 | |
| TH | 160740 | 1 | | 1 | 3.91 | 1 | | | | | 1 | 1 | | 1 | 4.25 | 1 |
| TH | 160750 | 1 | | 1 | 3.91 | 1 | | | | | 1 | 1 | | 1 | 4.25 | 1 |
| TH | 160510 | 1 | | 1 | 3.91 | 1 | 5 | | 1 | 4.11 | 1 | 6 | | 1 | 4.33 | |

| State | KR | Cluster ophthalmologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster neurologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster orthopaedics | Low rate | High rate | Average cluster supply | Moran's I q-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TH | 160610 | 1 | | 1 | 3.91 | 1 | 5 | | 1 | 4.11 | | 6 | | 1 | 4.33 | 1 |
| TH | 160640 | 1 | | 1 | 3.91 | 1 | 5 | | 1 | 4.11 | 1 | 6 | | 1 | 4.33 | 1 |
| TH | 160660 | 1 | | 1 | 3.91 | | 5 | | 1 | 4.11 | 1 | 6 | | 1 | 4.33 | |
| TH | 160670 | 1 | | 1 | 3.91 | 1 | 5 | | 1 | 4.11 | 1 | 6 | | 1 | 4.33 | 1 |
| TH | 160680 | 1 | | 1 | 3.91 | 1 | 5 | | 1 | 4.11 | 1 | 6 | | 1 | 4.33 | 1 |
| TH | 160690 | 1 | | 1 | 3.91 | 1 | 5 | | 1 | 4.11 | 1 | 6 | | 1 | 4.33 | 1 |
| TH | 160700 | 1 | | 1 | 3.91 | 1 | 5 | | 1 | 4.11 | 1 | 6 | | 1 | 4.33 | 1 |
| TH | 160620 | 1 | | 1 | 3.91 | 1 | | | | | 1 | 6 | | 1 | 4.33 | 1 |
| TH | 160650 | 1 | | 1 | 3.91 | 1 | | | | | 1 | 6 | | 1 | 4.33 | 1 |
| TH | 160720 | 1 | | 1 | 3.91 | 1 | 5 | | 1 | 4.11 | 1 | | | | | 1 |
| BE | 310016 | 2 | | 1 | 4.04 | 1 | | | | | 1 | | | | | 1 |
| BB | 120520 | 2 | | 1 | 4.04 | | 1 | | 1 | 4.51 | | 1 | | 1 | 4.25 | |
| BB | 120540 | 2 | | 1 | 4.04 | | 1 | | 1 | 4.51 | | 1 | | 1 | 4.25 | |
| BB | 120610 | 2 | | 1 | 4.04 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| BB | 120670 | 2 | | 1 | 4.04 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| BB | 120690 | 2 | | 1 | 4.04 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| BB | 120710 | 2 | | 1 | 4.04 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| BB | 120720 | 2 | | 1 | 4.04 | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| BB | 120600 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| BB | 120650 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| BB | 120680 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| BB | 120700 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | | 3 | | 1 | 4.28 | |
| BB | 120730 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| BB | 120640 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | | | | | 1 |
| BB | 120630 | 2 | | 1 | 4.04 | 1 | | | | | 1 | | | | | 1 |
| MV | 130030 | 2 | | 1 | 4.04 | | 3 | | 1 | 4.40 | | 3 | | 1 | 4.28 | |
| MV | 130510 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| MV | 130520 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| MV | 130530 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| MV | 130550 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| MV | 130560 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| MV | 130570 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| MV | 130580 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| MV | 130590 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| MV | 130600 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| MV | 130610 | 2 | | 1 | 4.04 | | 3 | | 1 | 4.40 | | 3 | | 1 | 4.28 | |
| MV | 130620 | 2 | | 1 | 4.04 | 1 | 3 | | 1 | 4.40 | 1 | 3 | | 1 | 4.28 | 1 |
| MV | 130540 | 2 | | 1 | 4.04 | | | | | | | 3 | | 1 | 4.28 | |
| ST | 150860 | 2 | | 1 | 4.04 | 1 | | | | | 1 | | | | | 1 |
| ST | 150900 | 2 | | 1 | 4.04 | 1 | | | | | 1 | | | | | 1 |
| BW | 81110 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 81150 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 81160 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |

| State | KR | Cluster ophthalmologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster neurologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster orthopaedics | Low rate | High rate | Average cluster supply | Moran's I q-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BW | 81170 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 81180 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 81190 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 81270 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 81350 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 81360 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 82350 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 82370 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 83250 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 83260 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 83270 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 83350 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 84150 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 84160 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 84170 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 84210 | 3 | 1 | | 3.90 | | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | |
| BW | 84250 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 84260 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 84350 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 84360 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 84370 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BY | 97730 | 3 | 1 | | 3.90 | | 2 | 1 | | 4.23 | | 2 | 1 | | 4.16 | |
| BY | 97740 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | |
| BY | 97750 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BY | 97780 | 3 | 1 | | 3.90 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | |
| BY | 91790 | 3 | 1 | | 3.90 | 3 | 4 | 1 | | 4.25 | 3 | 5 | 1 | | 4.75 | 3 |
| BY | 91810 | 3 | 1 | | 3.90 | 3 | 4 | 1 | | 4.25 | 3 | 5 | 1 | | 4.75 | 3 |
| BY | 91880 | 3 | 1 | | 3.90 | 3 | 4 | 1 | | 4.25 | 3 | 5 | 1 | | 4.75 | 3 |
| BY | 91900 | 3 | 1 | | 3.90 | | 4 | 1 | | 4.25 | 3 | 5 | 1 | | 4.75 | 3 |
| BY | 97710 | 3 | 1 | | 3.90 | 3 | 4 | 1 | | 4.25 | 3 | 5 | 1 | | 4.75 | 3 |
| BY | 97610 | 3 | 1 | | 3.90 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 97720 | 3 | 1 | | 3.90 | 3 | | | | | 3 | | | | | |
| BY | 97760 | 3 | 1 | | 3.90 | | | | | | | | | | | |
| BY | 97770 | 3 | 1 | | 3.90 | 3 | | | | | 3 | | | | | |
| BY | 97790 | 3 | 1 | | 3.90 | 3 | | | | | 3 | | | | | 4 |
| BY | 97800 | 3 | 1 | | 3.90 | | | | | | 3 | | | | | |
| BY | 93740 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | 1 | | 1 | 4.25 | |
| BY | 93770 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | 1 | | 1 | 4.25 | |
| BY | 94790 | 4 | 1 | | 4.05 | | | | | | | 1 | | 1 | 4.25 | |
| BY | 91620 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | 3 | 5 | 1 | | 4.75 | 3 |
| BY | 91740 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | 3 | 5 | 1 | | 4.75 | 3 |
| BY | 91750 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | | 5 | 1 | | 4.75 | 3 |
| BY | 91770 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | | 5 | 1 | | 4.75 | 3 |

| State | KR | Cluster ophthalmologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster neurologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster orthopaedics | Low rate | High rate | Average cluster supply | Moran's I q-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BY | 91780 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | 3 | 5 | 1 | | 4.75 | 3 |
| BY | 91830 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | | 5 | 1 | | 4.75 | 3 |
| BY | 91840 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | 3 | 5 | 1 | | 4.75 | 3 |
| BY | 91860 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | 3 | 5 | 1 | | 4.75 | 3 |
| BY | 91870 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | | 5 | 1 | | 4.75 | 3 |
| BY | 91610 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | 3 | | | | | |
| BY | 91710 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 91720 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | 4 |
| BY | 91760 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | | | | | | |
| BY | 91850 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | 3 | | | | | |
| BY | 91890 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 92710 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 92720 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 92730 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | | | | | | |
| BY | 92740 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | | | | | | |
| BY | 92750 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 92760 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 92770 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 92780 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 92790 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 93620 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 93710 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 93720 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 93730 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | | | | | | |
| BY | 93750 | 4 | 1 | | 4.05 | 3 | 4 | 1 | | 4.25 | | | | | | |
| BY | 93760 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 95740 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 95760 | 4 | 1 | | 4.05 | | 4 | 1 | | 4.25 | | | | | | |
| BY | 94720 | 4 | 1 | | 4.05 | | | | | | | | | | | |
| HB | 40120 | 5 | 1 | | 3.94 | | 7 | 1 | | 4.20 | | 4 | 1 | | 4.36 | |
| HH | 20000 | 5 | 1 | | 3.94 | 3 | 7 | 1 | | 4.20 | | 4 | 1 | | 4.36 | 3 |
| NI | 33520 | 5 | 1 | | 3.94 | | 7 | 1 | | 4.20 | 3 | 4 | 1 | | 4.36 | |
| NI | 33530 | 5 | 1 | | 3.94 | 3 | 7 | 1 | | 4.20 | 3 | 4 | 1 | | 4.36 | 3 |
| NI | 33570 | 5 | 1 | | 3.94 | | 7 | 1 | | 4.20 | | 4 | 1 | | 4.36 | 3 |
| NI | 33590 | 5 | 1 | | 3.94 | 3 | 7 | 1 | | 4.20 | | 4 | 1 | | 4.36 | 3 |
| SH | 10510 | 5 | 1 | | 3.94 | | 7 | 1 | | 4.20 | | 4 | 1 | | 4.36 | |
| SH | 10560 | 5 | 1 | | 3.94 | | 7 | 1 | | 4.20 | | 4 | 1 | | 4.36 | 3 |
| SH | 10580 | 5 | 1 | | 3.94 | | 7 | 1 | | 4.20 | | 4 | 1 | | 4.36 | 3 |
| SH | 10600 | 5 | 1 | | 3.94 | 3 | 7 | 1 | | 4.20 | | 4 | 1 | | 4.36 | 3 |
| SH | 10610 | 5 | 1 | | 3.94 | | 7 | 1 | | 4.20 | | 4 | 1 | | 4.36 | 3 |
| SH | 10620 | 5 | 1 | | 3.94 | | 7 | 1 | | 4.20 | | 4 | 1 | | 4.36 | 3 |
| SH | 10020 | 5 | 1 | | 3.94 | | | | | | | 4 | 1 | | 4.36 | |
| SH | 10570 | 5 | 1 | | 3.94 | | | | | | | 4 | 1 | | 4.36 | 3 |

| State | KR | Cluster ophthalmologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster neurologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster orthopaedics | Low rate | High rate | Average cluster supply | Moran's I q-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NI | 34540 | 6 | 1 | | 4.00 | | 7 | 1 | | 4.20 | | 8 | 1 | | 4.20 | |
| NI | 34590 | 6 | 1 | | 4.00 | 3 | 7 | 1 | | 4.20 | | 8 | 1 | | 4.20 | 3 |
| NI | 34600 | 6 | 1 | | 4.00 | | 7 | 1 | | 4.20 | | 8 | 1 | | 4.20 | |
| NI | 34040 | 6 | 1 | | 4.00 | | | | | | | 8 | 1 | | 4.20 | |
| NI | 34560 | 6 | 1 | | 4.00 | 3 | | | | | | 8 | 1 | | 4.20 | |
| NW | 55150 | 6 | 1 | | 4.00 | 3 | 9 | 1 | | 4.09 | | 8 | 1 | | 4.20 | |
| NW | 55540 | 6 | 1 | | 4.00 | | 9 | 1 | | 4.09 | | 8 | 1 | | 4.20 | |
| NW | 55580 | 6 | 1 | | 4.00 | 3 | 9 | 1 | | 4.09 | | 8 | 1 | | 4.20 | |
| NW | 55620 | 6 | 1 | | 4.00 | | 9 | 1 | | 4.09 | | 8 | 1 | | 4.20 | |
| NW | 55660 | 6 | 1 | | 4.00 | 3 | | | | | | 8 | 1 | | 4.20 | 3 |
| NW | 55700 | 6 | 1 | | 4.00 | 3 | | | | | | 8 | 1 | | 4.20 | |
| NW | 57540 | 6 | 1 | | 4.00 | | | | | | | 8 | 1 | | 4.20 | |
| NW | 59150 | 6 | 1 | | 4.00 | | | | | | | 8 | 1 | | 4.20 | |
| SL | 100410 | 7 | 1 | | 4.00 | 3 | 6 | 1 | | 4.40 | | 7 | 1 | | 4.60 | 3 |
| SL | 100420 | 7 | 1 | | 4.00 | | 6 | 1 | | 4.40 | | 7 | 1 | | 4.60 | 3 |
| SL | 100430 | 7 | 1 | | 4.00 | 3 | 6 | 1 | | 4.40 | | 7 | 1 | | 4.60 | 3 |
| SL | 100440 | 7 | 1 | | 4.00 | 3 | 6 | 1 | | 4.40 | 3 | 7 | 1 | | 4.60 | 3 |
| SL | 100460 | 7 | 1 | | 4.00 | | 6 | 1 | | 4.40 | | 7 | 1 | | 4.60 | |
| BW | 81210 | 8 | 1 | | 3.82 | | 2 | 1 | | 4.23 | | 2 | 1 | | 4.16 | |
| BW | 81250 | 8 | 1 | | 3.82 | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 81260 | 8 | 1 | | 3.82 | 3 | | | | | | | | | | 3 |
| BW | 81280 | 8 | 1 | | 3.82 | 3 | | | | | 3 | | | | | 3 |
| BW | 82150 | 8 | 1 | | 3.82 | | | | | | | | | | | 3 |
| BW | 82210 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| BW | 82220 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| BW | 82250 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| BW | 82260 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| BY | 96630 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| BY | 96710 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| BY | 96760 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| BY | 96770 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| BY | 96790 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| HE | 64350 | 8 | 1 | | 3.82 | | | | | | | 6 | | 1 | 4.33 | |
| HE | 64400 | 8 | 1 | | 3.82 | | | | | | | 6 | | 1 | 4.33 | |
| HE | 64110 | 8 | 1 | | 3.82 | | 8 | 1 | | 3.92 | | 9 | 1 | | 4.60 | |
| HE | 64330 | 8 | 1 | | 3.82 | | 8 | 1 | | 3.92 | | 9 | 1 | | 4.60 | 3 |
| HE | 64360 | 8 | 1 | | 3.82 | | 8 | 1 | | 3.92 | | 9 | 1 | | 4.60 | |
| HE | 64320 | 8 | 1 | | 3.82 | | | | | | | 9 | 1 | | 4.60 | |
| HE | 64140 | 8 | 1 | | 3.82 | 3 | 8 | 1 | | 3.92 | 3 | | | | | 4 |
| HE | 64120 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| HE | 64130 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| HE | 64310 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| HE | 64340 | 8 | 1 | | 3.82 | | | | | | | | | | | |

## Appendix F: Bernoulli model and Moran's I results of specialised physicians

| State | KR | Cluster ophthalmologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster neurologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster orthopaedics | Low rate | High rate | Average cluster supply | Moran's I q-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HE | 64370 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| HE | 64380 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| RP | 73150 | 8 | 1 | | 3.82 | | 8 | 1 | | 3.92 | | 9 | 1 | | 4.60 | |
| RP | 73310 | 8 | 1 | | 3.82 | | 8 | 1 | | 3.92 | | | | | | |
| RP | 73390 | 8 | 1 | | 3.82 | | 8 | 1 | | 3.92 | | | | | | |
| RP | 73140 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| RP | 73320 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| RP | 73380 | 8 | 1 | | 3.82 | | | | | | | | | | | |
| HE | 65320 | 9 | 1 | | 3.43 | | 10 | 1 | | 4.00 | | 6 | | 1 | 4.33 | |
| HE | 65340 | 9 | 1 | | 3.43 | | 10 | 1 | | 4.00 | | 6 | | 1 | 4.33 | |
| NW | 53740 | 9 | 1 | | 3.43 | | 10 | 1 | | 4.00 | | 12 | 1 | | 4.17 | |
| NW | 59580 | 9 | 1 | | 3.43 | | 10 | 1 | | 4.00 | | 12 | 1 | | 4.17 | |
| NW | 59660 | 9 | 1 | | 3.43 | | 10 | 1 | | 4.00 | | 12 | 1 | | 4.17 | |
| NW | 59700 | 9 | 1 | | 3.43 | | 10 | 1 | | 4.00 | | 12 | 1 | | 4.17 | |
| RP | 71320 | 9 | 1 | | 3.43 | | 10 | 1 | | 4.00 | | 12 | 1 | | 4.17 | |
| NW | 51110 | 10 | 1 | | 4.00 | | 11 | 1 | | 4.12 | | 11 | 1 | | 4.00 | |
| NI | 31550 | 11 | | 1 | 3.77 | | | | | | | 6 | | 1 | 4.33 | |
| NI | 32560 | 11 | | 1 | 3.77 | | 7 | 1 | | 4.20 | | 8 | 1 | | 4.20 | |
| NI | 32570 | 11 | | 1 | 3.77 | | | | | | | 8 | 1 | | 4.20 | |
| NI | 32520 | 11 | | 1 | 3.77 | | | | | | | 14 | | 1 | 4.00 | |
| NI | 33580 | 11 | | 1 | 3.77 | | 7 | 1 | | 4.20 | | | | | | |
| NI | 31010 | 11 | | 1 | 3.77 | | | | | | | | | | | |
| NI | 31020 | 11 | | 1 | 3.77 | | | | | | | | | | | |
| NI | 31030 | 11 | | 1 | 3.77 | | | | | | | | | | | |
| NI | 31510 | 11 | | 1 | 3.77 | | | | | | | | | | | |
| NI | 31530 | 11 | | 1 | 3.77 | 1 | | | | | | | | | | 1 |
| NI | 31570 | 11 | | 1 | 3.77 | | | | | | | | | | | |
| NI | 31580 | 11 | | 1 | 3.77 | | | | | | | | | | | |
| NI | 32411 | 11 | | 1 | 3.77 | | | | | | | | | | | |
| NI | 32412 | 11 | | 1 | 3.77 | | | | | | | | | | | |
| NI | 32540 | 11 | | 1 | 3.77 | | | | | | | | | | | |
| NI | 32550 | 11 | | 1 | 3.77 | | | | | | | | | | | |
| NI | 33510 | 11 | | 1 | 3.77 | | | | | | | | | | | |
| NW | 57700 | 11 | | 1 | 3.77 | | 7 | 1 | | 4.20 | | 8 | 1 | | 4.20 | |
| NW | 59110 | 12 | | 1 | 4.00 | | 12 | | 1 | 4.60 | | 13 | | 1 | 4.40 | |
| BY | 94780 | 13 | 1 | | 4.00 | | 5 | | 1 | 4.11 | | | | | | |
| BY | 96740 | 13 | 1 | | 4.00 | | 5 | | 1 | 4.11 | | | | | | |
| BY | 94710 | 13 | 1 | | 4.00 | | | | | | | | | | | |
| BY | 94740 | 13 | 1 | | 4.00 | | | | | | | | | | | |
| BY | 95720 | 13 | 1 | | 4.00 | | | | | | | | | | | |
| NW | 51120 | 14 | | 1 | 4.00 | | 14 | | 1 | 4.00 | | 16 | | 1 | 4.50 | |
| NW | 51140 | 14 | | 1 | 4.00 | | 14 | | 1 | 4.00 | | | | | | |
| NW | 51660 | 14 | | 1 | 4.00 | | 14 | | 1 | 4.00 | | | | | | |

## Appendix F: Bernoulli model and Moran's I results of specialised physicians

| State | KR | Cluster ophthalmologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster neurologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster orthopaedics | Low rate | High rate | Average cluster supply | Moran's I q-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BW | 82310 | | | | | | 2 | 1 | | 4.23 | | 2 | 1 | | 4.16 | 3 |
| BW | 82360 | | | | | 3 | 2 | 1 | | 4.23 | 3 | 2 | 1 | | 4.16 | 3 |
| BW | 82160 | | | | | | | | | | 4 | | | | | 3 |
| BY | 94770 | | | | | | | | | | | 1 | | 1 | 4.25 | |
| BY | 91730 | | | | | 3 | 4 | 1 | | 4.25 | 3 | 5 | 1 | | 4.75 | 3 |
| BY | 91820 | | | | | | 4 | 1 | | 4.25 | | 5 | 1 | | 4.75 | 3 |
| BY | 96720 | | | | | | 5 | | 1 | 4.11 | | 6 | | 1 | 4.33 | |
| BY | 96730 | | | | | | 5 | | 1 | 4.11 | | 6 | | 1 | 4.33 | |
| BY | 95770 | | | | | | 4 | 1 | | 4.25 | | | | | | |
| BY | 94730 | | | | | | 5 | | 1 | 4.11 | 1 | | | | | |
| BY | 96780 | | | | | | 5 | | 1 | 4.11 | | | | | | |
| BY | 91800 | | | | | | | | | | | | | | | 3 |
| BB | 120620 | | | | | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| BB | 120660 | | | | | 1 | 1 | | 1 | 4.51 | 2 | 1 | | 1 | 4.25 | 1 |
| HB | 40110 | | | | | | 7 | 1 | | 4.20 | | | | | | |
| HE | 65350 | | | | | | 5 | | 1 | 4.11 | | 6 | | 1 | 4.33 | |
| HE | 66310 | | | | | | 5 | | 1 | 4.11 | | 6 | | 1 | 4.33 | |
| HE | 66320 | | | | | | 5 | | 1 | 4.11 | | 6 | | 1 | 4.33 | |
| HE | 66360 | | | | | | 5 | | 1 | 4.11 | | 6 | | 1 | 4.33 | |
| HE | 65310 | | | | | | | | | | | 6 | | 1 | 4.33 | |
| HE | 66110 | | | | | | | | | | | 6 | | 1 | 4.33 | |
| HE | 66330 | | | | | | | | | | | 6 | | 1 | 4.33 | |
| HE | 66340 | | | | | | | | | | | 6 | | 1 | 4.33 | |
| HE | 66350 | | | | | | | | | | | 6 | | 1 | 4.33 | |
| HE | 64390 | | | | | | 8 | 1 | | 3.92 | | | | | | |
| NI | 31520 | | | | | | | | | | | 6 | | 1 | 4.33 | 1 |
| NI | 31560 | | | | | | | | | | | 6 | | 1 | 4.33 | 1 |
| NI | 32510 | | | | | | 7 | 1 | | 4.20 | 3 | 8 | 1 | | 4.20 | 3 |
| NI | 34530 | | | | | | 7 | 1 | | 4.20 | | 8 | 1 | | 4.20 | |
| NI | 34580 | | | | | | 7 | 1 | | 4.20 | | 8 | 1 | | 4.20 | |
| NI | 33550 | | | | | | 7 | 1 | | 4.20 | | | | | | |
| NI | 33560 | | | | | | 7 | 1 | | 4.20 | 3 | | | | | |
| NI | 33610 | | | | | | 7 | 1 | | 4.20 | | | | | | |
| NI | 34030 | | | | | | 7 | 1 | | 4.20 | | | | | | |
| NI | 34510 | | | | | | 7 | 1 | | 4.20 | | | | | | |
| NI | 34520 | | | | | | 7 | 1 | | 4.20 | | | | | | |
| NI | 34550 | | | | | | 7 | 1 | | 4.20 | | | | | | |
| NI | 34570 | | | | | | 7 | 1 | | 4.20 | | | | | | |
| NI | 34610 | | | | | | 7 | 1 | | 4.20 | | | | | | |
| NI | 34620 | | | | | | 7 | 1 | | 4.20 | | | | | | |
| NI | 33540 | | | | | 1 | | | | | | | | | | |
| NW | 57620 | | | | | | | | | | | 6 | | 1 | 4.33 | |
| NW | 59780 | | | | | | 12 | | 1 | 4.60 | | 8 | 1 | | 4.20 | |

| State | KR | Cluster ophthalmologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster neurologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster orthopaedics | Low rate | High rate | Average cluster supply | Moran's I q-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NW | 57740 | | | | | | 13 | 1 | | 4.00 | | 8 | 1 | | 4.20 | |
| NW | 57110 | | | | | | | | | | | 8 | 1 | | 4.20 | |
| NW | 57580 | | | | | | | | | | | 8 | 1 | | 4.20 | |
| NW | 57660 | | | | | | | | | | | 8 | 1 | | 4.20 | |
| NW | 59740 | | | | | | | | | | | 8 | 1 | | 4.20 | |
| NW | 53580 | | | | | | 11 | 1 | | 4.12 | | 10 | | 1 | 4.00 | |
| NW | 53341 | | | | | | | | | | | 10 | | 1 | 4.00 | |
| NW | 53342 | | | | | | | | | | | 10 | | 1 | 4.00 | |
| NW | 53660 | | | | | | | | | | | 10 | | 1 | 4.00 | |
| NW | 53700 | | | | | | | | | | | 10 | | 1 | 4.00 | |
| NW | 59620 | | | | | | 12 | | 1 | 4.60 | | 12 | 1 | | 4.17 | |
| NW | 55130 | | | | | | 9 | 1 | | 4.09 | | 13 | | 1 | 4.40 | |
| NW | 51130 | | | | | | 12 | | 1 | 4.60 | | 13 | | 1 | 4.40 | |
| NW | 59160 | | | | | | 12 | | 1 | 4.60 | | 13 | | 1 | 4.40 | |
| NW | 59540 | | | | | | 12 | | 1 | 4.60 | | 13 | | 1 | 4.40 | |
| NW | 51700 | | | | | | 9 | 1 | | 4.09 | | 15 | 1 | | 4.00 | |
| NW | 51190 | | | | | | | | | | | 15 | 1 | | 4.00 | |
| NW | 51170 | | | | | | | | | | | 16 | | 1 | 4.50 | |
| NW | 53820 | | | | | | | | | | | 17 | | 1 | 4.40 | |
| NW | 53140 | | | | | | 11 | 1 | | 4.12 | | 18 | 1 | | 5.00 | |
| NW | 55120 | | | | | | 9 | 1 | | 4.09 | | | | | | |
| NW | 51160 | | | | | | 11 | 1 | | 4.12 | | | | | | |
| NW | 51620 | | | | | | 11 | 1 | | 4.12 | | | | | | |
| NW | 53150 | | | | | | 11 | 1 | | 4.12 | | | | | | |
| NW | 53160 | | | | | | 11 | 1 | | 4.12 | | | | | | |
| NW | 53620 | | | | | | 11 | 1 | | 4.12 | | | | | | |
| NW | 53780 | | | | | | 11 | 1 | | 4.12 | | | | | | |
| NW | 51200 | | | | | | 12 | | 1 | 4.60 | | | | | | |
| NW | 51220 | | | | | | 12 | | 1 | 4.60 | | | | | | |
| NW | 51240 | | | | | | 12 | | 1 | 4.60 | | | | | | |
| NW | 59130 | | | | | | 12 | | 1 | 4.60 | | | | | | |
| NW | 59140 | | | | | | 12 | | 1 | 4.60 | | | | | | |
| RP | 71110 | | | | | | | | | | | 17 | | 1 | 4.40 | |
| RP | 71370 | | | | | | | | | | | 17 | | 1 | 4.40 | |
| RP | 71380 | | | | | | | | | | | 17 | | 1 | 4.40 | |
| RP | 71430 | | | | | | | | | | | 17 | | 1 | 4.40 | |
| SN | 340020 | | | | | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340029 | | | | | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340031 | | | | | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340032 | | | | | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340041 | | | | | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340042 | | | | | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |
| SN | 340043 | | | | | 1 | 1 | | 1 | 4.51 | 1 | 1 | | 1 | 4.25 | 1 |

## Appendix F: Bernoulli model and Moran’s I results of specialised physicians

| State | KR | Cluster ophthalmologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster neurologist | Low rate | High rate | Average cluster supply | Moran's I q-value | Cluster orthopaedics | Low rate | High rate | Average cluster supply | Moran's I q-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ST | 150830 | | | | | 1 | | | | | 1 | | | | | 1 |
| SH | 10530 | | | | | | 7 | 1 | | 4.20 | | | | | | |
| SH | 10540 | | | | | | 7 | 1 | | 4.20 | | | | | | |
| SH | 10550 | | | | | | | | | | | | | | | 3 |
| TH | 160630 | | | | | 1 | 5 | | 1 | 4.11 | 1 | 6 | | 1 | 4.33 | 1 |

Source: Geiger et al. [92]

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# Affidavit

LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Promotionsbüro Medizinische Fakultät

**Affidavit**

Geiger Isabel

Surname, first name

I hereby declare, that the submitted thesis entitled:

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The role of multimorbidity

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I further declare that the dissertation presented here has not been submitted in the same or similar form to any other institution for the purpose of obtaining an academic degree.

Munich 30.10.2023

place, date

Isabel Geiger

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# Confirmation of congruency

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The role of multimorbidity

is congruent with the printed version both in content and format.

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place, date

_______Isabel Geiger____________
Signature doctoral candidate

# Curriculum vitae

### Education

| | |
|---|---|
| 2018 – present<br>Munich, Germany | **Ludwig-Maximilians-University (LMU)**<br>Ph.D. Medical Research in Epidemiology & Public Health |
| 2016 – 2020<br>Liverpool, UK | **University of Liverpool**<br>M.Phil. in Epidemiology |
| 2014 – 2016<br>Innsbruck, Austria | **Management Center Innsbruck (MCI)**<br>M.A. in International Health and Social Management |
| 2013 – 2014<br>Vienna, Austria | **International Academy of Osteopathy (IAO)**<br>Training in Osteopathy |
| 2010 – 2013<br>Vienna, Austria | **University of Applied Sciences Vienna (FH Campus)**<br>B.Sc. in Physiotherapy |

### Professional experience

| | |
|---|---|
| 2021 – present<br>Munich, Germany | **Senior Project Manager at the European Foundation for the Care of Newborn Infants (EFCNI)**<br>Project manager of the European Standards of Care for Newborn Health |
| 2017 – 2021<br>Munich, Germany | **Research Associate at LMU, Department of Health Services Management**<br>Statistical and economic analysis of primary and secondary data, project management of new healthcare programmes and grant submissions |
| 2016 – 2016<br>Vienna, Austria | **Research writer at the Ludwig Boltzmann Institute for Health Technology Assessment**<br>Qualitative analysis of integrated care projects and a literature review |
| 2013 – 2014<br>Schruns, Austria | **Physiotherapist** at Reha-Klinik Montafon<br>Individual and group therapy in the field of orthopaedics, neurology, and cardiology |

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