Appendix

The German Oral Health studies DMS

As described, details on the DMS have been published elsewhere. Briefly, study participants were drawn from local residents’ registration offices in 90 randomly selected communities (sample points) using a cluster-random sampling stratified for regions and areas of urbanization. For the DMS III, 3,065 participants were included (response rate of 63.6 %); for DMS IV and V, these numbers were 4,631 (63.1 %) and 4,609 (50.1 %), respectively. Empirical non-responder analyses were conducted to compare the socio-dental characteristics of responders with the target population according to gender, educational level, dental visiting patterns, and dental/prosthetic status. Non-response bias was found to be minimal. The studies had been ethically approved. All participants provided written informed consent.

Clinical examinations and a socio-scientific survey were carried out at the local sample points. To ensure reproducibility, interviewers and dental investigators were trained and calibrated by experts, and multiple reliability checks were performed throughout the field phase. Missing variables occurred very rarely (<6% of cases). We imputed missing values using k-nearest neighbor imputation (Andridge and Little 2010) with k=5 and the Euclidean distance as distance metric. Before applying k-nearest neighbor imputation categorical features were one-hot encoded and numerical features were centered and scaled.

The following morbidity indicators were recorded: (1) Coronal caries experience in permanent teeth (DT, MT, FT) was recorded on 28 teeth (i.e. third molars were excluded), on five surfaces per posterior tooth (premolars and molars) and four surfaces per anterior tooth (incisors and
canines). (2) Root caries experience (untreated root caries and root surface restorations) were collected on the accessible surfaces. (3) Periodontal assessment was performed according to different partial-mouth protocols throughout the DMS waves, of which a partial mouth recording on two sites (mesio-vestibular and mid-vestibular) of six teeth (17, 16, 11, 44, 46, 47) was the common denominator among the waves. For the present study, the number of teeth with PPD≥4mm were of interested, as these teeth are regarded in need for periodontal treatment according statutory German healthcare regulations. Partial mouth numbers of teeth with PPD≥4mm were submitted to a transformation to full mouth numbers via ensemble-learning, as described and validated elsewhere (Schwendicke et al. 2018).

Adjusting for insurance status and utilization

Based on population estimates and morbidity indicators (see main text), a crude usage was estimated. This was adjusted for insurance status, as we only estimated the usage for statutorily health insured individuals (as no validation data were available for privately or non-insured individuals). The proportion of statutorily health insured individuals is shown in Fig. S1.

![Figure 1: Statutorily health insured individuals in millions (upper panel) and proportion (lower panel).](image-url)
The usage of preventive services was further adjusted for the reported utilization for these specific services, as reported on an annual basis (Fig. S2).

![Figure S2](image)

Figure S2: The utilization of preventive services in Germany by the eligible population (KZBV 2017b).

**Validation**

The validation of predicted usage was performed against claims data. We applied an approach we used before to link usage and claims (Jager et al. 2016; Schwendicke et al. 2016), using aggregations of specific services items within the German statutory insurance catalogue Bewertungsmaßstab, BEMA (KZBV 2017a).

For operative services, the following items were used:

- Fillings, excluding those adhesively placed (the number is limited to <1%, and these items were not available for the whole observational period), with 1 to 4 surfaces (BEMA positions 13a-d).

- Crowns. For crowns and fixed and removable dental prostheses, patients are reimbursed a fixed fee (Festzuschuss) for specific dental configurations (e.g. for specific gap configurations, fixed dental prostheses are reimbursed, while for others, only removable are reimbursed) by the statutory insurance. If patients want to deviate from these standard
therapies, they nevertheless receive the fee, but may need to pay for the additional costs emanating from dentists providing a more expensive (non-standard) treatment. Details can be found elsewhere (https://www.kzbv.de/festzuschusse-fur-zahnersatz.90.de.html).

The statutory health insurance has been using the fixed fee system since 2005 (which is why our validation of predicted usage of crowns or prosthetic services only starts in 2005). For crowns, the fixed fee items (Festzuschusspositionen) 1.1 (heavily destroyed tooth, requiring a full crown) and 1.2 (heavily destroyed tooth with one intact wall, requiring a partial crown) were used.

For prosthetic services, the following items were used:

- For fixed dental prostheses, fee items 2.1-2.4 (gaps with 1, 2, 3, 4 missing teeth, respectively, requiring fixed dental prostheses) and 2.5 (additional gaps to the ones reimbursed by 2.1-2.4, requiring fixed dental prostheses) were used.
- For removable dental prostheses, the fee items 3.1/3.2 (gaps not falling into 2.1-2.5, requiring partial dental prostheses) and 4.1-4.4 (3 or fewer teeth retained, requiring subtotal or total dentures) were used.

For periodontal services, BEMA items 200 and 201 were used (non-surgical periodontal treatment of single and multi-rooted teeth, respectively). In 2004, these positions were newly estimated, resulting in a 1-year massive decrease in claims. 2005 levels were back to 2003 levels, though, which is why we excluded 2004 from our estimations, but used the mean of 2003 and 2005 instead. Note that within the statutory insurance, surgical periodontal treatment may as well be provided. Claims data, however, indicate that only a minimum fraction of patients in fact receive these services under the tenets of the statutory insurance, which is why we excluded these.

For preventive services, the following BEMA items were used.
- IP1, oral health status.
- IP2, oral health education.
- IP4, local fluoride application.
  IP1,2,4 were assumed to be provided twice yearly.
- IP5, fissure sealing of permanent molars using resins. We assumed the 6-year molars to be sealed from age 6 onwards and the 12-year molars from age 12 onwards. We assumed a longevity of 7 years for a sealant, as described.

**Operative services**

The usage of operative services was derived from a combined estimation of the usage of fillings (Fig. S3) and crowns (Fig. S4).

![Figure S3: The predicted cumulative usage of fillings along different age groups (x-axis) and over time (colors).](image-url)
Figure S4: The predicted cumulative usage of crowns along different age groups (x-axis) and over time (colors).

The predicted usage was compared with the claimed use for validation purposes. In addition to the scatter plots in the main text, further details on this comparison are shown in Figures S5 (estimations for fillings) and S6 (estimations for crowns).

Figure S5: The predicted and claimed use of fillings.
Figure S6: The predicted and claimed use of crowns (claims records before 2005 not available).

Prosthetic services

The use of prosthetic services was based on sub-estimates for fixed (Fig. S7) and removable (Fig. S8) prostheses.

Figure S7: The predicted cumulative use of fixed dental prostheses along different age groups (x-axis) and over time (colors).
Figure S8: The predicted cumulative use of removable dental prostheses along different age groups (x-axis) and over time (colors).

The predicted use of prosthetic services was compared with the claimed use validation purposes. In addition to the scatter plots in the main text, further details on this comparison are shown in Figures S9.

Figure S9: The predicted and claimed use of prosthetic services (claims records before 2005 not available).
**Periodontal services**

The predicted use of periodontal services was compared with the claimed use for validation purposes. In addition to the scatter plots in the main text, further details on this comparison are shown in Figures S10.

![Figure S10: The predicted and claimed use of periodontal services.](image)

**Preventive services**

The predicted use of preventive services was compared with the claimed use for validation purposes. In addition to the scatter plots in the main text, further details on this comparison are shown in Figures S11.

![Figure S11: The predicted and claimed use of preventive services (claims records before 2005 not available/comparable).](image)
Sensitivity analyses

We performed sensitivity analyses for the periodontal and preventive services prediction models to identify which assumptions are critical to the estimation errors. The predictions of periodontal services are based on assumptions of periodontal treatment needs as outlined elsewhere (Schwendicke et al. 2018). The authors used spline-curve fitting and log-linear regression to model the tooth level probing-pocket depths (PPD ≥ 4 mm) from repeated waves of the nationally representative German Oral Health Studies. These are computed for different years (1997-2030) and age groups (ranges of uncertainty are reported, accordingly). In the present study these estimations are adjusted for the participation in statutory health insurance, which is a proportion of 86-87% of the population (Gesundheitsberichtserstattung 2018). Both the estimated morbidities (Schwendicke et al. 2018) and the proportion of people being insured by statutory health insurance are considered as fairly robust and are not included in the sensitivity analysis. Consequently, we evaluated the assumption of age- and time-specific utilization patterns as well as the retreatment period of APT. In the present study we used age- and time-specific utilization patterns based on the reporting of KZBV (see above) and a retreatment of APT assumed to be necessary every 10 years. For the sensitivity analysis we multiplied the utilization pattern with a (age and time invariant) factor of 0.8 to 1.2. Further, we assumed different retreatment periods for APT ranging from 8 to 15 years. As shown in figure S12 a clear pattern emerges which indicates that the default value combination is overestimating the actual utilization and underestimating the period for the retreatment of APT.
Figure S12: Sensitivity analysis for periodontal services. The heatmap shows the resulting RMSE (in millions) for predicted periodontal services vs. claimed periodontal services. The lowest RMSE is observed for a combination of 1.05% increase in the utilization pattern and an increase to 13.5 years for the retreatment period of APT.

The predictions of preventive services are based on assumptions that these services are available for all children aged 6-17 years. The population data is obtained from Statistisches Bundesamt (Statistisches Bundesamt 2012). In the present study these population estimates are adjusted for the participation in statutory health insurance, which is a proportion of 86-87% of the population (Gesundheitsberichtserstattung 2018). Both the estimated population of all children aged 6-17 years and the proportion of them being insured by statutory health insurance are considered as fairly robust and are not included in the sensitivity analysis. In the present study we further used age-specific utilization patterns based on the reporting of KZBV (as described) and assumed the longevity of sealants to be 7 years in mean. Consequently, we included the time-specific utilization patterns as well as the longevity of sealants into the sensitivity analysis. For the sensitivity analysis
we multiplied the utilization pattern with a (time-invariant) factor of 0.7 to 1.3. Further, we assumed different longevity of sealants ranging from 4 to 12 years. As shown in figure S13 a clear pattern emerges which indicates that the default value combination is underestimating the actual utilization. Further is appears that the longevity of sealants is less important for model performance compared to the utilization pattern. However, it is worth noting that the sensitivity analysis for preventive services does not alleviate the limitation of the model for preventive services, which does not account properly for the fairly stable number of claims (approx. 28 million each year).

Figure S13: Sensitivity analysis for preventive services. The heatmap shows the resulting RMSE (in millions) for predicted preventive services vs. claimed preventive services. The lowest RMSEs are encountered for utilizations 10 to 15% above the default value (as reported by KZBV).
Appendix References

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