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Long-term forecast for antibacterial drug consumption in Germany using ARIMA models

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Background

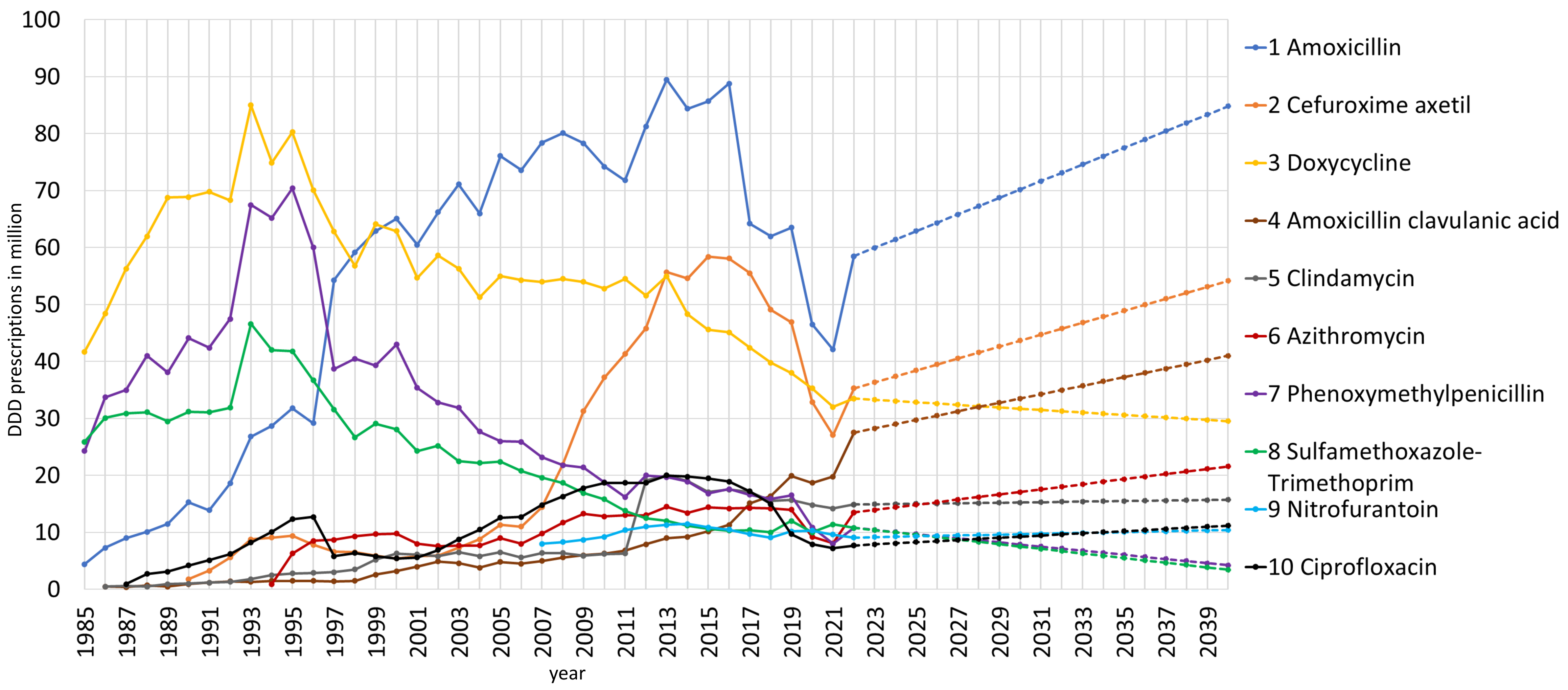
Frequent supply shortages of antibacterial drugs is a major public health challenge in Germany. As evolving bacterial resistance threatens the effectiveness of antibacterials, it is very important that the first-line therapy is available. Otherwise, irrational prescribing behaviour is reinforced, which is linked to increasing bacterial resistance [1].
To ensure effective and rational treatment of bacterial infections, the availability of the best treatment option is essential. Long-term forecasting makes it possible to estimate future consumption trends and to take the necessary precautions.

Methods

Covering the years 1985 to 2022, data on outpatient DDD (defined daily dose) prescriptions of antibacterial drugs in Germany were collected from the respective 'Arzneiverordnungsreport'. The ten most prescribed substances (TOP 10) were chosen by the year 2022.
ARIMA*(p,d,q)* (Auto Regressive Integrated Moving Average) models were developed to predict future trends. Optimal parameters were identified by significant lags in ACF (Autocorrelation Function) and PACF (Partial Autocorrelation Function), while data stationarity was ensured with one degree of differencing. Forecasts were made up to 2040.

Results

1. Past development and forecast for DDD prescriptions of antibacterial drugs



2. Determination of ARIMA(p,*d*,*q*) parameters

The **autoregressive term (*p*)** incorporates past observations for better pattern detection but risks overfitting by misinterpreting fluctuations as trends. It is determined using the PACF plot.

The **differencing order (*d*)** removes trends for stationarity, improving focus on changes but risking the loss of key patterns. It is determined by the degree of differencing.

The **moving average term (*q*)** incorporates past prediction errors for better short-term accuracy but may lead to unrealistic long-term forecasts. It is determined using the ACF plot.

3. Results and fit metrics for ARIMA(0,1,0) predictions

Ranking TOP10 **Antibacterial drug**	**1** **Amoxicillin**	**2** **Cefuroxime axetil**	**3** **Doxycycline**	**4** **Amoxicillin clavulanic acid**	**5** **Clindamycin**	**6** **Azithromycin**	**7** **Phenoxymethyl-penicillin**	**8** **Sulfamethoxazole-Trimethoprim**	**9** **Nitrofurantoin**	**10** **Ciprofloxacin**
Consumption trend	↑	↑	↓	↑	↑	↑	↓	↓	↑	↑
Relative change 2022 to 2040	+ 45.0%	+ 52.4 %	- 11.9 %	+ 49.1 %	+ 16.3 %	+ 60.0 %	- 61.1 %	- 67.6 %	+ 14.3 %	+ 45.5 %
DDD prescriptions in 2022	58.5	35.3	33.5	27.5	13.5	13.5	10.8	10.8	9.1	7.7
DDD prescriptions in 2040	84.8	54.1	29.5	41	15.7	21.6	4.2	3.5	10.4	11.2
Range of LCL and UCL (Lower and Upper Confidence Limit)	239.3%	231.4%	229.2%	97.4%	94.8%	251.8%	533.3%	293.5%	129.7%	364.9%
Stationary R-squared	0	0	0	0	0.89	0	0	0	0	0
R-squared	0.90	0.94	0.80	0.95	0.99	0.49	0.85	0.90	0.56	0.88
MAPE (Mean Absolute Percentage Error)	10.86	16.51	7.04	31.17	10.14	13.70	12.56	7.51	5.44	16.16
MaxAPE (Maximum Absolute Percentage Error)	43.53	45.74	19.91	212.50	39.36	78.57	54.10	32.42	10.83	122.31
Normalized BIC (Bayesian Information Criterion)	4.29	3.21	3.51	0.94	-0.39	1.454	3.75	2.47	-0.69	1.45
Assessment of reliability	potential deviation	potential deviation	trend correct	trend correct	potential deviation	accurate	accurate	accurate	trend correct	trend correct

Table 3: *Predicted relative changes are highlighted in colour. Slight decreases are light green and large decreases are dark green. Slight increases are yellow and large increases are orange.*

Conclusions and outlook

- ARIMA(0,1,0) is the best model for all antibacterial drugs due to its simplicity and realistic forecasts
- More complex ARIMA models have slightly better fit metrics but predict unrealistic changes; in the short term, suitable models agree in their prediction
- Stable trajectories and consistent trends result in reliable forecasts, while uncertainties arise from volatile developments
- Most predictions are consistent with recent trends and events, while deviations can be explained by external factors [2]
- Long-term predictions are more useful for trends rather than precise values, because they assume stable conditions and can't foresee sudden changes
- Further research is needed to assess whether predictions represent desirable changes or problematic prescribing behaviour that need to be counteracted

➢ **Capacities need to be expanded in particular for amoxicillin, cefuroxime axetil, amoxicillin clavulanic acid, azithromycin and ciprofloxacin**

References

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[2] Bindel, L.J., Seifert, R. (2024). Costs are a major driver of antibacterial drug prescriptions in Germany: market analysis from 1985 to 2022. Naunyn-Schmiedeberg's Arch Pharmacol 397, 8785–8801. https://doi.org/10.1007/s00210-024-03171-y

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