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Distance to Radiotherapy and Demand – Projection of the Effects of Establishing New Radiotherapy Facilities in Poland by 2025

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Abstract: In 2015, the Ministry of Health of the Republic of Poland introduced the Polish strategic plan for radiotherapy development and investment. Given that radiotherapy utilisation depends on the distance a patient must travel to undergo the treatment, the main goal of the plan was to increase equitable access to radiotherapy in Poland by establishing new facilities in new locations by 2025. This study constitutes the first step towards an economic evaluation of this plan by adopting spatial interaction models to project the expected increase in the demand for radiotherapy (3%). Moreover, it adds to the current research on the relation between distance and demand for healthcare services in the following ways. First, it flags the importance of using spatial econometrics to healthcare utilisation studies in the presence of spatial autocorrelation. Furthermore, it proposes a quantitative method for assessing the expected impact of establishing new facilities on utilisation. Finally, it formally confirms the dependence between radiotherapy utilisation and distance in Poland, which has been previously shown to exist in other countries.

Keywords: radiotherapy, demand for healthcare, spatial interaction models

JEL Codes: I11

1 Introduction

External beam radiotherapy (EBRT) is one of the key treatment modalities for patients with cancer. It is a method for delivering high-energy X-ray beams to a patient's tumour. The most common machine used for EBRT is called a linear accelerator (linac). It is estimated that approximately 50% of patients with cancer are indicated for EBRT (Barton *et al.* 2014; Delaney and Barton 2015; Borras *et al.* 2016).

Access is a key factor influencing EBRT efficiency. Access to EBRT depends on many aspects, including financial resources, human resources, quality of equipment and so on. It also depends on the distance a patient must travel to undergo EBRT. It has been shown that distance may impact on EBRT utilisation (Mackillop *et al.* 1997; Pungalia *et al.* 2006; Pagano *et al.* 2007; Ministry of Health of the Republic of Poland 2015; Więckowska and Czerwiński 2015), the treatment of choice (Athas *et al.* 2000; Nattinger *et al.* 2001; Celaya *et al.* 2006), survival outcomes (Baade *et al.* 2011) and length of stay (Więckowska and Czerwiński 2015). Another factor curtailing the quality of EBRT is the insufficient supply of services. It has been estimated that worldwide more than 2 million people are unable to access EBRT because of a lack of linacs (Yap *et al.* 2016).

Access barriers in the form of long distances and insufficient supply of EBRT services are clearly visible in Poland (Więckowska and Czerwiński 2015). Given the existence of such dependencies, the Ministry of Health of the Republic of Poland implemented the national strategic plan for EBRT development and investment (Czerwiński and Więckowska 2018). The plan was incorporated into the Oncology Healthcare Needs Maps (HNM), an official strategic document that aims at assessing the state of the Polish healthcare system as well as forecasting the future health needs of the population (Ministry of Health of the Republic of Poland 2015). The plan was based on the results of a mixed-integer linear programming model and indicated the construction of at least 19 new radiotherapy centres in 19 new locations by 2025 (compared to 2016).

Model endpoint was set at 2025, as sufficient time had to be provided to implement the changes. The model was estimated using Central Statistical Office's demographic forecast and under the assumption that EBRT utilisation rates will be constant over time. However, given the aforementioned relation between distance and the demand for EBRT, it can be expected that establish-

ing new facilities and reducing patients' travel times will positively influence EBRT utilisation rates.

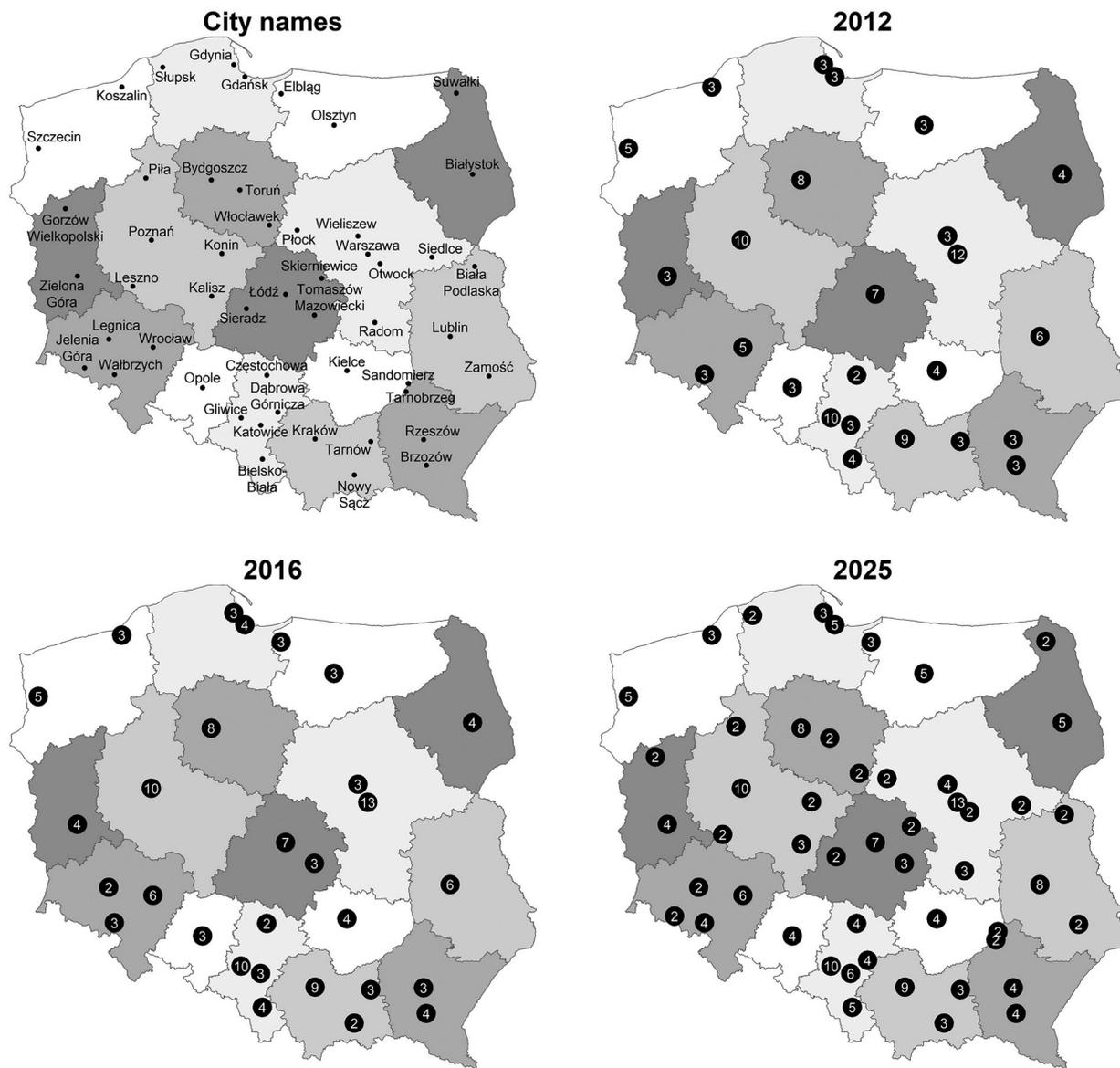
This article proposes a quantitative method, based on spatial interaction models, for assessing the expected impact of establishing new healthcare facilities on the demand for health services. As such assessments allow for a more precise estimation of the mean per patient costs and benefits, they are essential for the purpose of healthcare economic evaluations of interventions aiming at improving population health by establishing new facilities. Moreover, this study provides estimates for the expected increase in the demand for EBRT attributed to the implementation of the national radiotherapy development plan in Poland by 2025. As of February 2018, no economic evaluation of this plan has been conducted, and the results and methodology presented in this study form a foundation for such evaluations in the future. Finally, the article shows the importance of using spatial econometrics to healthcare utilisation studies in the presence of spatial autocorrelation.

2 Materials and methods

2.1 EBRT development plan

Relation between distance and the demand for EBRT has been shown by many researchers in various settings, including Poland. On the other hand, utilisation of alternative treatment modalities of patients with cancer, that is, surgery and chemotherapy, does not seem to be highly dependent on distance (Jones *et al.* 2008). Such difference derives from high costs of establishing new radiotherapy departments. Chemotherapy can be administered in virtually any medical facility, provided the appropriate personnel is available, and for most oncological surgical procedures, a regular operating theatre is sufficient. Meanwhile, the market price for a new linac is around 10M PLN (€2.5M). Moreover, specialised bunkers have to be constructed to house radiotherapy imaging and treatment equipment. That is why the cost of establishing a new radiotherapy facility with two working linacs can be estimated at around 40–50M PLN (€10–12.5M). High setup costs mean that a much smaller number of hospitals provide radiotherapy than chemotherapy or surgery. This phenomenon, combined with long radiotherapy course duration, is the primary cause of the underutili-

Fig. 1: Linear accelerator locations in 2012 and 2016 and planned locations in 2025



sation of radiotherapy services in Poland (Więckowska and Czerwiński 2015). Thus, the radiotherapy development plan was introduced, as mentioned (Czerwiński and Więckowska 2018). Fig. 1 presents the planned linac allocation in 2025, together with linac locations in 2012 and 2016 (starting point of the mixed-integer model).

2.2 Data sources

In Poland, all publicly funded health services are recorded by the National Health Fund (NHF) in a cen-

trally managed database. The main purpose of this database is to document all financial transactions between the public payer and healthcare providers. Every publicly funded medical service is registered in this database together with the patient’s national identification number (PESEL), patient’s demographic characteristics (age, sex, place of residence) as well as reported diagnosis-related groups, procedures and diagnoses. In the scope of oncology, the NHF database for 2012 was linked with the National Cancer Registry (Więckowska *et al.* 2015a). This linked data set was used in this study. In Poland, practically, no EBRT services are being financed

Tab. 1: Malignant neoplasm groups defined for the purpose of cancer-specific utilisation rates

	Cancer group	ICD-10*	Utilisation rate in 2012	Counties with 0 courses in 2012
1.	Central nervous system	C70-C72	0.493	18
2.	Melanoma of skin	C43	0.260	108
3.	Head and neck	C00-C14, C30-C32	0.799	2
4.	Trachea, bronchus and lung	C33, C34	0.520	0
5.	Breast	C50, D05	0.787	0
6.	Lower gastrointestinal tract	C18-C21	0.264	2
7.	Upper gastrointestinal tract	C15, C16, C22-26	0.138	41
8.	Prostate	C61	0.717	3
9.	Female genital organs	C53, C54, C56, C57	0.458	3
10.	Kidney	C64-C66	0.159	83
11.	Bladder	C67	0.157	78
12.	Thyroid	C73	0.870	210
13.	Testicle	C62	0.136	211
14.	Other	C17, C37-C41, C45-C49, C51, C52, C55, C58, C60, C63, C68, C69, C74-C80, C97	0.547	1

* International Statistical Classification of Diseases and Related Health Problems revision 10 (ICD-10) codes

outside of the public system. Private centres without contract with the NHF, who deliver RT pro bono in hopes of receiving such contracts, are the only major exception (e.g. currently a centre located in Otwock operates in this manner). However, in 2012, no such provider operated. Other possible exceptions include financing RT out-of-pocket or through private, voluntary insurance schemes as well as RT courses received abroad. Such events would not be recorded in the NHF data set, and the data on them are not obtainable, which could potentially bias the results of this study. Nevertheless, the fact that every Polish citizen is publicly insured or can obtain insurance in a relatively simple way (e.g. by registering as unemployed) as well as relatively short radiotherapy waiting times (Dziadziuszko 2015) suggest that even if such bias exists, its impact on the results should be minimal. Hence, this oncological data set comprises virtually all EBRT courses delivered in Poland in 2012 and thus can be used to precisely examine EBRT utilisation patterns.

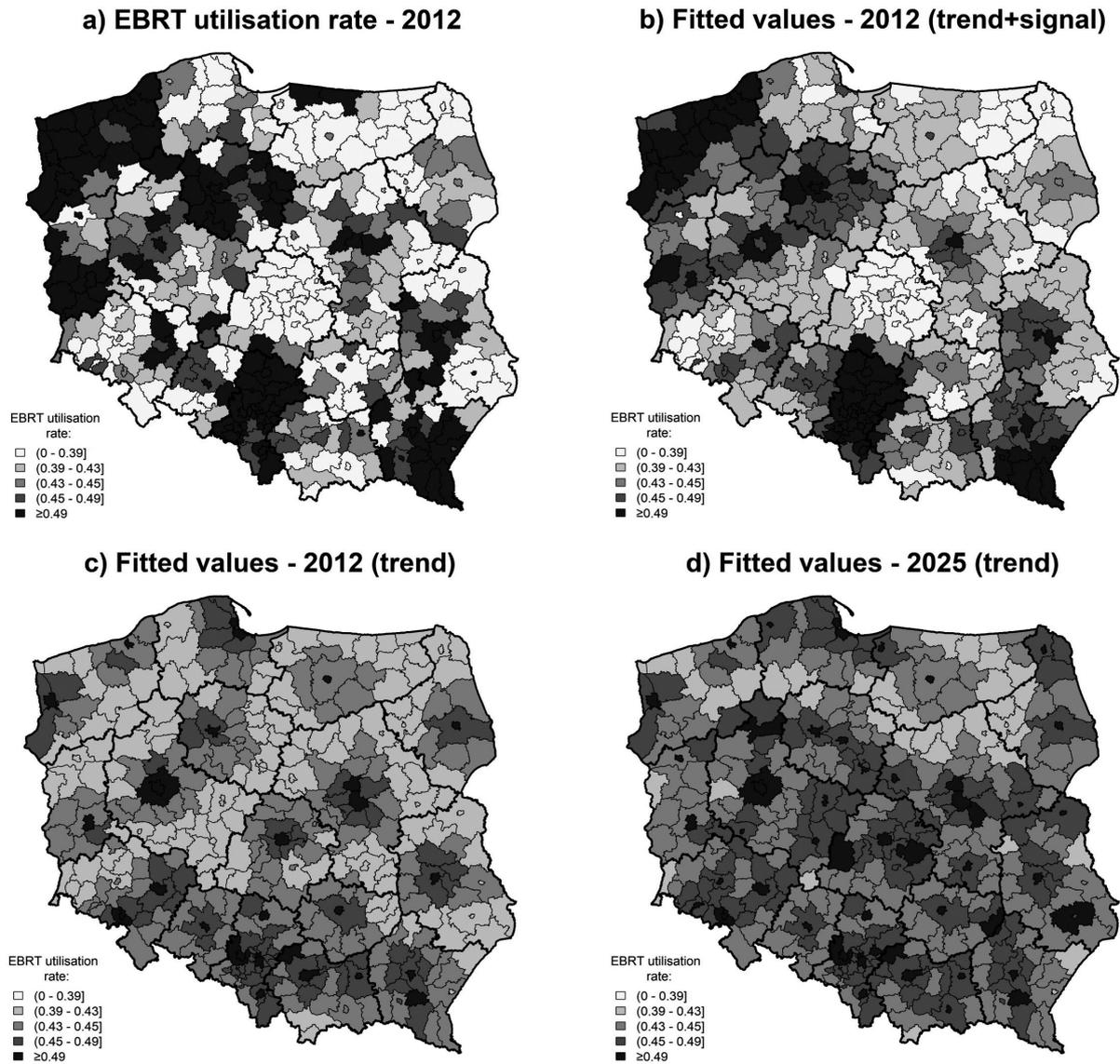
2.3 EBRT utilisation rates

Using the 2012 oncological data set, EBRT utilisation rates were calculated for every Polish county (the overall utilisation rate and 14 cancer-specific rates – Tab. 1). EBRT utilisation rate for cancer group g (UR_g) is defined as the ratio of all EBRT courses for new group g cases (NCr_g) and retreatments (R_t) divided by the number of new group g cancer cases (NC_g) (Equation 1):

$$UR_g = \frac{NCr_g + R_g}{NC_g} \quad (1)$$

Definition of the overall rate is analogical. Fig. 2a presents the overall EBRT utilisation rate. A considerable number of counties with no cancer cases will cause a limited dependent variable problem. In order to avoid this problem, the following groups were incorporated into the Other group, Melanoma of skin, Upper gastrointestinal tract, Testicle, Bladder, Kidney and Thyroid, and were treated collectively in subsequent analyses.

Fig. 2: Observed overall EBRT utilisation rate (a), and fitted values of the best overall EBRT utilisation spatial model (*standard(1)*, power*) in 2012 with trend and signal (b), in 2012 with trend (c) and in 2025 with trend (d)



2.4 Distance measures

Ten different distance measures were defined to verify which best describes the relation between county locations and the localisations of EBRT departments. First, the orthodromic (Euclidean) distances between the counties' capital cities and cities with radiotherapy facilities were calculated. First five distance measures were defined as the mean distance to a given number (1–5) of closest radiotherapy centres. Those measures are further referred to as *standard(1)*–*standard(5)*, respectively. The use of Euclidean distance is motivated by

two reasons. First, it is consistent with the methodology applied to develop the Polish national plan for radiotherapy development and investments (Czerwiński and Więckowska 2018). Second, even though other measures (such as road distance or travel time) might be considered to better reflect a patient's discomfort, their reliance on other factors, such as road network or commuting network, makes them variant over time and thus problematic when forecasting. Meanwhile, Euclidean distance is constant over time, which means that the same distances can be used for 2012 and 2025. For Poland, the following approximations were suggested: 1 km of

Euclidean distance = 1.2 km of road distance = 1.27 min of travel time (Kopczewska 2013). Second five distance measures were gravitational. A number of working linear accelerators in 2012 was used as a proxy of the size of a location. Gravitational measures were examined, as larger centres may have influence over larger areas, because of, for example, reputation, experience, connections within the medical community or the capability to provide more advanced treatment. First, gravitational indices for the pairs of counties and EBRT facility locations were defined as a quotient of the orthodromic distance and the number of linacs in a location (as the analysis is discrete, no distinction was made between different providers located in the same county). Proposed definition is an inversion of the standard definition of gravitational indices (quotient of mass and distance). However, such construction should facilitate the interpretation of results. EBRT utilisation is negatively correlated with distance, thus the proposed definition allows to expect that gravitational measures are negatively correlated with utilisation as well. Subsequently, five gravitational measures were defined as the mean of a given number of gravitational indices (1–5) for the respective number of closest radiotherapy centre locations (in terms of gravitational indices). These measures are further referred to as *gravitational(1)–gravitational(5)*. Formally, proposed distance measures can be denoted as follows. Let

I be the set of counties,
 J be the set of radiotherapy facility locations,
 d_{ij} be the orthodromic distance between county $i \in I$ and location $j \in J$,
 x_j be the number of linear accelerators in location $j \in J$

If the sets of distances and gravitational indices are denoted as

$D = \{d_{ij}; i \in I \wedge j \in J\}$ the set of orthodromic distances,
 $X = \{\frac{d_{ij}}{x_j}; i \in I \wedge j \in J\}$ the set of gravitational indices,

then the measures *standard(1)–standard(5)* and *gravitational(1)–gravitational(5)* for the county $\hat{i} \in I$ can be expressed as shown by Equations (2) and (3).

$$\text{standard}(n) = \frac{1}{n} \min_G \sum_{k \in G} k,$$

where $G \in \{D' \in D; i = \hat{i} \wedge \#D' = n\}$, for $n = 1, \dots, 5$ (2)

$$\text{gravitational}(n) = \frac{1}{n} \min_G \sum_{k \in G} k,$$

where $G \in \{X' \in X; i = \hat{i} \wedge \#X' = n\}$, for $n = 1, \dots, 5$. (3)

2.5 Spatial interaction models

One-way spatial interaction models (Fotheringham and O’Kelly 1989) and linear regression models were used to assess the relation between distance and EBRT utilisation, as well as to forecast the demand for EBRT in 2025. For every utilisation rate (overall and cancer-specific), 280 models with different functional forms and different independent variables were estimated. Afterwards, the Akaike information criterion (AIC; Akaike 1998) was used to select the model with the best fit. For every distance measure (10 in total), 14 linear models and 14 spatial error models were estimated. Spatial error models evaluate spatial autocorrelation in the residuals. In terms of EBRT utilisation, this autocorrelation can be caused by a plethora of factors, including communication (roads, railways, urban transport), behaviour patterns of healthcare providers in the area (in particular cancer detection patterns), demographic and socio-economic structure of the region and so on. The main purpose of the estimated models was to forecast EBRT utilisation. It is hardly possible to project all factors associated with the above-mentioned possible reasons for spatial autocorrelation as their impact may change rapidly over time, especially given the relatively long time horizon of the analysis. Therefore, it was assumed that the functional forms should include only those geographical and administrative variables, which are known for 2025. As the main purpose of modelling was to estimate the influence of distance on the demand for EBRT services, the spatial interaction models were considered in a one-way version. Counties were connected neighbours. Functional forms of the models comprised two components, a function of a distance measure and a binary variable indicating, whether a radiotherapy facility was present in the county. The binary indicator was included, because it was observed that Polish counties with a working radiotherapy facility had lower EBRT utilisation rates than their neighbours (Więckowska and Czerwiński 2015).

Seven distance measure functions were considered: exponential, power and polynomial (degrees of 1–5). Formally, each of the 280 functional forms can be represented by the following equation:

$$\mathbb{Q}(UR) = \beta_0 + f(d) + \beta_{ind} \cdot ind + e, \quad (4)$$

where $\mathbb{Q}(UR)$ is a function of the utilisation rate; $f(d)$ is a function of the distance measure; *ind* is a dichotomous variable equal to 1, if a radiotherapy facility was located

in the county (0 otherwise); and e is the error term. Models are clearly defined by four features:

1. Distance measure (d) – 10 previously defined distance measures: *standard(1)–standard(5)*, *gravitational(1)–gravitational(5)*.
2. Distance measure function $f(d)$, and utilisation rate function $\mathbb{Q}(UR)$ – seven forms:
 - a. polynomial(n), for $n = 1, \dots, 5$

$$f(d) = \sum_{i=1}^n \gamma_i \cdot d^i \quad \mathbb{Q}(UR) = UR \quad (5)$$

- b. power

$$f(d) = \gamma_1 \cdot \ln(d + 1) \quad \mathbb{Q}(UR) = \ln(UR + 1) \quad (6)$$

- c. exponential

$$f(d) = \gamma_1 \cdot d \quad \mathbb{Q}(UR) = \ln(UR + 1) \quad (7)$$

3. Inclusion or exclusion ($\beta_{ind} = 0$) of the *ind* variable. For the purpose of notation, models with the *ind* variable will be further referred to with an asterisk (e.g. exponential*).
4. Error term distribution:
 - a. Normal distribution (linear regression)

$$e \sim N(0, \sigma^2) \quad (8)$$

- b. Spatial distribution (spatial error model)

$$e = \lambda W + u$$

where $u \sim N(0, \sigma^2)$, and W is a row-standardised spatial weight matrix.

2.6 Prognosis

Models with the best fit according to AIC were used to calculate the expected utilisation rates in 2025. It was assumed that linac distribution will be consistent with the radiotherapy development plan (Fig. 1). National utilisation rates were calculated using the estimated utilisation rates for counties and the cumulative cancer incidence forecast for 2025 (Więckowska *et al.* 2015b).

In case of spatial error models, in contrast to linear regression, forecasting for the new set of explanatory variables (2025) will differ from calculating predicted

values for the present (2012) (Haining 1990; Bivand 2002). For the linear regression model,

$$y = X\beta + e, \quad e \sim N(0, \sigma^2). \quad (9)$$

Predicted values \hat{y} are calculated as follows:

$$\hat{y} = X\hat{\beta} \quad (10)$$

where $\hat{\beta}$ is the vector of coefficients. Equation (10) will be correct for the estimation data set and for every new set of observations. In case of spatial error models,

$$y = X\beta + u, \text{ where } u = \lambda W u + e \text{ and } e \sim N(0, \sigma^2). \quad (11)$$

Equation (11) can be rewritten as

$$(1 - \lambda W)y = (1 - \lambda W)X\beta + e. \quad (12)$$

And y can be presented as a sum of three components: trend, signal and noise (Bivand 2002).

$$y = \underbrace{X\beta}_{trend} + \underbrace{\lambda W(y - X\beta)}_{signal} + \underbrace{e}_{noise} \quad (13)$$

Therefore, predicted values for the estimation data set can comprise either the trend alone or the trend and signal components. However, in case of the new data set (forecasting), y is not known, and thus, the predicted values can only comprise the trend. Despite not differing much from the linear regression, forecasting with spatial error models (in the presence of spatial autocorrelation) ensures that the estimators are not only unbiased but also efficient (Anselin 2001).

In order to establish the impact of the implementation of the radiotherapy development plan on the demand for EBRT, a base-case scenario was developed. This scenario assumed that in 2025, utilisation rates (overall or cancer-specific) in every county will be equal to the utilisation rates observed in this county in 2012. Subsequently, base-case national utilisation rates were calculated using the cumulative cancer incidence forecast for 2025.

3 Results

3.1 Utilisation models

Tab. 2 presents the overall utilisation models with the best fit (linear and spatial). According to the AIC, spatial models were characterised by a much better fit. For the best model (*standard(1)*, *power**), the AIC value for the spatial version was equal to $-1,247.33$, whilst the AIC value for the linear version was $-1,062.53$ (lowest value amongst linear models). For every pair of linear and spatial models with the same functional form and the same distance measure, the spatial version was characterised by a lower AIC value. Spatial coefficient λ was significant at 1% and positive for every specification, which confirms the validity of the use of spatial models. Relatively high differences between the coefficient estimates of the best linear model and the best spatial model, as well as the discrepancy between the projected national EBRT utilisation rates in 2025 (Tab. 2), highlight the importance of using spatial models to health-care services utilisation studies in the presence of spatial autocorrelation. For every model, the relation between EBRT utilisation rates and a given distance measure was negative, which confirms that as the distance to the EBRT facility increases, the EBRT utilisation diminishes. Fig. 2b and 2c compares the fitted values from the best spatial model (*standard(1)*, *power**) depending on whether the signal component is included.

Similar to the overall utilisation modelling, cancer-specific spatial models were characterised by lower AIC values than their linear counterparts (Tab. 3).

For all cancer-specific cases, excluding the central nervous system (where AIC of the spatial specification was still lower than the AIC of the linear specification), the parameter was positive and significant at $p < 0.001$. According to the adopted modelling approach, the pace at which the EBRT utilisation rate decreases with distance differs between cancer groups (Fig. 3).

Utilisation rates for two cancer groups (prostate and central nervous system) are exponentially related to the distance. In other words, counties located closer to the radiotherapy centres suffer higher decrements in utilisation per kilometre than the more remote counties. This has a simple quantitative interpretation in case of prostate cancer, as distance to the nearest radiotherapy centre, *standard(1)*, is used in the best prostate cancer model. For prostate cancer, a 10-km distance

Tab. 2: Comparison of the results of the SEM and OLS overall EBRT utilisation models with the best fit according to the AIC criterion

Distance measure Functional form Model version		<i>standard(1)</i> <i>power*</i>	
		SEM	OLS
β_0	Coefficient	0.452	0.501
	CI(95%)	(0.405, 0.498)	(0.461, 0.540)
	<i>p</i> -value (Wald)	<0.001	<0.001
γ	Coefficient	-0.024	-0.038
	CI(95%)	(-0.035, -0.012)	(-0.048, -0.027)
	<i>p</i> -value (Wald)	<0.001	<0.001
<i>ind</i>	Coefficient	-0.046	-0.086
	CI(95%)	(-0.085, -0.008)	(-0.132, -0.040)
	<i>p</i> -value (Wald)	0.018	<0.001
λ	Coefficient	0.710	-
	CI(95%)	(0.625, 0.795)	-
	<i>p</i> -value (Wald)	<0.001	-
AIC		-1,247.33	-1,062.53
SRMSE		0.120	0.163
Projected utilisation rate (2025)		0.466	0.473

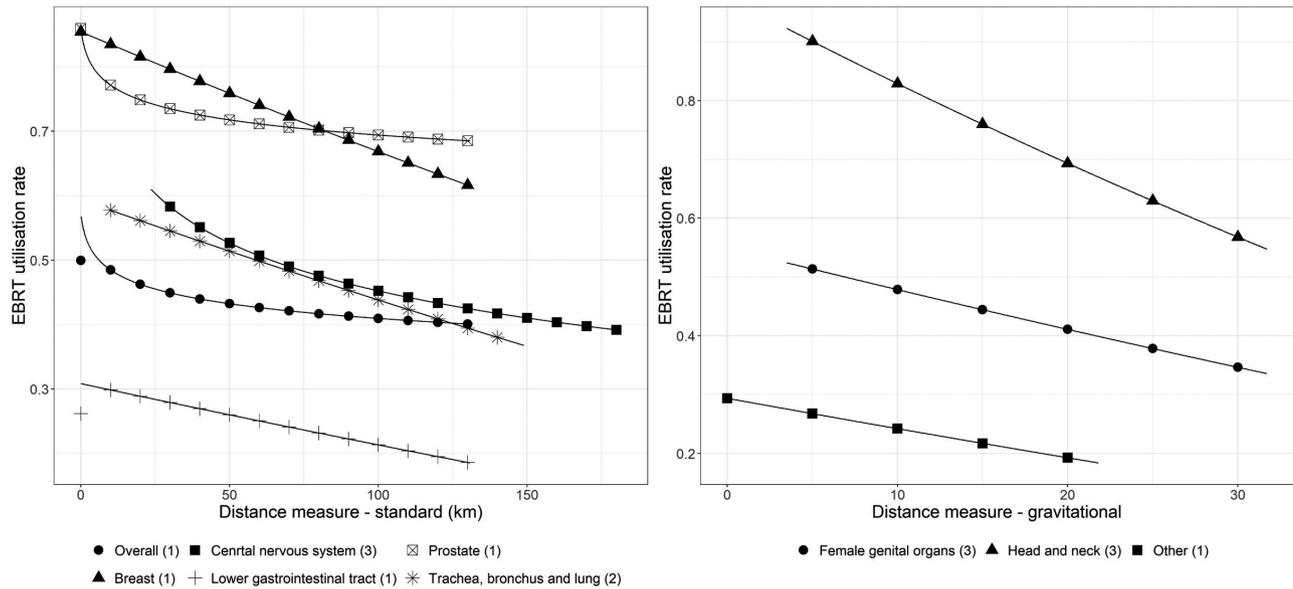
SRMSE, standardised root mean square error.

increase near radiotherapy centres is associated with a 0.09 decrease in the utilisation rate, whilst at around 100 km, the drop is more than 20 times smaller (0.004). To put it differently, at the distance equal to zero (cities where radiotherapy centres are located), on an average, 860 radiotherapy courses are administered per 1,000 new patients with prostate cancer, whilst this number declines to 771 at 10 km, to 694 at 100 km and to 690 at 110 km. Utilisation rates for the remainder of cancer groups decline at a pace close to linear (with respect to the appropriate distance measure). Again, simple quantitative interpretation can be done for the models with *standard(1)* distance measure. For example, breast cancer EBRT utilisation rate decreases at the rate of approximately 0.019 per 10 km in the first 50 km and at approximately 0.018/10 km between 50 and 100 km from the nearest radiotherapy centre, which corresponds to 19 and 18 less courses per 1,000 new patients with breast cancer. The overall utilisation is given by the exponential function, similar to prostate and central nervous system cancers; however, because of a signif-

Tab. 3: Results of the cancer-specific models with the best fit according to the AIC

EBRT utilisation rate	Central nervous system	Lower gastrointestinal tract	Female genital organs	Head and neck	Breast	Trachea, bronchus and lung	Prostate	Other
Distance measure	<i>standard(3)</i>	<i>standard(1)</i>	<i>gravitational(3)</i>	<i>gravitational(3)</i>	<i>standard(1)</i>	<i>standard(2)</i>	<i>standard(1)</i>	<i>gravitational(1)</i>
Functional form	power	exponential*	exponential	exponential	exponential	exponential*	power	exponential
β_0	Coefficient	0.269	0.438	0.681	0.618	0.466	0.620	0.258
	CI(95%)	(0.244, 0.285)	(0.388, 0.487)	(0.617, 0.745)	(0.583, 0.652)	(0.415, 0.517)	(0.543, 0.697)	(0.232, 0.284)
	p-value (Wald)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
γ_1	Coefficient	-0.0008	-0.005	-0.008	-0.0011	-0.0011	-0.020	-0.004
	CI(95%)	(-0.0011, -0.0003)	(-0.008, -0.001)	(-0.012, -0.003)	(-0.0017, -0.0004)	(-0.0017, -0.0003)	(-0.040, -0.0003)	(-0.006, -0.002)
	p-value (Wald)	<0.001	0.005	<0.001	<0.001	0.003	0.046	<0.001
ind	Coefficient	-0.037	-	-	-	0.056	-	-
	CI (95%)	(-0.072, -0.001)	-	-	-	(0.017, 0.095)	-	-
	p-value (Wald)	0.044	-	-	-	0.005	-	-
λ	Coefficient	-0.132	0.321	0.270	0.373	0.560	0.486	0.682
	CI (95%)	(-0.288, 0.022)	(0.189, 0.452)	(0.134, 0.405)	(0.245, 0.500)	(0.452, 0.666)	(0.370, 0.601)	(0.593, 0.772)
	p-value (Wald)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
AIC		-186.87	-536.84	-297.09	-487.41	-670.97	-193.55	-980.25
AIC(linear)		-186.26	-517.20	-248.70	-456.69	-579.02	-141.71	-822.23
SRMSE		0.474	0.315	0.281	0.218	0.238	0.327	0.281

Fig. 3: Fitted EBRT utilisation rates of the best overall and cancer-specific models in relation to their respective distance measures



Lines are restricted to the maximum and minimum values of the appropriate distance measure observed in 2012. Numbers in brackets, together with the x-axis, indicate the distance measure of the respective model with the best fit.

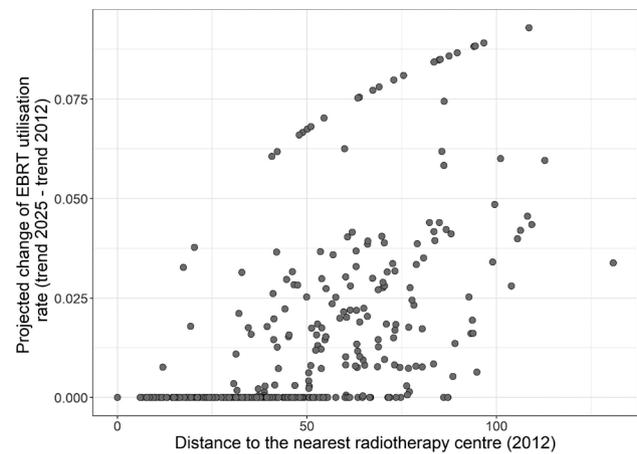
icant decline in utilisation in cities with radiotherapy centres (relative to the utilisation curve – Fig. 3), the per kilometre decrease is less steep. At the distance of zero, 500 courses are given per 1,000 new cancer cases; this number falls to 432 at the distance of 50 km and to 409 at the distance of 100 km.

3.2 Prognosis

Prognosis results are presented in Tab. 4. Fig. 2 allows to compare fitted values for 2025 (d), fitted values for 2012 (b, c) and observed utilisation in 2012 (a).

Prognosis results for the overall utilisation rates show that the Polish national plan for radiotherapy development and investment should fulfil its main goal, that is, assuring better equity in access to this treatment modality for the entire population. As shown in Fig. 4, the highest utilisation increase is projected in the most remote counties, where currently the uptake is smallest because of geographical and transportation barriers. The expected increase in utilisation for counties that were located closer than 50 km from the nearest radiotherapy centre in 2012 is equal to 4 courses per 1,000 new cancer cases (simple county average, not accounting for population), whilst this value is equal to 23 for counties

Fig. 4: Projected change of expected EBRT utilisation rates for counties between 2012 (trend) and 2025 according to the best overall spatial model



with the distance between 50 and 100 km and 49 for counties with the distance more than 100 km.

Using the estimated 2025 utilisation rates and the cumulative cancer incidence forecast, the projected number of EBRT courses was calculated for every county. In total, the expected number of EBRT courses in 2025 in the overall utilisation model was 95,312, and the can-

Tab. 4: Prognosis results for 2025

Model	Base-case utilisation	Prognosis utilisation	Utilisation change (%)
Overall	0.453	0.466	+3.05
Cancer-specific	0.464	0.479	+3.15
<i>Central nervous system</i>	0.510	0.542	+6.30
<i>Lower gastrointestinal tract</i>	0.268	0.273	+1.95
<i>Female genital organs</i>	0.461	0.479	+3.88
<i>Head and neck</i>	0.813	0.828	+1.88
<i>Breast</i>	0.801	0.819	+1.33
<i>Trachea, bronchus and lung</i>	0.523	0.561	+7.30
<i>Prostate</i>	0.770	0.774	+0.46
<i>Other</i>	0.261	0.270	+3.74

cancer-specific models amounted to 97,932 courses, compared to 64,803 courses delivered in 2012, 92,483 courses in the overall base-case scenario and 94,940 courses in the cancer-specific base-case scenario. Hence, the overall (cancer-specific) utilisation modelling indicates that the full implementation of the EBRT development plan by 2025 will increase the EBRT utilisation by 3.05% (3.15%).

4 Discussion

Taking into account the relationship between distance and the demand for EBRT, which has been shown by many researchers in various national and local settings (including Poland), a linear programme was developed to optimise the allocation of linacs in Poland (Czerwiński and Więckowska 2018). One of the solutions of this programme was incorporated into Healthcare Needs Maps for Poland and currently serves as the national plan for radiotherapy development and investment (Ministry of Health of the Republic of Poland 2015). The primary goal of this investment plan is to ensure equitable access to EBRT services in Poland through two main channels: reducing the mean distance a patient must travel to undergo EBRT and assuring the equality between the demand for and the supply of EBRT.

In this article, the possible extent to which this goal can be achieved was assessed with the use of spatial interaction models (spatial error models). It was shown that EBRT utilisation (overall and cancer-specific) exhibits spatial autocorrelation and that spatial EBRT utilisation models have better properties than linear. Statistical analysis evaluating the change in the demand for

EBRT showed that the construction of new centres and the installation of new linacs should increase the use of EBRT by 3% by 2025 (3.05% for general models, 3.15% for models in cancer groups).

However, it has to be emphasised that the analysis presented in this article takes into account only one of the two channels through which equitable access to EBRT is to be achieved. Estimation considers only the reduction of distance. In particular, it does not account for the expected change in the patterns of qualifying patients with cancer for EBRT, which are currently not optimal because of the limited supply of EBRT services in Poland. Therefore, it can be expected that patients with cancer, who should be treated with EBRT according to the best-practice guidelines and who are not currently being qualified for EBRT because of the insufficient supply, should also contribute to the increment of utilisation rates. Thus, as the prognosis assumes that qualification patterns will not change, it seems that the value of 3% should be treated as the lower bound of the possible increase in utilisation in 2025 compared to 2012.

The cost of establishing a new radiotherapy facility can be estimated at €10–12.5M and the cost of a new linac at around €2.5M. In addition to this, other costs should be considered such as staff training, wages, purchase of other necessary equipment and costs of organising a specialised hospital ward. Standard methods of economic evaluation of healthcare interventions require the estimation of the mean per patient costs and benefits (expressed in, e.g. QALYs gained). As a large proportion of the costs of the EBRT development plan should be considered fixed (construction of new facilities, purchase of linear accelerators), both these values (mean per patient costs and benefits) will be highly dependent on the utilisation rates. Thus, the results of this study con-

stitute the first step towards a detailed economic evaluation of the radiotherapy development plan, which as of February 2018 has not been conducted.

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