Using statistical methods and reproducible tools to gain new insights from biomedical and public health data

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- In this talk I will focus on two examples that showcase how we can get more insight from data

The Case of Public Health Data

COVID-19

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- COVID-19 vaccination has been an important component of public health strategies aimed at managing the pandemic.
- However, COVID-19 vaccination has not been equal across different population segments.
- Individuals with lower income, and those belonging to a racial/ethnic minority have had lower vaccination uptake[1,2].

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COVID-19: The Case of Ontario

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  - The survey ran between late 2021 and early 2022 and collected socio-demographic information along with self-reported vaccination status ("Have you received the first dose of the Covid vaccine?")

COVID-19: The Case of Ontario

Table 1: Selected socio-economic factors from the survey

Variable	Levels
Age group	16-34,35-54,55 and over
Income bracket (CAD)	under 25,000, 25,000-59,999, 60,000 and above
Race/ethnicity	Arab/Middle Eastern, Black, East Asian/Pacific Islander, Indigenous, Latin American, Mixed, South Asian, White Caucasian, Other

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- We could do the same, but what other information could we get from this data?
- From a Public Health Perspective, there have been some relatively recent developments in Ontario.

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- However, Ontario adopted in late 2019 the Health Regions for healthcare and phased out the Local Health Integration Network (LHIN) approach.
- The change is relatively new, and therefore, geographical data can be used to analyze data within the different Health Regions.

COVID-19: The Case of Ontario

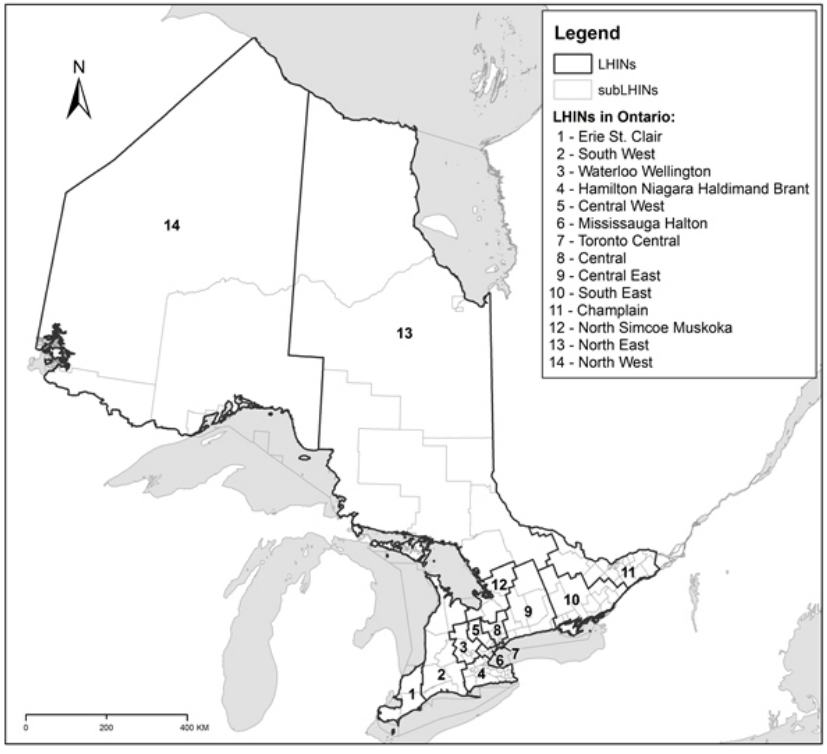

Figure 1: Ontario LHINs (Crighton et al. 2015)

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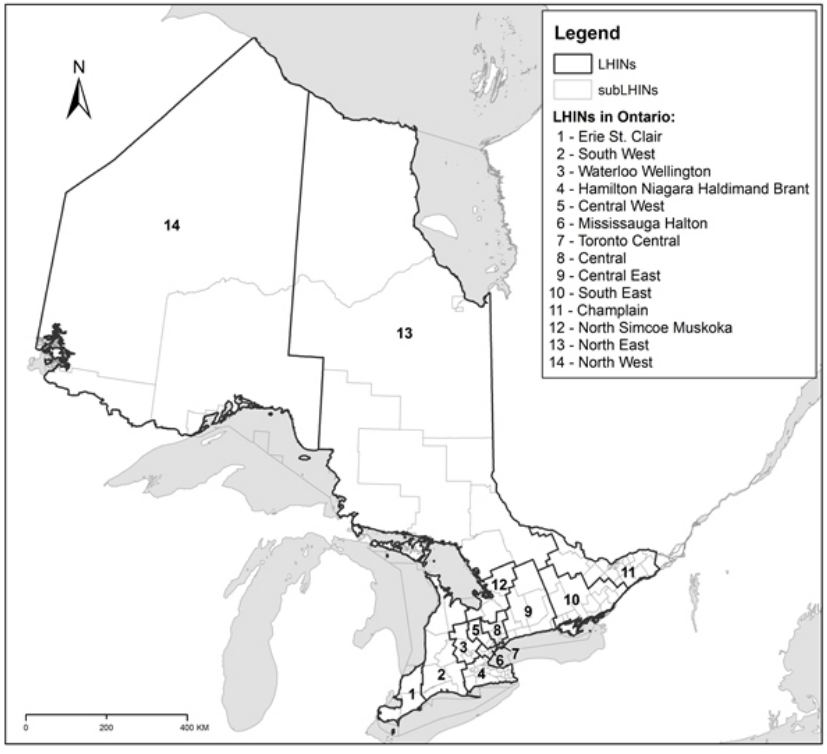

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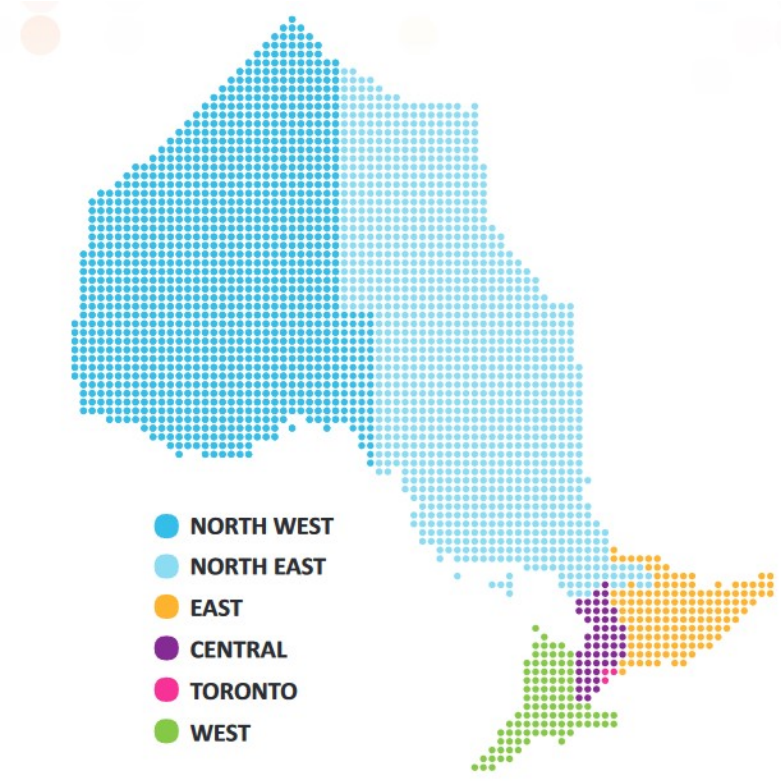

Figure 2: Ontario Health Regions (Ontario Business Health Plan 2022-2023)

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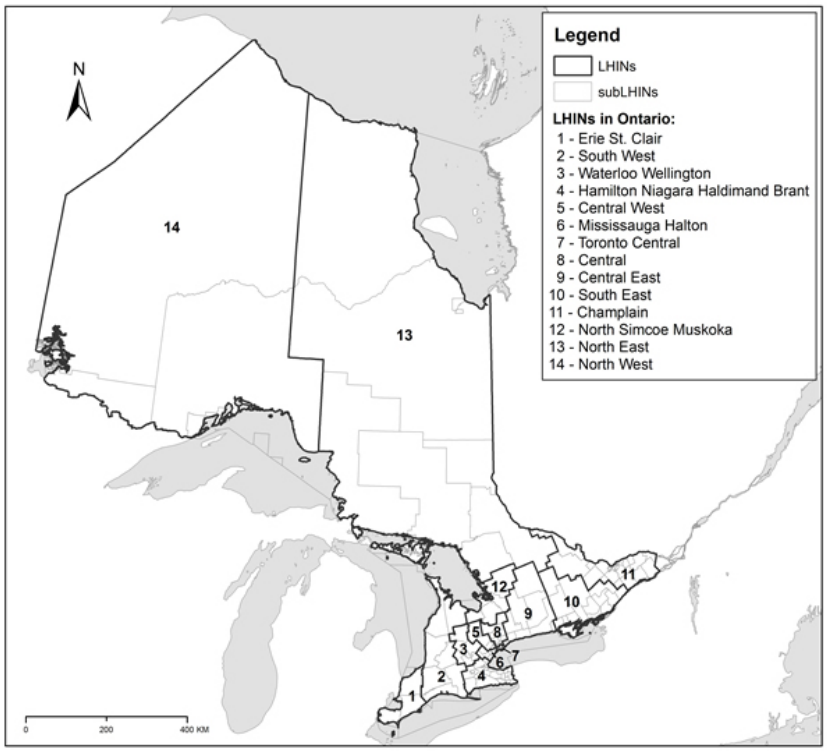

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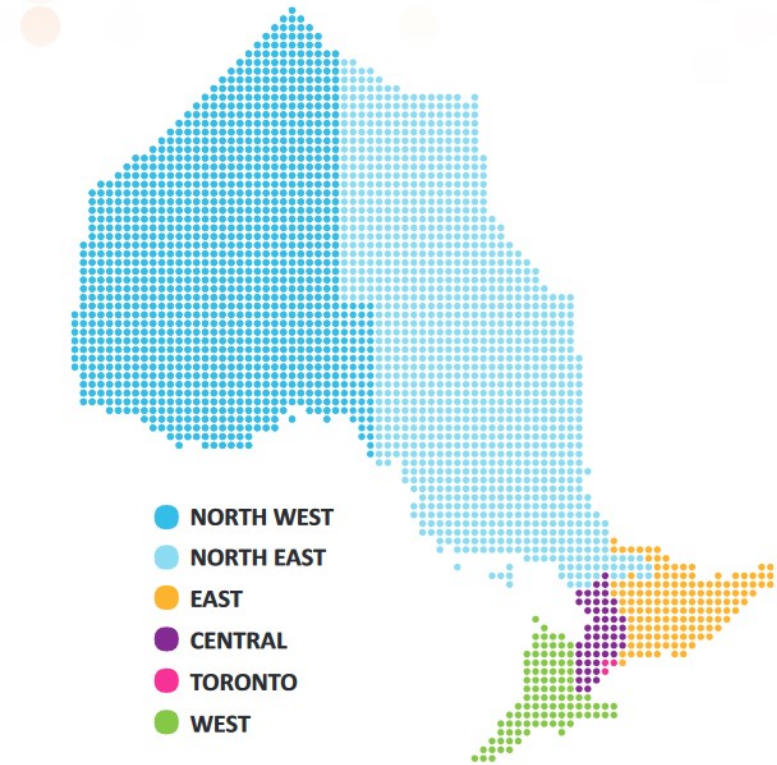

Figure 2: Ontario Health Regions (Ontario Business Health Plan 2022-2023)

- Data cleaning is **important**

COVID-19: The Case of Ontario

- Therefore, we decided to integrate the different Health Regions in our analysis to determine the odds of vaccination.

$$\log\left(\frac{p(\text{vac})}{1-p(\text{vac})}\right) = \beta_0 + \beta_1(\text{Age group}) + \beta_2\ \text{Race} + \beta_3\ \text{Health Region} + \beta_4\ \text{Income} + \beta_5(\text{Health Region} \times \text{Race}) + \beta_6\ (\text{Income} \times \text{Race}) \quad (1)$$

Results

Table 2: **Selected** Multivariable Regression Results

Characteristic	OR	95% CI	p-value
Income (CAD)			
60000 and above	—	—	
25000-59999	0.59	0.39, 0.89	0.011
under 25000	0.37	0.25, 0.56	<0.001
Race			
White/Caucasian	—	—	
Arab/Middle Eastern	0.31	0.14, 0.69	0.004
Black	0.32	0.17, 0.60	<0.001
East Asian/Pacific Islander	1.15	0.50, 2.66	0.7
Indigenous	0.44	0.19, 1.02	0.056
Latin Aamerican	0.28	0.11, 0.67	0.004
Mixed	0.64	0.25, 1.65	0.4
Other	0.22	0.12, 0.41	<0.001
South Asian	0.91	0.49, 1.69	0.8
Health Region			
Toronto	—	—	
Central	1.47	0.92, 2.35	0.11
East	1.42	0.90, 2.23	0.13
West	1.55	1.05, 2.30	0.029
Income and Race			
25000-59999 * Arab/Middle Eastern	1.79	0.67, 4.83	0.2
under 25000 * Arab/Middle Eastern	3.05	1.26, 7.39	0.013
25000-59999 * Black	1.34	0.59, 3.05	0.5
under 25000 * Black	3.19	1.45, 6.99	0.004
25000-59999 * East Asian/Pacific Islander	0.42	0.17, 1.05	0.062
under 25000 * East Asian/Pacific Islander	1.16	0.47, 2.86	0.8
25000-59999 * Indigenous	1.36	0.48, 3.89	0.6
under 25000 * Indigenous	1.45	0.55, 3.80	0.5
25000-59999 * Latin American	1.24	0.45, 3.43	0.7

Results

Characteristic	OR	95% CI	p-value
under 25000 * Latin American	2.80	1.04, 7.51	0.041
25000-59999 * Mixed	0.85	0.32, 2.26	0.7
under 25000 * Mixed	1.10	0.37, 3.27	0.9
25000-59999 * Other	6.93	2.65, 18.1	<0.001
under 25000 * Other	4.59	2.33, 9.05	<0.001
25000-59999 * South Asian	1.20	0.51, 2.85	0.7
under 25000 * South Asian	2.00	0.93, 4.30	0.077
Race and Health Region			
Arab/Middle Eastern * Central	0.66	0.26, 1.70	0.4
Black * Central	0.44	0.19, 0.98	0.046
East Asian/Pacific Islander * Central	0.98	0.38, 2.53	>0.9
Mixed * East	0.91	0.28, 3.03	0.9
other * East	1.05	0.39, 2.83	>0.9
South Asian * East	0.52	0.19, 1.45	0.2
Arab/Middle Eastern * West	1.00	0.37, 2.73	>0.9
Black * West	0.76	0.32, 1.80	0.5
East Asian/Pacific Islander * West	0.52	0.20, 1.34	0.2
Indigenous * West	0.39	0.14, 1.09	0.073
Latin American * West	0.94	0.32, 2.72	>0.9
Mixed * West	0.37	0.12, 1.16	0.089
Other * West	0.41	0.18, 0.93	0.032
South Asian * West	0.41	0.18, 0.95	0.037

[1] OR = Odds Ratio, CI = Confidence Interval

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- People in certain racial minority groups had lower odds of vaccination than White/Caucasian individuals.
- However, individuals that identified with a racial/ethnic minority and that were in a low household income bracket (<60k CAD) had higher odds of vaccination than individuals with a high household income.

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- People in certain racial minority groups had lower odds of vaccination than White/Caucasian individuals.
- However, individuals that identified with a racial/ethnic minority and that were in a low household income bracket (<60k CAD) had higher odds of vaccination than individuals with a high household income.
- This is likely caused by the type of occupation: people in racial minorities, and those with a low household income work in essential occupations[3], and thus potentially got the vaccine to be able to work.

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- But there are also intra-provincial differences in vaccine uptake within the Health Regions:
  - For example, South Asian individuals in the West Health Region had lower odds of vaccination that in other Health Regions.
  - These results provide a more comprehensive assessment of COVID-19 vaccination rates within Ontario, as they showed that certain minority groups within specific income brackets and certain Health Regions had differences in vaccination.

The Case of Biomedical Data

Longitudinal Data

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- Biomedical studies often collect longitudinal data to see the effect of an intervention over time:
  - How a chemotherapy treatment changes the metabolism of a tumor
  - How the concentration of a drug changes over time in the blood
- How is this data typically analyzed?

Linear Models

$$y_{ijt} = \beta_0 + \beta_1 \times treatment_j + \beta_2 \times time_t + \beta_3 \times time_t \times treatment_j + \varepsilon_{ijt} \quad (2)$$

where,

y_{ijt}: is the response for subject i in treatment group j at time t

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A LMEM follows the same exact structure, only incorporates a random effect α_{ij}, which allows for different intercepts.

Trends Over Time

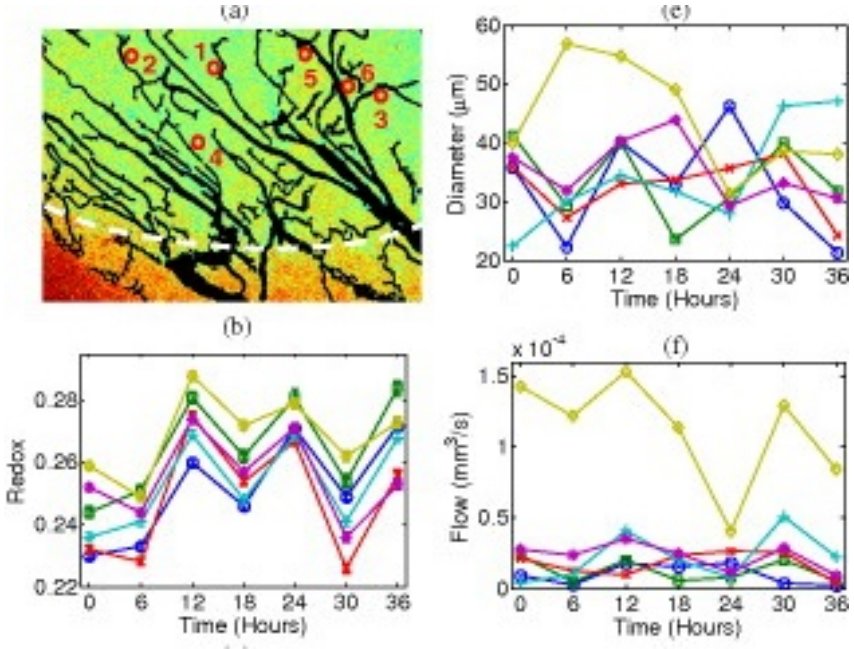

Figure 3: Tumor imaging data (Skala et al. 2010)

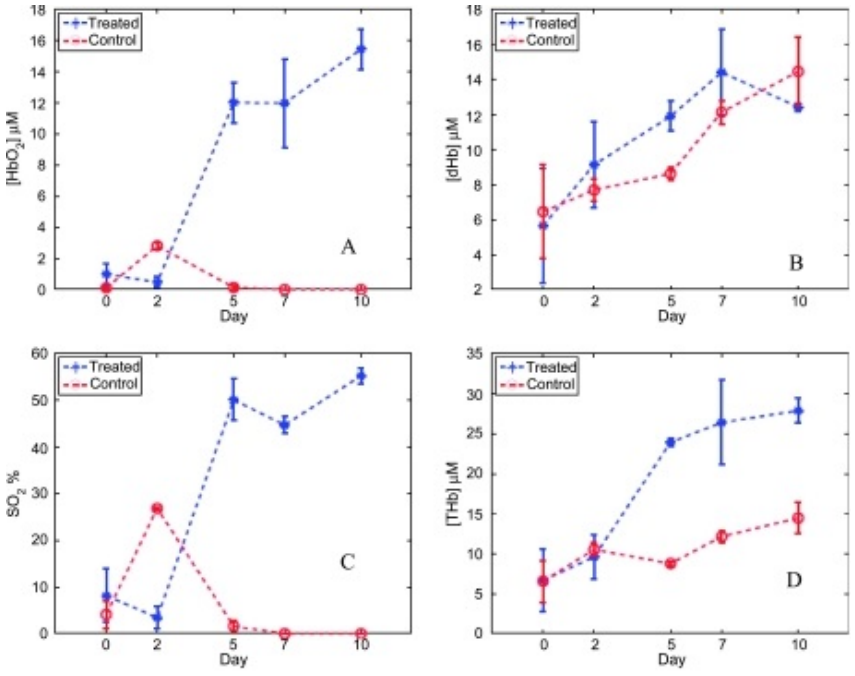

Figure 4: Tumor oxygenation data (Vishwanath et al. 2009)

Trends Over Time

- The issue in those data is that the trends are not linear, and therefore, a linear model will miss changes in the signal where some metabolic or physiological relevant change is taking place.

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Trends Over Time

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- Polynomial effects can be used, but they create biases at the boundaries of the covariates[4].

[4] Beck and Jackman 1998.

Generalized Additive Models (GAMs)

$$y_{ijt} = \beta_0 + \beta_1 \times treatment_j + f(time_t \mid \beta_j) + \varepsilon_{ijt} \qquad (3)$$

- The change of y_{ijt} over time is represented by the *smooth function* $f(time_t \mid \beta_j)$ with inputs as the covariates $time_t$ and parameters β_j.

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- We can use a *basis function* to estimate the smooth function.
- Splines are helpful as basis functions: Thin plate regression splines (TPRS) are computationally efficient, and the underlying principle is that of polynomial pieces "joined" together

How GAMs work

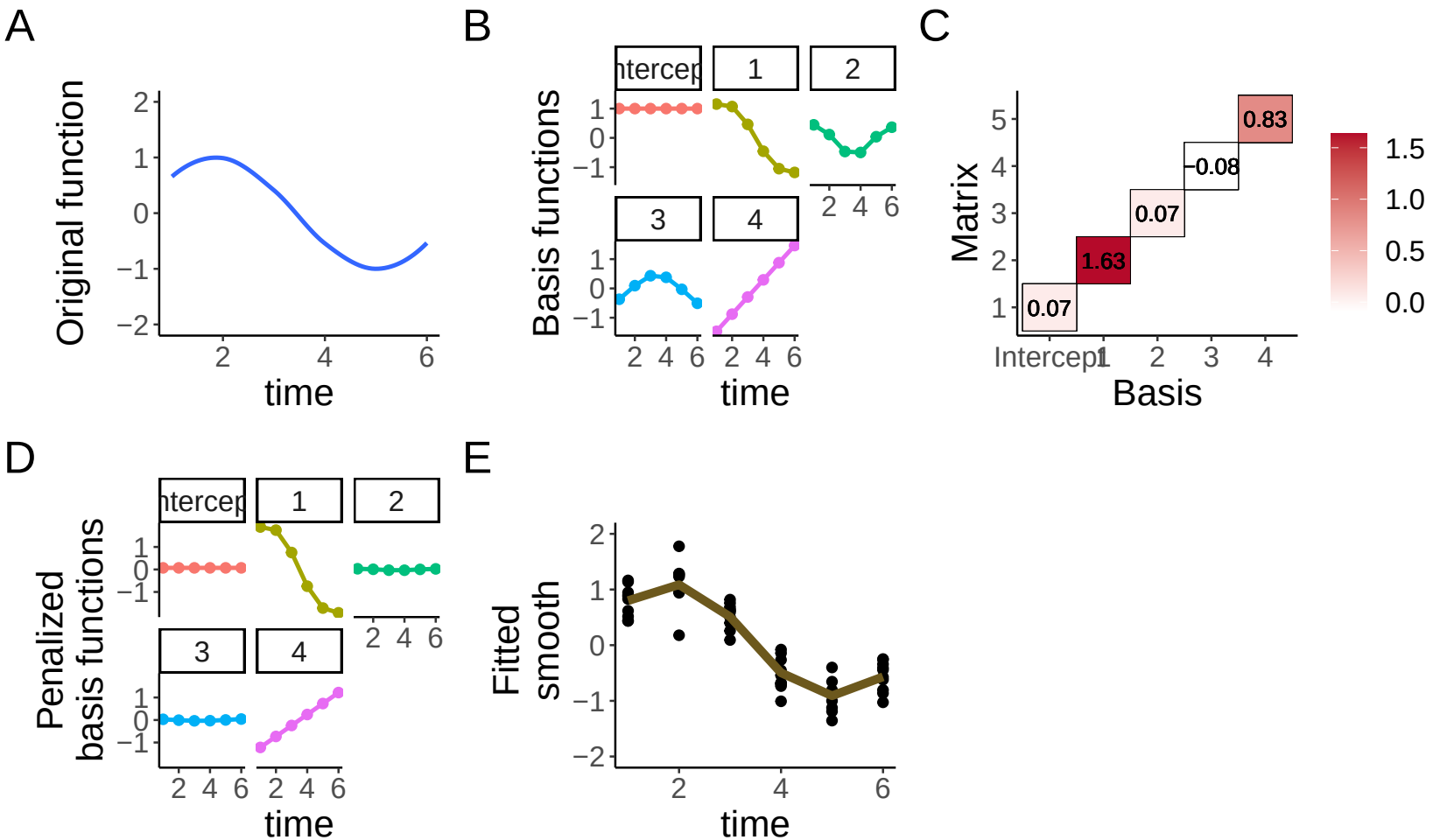

Figure 5: Fitting process of a GAM.

An Example

- Simulated data from a study on radiotherapy in a mouse model of melanoma[5].

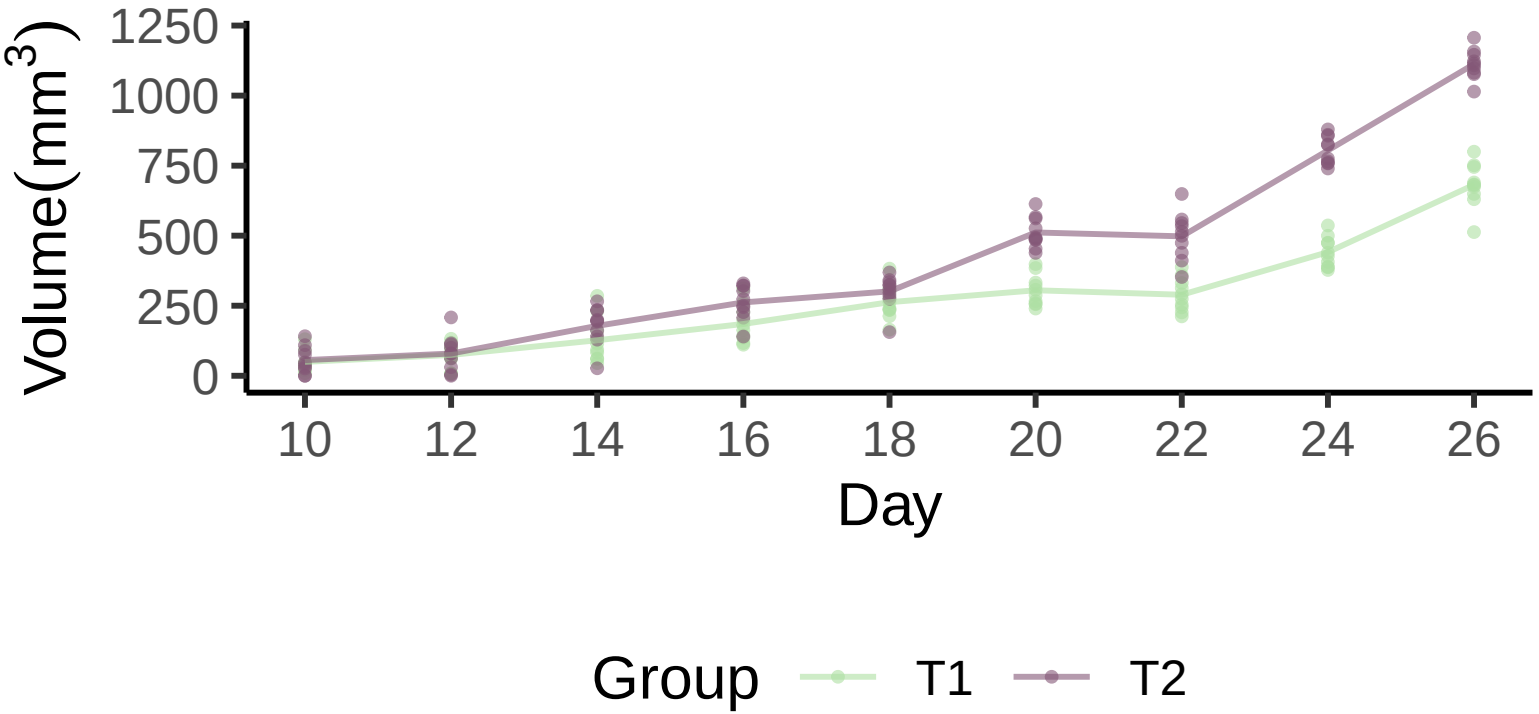

Figure 6: Tumor volume in two groups of tumors under radiotherapy

[5]Sen et al. 2011.

Fitting a GAM

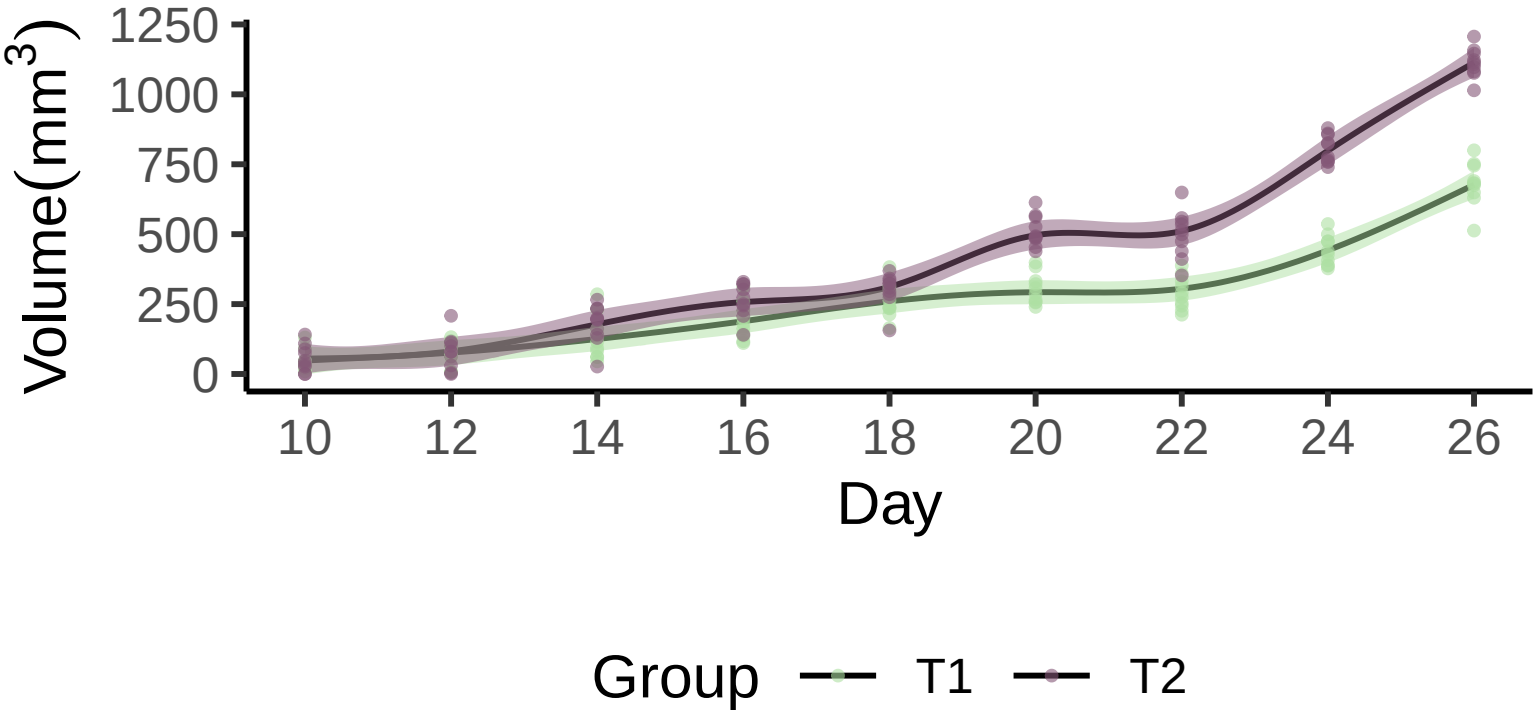

Figure 7: GAM fitted to simulated data

- The model captures the trend of the data

Differences

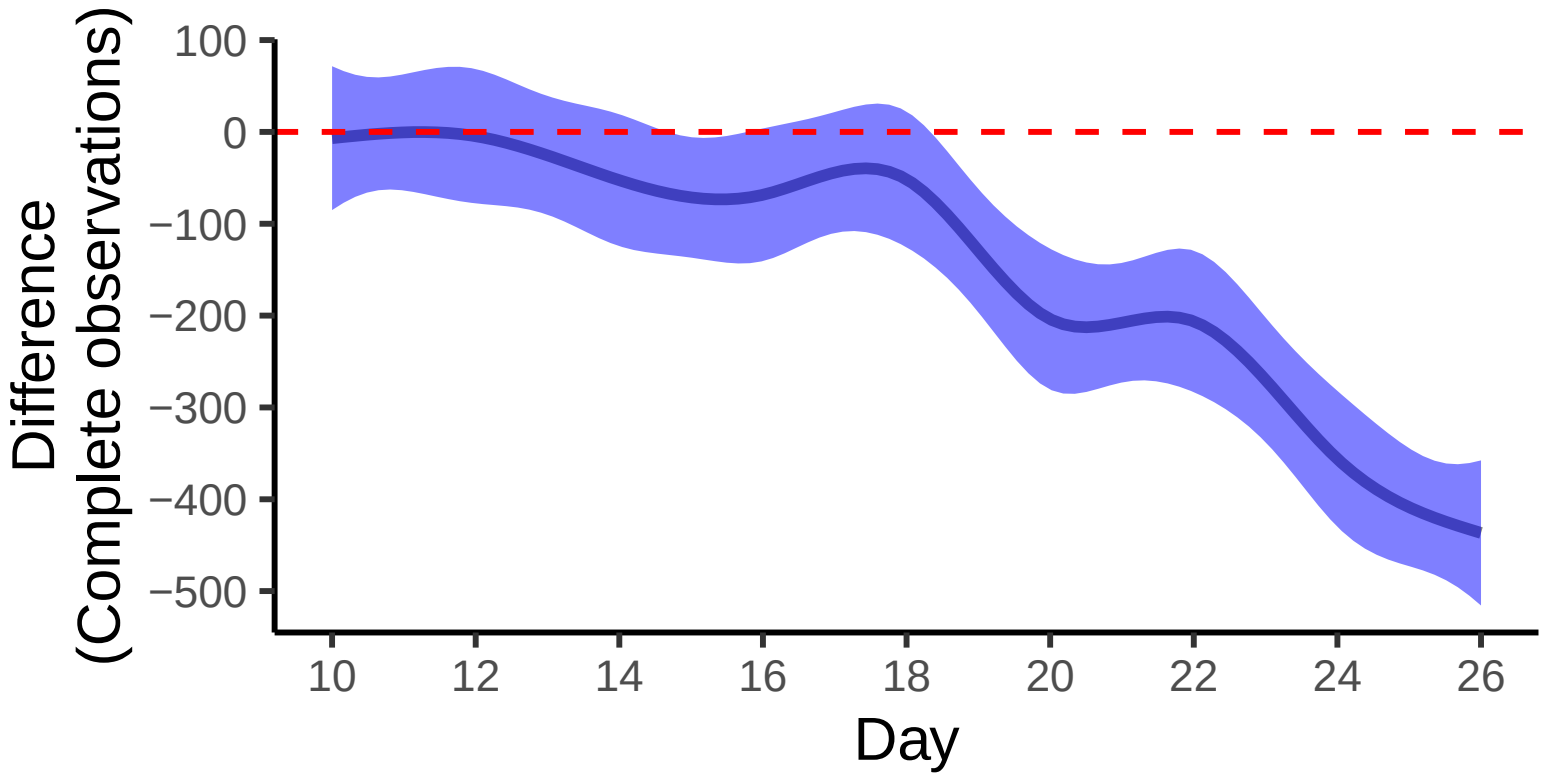

Figure 8: Pairwise comparisons

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 Sen, Arindam et al. (May 2011). "Mild Elevation of Body Temperature Reduces Tumor Interstitial Fluid Pressure and Hypoxia and Enhances Efficacy of Radiotherapy in Murine Tumor Models". In: *Cancer Research* 71.11, pp. 3872–3880. DOI: 10.1158/0008-5472.can-10-4482. URL: https://doi.org/10.1158/0008-5472.can-10-4482.