Analyzing COVID-19 Time-Series Data & Government Policy Responses for Forecasting Deaths

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Introduction & Background

- Governments around the world implemented various **public health** and **policy countermeasures** intended to slow the continued outbreak of COVID-19 disease in 2020 and 2021
- How effective are these countermeasures, and is there a predictive relationship between **government policy response**, **confirmed case counts**, and **deaths** that would allow for better forecasting?

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Research Hypothesis

H_1: More stringent government public health policy measures have some predictive power – *not necessarily causal* – which can improve forecast accuracy of COVID-19 deaths.

H_2: COVID-19 deaths can be forecast accurately using vector auto-regression and vector error correction models.

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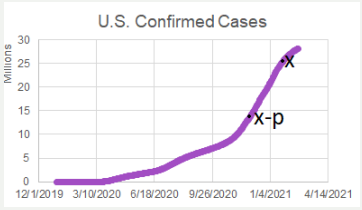
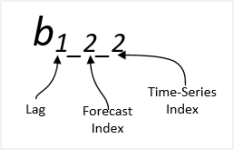
Vector Auto-Regression

- An Auto-Regressive (AR) model forecasts future data points of a time series using its own past steps
- Vector Auto-Regression (VAR) extends the concept of AR to include ***multiple time-series*** in the model. The relationships between each time series can be modeled as dependent (endogenous) or independent (exogenous) variables





$$x_t = c_1 + b_{1\_1\_1} * x_{t-1} + b_{1\_1\_2} * y_{t-1} + b_{2\_1\_1} * x_{t-2} + b_{2\_1\_2} * y_{t-2} + e_{1,t} \quad (1)$$

$$y_t = c_2 + b_{1\_2\_1} * x_{t-1} + b_{1\_2\_2} * y_{t-1} + b_{2\_2\_1} * x_{t-2} + b_{2\_2\_2} * y_{t-2} + e_{1,t} \quad (2)$$

$$Deaths_t = c_1 + b_{1\_1\_1} * Deaths_{t-1} + b_{1\_1\_2} * Cases_{t-1} + b_{1\_1\_3} * StringencyIndex_{t-1} + \cdots + b_{p\_1\_1} * Deaths_{t-p} + b_{p\_1\_2} * Cases_{t-p} + b_{p\_1\_3} * StringencyIndex_{t-p} + e_{1,t} \quad (3)$$

$$Cases_t = c_2 + b_{1\_2\_1} * Deaths_{t-1} + b_{1\_2\_2} * Cases_{t-1} + b_{1\_2\_3} * StringencyIndex_{t-1} + \cdots + b_{p\_2\_1} * Deaths_{t-p} + b_{p\_2\_2} * Cases_{t-p} + b_{p\_2\_3} * StringencyIndex_{t-p} + e_{2,t} \quad (4)$$

$$StringencyIndex_t = c_3 + b_{1\_3\_1} * Deaths_{t-1} + b_{1\_3\_2} * Cases_{t-1} + b_{1\_3\_3} * StringencyIndex_{t-1} + \cdots + b_{p\_3\_1} * Deaths_{t-p} + b_{p\_3\_2} * Cases_{t-p} + b_{p\_3\_3} * StringencyIndex_{t-p} + e_{3,t} \quad (5)$$

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Data

- The source dataset was obtained from the Oxford University COVID-19 Government Response Tracker (OxCGRT) (Hale et al., 2020)
- The OxCGRT systematically collects 19 **indicators of government responses** for over 180 countries and many sub-national regions
  - Aggregates the indicators into the *government response index*, *containment and health index*, *economic support index*, and *stringency index*
- The source dataset originally had 49 columns and 120,268 rows from 1/1/2020 to 3/1/2021

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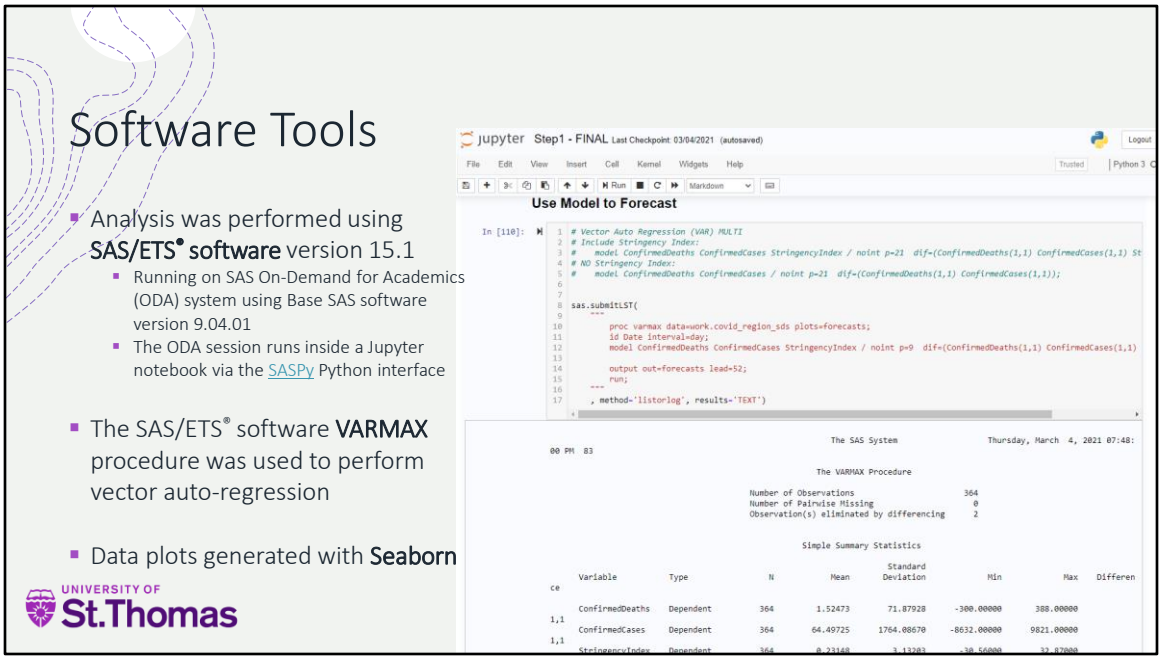
Data Source: https://github.com/OxCGRT/covid-policy-tracker (Hale et al., 2020)
University of Oxford - Blavatnik School of Government - Project Page: https://www.bsg.ox.ac.uk/research/research-projects/covid-19-government-response-tracker
Cleansed data is available here: https://github.com/joshhammond/IIS_COVID19_Data.
Data was sourced in March 2021.



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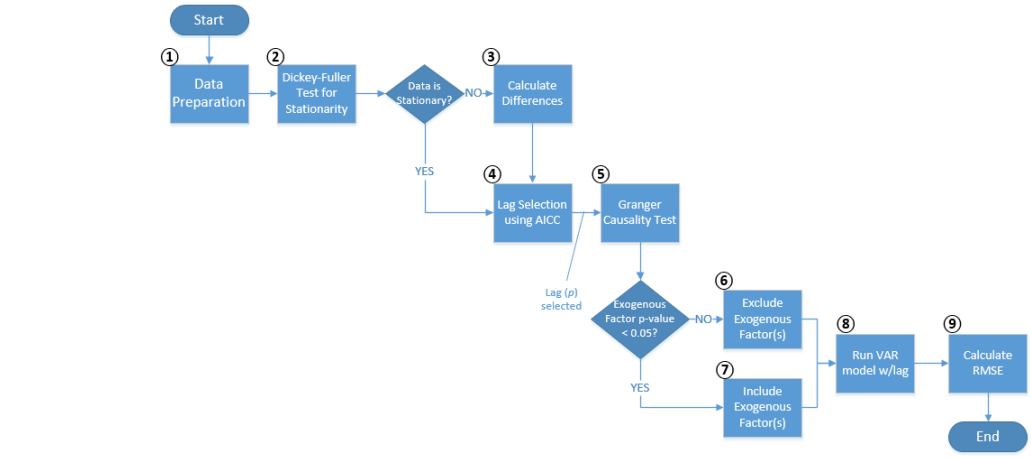
"ETS" – Econometric & Time Series analysis
"VARMAX" – Vector AutoRegressive Moving-Average processes with eXogenous regressor models (SAS Institute Inc., 2018).

Technical details on how SAS implements vector autoregression, vector error correction, Granger causality, the Dickey-Fuller test for stationarity, and Akaike's information corrected criteria (AICC) are provided in the

online documentation for the VARMAX procedure located here: https://support.sas.com/documentation/onlinedoc/ets/151/varmax.pdf (SAS Institute Inc., 2018).

SASPy interface is documented here:
https://sassoftware.github.io/saspy/
https://support.sas.com/ondemand/saspy.html#one

Methodology



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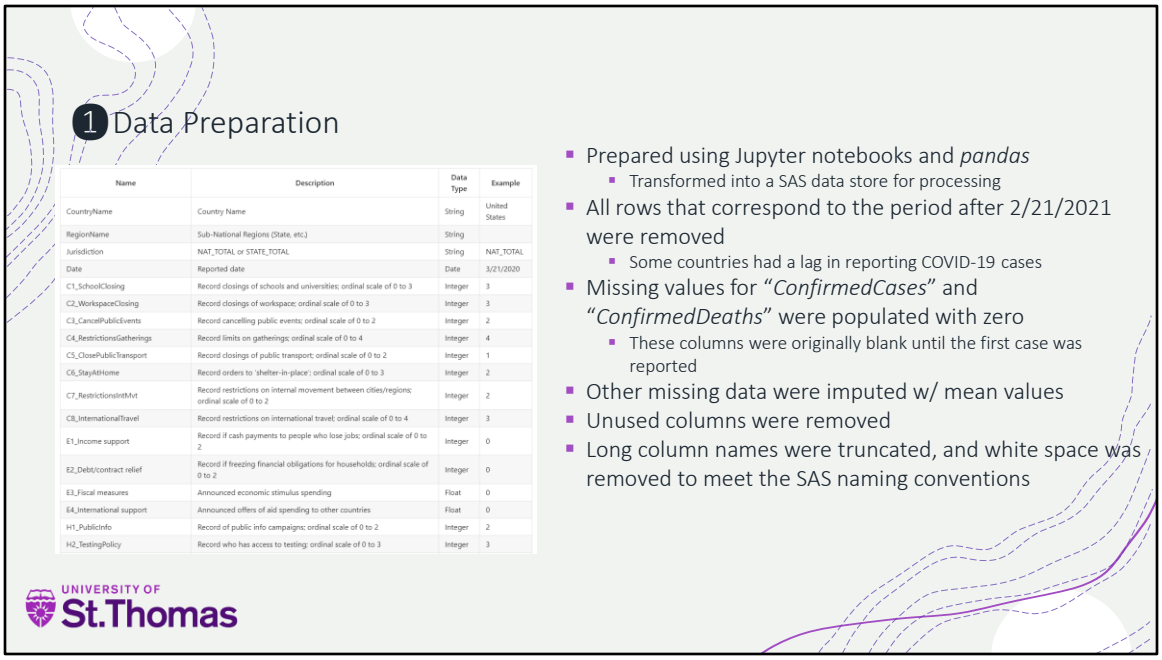

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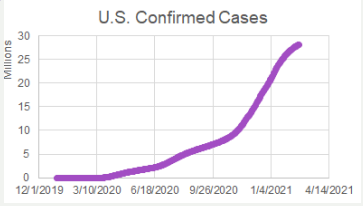
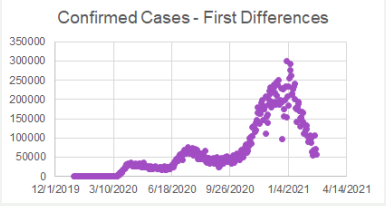
Data Source: https://github.com/OxCGRT/covid-policy-tracker (Hale et al., 2020)
Cleansed data is available here:
https://github.com/joshhammond/IIS_COVID19_Data.

2 Test for Stationarity

- Time-Series analysis techniques generally require the data to be “stationary” – mean and variance are constant over time
- Dickey-Fuller test for Stationarity tells us if we need to transform the data





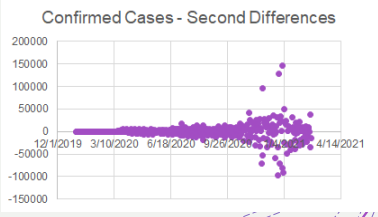


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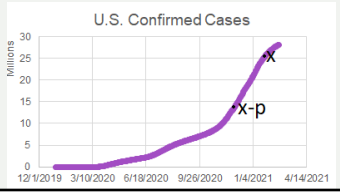
Image source – Joshua Hammond, Melinda Caouette, and Dr. Manjeet Rege

3 Calculate Differences

- We can make the data stationary by performing first or second differences on the data if necessary ($t_i = t_i - t_{i-1}$)

4 Lag Selection for Auto-Regression

- The lag (p) is the number of steps in the past to look
  - The optimal lag can vary by data set
- We used Akaike's information corrected criteria (AICC) looking out to a maximum of 21 days (lags)
  - The model with the smallest AICC value was selected and this number of lags was used in the forecast model



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5 Granger Causality

- Given two time-series, a **policy stringency index** and **confirmed deaths**, you can state that the stringency index *granger-causes* confirmed deaths if including the past values of the stringency index improves the predictive accuracy of confirmed deaths in a model *more* than considering confirmed deaths alone
- This fits well with VAR models as there can be multiple time-series influencing each other
- The test states a *null-hypothesis* that stringency index does not granger-cause confirmed deaths, with a significantly small p-value indicating that the null-hypothesis can be rejected
  - Our threshold for p-value cut off was 0.05
- Time-series that were above the threshold were excluded from the forecast models
- The SAS code is shown in the appendix

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8 Run VAR Model(s)

- Models were trained on one year of data running from 1/1/2020 to 12/31/2020
- Four models were used for each country:
  1. Multivariate Vector Auto Regression (VAR)
  2. Univariate Auto Regression (AR)
  3. Multivariate Vector Error Correction (VEC)
  4. Univariate Vector Error Correction (VEC)

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9 Calculate Root Mean Squared Error (RMSE)

- Models were evaluated by calculating the root mean square error (RMSE) for 52 days of forecasted deaths running from 1/1/2021 to 2/21/2021

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(\hat{y}_i - y_i)^2}{N}}$$

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- **Multivariate models consist of** at least confirmed cases and confirmed deaths, and including other time-series if granger-causation can be confirmed
- **Univariate models** use only confirmed deaths time-series

Results

- The Granger causality p-values for most of the OxCGRT composite indexes (government response index, containment and health index, economic support index, and stringency index) were very high (>> 0.05) indicating that **we cannot reject the null hypothesis that these indexes do not granger-cause confirmed deaths**
  - In a handful of countries, we did find that the stringency index granger-caused confirmed deaths and we included it in the model
- The OxCGRT Stringency Index was found to granger-cause confirmed deaths in the models for Brazil, Italy and Japan
  - The RMSE was improved for Italy and Brazil while the error rate was improved for all three countries
- The forecasts for 52 days out have less than 5% error for 11 out of 14 countries

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Results: Summary of 52-Day Forecast

RMSE: Lower is better

Country	Multivariate VAR's RMSE	Univariate AR's RMSE	Multivariate VEC's RMSE	Univariate VEC's RMSE	Forecast on 02/21/2021	Cumulative Deaths on 02/21/2021	Error Rate
China	1.7	1.5	81.6	146.4	4,634	4,636	-0.04%
United States	6494.7	5985.6	9833.9	11733.3	500028	499009	0.20%
Australia	10.0	2.4	19.2	21.5	913	909	0.44%
Brazil	2149.5	7368.5	3793.4	7957.4	244955	246504	-0.63%
Japan	1036.7	988.9	266.7	718.4	7,421	7,485	-0.86%
Israel	117.6	605.2	191.3	634.6	5643	5577	1.18%
Sweden	670.3	840.8	606.6	952.1	12415	12649	-1.85%
India	6358.7	1300.8	2304.7	7262.0	159,386	156,385	1.92%
Italy	4245.2	3304.5	1183.4	3270.0	98,521	95,718	2.93%
New Zealand	2.3	0.4	2.6	0.5	25	26	-3.85%
South Africa	1768.3	2284.1	7695.7	2178.3	51,013	49,053	4.00%
United Kingdom	5977.5	5644.1	7092.9	8593.3	128803	120580	6.82%
Spain	2930.8	3788.8	3750.5	2956.9	61,260	67,101	-8.70%
South Korea	206.6	259.2	169.6	680.8	1,901	1,562	21.70%

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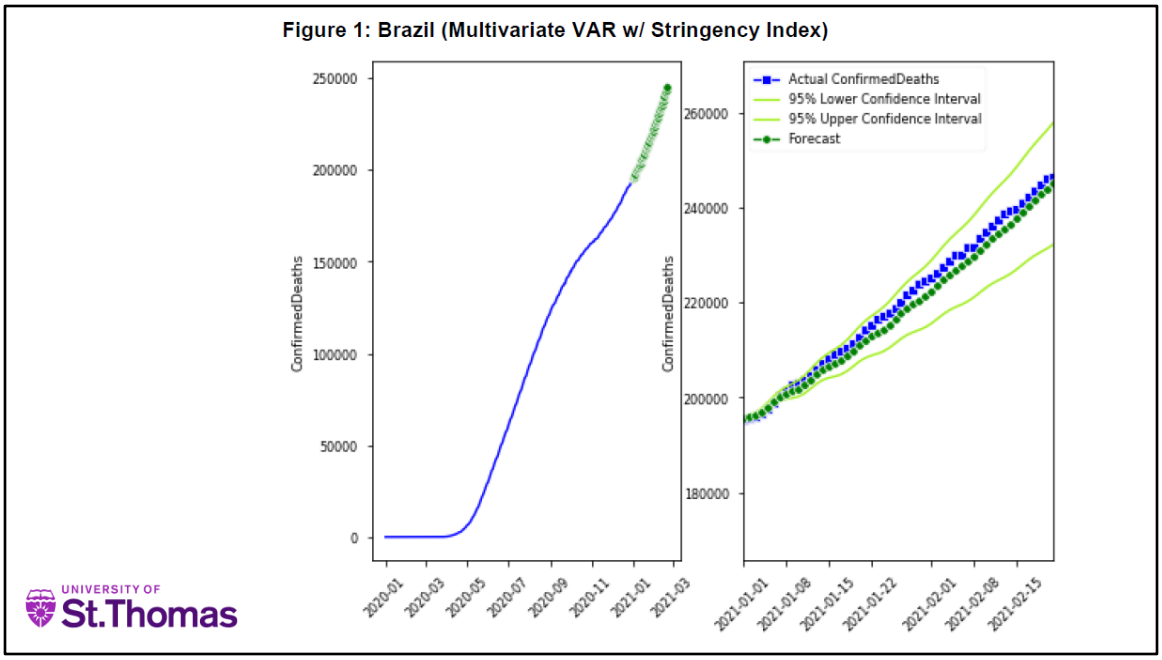
The "Error Rate" is calculated by comparing the forecasted cumulative deaths to the actual cumulative deaths on 2/21/2021.



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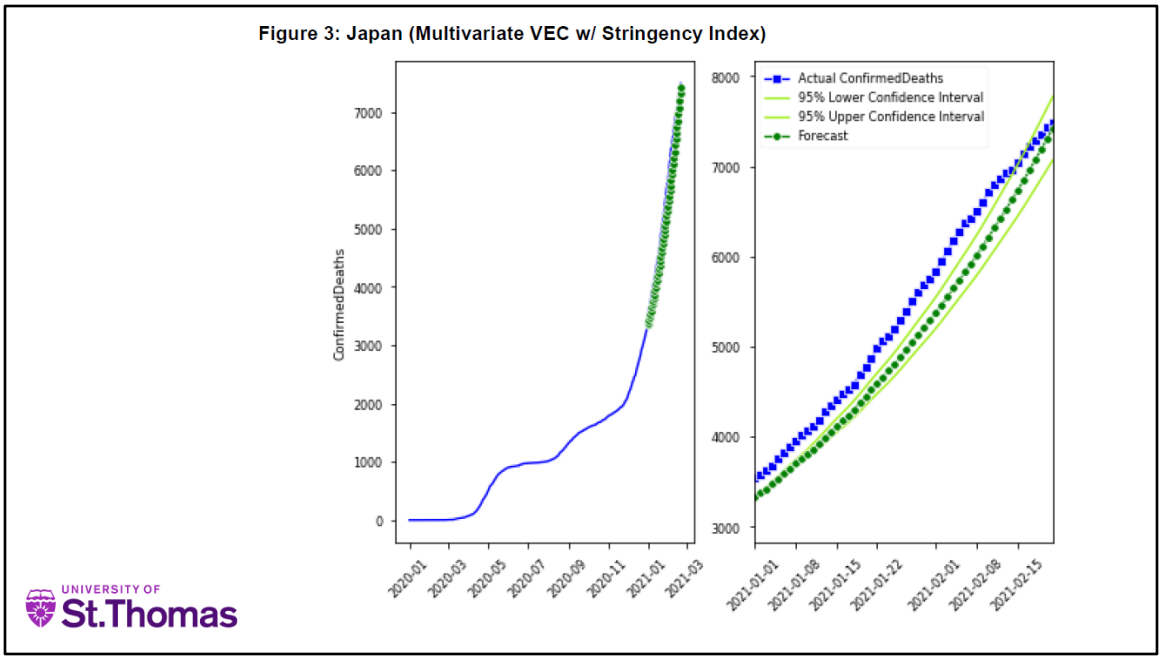

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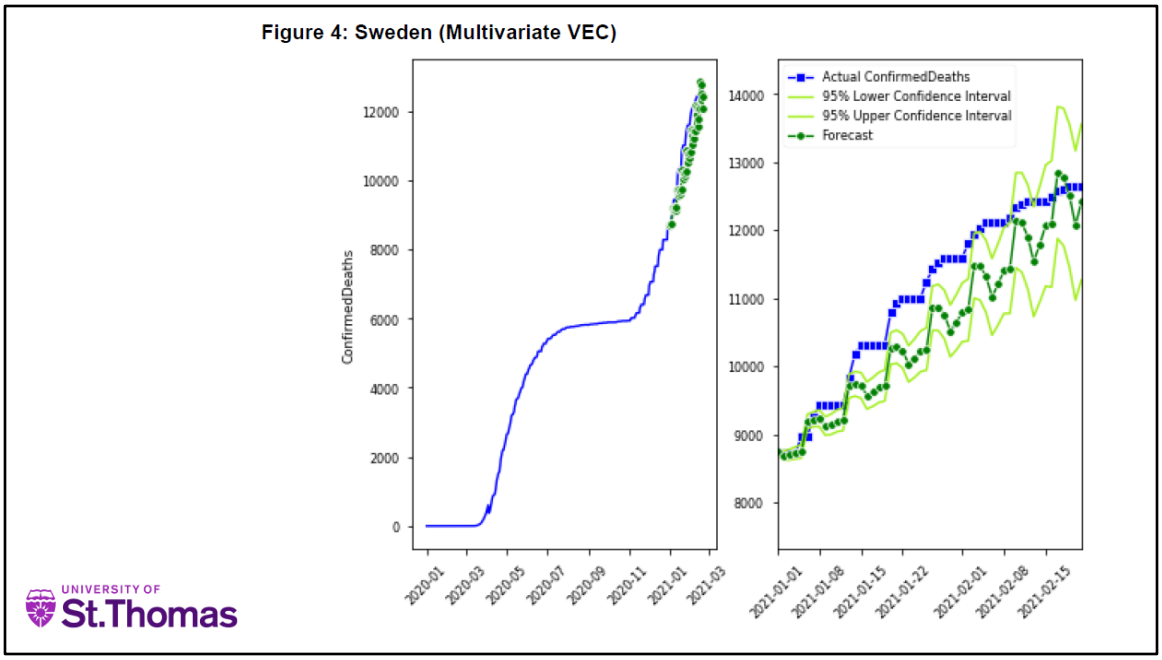

Image source – Joshua Hammond, Melinda Caouette, and Dr. Manjeet Rege

Conclusions

- In this study we attempted to identify relationships between various indexes of government policy, confirmed case count, and confirmed deaths and quantify their predictive power using Vector Auto Regression (VAR) methods
- *H_1: More stringent government public health policy measures have some predictive power – not necessarily causal – which can improve forecast accuracy of COVID-19 deaths*
  - In a handful of countries (3) including the stringency index also improved the forecast, however most of the other policy indexes did not improve the forecast accuracy.
- *H_2: COVID-19 deaths can be forecast accurately using vector auto-regression and vector error correction models*
  - We found that the multivariate VAC and VEC models outperformed the univariate models in eight out of fourteen countries studied
  - We interpret this to mean that for most countries the multivariate models outperform simple univariate AR/VEC models.

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Questions?

Cleansed data and related materials are located here: https://github.com/joshhammond/IIS_COVID19_Data

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Special thanks to Dr. Rege for his guidance and feedback on this project as well as my co-author Melinda Caouette!

Appendix

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VARMAX Code Example

– Use dif to convert data to stationary
– Use minic to find the best lag

```
proc varmax data=work.covid_region_sds plots;
id Date interval=day;
model ConfirmedDeaths ConfirmedCases StringencyIndex /
minic=(type=aicc p=21 q=0)  dif=(ConfirmedDeaths(1,1)
ConfirmedCases(1,1) StringencyIndex(1));
```

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Code by:

Joshua Hammond, Melinda Caouette, and Dr. Manjeet Rege

VARMAX Code Example

– Test granger causality

```
proc varmax data=work.covid_region_sds;
id Date interval=day;
model ConfirmedDeaths ConfirmedCases StringencyIndex /
noint p=11  dif=(ConfirmedDeaths(1,1) StringencyIndex(1)
GovernmentResponseIndex(1) ContainmentHealthIndex(1)
ConfirmedCases(1,1));
causal group1=(ConfirmedDeaths) group2=(StringencyIndex);
causal group1=(ConfirmedDeaths) group2=(ConfirmedCases);
```

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VARMAX Code Example

– Generate forecasts
– Use cointeg for VEC, omit for VAR

```
proc varmax data=work.covid_region_sds plots=forecasts;
id Date interval=day;
model ConfirmedDeaths ConfirmedCases StringencyIndex /
noint p=11  dif=(ConfirmedDeaths(1,1) StringencyIndex(1)
GovernmentResponseIndex(1) ContainmentHealthIndex(1)
ConfirmedCases(1,1));
cointeg rank=1;
output out=forecasts lead=52;
```

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