Impact of different control measures during COVID-19 outbreak on the aviation service industry: a comparison between China, Singapore and the US

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Outline

COVID-19 Outbreak and Responses

On 31st December 2019, the WHO identified **the first case of COVID-19** in Wuhan China

- China
  - Civil Aviation Administration formally initiated Level II emergency response (2020.1.22)
  - National travel agencies suspended the “air ticket + hotel” travel products (2020.1.23)
  - Roughly two-thirds of international flights to and from China were canceled (2020.1.31)
- Singapore
  - Singapore Airlines and Silk Air reduced flights to China (2020.1.31)
  - Authorities raised the nation’s Disease Outbreak Response System Condition level (2020.2.7)
- USA
  - U.S. declared a public health emergency (2020.1.31)
  - U.S. travel restrictions became effective on February (2020.2.8)

COVID-19 Outbreak and Responses

On March 11 2020, the WHO declared COVID-19 virus as a **pandemic**

- China
  - All international flights to and from China were reduced, with flight limit (2020.3.26)
  - Domestic passenger and cargo flights were resumed (2020.3.29)
  - Special freight channel were established (2020.4.3)
- Singapore
  - Singapore citizens, permanent residents and long-term pass holders returning were banned (2020.3.3)
  - Aviation aircrafts were required to make a health declaration (2020.3.12)
- USA
  - President Trump issued an order restricting travel from certain European countries (2020.3.11)
  - The federal government closed schools and canceled public meetings (2020.3.11)

Impact on the aviation service industry

- Travel restrictions
  - The slump in demand among travelers and cargoes
- Higher public health emergency level
  - Public transportation was restricted
- Locked down and work at home
  - Business travels were decreased
- Others · · · · · ·

Research Aims

- This paper assumes that
  - The intervention **aggregates multiple control measures**
  - Intervention time for different countries varies
  - Intervention consists of **six-month intervention** and **full Intervention**

Research Aims

- This paper assumes that
  - The intervention **aggregates multiple control measures**
  - Intervention time for different countries varies
  - Intervention consists of **six-month intervention** and **full Intervention**
- This paper presents the application of time series **SARIMA** with **linear and nonlinear intervention** in forecasting aviation service demand
  - Bureau of Transportation Statistics (https://www.bts.gov/), CIEC Dataset (https://insights.ceicdata.com/)
  - Time series analysis and forecast, **Intervention analysis and forecast**
  - **Comparison of intervention models**
  - Comparison of **intervention impact** between China, Singapore and the US

Outline

Literature Reviews: Seasonal ARIMA Model

Most of the variations are resulted from **seasonal factor** in time series analysis

- **Seasonal adjustment filters**, lose valuable information [1]
- **Seasonal dummy variable**, inaccurate regression results [2]
- **Identify seasonality (SARIMA)** [3]
  - $$(1-B)^d \left(1-B^s\right)^D Y_t = \frac{\theta(B)\Theta\left(B^s\right)}{\phi(B)\Phi\left(B^s\right)}\epsilon_t$$
  - $$\phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_p B^p$$
    $$\Phi\left(B^s\right) = 1 - \Phi_1 B^s - \Phi_2 B^{2s} - \cdots - \Phi_P B^{Ps}$$
    $$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q$$
    $$\Theta\left(B^s\right) = 1 - \Theta_1 B^s - \Theta_2 B^{2s} - \cdots - \Theta_Q B^{Qs}$$

Literature Reviews: Full Intervention Model

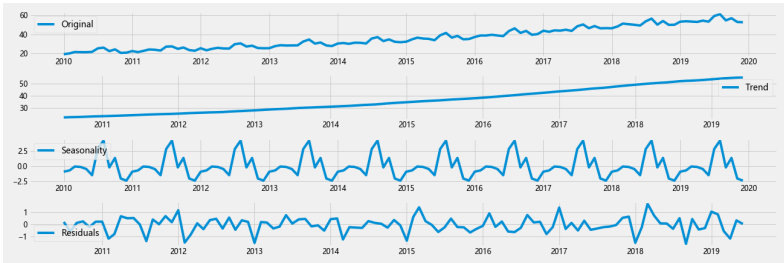
The impact of exceptional external events can be modeled by using **exogenous variables** [4]

- **Intervention** ξ : SARIMAX(exog), pulse function($P(t)$) and step function($S(t)$)
  - $$exog = \begin{Bmatrix} 0 & others \\ 1 & exogenous\ exsit \end{Bmatrix}, \quad P(t) = \begin{Bmatrix} 0 & t \neq T \\ 1 & t = T \end{Bmatrix}, \quad S(t) = \begin{Bmatrix} 0 & t < T \\ 1 & t \geq T \end{Bmatrix}$$
- Model formula: **intervention indicator** and **seasonal ARIMA indicator**
  - $$(1-B)^d (1-B^s)^D Y_t = (1-B)^d (1-B^s)^D \frac{\omega(B)}{\delta(B)} \xi_t + \frac{\theta(B)\Theta(B^s)}{\phi(B)\Phi(B^s)} \epsilon_t$$

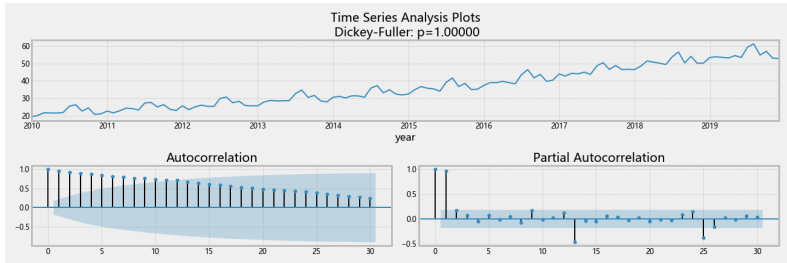
Four practical steps of model building

- Identification: Identify the SARIMA (p,d,q)(P,D,Q)s structure
- Estimation: Estimate unknown parameters
- Diagnostic checking on estimated residual
- **Forecast future outcomes**

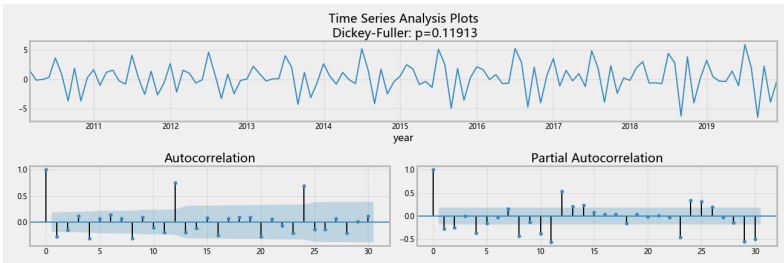
Seasonal ARIMA Identification



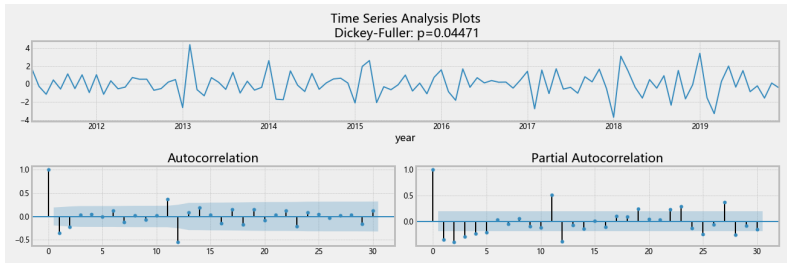
(a) Decomposition



(b) Dickey-Fuller test



(c) Difference



(d) Seasonal difference

Seasonal ARIMA Estimation

SARIMAX Results

Dep. Variable:	Air_Passengers	**No. Observations:**	90
Model:	SARIMAX(0, 1, 1)x(0, 1, 1, 12)	**Log Likelihood**	-80.976
Date:	Mon, 29 Jun 2020	**AIC**	167.953
Time:	16:44:47	**BIC**	174.382
Sample:	01-01-2010	**HQIC**	170.482
	- 06-01-2017		
Covariance Type:	opg		

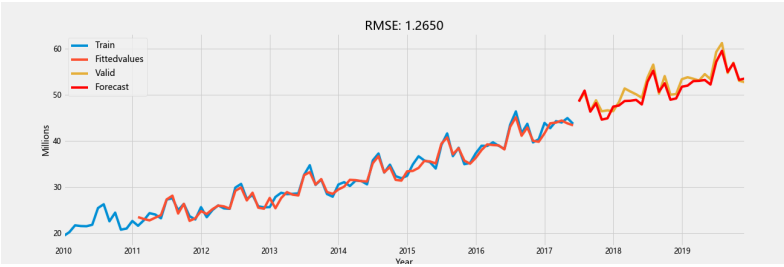
	coef	std err	z	P>|z|	[0.025	0.975]
ma.L1	-0.6964	0.095	-7.344	0.000	-0.882	-0.511
ma.S.L12	-0.5274	0.127	-4.147	0.000	-0.777	-0.278
sigma2	0.7540	0.116	6.515	0.000	0.527	0.981

Ljung-Box (Q):	38.16	**Jarque-Bera (JB):**	2.84
Prob(Q):	0.55	**Prob(JB):**	0.24
Heteroskedasticity (H):	0.90	**Skew:**	0.33
Prob(H) (two-sided):	0.82	**Kurtosis:**	3.81

$$\phi(B) = \Phi\left(B^{12}\right) = 1, \qquad \theta(B) = 1+0.6964B, \qquad \Theta\left(B^{12}\right) = 1+0.5274B^{12}$$

$$(1-B)\left(1-B^{12}\right)Y_t = \frac{\theta(B)\Theta\left(B^{12}\right)}{\phi(B)\Phi\left(B^{12}\right)}\epsilon_t = (1+0.6964B)(1+0.5274B^{12})\epsilon_t$$

Seasonal ARIMA Diagnostic Checking

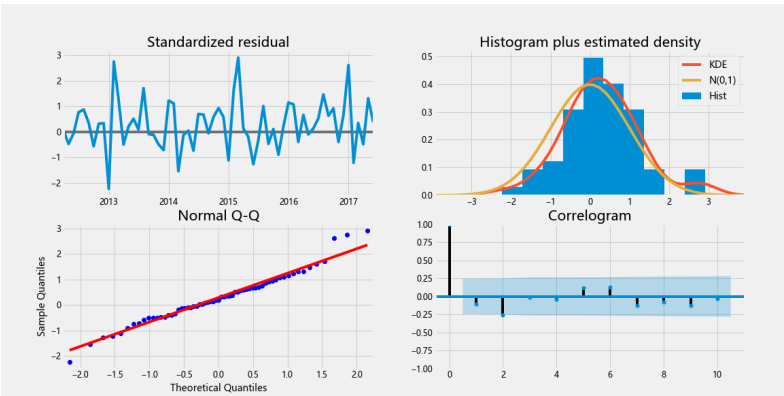


(f) Model-fitted

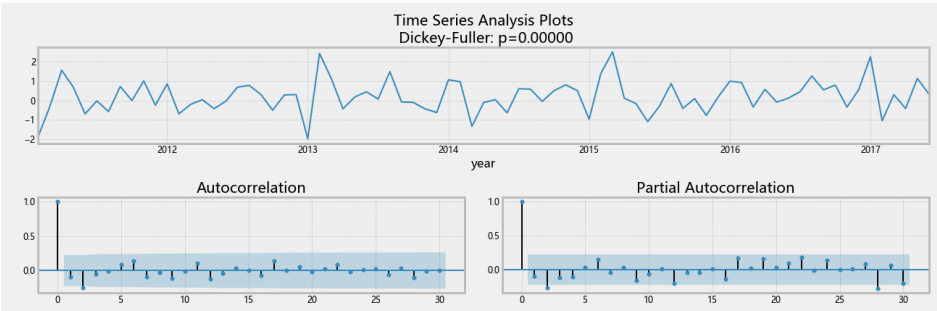
```
evaluate_forecast(valid.values, valid_forecast.values) # Air_Passengers
```

	r2_score	mean_absolute_error	median_absolute_error	mse	msle	mape	rmse
0	0.879059	1.063192	1.03997	1.600321	0.000587	7.862017	1.265038

(g) Evaluation criterial in valid data

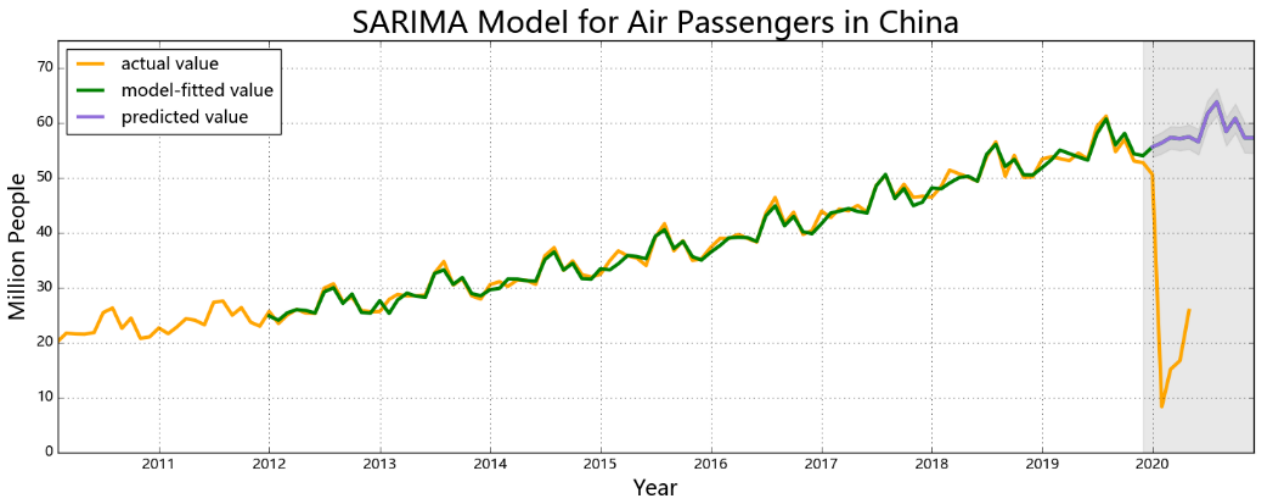


(h) Diagnostic



(i) Residual

Seasonal ARIMA Forecasting



(j) Forecasting

- The Covid-19 outbreak has **huge impact on aviation services industry**
- The impact of Covid-19 outbreak should be assessed by **seasonal ARIMA and intervention model**

Linear Intervention Model Result

SARIMAX Results

Dep. Variable:	Air_Passengers	**No. Observations:**	124
Model:	SARIMAX(0, 1, 1)x(0, 1, 1, 12)	**Log Likelihood**	-259.910
Date:	Mon, 29 Jun 2020	**AIC**	527.820
Time:	16:47:54	**BIC**	538.119
Sample:	02-01-2010	**HQIC**	531.985
	- 05-01-2020		
Covariance Type:	opg		

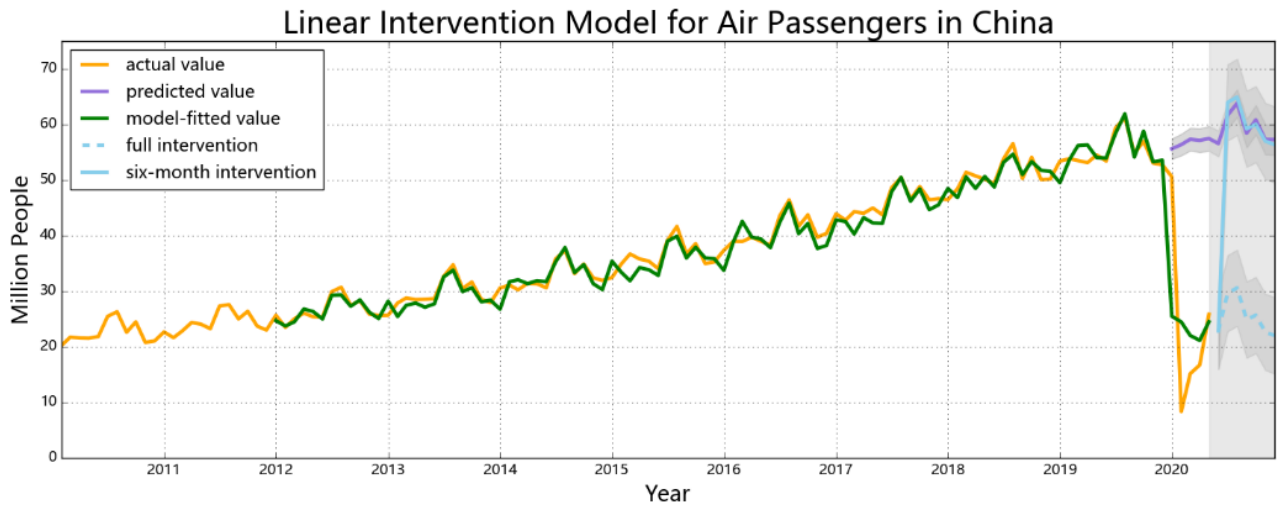
	coef	std err	z	P>|z|	[0.025	0.975]
Covid	-34.3445	1.450	-23.692	0.000	-37.186	-31.503
ma.L1	-0.9739	0.059	-16.602	0.000	-1.089	-0.859
ma.S.L12	0.5843	0.224	2.611	0.009	0.146	1.023
sigma2	12.2341	1.174	10.420	0.000	9.933	14.535

Ljung-Box (Q):	16.31	**Jarque-Bera (JB):**	3507.58
Prob(Q):	1.00	**Prob(JB):**	0.00
Heteroskedasticity (H):	22.38	**Skew:**	2.47
Prob(H) (two-sided):	0.00	**Kurtosis:**	32.04

(k) Linear Intervention Model Result

$$Y_t = -34.34 \times exog_t + \frac{(1 + 0.973B)\,(1 - 0.584B^{12})}{(1 - B)\,(1 - B^{12})}\epsilon_t$$

Linear Intervention Model Performance



(I) Forcasting

$$MAPE(Mean\ Absolute\ PercentError) = 0.478$$
$$MAE(Mean\ Absolute\ Error) = 7.19$$
$$RMSE(Root\ Mean\ Squared\ Error) = 9.06$$

Nonlinear Intervention Model Result

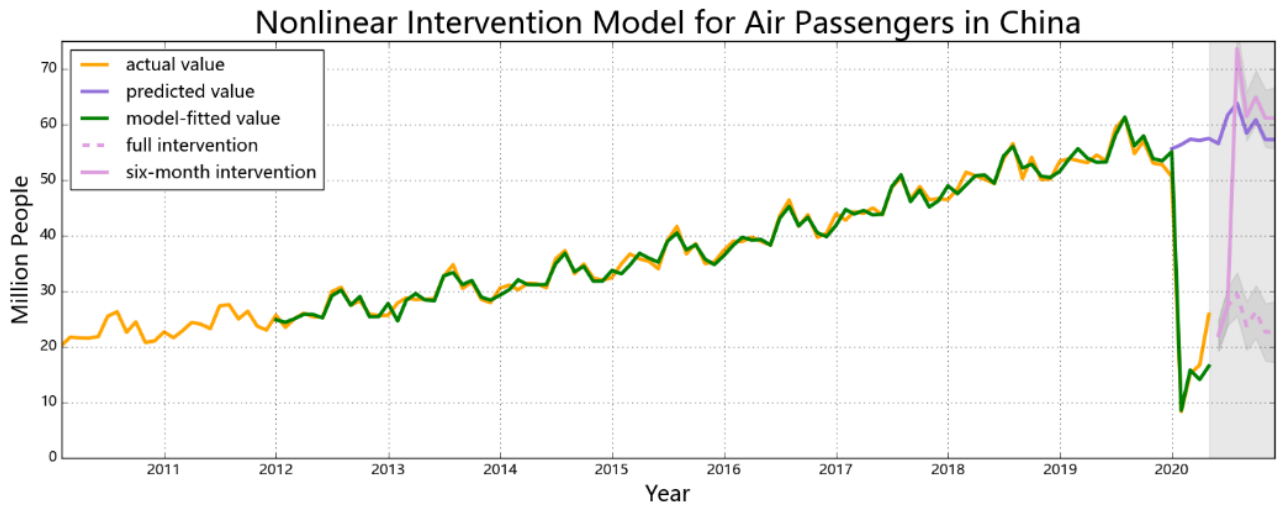
最大似然估计							
参数	估计	标准误差	t 值	近似 Pr > |t|	滞后	变量	位移
MA1,1	0.30180	0.14105	2.14	0.0324	1	air	0
MA2,1	0.58040	0.15373	3.78	0.0002	12	air	0
NUM1	-44.14252	1.54234	-28.62	<.0001	0	x	0
DEN1,1	-0.14662	0.03177	-4.62	<.0001	1	x	0

方差估计	1.998368
标准误差估计	1.413636
AIC	400.8038
SBC	411.6419
残差数	111

(m) Nonlinear Intervention Model Result

$$Y_t = \frac{-44.14252}{(1+0.14662B)} S_t^{(1)} + \frac{(1-0.3018B)(1-0.5804B^{12})}{(1-B)(1-B^{12})} \epsilon_t$$

Nonlinear Intervention Model Performance



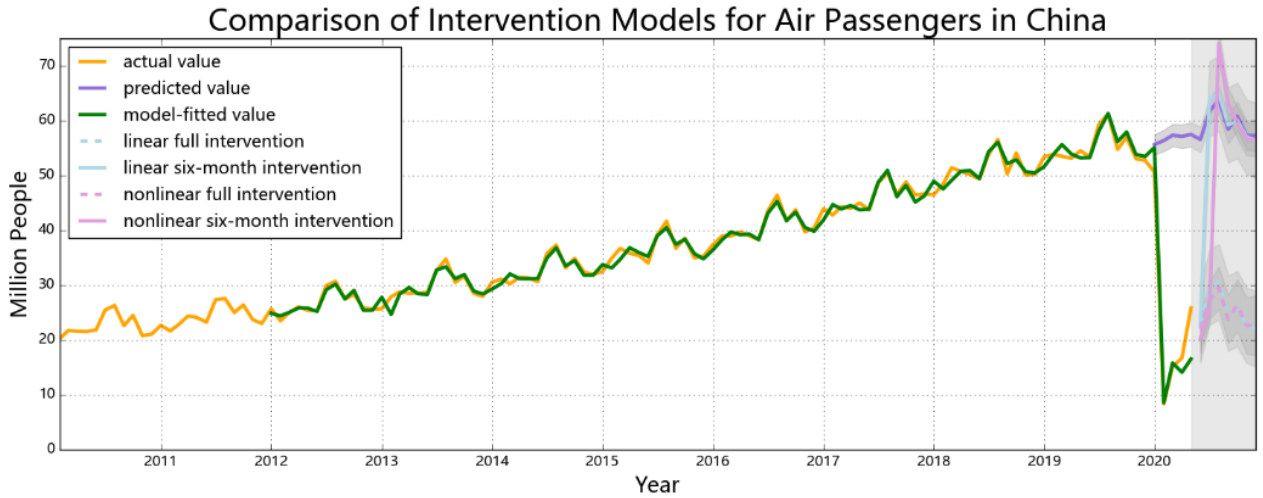
(n) Model Result

$$MAPE(Mean\ Absolute\ PercentError) = 0.179$$

$$MAE(Mean\ Absolute\ Error) = 3.09$$

$$RMSE(Root\ Mean\ Ruared\ Error) = 3.77$$

Linear and Nonlinear Intervention Models Comparison

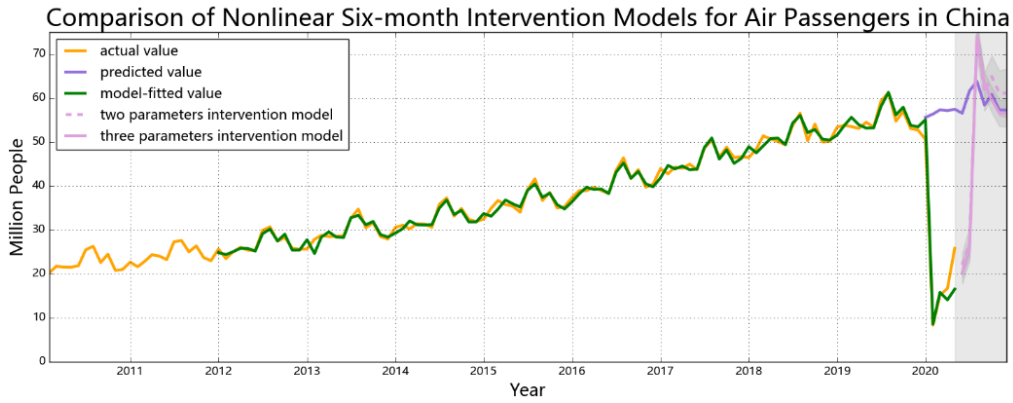


(o) Intervention Model Comparison

$$
\begin{aligned}
AIC = & \quad 527 & \mathbf{400} \\
MAPE = & \quad 0.478 & \mathbf{0.179} \\
MAE = & \quad 7.19 & \mathbf{3.09} \\
RMSE = & \quad 9.06 & \mathbf{3.77}
\end{aligned}
$$

Nonlinear intervention model performance better than linear intervention model!

Six-month Intervention Models Comparison



(p) Model Comparison

$$Y_t = \sum_{i=2}^{7} \frac{-44.14252}{(1+0.14662B)} P_t^{(i)} + \frac{(1-0.3018B)(1-0.5804B^{12})}{(1-B)(1-B^{12})}\epsilon_t$$

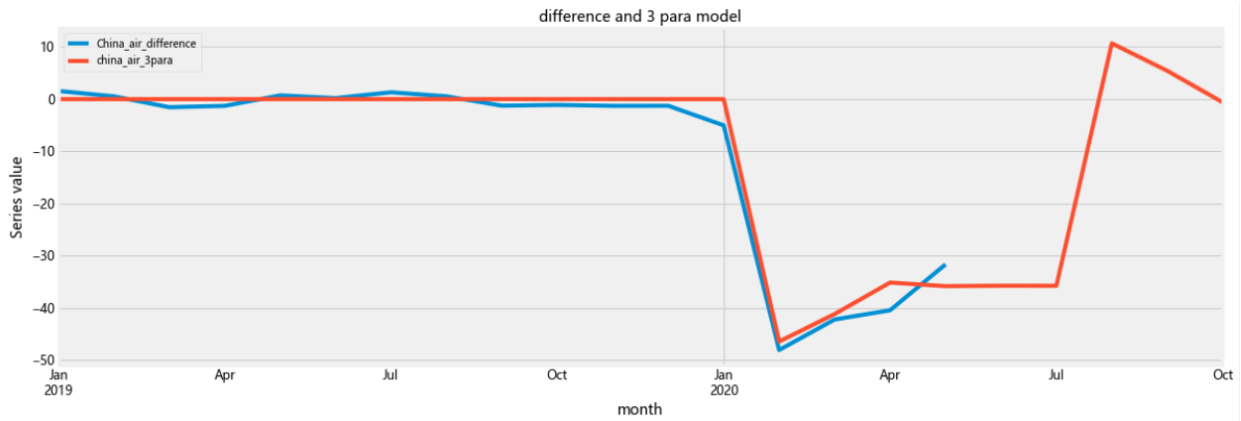
AIC = 400.8038

$$Y_t = \frac{-46.41429+6.62760B^2}{(1+0.11325B)}(S_t^{(2)} - S_t^{(8)}) + \frac{(1-0.72186B)(1-0.53775B^{12})}{(1-B)(1-B^{12})}\epsilon_t$$

AIC = 378.074

Six-month Intervention Models Comparison

(q) two parameter structure



(r) three parameter structure

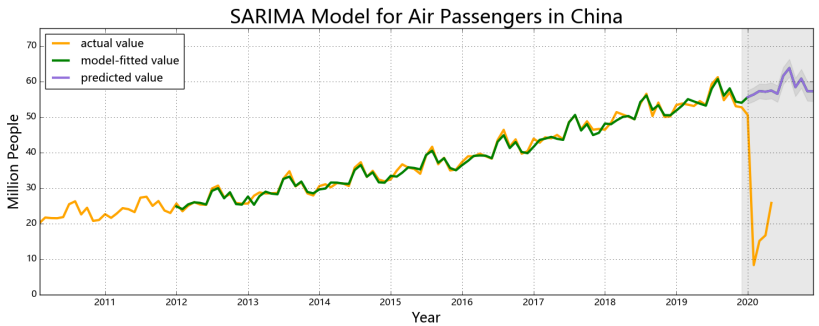
Outline

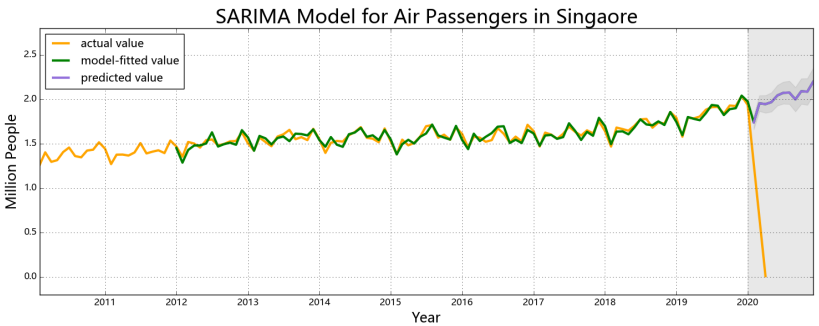
Model Choice

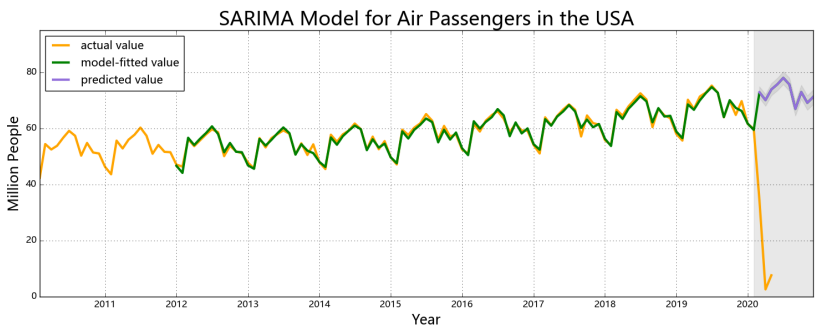
	Parameters of SARIMA (p,d,q),(P,D,Q),s	R square	MAPE
Passengers_China	(0,1,1),(0,1,1),12	0.879059	7.862017
Passengers_Singapore	(0,1,1),(0,1,0),12	0.410515	9.730751
Passengers_USA	(0,1,1),(0,1,1),12	0.82178	9.155471
Freight_China	(1,1,1),(0,1,0),12	0.670517	12.545388
Freight_Singapore	(0,1,1),(0,1,1),12	0.424412	8.186086
Freight_USA	(1,1,0),(0,1,1),12	0.621635	9.774325

	Criterial	Linear Model	Nonlinear Model
Passengers_China	AIC	527.82	400.8038
	MAPE	67.59675	17.94613
	MAE	7.19158	3.45651
	RMSE	9.064	4.77013
Freight_China	AIC	-443.734	-453.998
	MAPE	7.38076	5.09656
	MAE	0.03506	0.02353
	RMSE	0.03712	0.02765
Passengers_Singapor	AIC	799.791	722.2359
	MAPE	961.07819	29.74787
	MAE	0.39748	0.1155
	RMSE	0.43353	0.19204
Freight_Singapore	AIC	592.496	634.7668
	MAPE	31.46149	12.33971
	MAE	0.01591	0.00712
	RMSE	0.01606	0.00737
Passengers_USA	AIC	478.867	321.9073
	MAPE	196.95953	38.48622
	MAE	13.01534	3.09424
	RMSE	13.62443	3.88373
Freight_USA	AIC	848.367	920.5389
	MAPE	27.42191	0.00022
	MAE	58.49236	0.00061
	RMSE	60.30518	0.00071

Air Passengers







China

- Level II emergency response (2020.1.22)
- Travel restrictions (2020.1.31)
- Resumed of domestic passenger and cargo flights (2020.3.29)

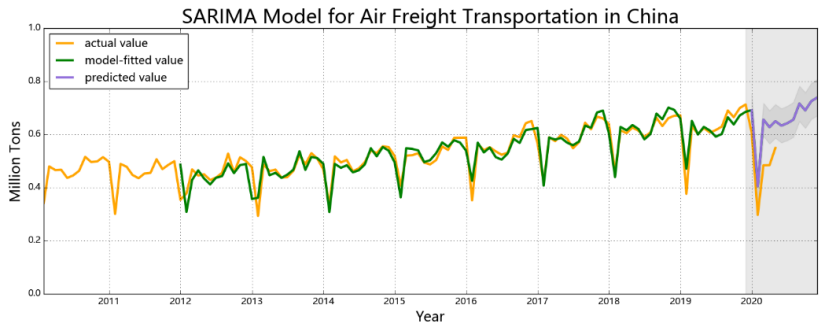
Singapore

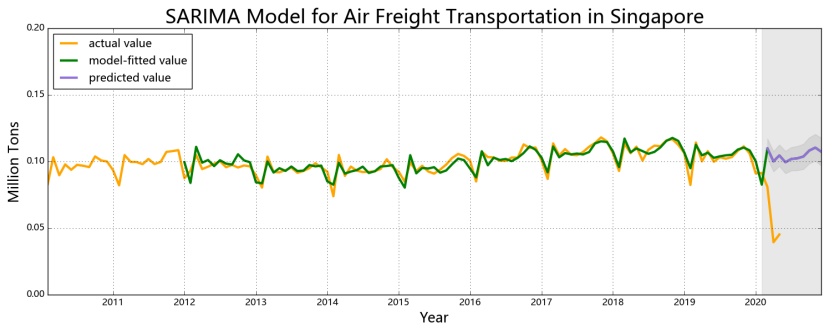
- Raised Disease Outbreak Response level (2020.2.7)
- Travel Bans (2020.3.3)
- Students Entry Restriction (2020.3.29)

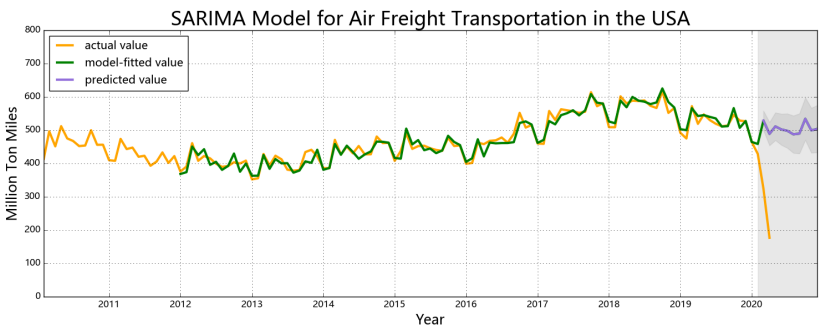
USA

- Travel restrictions (2020.3.11)
- Closed schools and canceled public meeting (2020.3.11)

Air Freight







China

- Level II emergency response (2020.1.22)
- Resumed domestic passenger and cargo flights (2020.3.29)
- Improved the air cargo capacity (2020.4.3)

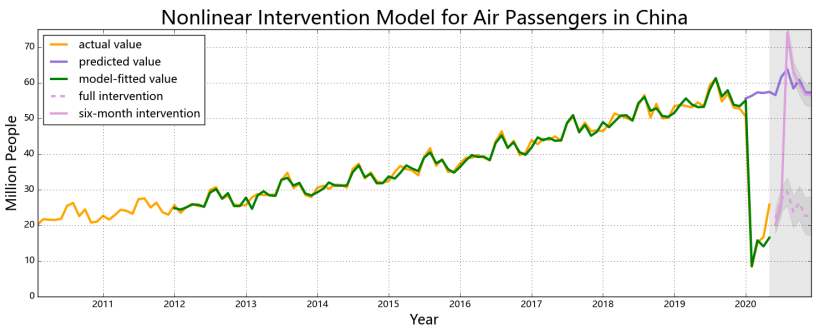
Singapore

- Raised Disease Outbreak Response level (2020.2.7)
- Travel Bans (2020.3.3)
- Some Circuit Breaker measures were eased (2020.5.2)

USA

- Travel restrictions (2020.3.11)
- International trade suspended (2020.3.11)

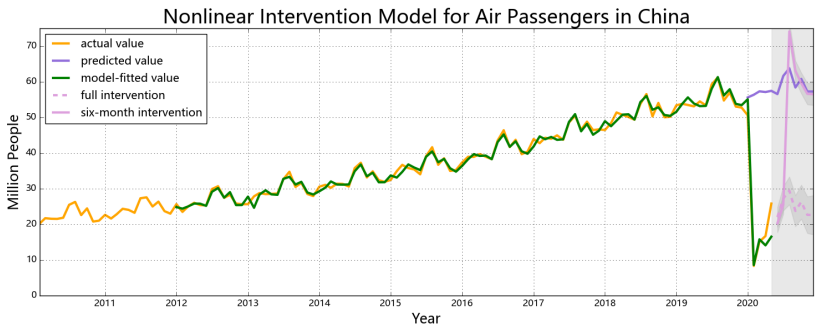
Six-month and full intervention

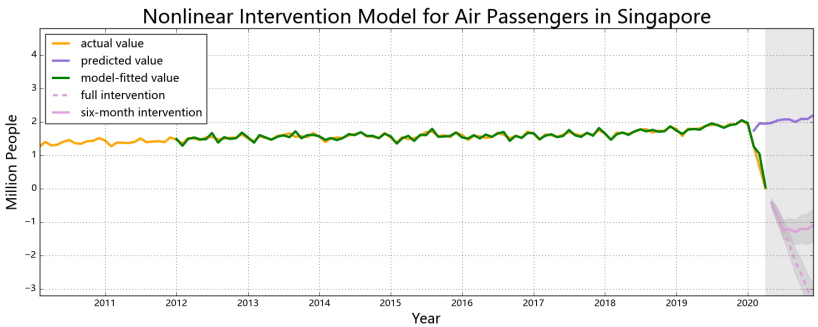


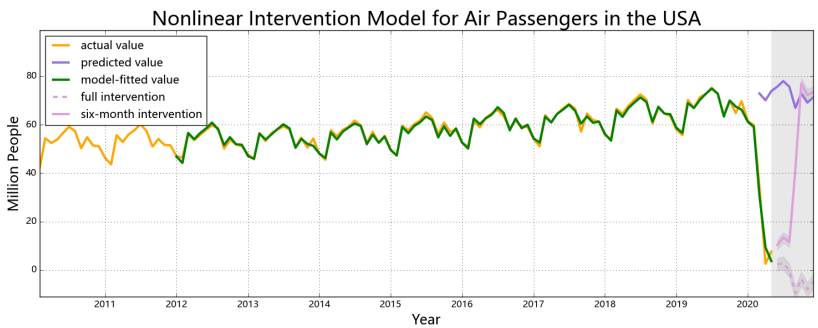
China Air Passengers		
Month	Six-month Intervention	Full Intervention
Jan	-5.024967911	-5.024967911
Feb	-48.04131548	-48.04131548
Mar	-42.197786	-42.197786
Apr	-40.43065012	-40.43065012
May	-31.64861297	-31.64861297
Jun	-36.28092562	-34.52383032
Jul	-36.13759741	-34.41220528
Aug	10.32605165	-34.36765818
Sep	4.681251621	-34.64872888
Oct	-1.211869178	-34.53957777
Nov	-0.663975326	-34.63692187
Dec	-0.774495376	-34.65518508

- Prediction Loss: seasonal ARIMA prediction - intervention model prediction
  - Six-month: 227.4 millions people $\times$ Per capita consumption
  - Full: 409.1 millions people $\times$ Per capita consumption
- Six-month intervention effects
  - China's intervention performance better than other countries

Intervention Model Results







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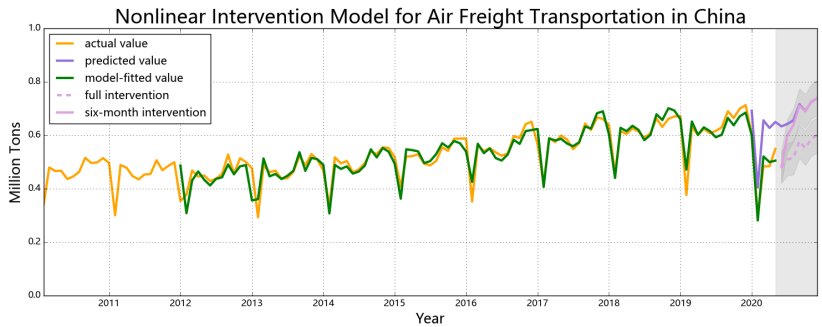
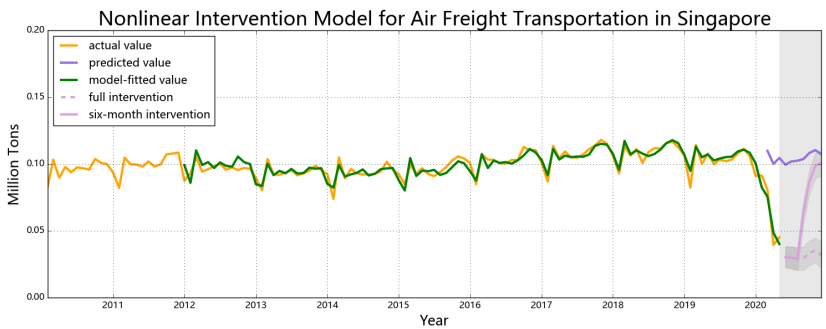
Sep	4.681251621	-34.64872888
Oct	-1.211869178	-34.53957777
Nov	-0.663975326	-34.63692187
Dec	-0.774495376	-34.65518508

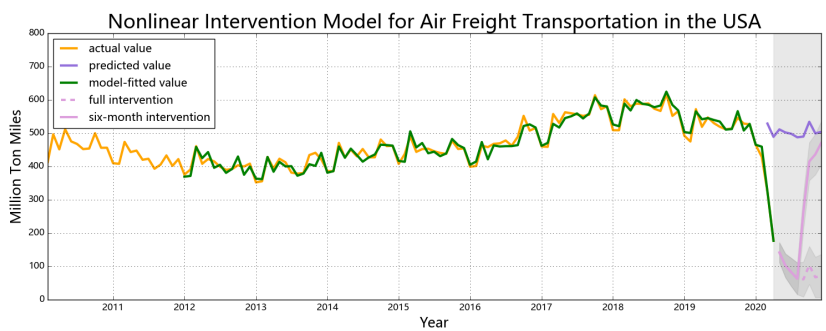
Singapore Air Passengers		
Month	Six-month Intervention	Full Intervention
Jan		
Feb	-0.467205181	-0.467205181
Mar	-1.290205181	-1.290205181
Apr	-1.937005181	-1.937005181
May	-1.968205181	-1.968205181
Jun	-2.044205181	-2.044205181
Jul	-2.073205181	-2.073205181
Aug	-2.076205181	-2.076205181
Sep	-1.999205181	-1.999205181
Oct	-2.091205181	-2.091205181
Nov	-2.086205181	-2.086205181
Dec	-2.198205181	-2.198205181

USA Air Passengers		
Month	Six-month Intervention	Full Intervention
Jan		
Feb		
Mar	-38.49712173	-38.49712173
Apr	-67.48778561	-67.48778561
May	-66.27598995	-66.27598995
Jun	-65.32757825	-73.47408745
Jul	-64.62727961	-75.08736243
Aug	-64.08236211	-75.69729456
Sep	-25.19159949	-66.9819274
Oct	4.088621345	-72.97741783
Nov	3.111677857	-69.1512605
Dec	2.259733507	-71.23239842

Intervention Model Results







China Air Freight		
Month	Six-month Intervention	Full Intervention
Jan	-0.086183999	-0.086183999
Feb	-0.107870419	-0.107870419
Mar	-0.172587946	-0.172587946
Apr	-0.143703626	-0.143703626
May	-0.101262164	-0.101262164
Jun	-0.152164318	-0.152164318
Jul	-0.043695227	-0.133761029
Aug	-0.018583245	-0.140680935
Sep	-0.004685715	-0.138175541
Oct	-0.00157491	-0.139116348
Nov	0.00020712	-0.138775272
Dec	0.000591676	-0.138903191

Singapore Air Freight		
Month	Six-month Intervention	Full Intervention
Jan		
Feb	-0.008744939	-0.008744939
Mar	-0.001633193	-0.001633193
Apr	-0.070446469	-0.070446469
May	-0.054835856	-0.054835856
Jun	-0.074084733	-0.074084733
Jul	-0.069451261	-0.069451261
Aug	-0.072901822	-0.072901822
Sep	-0.038790496	-0.073065814
Oct	-0.017279076	-0.070346037
Nov	-0.009475923	-0.072845511
Dec	-0.009478747	-0.078496811

USA Air Freight		
Month	Six-month Intervention	Full Intervention
Jan		
Feb		
Mar	-204.1253617	-204.1253617
Apr	-311.9748132	-311.9748132
May	-369.3527528	-369.3527528
Jun	-399.6852897	-399.6852897
Jul	-415.688444	-415.688444
Aug	-424.3218933	-424.3218933
Sep	-225.0066238	-428.7451547
Oct	-119.1656201	-430.9561569
Nov	-63.08244678	-432.177981
Dec	-33.33744681	-432.8244828

Intervention Model Results

country	sum of 6-month intervention	sum of full intervention
Passengers_China	-227.4048921	-409.1274399
Passengers_Singapore	-20.23105699	-20.23105699
Passengers_USA	-382.029684	-676.8626459
Freight_China	-0.831512772	-1.593184787
Freight_Singapore	-0.427122514	-0.646852445
Freight_USA	-2565.740692	-3849.85233

Ongoing Study

- Discussion on the model results
- Preparation for paper draft

Thank you

Thank you for listening!

Questions?

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