Toronto HP

Ozel, Sinan

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Price Index (HPI)

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Forecast the

Validation Framework

Framework: Vector AutoRegressive

Forecasts &

Conclusions & Future Work

Toronto Home Price Index A Time Series Analysis

S. Ozel

AISC Time Series Discussion Group, 2021

Outline

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- Purpose: Forecast Home Price Index (HPI) in Toronto by neighborhood.
- Validation: MSE calculated for each time period & neighborhood.
- Benchmark: Moving average return.
- Code: https://github.com/sinan-ozel/toronto-hpi

Home Price Index (HPI)

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Home Price Index

- Based on the sold prices of residential real estate.
- Corrects for the estate's features to make it less volatile, compared to averages.
- https://trreb.ca/index.php/market-news/mls-home-price-index/

Area	Date Type	2020-06-01	2020-07-01	2020-08-01	2020-09-01	2020-10-01	2020-11-01	2020-12-01	2021-01-01	2021-02-01	2021-03-01	2021-04-0
PI Milton	Apartment	287.6	289.8	290.9	287.8	288.9	288.7	NaN	292.4	298.8	306.6	320.2
	Composite	289.5	285.5	289.1	294.5	297.8	301.7	NaN	325.5	341.9	346.0	347.6
	Single-Family Attached	303.2	297.4	303.4	308.9	314.2	320.5	NaN	349.1	367.8	368.1	369.0
	Single-Family Detached	283.2	284.7	287.9	294.2	297.5	301.8	NaN	329.3	346.5	349.4	348.7
	Townhouse	291.9	302.8	309.3	319.3	317.3	319.9	NaN	324.5	344.2	362.5	363.2
Mississauga	Apartment	307.2	308.5	309.4	310.6	308.0	307.1	303.0	302.6	309.2	321.3	329.5
	Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	332.
	Single-Family Attached	275.3	280.0	285.2	288.0	290.1	292.4	295.7	302.7	320.1	333.3	336.
	Single-Family Detached	273.5	278.5	282.9	285.8	287.3	288.8	292.3	300.0	316.3	330.2	334.
	Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	332.
Toronto C1) Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326.
	Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317.
	Single-Family Attached	254.0	271.8	272.2	266.5	262.9	269.3	269.4	279.0	287.9	288.8	292.
	Single-Family Detached	265.6	283.1	282.1	277.2	275.0	278.2	277.1	287.3	295.6	295.3	301
	Townhouse	279.9	279.1	281.8	277.0	282.5	282.2	279.0	266.5	272.5	273.2	284

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Granularity

• Area: Defined by the Toronto Region Real Estate Board (TRREB). (Toronto C10, Mississauga, Milton, etc...)

Type: Housing type

Date: Monthly, first of every month

A	Area	Date Type	2020-06-01	2020-07-01	2020-08-01	2020-09-01	2020-10-01	2020-11-01	2020-12-01	2021-01-01	2021-02-01	2021-03-01	2021-04-0
PI N	Milton	Apartment	287.6	289.8	290.9	287.8	288.9	288.7	NaN	292.4	298.8	306.6	320
		Composite	289.5	285.5	289.1	294.5	297.8	301.7	NaN	325.5	341.9	346.0	34
		Single-Family Attached	303.2	297.4	303.4	308.9	314.2	320.5	NaN	349.1	367.8	368.1	369
		Single-Family Detached	283.2	284.7	287.9	294.2	297.5	301.8	NaN	329.3	346.5	349.4	34
		Townhouse	291.9	302.8	309.3	319.3	317.3	319.9	NaN	324.5	344.2	362.5	36:
N	Mississauga	Apartment	307.2	308.5	309.4	310.6	308.0	307.1	303.0	302.6	309.2	321.3	32
	-	Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	33:
		Single-Family Attached	275.3	280.0	285.2	288.0	290.1	292.4	295.7	302.7	320.1	333.3	33
		Single-Family Detached	273.5	278.5	282.9	285.8	287.3	288.8	292.3	300.0	316.3	330.2	33
		Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	33
Т	Toronto C10	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	32
		Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	31
		Single-Family Attached	254.0	271.8	272.2	266.5	262.9	269.3	269.4	279.0	287.9	288.8	29
		Single-Family Detached	265.6	283.1	282.1	277.2	275.0	278.2	277.1	287.3	295.6	295.3	30
		Townhouse	279.9	279.1	281.8	277.0	282.5	282.2	279.0	266.5	272.5	273.2	28

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Panel Data

- Each panel is an Area x Type pair, i.e. each row in the below table.
- Each panel has either 103 or 69 data points (months)
- We can run multivariate analysis or multiple univariate analyses.

	Area	Date Type	2020-06-01	2020-07-01	2020-08-01	2020-09-01	2020-10-01	2020-11-01	2020-12-01	2021-01-01	2021-02-01	2021-03-01	2021-04-0
IPI	Milton	Apartment	287.6	289.8	290.9	287.8	288.9	288.7	NaN	292.4	298.8	306.6	320.
		Composite	289.5	285.5	289.1	294.5	297.8	301.7	NaN	325.5	341.9	346.0	347.
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		Townhouse	291.9	302.8	309.3	319.3	317.3	319.9	NaN	324.5	344.2	362.5	363
	Mississauga A	Apartment	307.2	308.5	309.4	310.6	308.0	307.1	303.0	302.6	309.2	321.3	329
		Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	332
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		Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	332
	Toronto C10	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326
		Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317
		Single-Family Attached	254.0	271.8	272.2	266.5	262.9	269.3	269.4	279.0	287.9	288.8	29
		Single-Family Detached	265.6	283.1	282.1	277.2	275.0	278.2	277.1	287.3	295.6	295.3	30
		Townhouse	279.9	279.1	281.8	277.0	282.5	282.2	279.0	266.5	272.5	273.2	28

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Forecast HPI

- Come up with the best forecast of HPI possible.
- Refresh knowledge of time series models in the process.
- Present results to spark discussion.

Research Questions

- Can we beat a basic benchmark?
- Which approach will work best?
- Can we develop a better approach?

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A	\rea	Date Type	2020-06-01	2020-07-01	2020-08-01	2020-09-01	2020-10-01	2020-11-01	2020-12-01	2021-01-01	2021-02-01	2021-03-01	2021-04-01
HPI N	Ailton	Apartment	287.6	289.8	290.9	287.8	288.9	288.7	NaN	292.4	298.8	306.6	320.2
		Composite	289.5	285.5	289.1	294.5	297.8	301.7	NaN	325.5	341.9	346.0	347.6
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		Townhouse	291.9	302.8	309.3	319.3	317.3	319.9	NaN	324.5	344.2	362.5	363.2
n.	Aississauga	Apartment	307.2	308.5	309.4	310.6	308.0	307.1	303.0	302.6	309.2	321.3	329.5
		Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	332.6
		Single-Family Attached	275.3	280.0	285.2	288.0	290.1	292.4	295.7	302.7	320.1	333.3	336.5
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		Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	332.2
1	Toronto C10	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326.2
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		Single-Family Attached	254.0	271.8	272.2	266.5	262.9	269.3	269.4	279.0	287.9	288.8	292.2
		Single-Family Detached	265.6	283.1	282.1	277.2	275.0	278.2	277.1	287.3	295.6	295.3	301.8
		Townhouse	279.9	279.1	281.8	277.0	282.5	282.2	279.0	266.5	272.5	273.2	284.8

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Area	Date Type	2020-06-01	2020-07-01	2020-08-01	2020-09-01	2020-10-01	2020-11-01	2020-12-01	2021-01-01	2021-02-01	2021-03-01	2021-04-0
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Mississauga	Apartment	307.2	308.5	309.4	310.6	308.0	307.1	303.0	302.6	309.2	321.3	329
	Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	332
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	Single-Family Attached	254.0	271.8		266.5	262.9	269.3	269.4	279.0	287.9	288.8	292
	Single-Family Detached	265.6	283.1	282.1		275.0	278.2	277.1	287.3	295.6	295.3	301
	Townhouse	279.9		281.8		282.5	282.2	279.0	266.5	272.5	273.2	284

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		Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	332.
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		Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317.
		Single-Family Attached	254.0	271.8		266.5	262.9	269.3	269.4	279.0	287.9	288.8	292.
		Single-Family Detached	265.6	283.1	282.1			278.2	277.1	287.3	295.6	295.3	301.
		Townhouse	279.9		281.8			282.2	279.0	266.5	272.5	273.2	284.

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	Area	Date Type	2020-06-01	2020-07-01	2020-08-01	2020-09-01	2020-10-01	2020-11-01	2020-12-01	2021-01-01	2021-02-01	2021-03-01	2021-04-0
IPI	Milton	Apartment	287.6	289.8	290.9	287.8	288.9	288.7	NaN	292.4	298.8	306.6	320
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		Single-Family Attached	303.2	297.4	303.4	308.9	314.2		NaN	349.1	367.8	368.1	369
		Single-Family Detached	283.2	284.7	287.9	294.2	297.5	301.8	NaN	329.3	346.5	349.4	348
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	Mississauga	Apartment	307.2	308.5	309.4	310.6	308.0	307.1	303.0	302.6	309.2	321.3	329
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		Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	333
	Toronto C10	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326
		Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317
		Single-Family Attached	254.0	271.8		266.5	262.9	269.3	269.4	279.0	287.9	288.8	29
		Single-Family Detached	265.6	283.1	282.1		275.0	278.2	277.1	287.3	295.6	295.3	30
		Townhouse	279.9	279.1	281.8				279.0	266.5	272.5	273.2	284

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	Date	2020-06-01	2020-07-01	2020-08-01	2020-09-01	2020-10-01	2020-11-01	2020-12-01	2021-01-01	2021-02-01	2021-03-01	2021-04-0
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Toronto C1	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326
	Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317
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		Date	2020-06-01	2020-07-01	2020-08-01	2020-09-01	2020-10-01	2020-11-01	2020-12-01	2021-01-01	2021-02-01	2021-03-01	2021-04-01
Area	1	Type											
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		Composite	289.5	285.5	289.1	294.5	297.8	301.7	NaN	325.5	341.9	346.0	347.6
		Single-Family Attached	303.2	297.4	303.4	308.9	314.2	320.5	NaN	349.1	367.8	368.1	369.0
		Single-Family Detached	283.2	284.7	287.9	294.2	297.5	301.8	NaN	329.3	346.5	349.4	348.7
		Townhouse	291.9	302.8	309.3	319.3		319.9	NaN	324.5	344.2	362.5	363.2
Miss	sissauga	Apartment	307.2	308.5	309.4	310.6	308.0	307.1	303.0	302.6	309.2	321.3	329.5
		Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	332.6
		Single-Family Attached	275.3	280.0	285.2	288.0	290.1	292.4	295.7	302.7	320.1	333.3	336.
		Single-Family Detached	273.5	278.5	282.9	285.8	287.3	288.8	292.3	300.0	316.3	330.2	334.
		Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	332
Toro	onto C10	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326.2
		Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317.
		Single-Family Attached	254.0	271.8		266.5	262.9	269.3	269.4	279.0	287.9	288.8	292.
		Single-Family Detached	265.6	283.1	282.1			278.2	277.1	287.3	295.6	295.3	301.
		Townhouse	279.9		281.8			282.2	279.0	266.5	272.5	273.2	284.

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IPI I	Milton	Apartment	287.6	289.8	290.9	287.8	288.9	288.7	NaN	292.4	298.8	306.6	320.
		Composite	289.5	285.5	289.1	294.5	297.8	301.7	NaN	325.5	341.9	346.0	347.
		Single-Family Attached	303.2	297.4	303.4	308.9	314.2	320.5	NaN	349.1	367.8	368.1	369.
		Single-Family Detached	283.2	284.7	287.9	294.2	297.5	301.8	NaN	329.3	346.5	349.4	348.
		Townhouse	291.9	302.8	309.3	319.3	317.3	319.9	NaN	324.5	344.2	362.5	363.
	Mississauga	Apartment	307.2	308.5	309.4	310.6	308.0	307.1	303.0	302.6	309.2	321.3	329.
		Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	332.
		Single-Family Attached	275.3	280.0	285.2	288.0	290.1	292.4	295.7	302.7	320.1	333.3	336.
		Single-Family Detached	273.5	278.5	282.9	285.8	287.3	288.8	292.3	300.0	316.3	330.2	334
		Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	332.
	Toronto C10	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326.
		Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317.
		Single-Family Attached	254.0	271.8		266.5	262.9	269.3	269.4	279.0	287.9	288.8	292
		Single-Family Detached	265.6	283.1	282.1		275.0	278.2	277.1	287.3	295.6	295.3	301
		Townhouse	279.9		281.8				279.0	266.5	272.5	273.2	284

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Area	Type											
PI Milton	Apartment	287.6	289.8	290.9	287.8	288.9	288.7	NaN	292.4	298.8	306.6	320.
	Composite	289.5	285.5	289.1	294.5	297.8	301.7	NaN	325.5	341.9	346.0	347.
	Single-Family Attached	303.2	297.4	303.4	308.9	314.2	320.5	NaN	349.1	367.8	368.1	369.
	Single-Family Detached	283.2	284.7	287.9	294.2	297.5	301.8	NaN	329.3	346.5	349.4	348.
	Townhouse	291.9	302.8	309.3	319.3	317.3	319.9	NaN	324.5	344.2	362.5	363.
Mississauga	Apartment	307.2	308.5	309.4	310.6	308.0	307.1	303.0	302.6	309.2	321.3	329
	Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	332
	Single-Family Attached	275.3	280.0	285.2	288.0	290.1	292.4	295.7	302.7	320.1	333.3	336
	Single-Family Detached	273.5	278.5	282.9	285.8	287.3	288.8	292.3	300.0	316.3	330.2	334
	Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	332
Toronto C10	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326
	Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317
	Single-Family Attached	254.0	271.8		266.5	262.9	269.3	269.4	279.0	287.9	288.8	292
	Single-Family Detached	265.6	283.1	282.1		275.0	278.2		287.3	295.6	295.3	303
	Townhouse	279.9	279.1	281.8			282.2		266.5	272.5	273.2	284

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HPI I	Milton	Apartment	287.6	289.8	290.9	287.8				292.4	298.8	306.6	320.2
		Composite	289.5	285.5	289.1		297.8		NaN		341.9	346.0	347.6
		Single-Family Attached	303.2	297.4	303.4	308.9			NaN		367.8	368.1	369.0
		Single-Family Detached	283.2	284.7	287.9			301.8	NaN		346.5	349.4	348.7
		Townhouse	291.9	302.8	309.3	319.3	317.3	319.9	NaN	324.5	344.2	362.5	363.2
	Mississauga	Apartment	307.2	308.5	309.4	310.6		307.1	303.0	302.6	309.2	321.3	329.5
		Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	332.6
		Single-Family Attached	275.3	280.0	285.2	288.0	290.1	292.4	295.7	302.7	320.1	333.3	336.5
		Single-Family Detached	273.5	278.5	282.9	285.8	287.3	288.8	292.3	300.0	316.3	330.2	334.9
		Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	332.2
	Toronto C10	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326.2
		Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317.0
		Single-Family Attached	254.0	271.8	272.2	266.5	262.9	269.3	269.4	279.0	287.9	288.8	292.2
		Single-Family Detached	265.6	283.1	282.1		275.0	278.2		287.3	295.6	295.3	301.8
		Townhouse	279.9	279.1	281.8						272.5	273.2	284.8

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IPI Milton	Apartment	287.6	289.8	290.9	287.8	288.9	288.7	NaN	292.4	298.8	306.6	320.
	Composite	289.5	285.5	289.1	294.5	297.8	301.7	NaN	325.5	341.9	346.0	347.
	Single-Family Attached	303.2	297.4	303.4	308.9	314.2	320.5	NaN	349.1	367.8	368.1	369.
	Single-Family Detached	283.2	284.7	287.9	294.2	297.5	301.8	NaN	329.3	346.5	349.4	348.
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Mississauga	Apartment	307.2	308.5	309.4	310.6	308.0	307.1	303.0	302.6	309.2	321.3	329.
	Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	332
	Single-Family Attached	275.3	280.0	285.2	288.0	290.1	292.4	295.7	302.7	320.1	333.3	336
	Single-Family Detached	273.5	278.5	282.9	285.8	287.3	288.8	292.3	300.0	316.3	330.2	334
	Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	332
Toronto C10	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326
	Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317
	Single-Family Attached	254.0	271.8		266.5	262.9	269.3	269.4	279.0	287.9	288.8	292
	Single-Family Detached	265.6	283.1	282.1		275.0	278.2		287.3	295.6	295.3	301
	Townhouse	279.9		281.8		282.5	282.2		266.5	272.5	273.2	284

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Area	Date Type	2020-06-01	2020-07-01	2020-08-01	2020-09-01		2020-11-01	2020-12-01		2021-02-01	2021-03-01	2021-04-01
PI Milton	Apartment	287.6					288.7	NaN	292.4	298.8	306.6	320.2
	Composite	289.5	285.5	289.1	294.5	297.8	301.7	NaN	325.5	341.9	346.0	347.6
	Single-Family Attached	303.2	297.4	303.4	308.9	314.2	320.5	NaN	349.1	367.8	368.1	369.0
	Single-Family Detached	283.2	284.7	287.9	294.2	297.5	301.8	NaN	329.3	346.5	349.4	348.7
	Townhouse	291.9	302.8	309.3	319.3	317.3	319.9	NaN	324.5	344.2	362.5	363.2
Mississauga	Apartment	307.2	308.5	309.4	310.6	308.0	307.1	303.0	302.6	309.2	321.3	329.
	Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	332.
	Single-Family Attached	275.3	280.0	285.2	288.0	290.1	292.4	295.7	302.7	320.1	333.3	336.
	Single-Family Detached	273.5	278.5	282.9	285.8	287.3	288.8	292.3	300.0	316.3	330.2	334.
	Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	332.
Toronto C10	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326.
	Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317.
	Single-Family Attached	254.0	271.8		266.5	262.9	269.3	269.4	279.0	287.9	288.8	292.
	Single-Family Detached	265.6	283.1	282.1		275.0	278.2	277.1	287.3	295.6	295.3	301.
	Townhouse	279.9		281.8			282.2	279.0		272.5	273.2	284

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HPI 1	Milton	Apartment	287.6	289.8	290.9			288.7	NaN	292.4	298.8	306.6	320.
		Composite	289.5	285.5			297.8		NaN	325.5	341.9	346.0	347
		Single-Family Attached	303.2	297.4	303.4	308.9	314.2		NaN	349.1	367.8	368.1	369
		Single-Family Detached	283.2	284.7	287.9				NaN	329.3	346.5	349.4	348
		Townhouse	291.9	302.8	309.3	319.3	317.3		NaN	324.5	344.2	362.5	363
	Mississauga	Apartment	307.2	308.5	309.4	310.6		307.1	303.0	302.6	309.2	321.3	329
		Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	332
		Single-Family Attached	275.3	280.0	285.2	288.0	290.1	292.4	295.7	302.7		333.3	336
		Single-Family Detached	273.5	278.5	282.9	285.8	287.3	288.8	292.3	300.0	316.3	330.2	334
		Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8		326.7	332
	Toronto C10	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326
		Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317
		Single-Family Attached	254.0	271.8		266.5	262.9	269.3	269.4	279.0	287.9	288.8	29
		Single-Family Detached	265.6	283.1	282.1		275.0	278.2	277.1	287.3	295.6	295.3	30
		Townhouse	279.9	279.1	281.8				279.0	266.5	272.5	273.2	28

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HPI	Milton	Apartment	287.6	289.8	290.9	287.8	288.9	288.7	NaN	292.4	298.8	306.6	320.
		Composite	289.5	285.5	289.1	294.5	297.8	301.7	NaN	325.5	341.9	346.0	347.
		Single-Family Attached	303.2	297.4	303.4	308.9	314.2	320.5	NaN	349.1	367.8	368.1	369.
		Single-Family Detached	283.2	284.7	287.9	294.2	297.5	301.8	NaN	329.3	346.5	349.4	348.
		Townhouse	291.9	302.8	309.3	319.3	317.3	319.9	NaN	324.5	344.2	362.5	363
	Mississauga	Apartment	307.2	308.5	309.4	310.6	308.0	307.1	303.0	302.6	309.2	321.3	329
		Composite	287.4	291.1	294.3	296.0	295.8	296.2	296.9	301.5	313.8	327.0	332
		Single-Family Attached	275.3	280.0	285.2	288.0	290.1	292.4	295.7	302.7	320.1		336
		Single-Family Detached	273.5	278.5	282.9	285.8	287.3	288.8	292.3	300.0	316.3	330.2	334
		Townhouse	288.2	294.7	298.8	298.8	298.0	297.9	299.2	301.8	312.7	326.7	333
	Toronto C10	Apartment	315.5	307.4	306.7	305.6	302.1	305.0	303.0	298.9	305.6	313.8	326
		Composite	299.4	298.5	297.8	295.6	292.7	295.7	294.0	293.3	300.5	306.1	317
		Single-Family Attached	254.0	271.8	272.2	266.5	262.9	269.3	269.4	279.0	287.9	288.8	292
		Single-Family Detached	265.6	283.1	282.1		275.0	278.2		287.3	295.6	295.3	30
		Townhouse	279.9	279.1	281.8		282.5	282.2	279.0	266.5	272.5		28

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AR(2) Model

I start with the AR(2) model.

$$Y_t = \beta_0 + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \epsilon_t$$

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AR(2) Model on One Panel

I added the subscript 1 to show that this is one panel.

$$Y_{1,t} = \beta_0 + \beta_{1,1} Y_{1,t-1} + \beta_{1,2} Y_{1,t-2} + \epsilon_t$$

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AR(2) Model on One Panel

Now I added two more terms from <u>another</u> panel.

$$Y_{1,t} = \beta_0 + \beta_{1,1} Y_{1,t-1} + \beta_{1,2} Y_{1,t-2} + \beta_{2,1} Y_{2,t-1} + \beta_{2,2} Y_{2,t-2} + \epsilon_t$$

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VAR(2) Model on Two Panels

Finally, I do the same for Panel 2.

$$Y_{1,t} = \beta_0 + \beta_{11,1} Y_{1,t-1} + \beta_{11,2} Y_{1,t-2} + \beta_{12,1} Y_{2,t-1} + \beta_{12,2} Y_{2,t-2} + \epsilon_{1,t}$$

$$Y_{2,t} = \beta_0 + \beta_{21,1} Y_{1,t-1} + \beta_{21,2} Y_{1,t-2} + \beta_{22,1} Y_{2,t-1} + \beta_{22,2} Y_{2,t-2} + \epsilon_{2,t}$$

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- Why not: we have additional data, so why not use it?
- Explanatory power: Impulse Response Functions (IRF)
- Granger Causality

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- Explanatory power: Impulse Response Functions (IRF)
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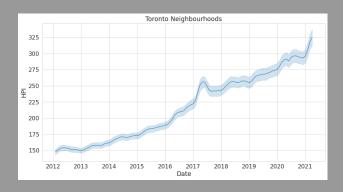
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- Visually, it is clear that the panels are not stationary.
- For each panel, I run the Augmented Dickey-Fuller test
- I reject non-stationarity for over 99% of the panels.

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- I reject non-stationarity for over 99% of the panels

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Introductio

Data: Hom Price Index (HPI)

Problem Statement: Forecast the HPI

Validation Framework

Model Framework: Vector AutoRegressive (VAR)

Forecasts &

Conclusions & Future Work

- Visually, it is clear that the panels are not stationary.
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Differencing & Percent Changes

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Differencing

$$\Delta Y_t = Y_t - Y_{t-1}$$

Percent Changes, i.e. "Returns"

$$r_t = \frac{Y_t - Y_{t-1}}{Y_{t-1}} \approx \log Y_t - \log Y_{t-1}$$

Justification for Percent Changes

- Easier to interpret
- Easier to discuss with stakeholders and laypeople
- Normalizes the amount of change to each period.

Differencing & Percent Changes

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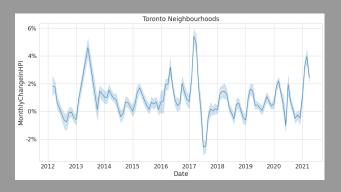
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A Good Example

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Data: Homo Price Index (HPI)

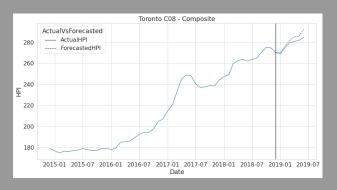
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Too Good An Example (To Be True)

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Looks good, but...

- This only works this well when trained from 2014 Dec to 2018 Dec & validated against 2019 Jan to 2019 Jun.
- ... hence my justification for the "rolling window" validation.
- If we modelled on the right date (July 2019), we would "believe" in our model, but only by mistake.

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Conclusions & Future Work "Return" Moving Average

- Obtain the return.
- Calculate the moving average over the rolling window.
- Use this return to forecast the next month.
- Use exponential growth formula to obtain a forecast for n months into the future.

Average "Return"

$$r_t = \frac{Y_t - Y_{t-1}}{Y_{t-1}}$$

1-month forecast

$$\hat{r}_{t+1} = \sum_{t=T}^{t} r_t / T$$

$$\hat{r}_{t+n} = (1 + \hat{r}_{t+1})^n - 1$$

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MSE: Benchmark vs VAR model

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Introduction

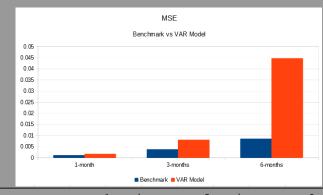
Data: Home Price Index (HPI)

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Forecasts & Validation



	1-month	3-months	6-months
Benchmark	0.001016761439712	0.00366345390135	0.008432082243063
VAR Model	0.001587714029696	0.007939166535112	0.044613766619586

Conclusions & Final Thoughts

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- VAR for explainability: IRF

Conclusions & Final Thoughts

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Future Work

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Forecasts &

Conclusions & Future Work I would like to repeat the work with the following sets of models:

- ARMA and derivative models (ARIMA, ARIMAX, etc...)
- VECM
- ARCH & GARCH models
- LSTM networks
- Idea: A bootstrapping of VAR models with different sets of neighbourhoods and years.