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Mortality Granger-Causality

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Outline of Presentation

1. Motivation.
2. Data Collection Exercise (Asia-Pacific).
3. Methodology.
4. Descriptive Statistics.
5. Results.
6. Why Longevity Risk Transfer makes sense?
7. Conclusion.

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1. Motivation

- Emerging countries may be lagging behind increases in longevity risk compared to more developed countries.
- However, they may be lagging in predictable ways. Granger causality can reveal such lead-lag relationships.
- Bivariate Granger-causality allows us to establish predictive relationships between pairs of time-series data.
- Predictive relationships established through Granger-causality analysis on *mortality* time-series data, could provide incentives for risk sharing opportunities.
- These incentives will emerge through the direction of the predictability established (positive/negative).

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1. Motivation

- We focus on an unexplored geographic region in terms of mortality/longevity risk: Asia-Pacific (APAC).
- APAC has ample heterogeneity across countries (but also within countries: Biffis, Lin and Milidonis (2014)).
- Analysis conducted on APAC and Western countries.
- High Insurance growth and low penetration in APAC, provides longevity risk sharing opportunities.

2. Data Collection Exercise: Target Countries in APAC

	DEVELOPED			REGION				
Country	Yes	Less	Least	Australia /New Zealand	Melanesia	Eastern Asia	South-Central Asia	South-Eastern Asia
Australia	√			√				
Bangladesh			√				√	
China		√				√		
Hong Kong		√				√		
India		√					√	
Indonesia		√						√
Japan	√					√		
Laos			√					√
Malaysia		√						√
Myanmar			√					√
Nepal			√				√	

2. Data Collection Exercise: Target Countries in APAC

Country	DEVELOPED			REGION				
	Yes	Less	Least	Australia /New Zealand	Melanesia	Eastern Asia	South-Central Asia	South-Eastern Asia
New Zealand	√			√				
Pakistan		√					√	
Papua New Guinea		√			√			
Philippines		√						√
South Korea		√				√		
Singapore		√						√
Sri Lanka		√					√	
Taiwan	√					√		
Thailand		√						√
Vietnam		√						√

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2. Data Collection Exercise

- **Main Data objective**: APAC mortality data collection **in a consistent, transparent, replicable manner.**
- Identified data sources from academic & industry papers:
  - Journal of Risk and Insurance
  - Insurance, Mathematics and Economics
  - ASTIN Bulletin
  - North American Actuarial Journal
  - Scandinavian Actuarial Journal
  - Presentations from the International Longevity Risk and Capital Market Solutions Conferences 2011-2013
- Keywords used:
  - "mortality" or "longevity", "data", "country name"

2. Data Collection Exercise: Mortality Data Sources

- A bit over 200 papers/presentations identified.
  - 74 papers used APAC data
  - 34 papers used APAC data that were not on HMD and HLT.
  - APAC data (non-HMD non-HLT) used: not available.
- Main data sources (additional to HMD and HLT)
  - *Department of Statistics,*
  - *Ministry of Health,*
  - *Statistical Yearbooks, Censuses (for each country)*
  - *Sample registration system (SRS) – India*
  - *World Bank*

2. Data Collection Exercise: Mortality Data Sources

- Other data sources:
  - *Vital Registration systems*
  - *Population studies journal*
  - *Measure DHS (Demographic and health surveys)*
  - *Global Health Data Exchange*
  - *World Health Organisation (WHO)*
  - *CEIC database*
  - *International Database on Longevity (IDL)*
  - *Datastream*
  - *OECD*

2. Data Collection Exercise: Output

- Resulted in 2 databases, and two separate projects:

1. **A**sia-**P**acific **A**ggregate (**APA**) Mortality Database
   - *Milidonis and Efthymiou, 2014*

2. **A**sia-**P**acific **A**ge-**G**ender (**APAG**) Mortality Database
   - Biffis, Lin & Milidonis, 2014

- Both databases freely available for future research from the **Insurance Risk & Finance Research Centre, Nanyang Business School, NTU**.

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3. Methodology - APA

- Mortality data (death rates) are not stationary.
- Hence a transformation is needed.
- To obtain stationarity we use

  – First difference: $CDR_t - CDR_{t-1}$

  – **Log of ratio of mortality rates:**

$$\log\left(CDR_t / CDR_{t-1}\right)$$

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3. Methodology: Lead-Lag

- **Bivariate Granger Causality**

- ΔA_t : logarithmic change in mortality of country A, on year *t*.
- ΔB_t : logarithmic change in mortality of country B, on year *t*.

Do lagged changes in B help predict current changes in A?

$$\Delta A_t = c_1 + \sum_{k=1}^{5} a_k \, \Delta A_{t-k} + g_t \quad (1)$$

$$\Delta A_t = c_2 + \sum_{k=1}^{5} a_k \, \Delta A_{t-k} + \sum_{k=1}^{5} b_k \Delta B_{t-k} + g_t \quad (2)$$

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3. Methodology: Lead-Lag

- **Bivariate Granger Causality**

  Do lagged changes in B help predict current changes in A?

$$\Delta A_t = c_1 + \sum_{k=1}^{5} a_k \, \Delta A_{t-k} + g_t \qquad (1)$$

$$\Delta A_t = c_2 + \sum_{k=1}^{5} a_k \, \Delta A_{t-k} + \sum_{k=1}^{5} b_k \Delta B_{t-k} + g_t \qquad (2)$$

$$S = (RSS_0 - RSS_1)\, p \,/\, RSS_1 (T - 2p - 1) \sim F_{p,T-2p-1} \qquad (3)$$

RSS_0 : Residual Sum of Squares of model (1)

RSS_1 : Residual Sum of Squares of model (2)

p : Number of lags used

T : Number of observations

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3. Methodology: Lead-Lag

- **Bivariate Granger Causality – Reverse Relation**

  Do lagged changes in A help predict current changes in B?

$$\Delta B_t = c_1 + \sum_{k=1}^{5} a_k \, \Delta B_{t-k} + g_t \qquad (4)$$

$$\Delta B_t = c_2 + \sum_{k=1}^{5} a_k \, \Delta B_{t-k} + \sum_{k=1}^{5} b_k \Delta A_{t-k} + g_t \qquad (5)$$

$$S = (RSS_0 - RSS_1)\, p \,/\, RSS_1 (T - 2p - 1) \sim F_{p,T-2p-1} \qquad (6)$$

RSS_0 : Residual Sum of Squares of model (4)

RSS_1 : Residual Sum of Squares of model (5)

p : Number of lags used

T : Number of observations

4. Descriptive Statistics: APA Mortality Database

- Aggregate Population mortality.
- Crude death rates.
- Target: largest 21 APAC countries.
- Data identified and collected on 11 countries.
- Annual frequency.
- Earliest year in the sample: 1896 (Japan).
- Analysis focused on 1950 onwards.

*We also use one age group from APAG (males age 60) as an example for age-specific analysis (back-up slides).

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4. Descriptive Statistics: Sample

Region	Country	Code	Population (million)	% of World population
APAC	Australia	AUS	23	0.3%
	China	CHN	1,351	18.8%
	Hong Kong	HKG	7	0.1%
	India	IND	1,237	17.2%
	Japan	JPN	128	1.8%
	Republic of Korea	KOR	50	0.7%
	New Zealand	NZL	4	0.1%
	Philippines	PHL	97	1.3%
	Singapore	SGP	5	0.1%
	Sri Lanka	SLK	20	0.3%
	Taiwan	TWN	23	0.3%
Rest of Sample	Canada	CAN	35	0.5%
	France	FRA	66	0.9%
	Germany	GER	82	1.1%
	United Kingdom	UK	63	0.9%
	United States of America	USA	314	4.4%
	Total		3,505	48.8%

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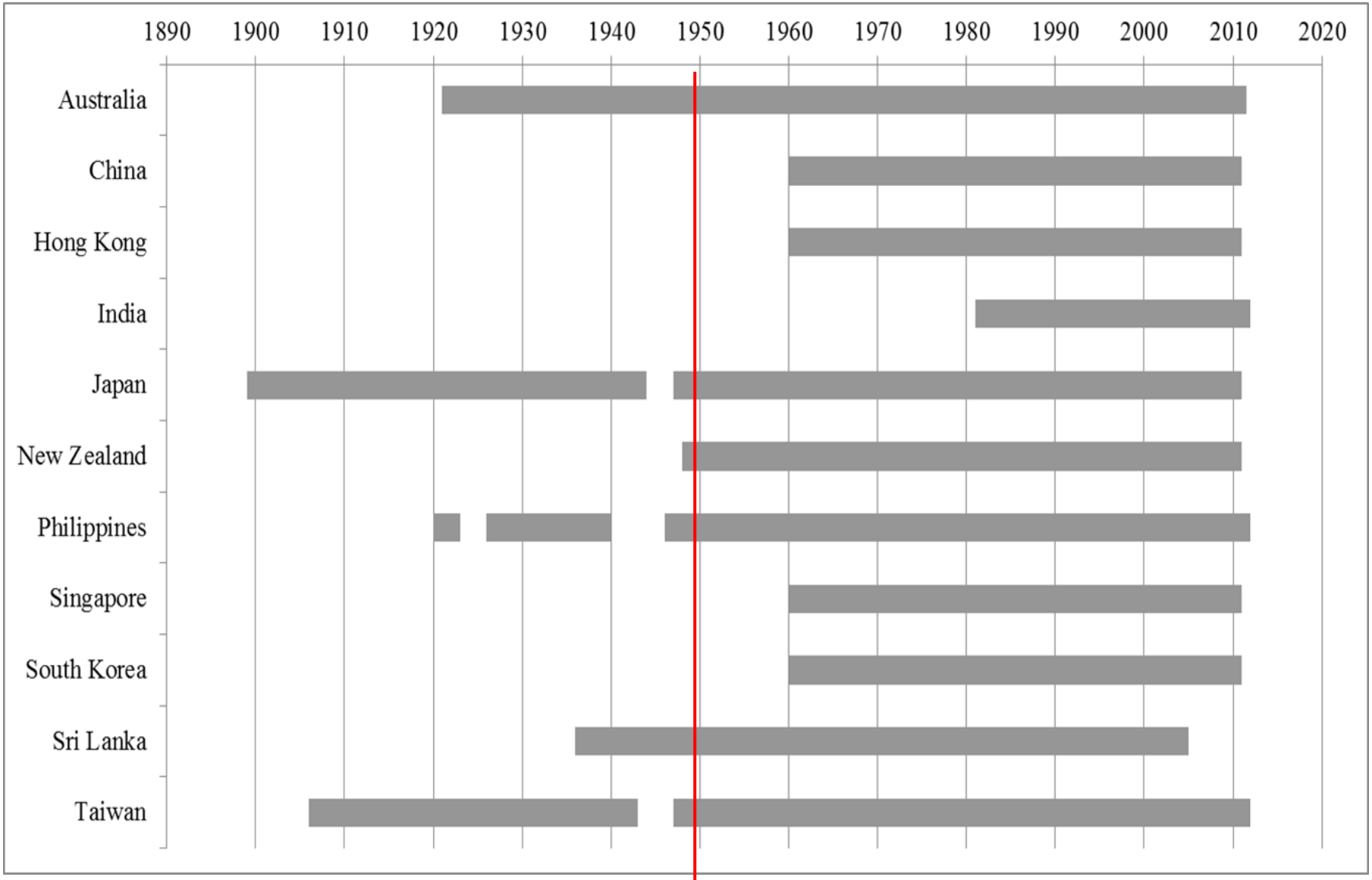
4. Descriptive Statistics: APA Mortality Database



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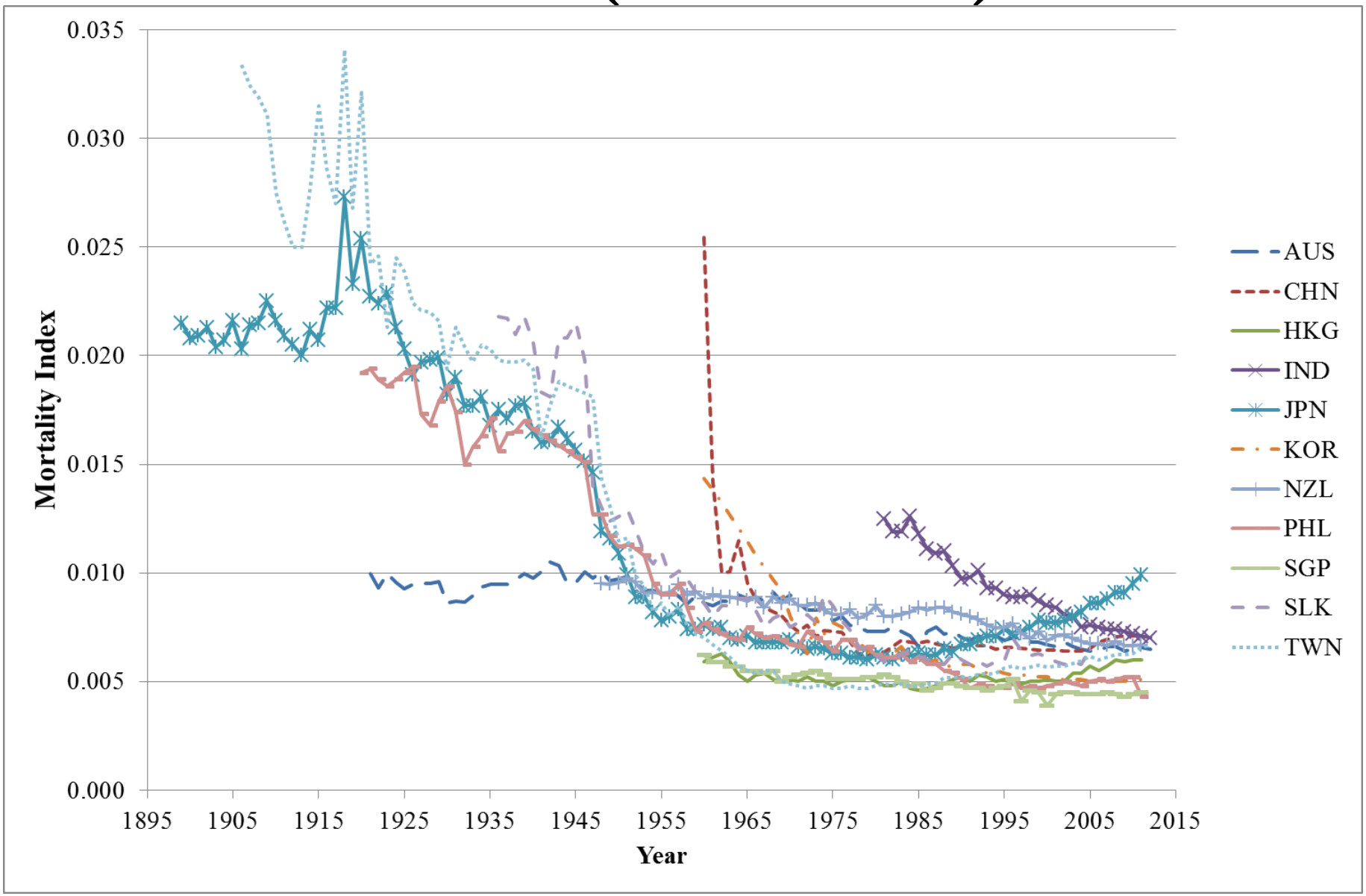
4. Mortality Indices-APA (1890 - 2012)



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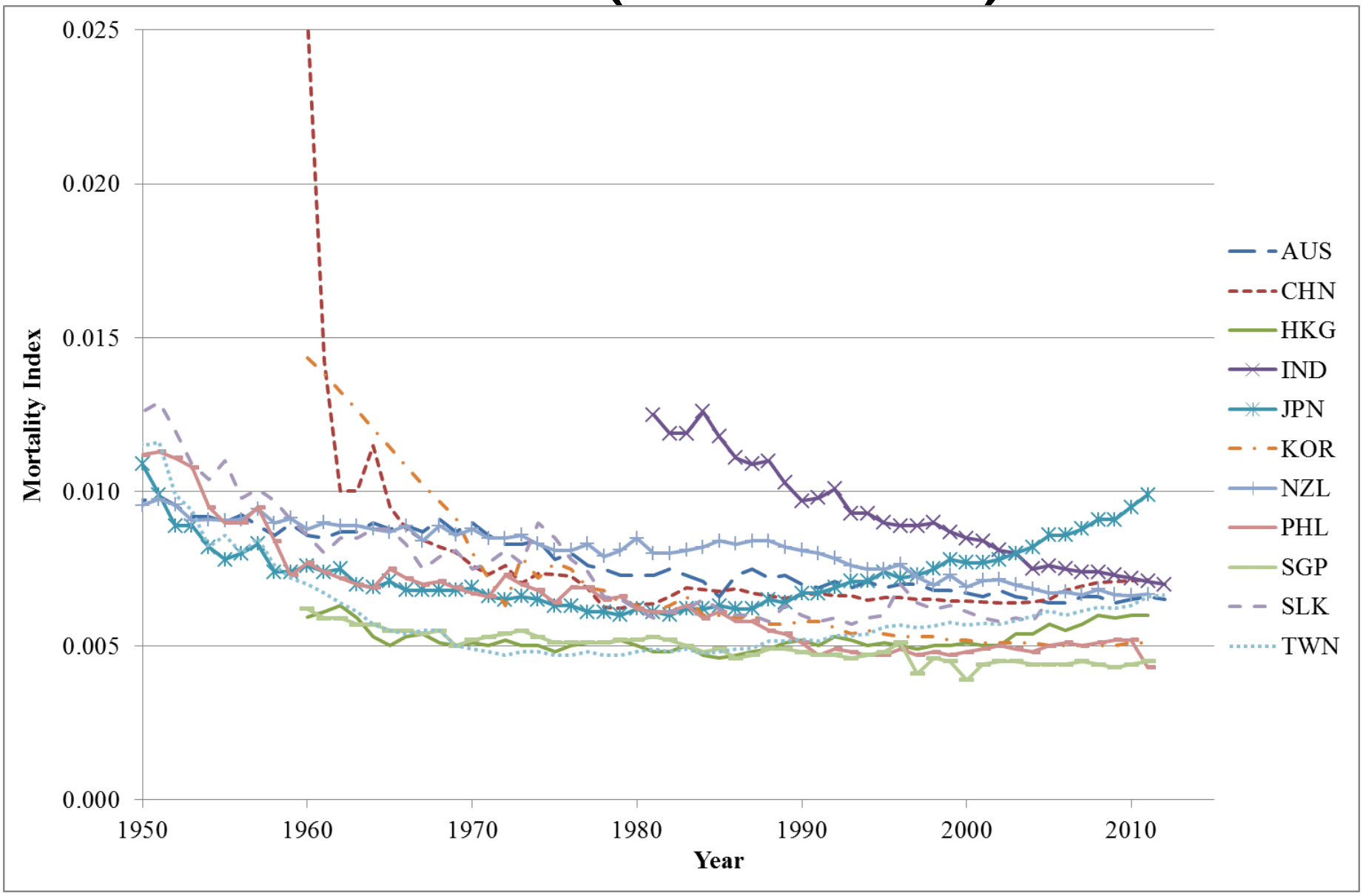
4. Mortality Indices-APA (1950 - 2012)



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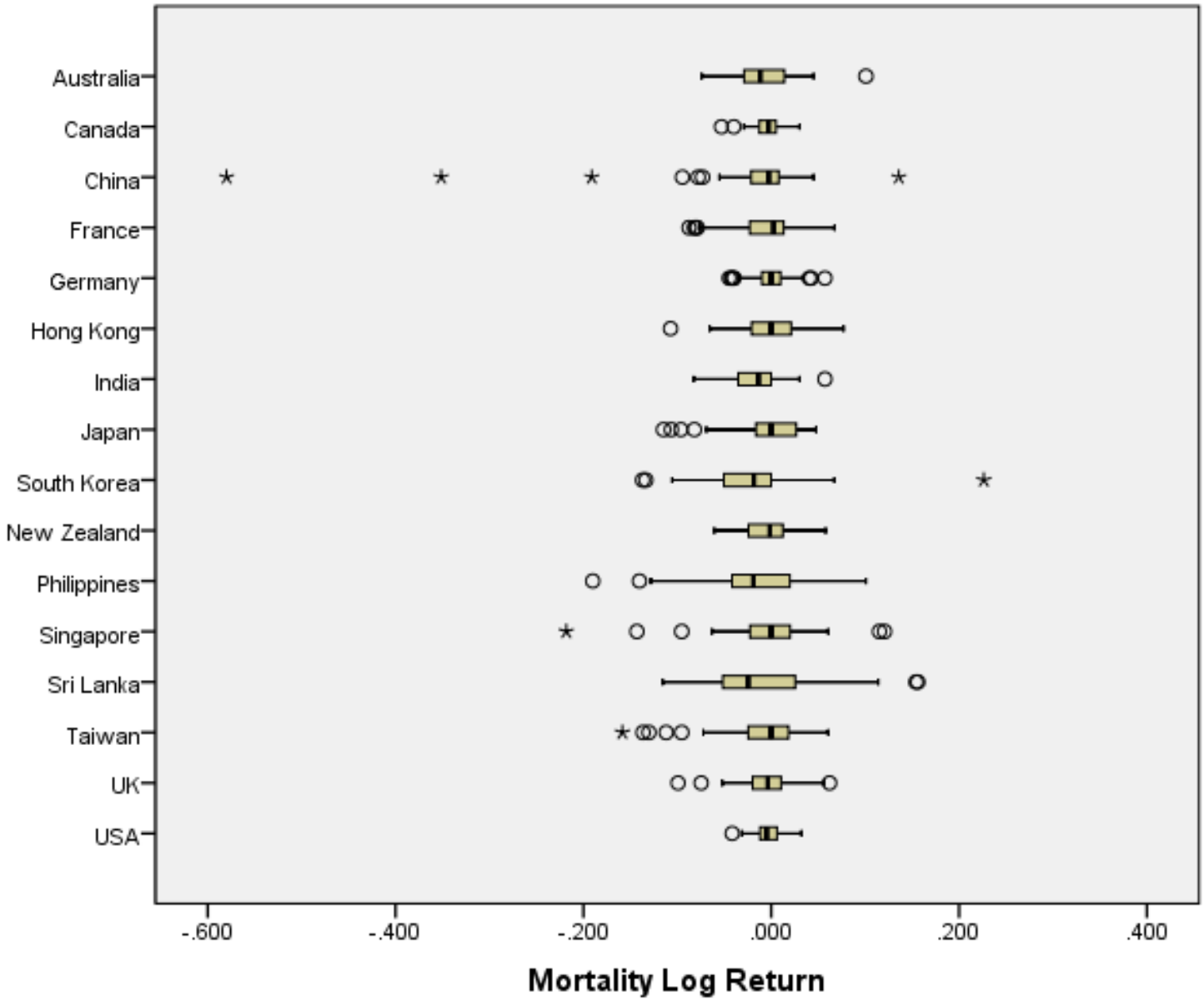
4. Log Mortality Returns - APA



4. Spearman Correlations – APA

	CAN	CHN	FRA	GER	HKG	IND	JPN	KOR	NZL	PHL	SGP	SLK	TWN	UK	USA
AUS	0.17	0.03	-0.19	-0.15	0.05	-0.05	-0.06	0.08	0.26	-0.05	0.19	0.14	-0.01	-0.01	-0.06
CAN		0.219	0.268	0.265	0.015	-0.09	0.438	0.034	0.24	0.057	0.162	0.254	0.358	0.389	0.471
CHN			-0.08	0.09	-0.01	-0.10	0.20	0.31	-0.05	0.16	-0.07	0.29	0.21	-0.16	-0.04
FRA				0.64	-0.03	0.04	0.32	0.06	-0.18	0.19	-0.04	0.03	0.13	0.38	0.41
GER					-0.01	-0.21	0.28	0.11	-0.02	0.13	0.07	-0.03	0.04	0.26	0.48
HKG						0.04	0.22	0.02	0.02	0.24	0.09	0.01	0.34	0.17	0.10
IND							0.16	-0.22	0.00	0.13	0.11	0.27	0.12	-0.19	0.03
JPN								0.30	0.08	0.20	0.16	-0.02	0.50	-0.08	0.39
KOR									-0.10	-0.02	0.01	-0.14	0.28	-0.20	-0.05
NZL										0.11	0.28	0.11	0.17	0.16	0.29
PHL											0.25	0.29	0.17	0.04	0.22
SGP												0.08	0.37	0.03	0.14
SLK													0.22	0.05	0.13
TWN														-0.12	0.21
UK															0.40

Statistical Significance denoted at 5% (shaded).

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5. Results

Granger-Causality (APA)

Examples

5. Granger-Causality (APA)
Country B predicts Country A

A	B	1 LAG			2 LAGS			3 LAGS			4 LAGS			5 LAGS		
		N	Test	P	N	Test	P	N	Test	P	N	Test	P	N	Test	P
GER	JPN				59	4.21	0.02									
GER	KOR															
GER	TWN										58	3.59	0.01	57	2.49	0.05
GER	USA	59	5.91	0.02	58	4.99	0.01	57	3.86	0.02	56	3.25	0.02			
HKG	UK							48	4.47	0.01						
IND	KOR	29	10.70	0.00	28	7.03	0.00									
IND	UK															
JPN	SLK															
JPN	TWN				60	9.50	0.00	59	3.15	0.03						
JPN	UK													57	5.29	0.00
JPN	USA	60	7.08	0.01	59	3.94	0.03	58	4.77	0.01	57	3.93	0.01	56	2.87	0.03

5. Granger-Causality (APA)
Country A predicts Country B

A	B	1 LAG			2 LAGS			3 LAGS			4 LAGS			5 LAGS		
		N	Test	P	N	Test	P	N	Test	P	N	Test	P	N	Test	P
GER	JPN	60	8.87	0.00	59	3.75	0.03	58	4.51	0.01	57	3.58	0.01			
GER	KOR										47	3.46	0.02			
GER	TWN	61	7.59	0.01							58	2.92	0.03			
GER	USA															
HKG	UK															
IND	KOR	29	6.70	0.02												
IND	UK	29	5.23	0.03												
JPN	SLK	55	5.09	0.03												
JPN	TWN	61	7.84	0.01	60	3.30	0.04									
JPN	UK													57	2.75	0.03
JPN	USA													56	2.07	0.09

5. Granger-Causality (APA)
Country B predicts Country A

A	B	1 LAG			2 LAGS			3 LAGS			4 LAGS			5 LAGS		
		N	Test	P	N	Test	P	N	Test	P	N	Test	P	N	Test	P
KOR	SGP							48	3.13	0.04						
KOR	SLK															
KOR	TWN	50	4.18	0.05	49	4.42	0.02	48	3.76	0.02	47	4.77	0.00			
NZL	SGP															
SGP	SLK	44	11.56	0.00	43	4.54	0.02	42	3.15	0.04						
SGP	USA															
TWN	UK	61	3.06	0.09				59	3.15	0.03	58	3.49	0.01			
TWN	USA	60	6.28	0.02	59	3.65	0.03									

5. Granger-Causality (APA)
Country A predicts Country B

A	B	1 LAG			2 LAGS			3 LAGS			4 LAGS			5 LAGS		
		N	Test	P	N	Test	P	N	Test	P	N	Test	P	N	Test	P
KOR	SGP															
KOR	SLK							42	3.28	0.03						
KOR	TWN															
NZL	SGP	50	6.10	0.02												
SGP	SLK															
SGP	USA							47	3.22	0.03						
TWN	UK															
TWN	USA															

5. Granger-Causality (APA)

Example: Taiwan predicts Korea

A	B	Variable	1 LAG		2 LAGS		3 LAGS		4 LAGS	
			Est	P	Est	P	Est	P	Est	P
KOR	TWN	Intercept	-0.02	0.01	-0.02	0.01	-0.03	0.01	-0.03	0.01
KOR	TWN	KOR-1st lag	-0.23	0.11	-0.28	0.06	**-0.34**	0.04	**-0.32**	0.05
KOR	TWN	TWN-1st lag	**0.58**	0.05	0.36	0.24	0.36	0.25	0.55	0.08
KOR	TWN	KOR-2nd lag			0.04	0.78	-0.05	0.76	0.08	0.64
KOR	TWN	TWN-2nd lag			**0.71**	0.02	**0.74**	0.02	**0.76**	0.01
KOR	TWN	KOR-3rd lag					-0.17	0.27	-0.11	0.47
KOR	TWN	TWN-3rd lag					0.44	0.16	0.60	0.06
KOR	TWN	KOR-4th lag							-0.09	0.52
KOR	TWN	TWN-4th lag							**-0.71**	0.03

5. Granger-Causality (APA)

Example: Sri Lanka predicts Singapore

A	B	Variable	1 LAG		2 LAGS		3 LAGS	
			Est	P	Est	P	Est	P
SGP	SLK	Intercept	-0.01	0.06	-0.02	0.03	-0.02	0.05
SGP	SLK	SGP-1st lag	**-0.38**	0.00	**-0.54**	0.00	**-0.52**	0.00
SGP	SLK	SLK-1st lag	**-0.40**	0.00	**-0.36**	0.00	**-0.38**	0.01
SGP	SLK	SGP-2nd lag			-0.26	0.07	-0.25	0.22
SGP	SLK	SLK-2nd lag			-0.07	0.59	-0.11	0.45
SGP	SLK	SGP-3rd lag					0.13	0.42
SGP	SLK	SLK-3rd lag					-0.10	0.45

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6. Why does Longevity Risk Transfer make sense?

Results show predictability from Country A to B.

- **Risk-increasing cases**: **Positive** parameter estimates
  - Use the predictability for forecasting Country B's exposures

- **Risk-decreasing cases**: **Negative** parameter estimates
  - **Assume:** pension plan in countries A and B.
  - Hence set up a **forward contract on A' mortality index**
  - **A** has incentive to **go short on A's mortality** index.
  - **B** has incentive to **go long on A's mortality** index.

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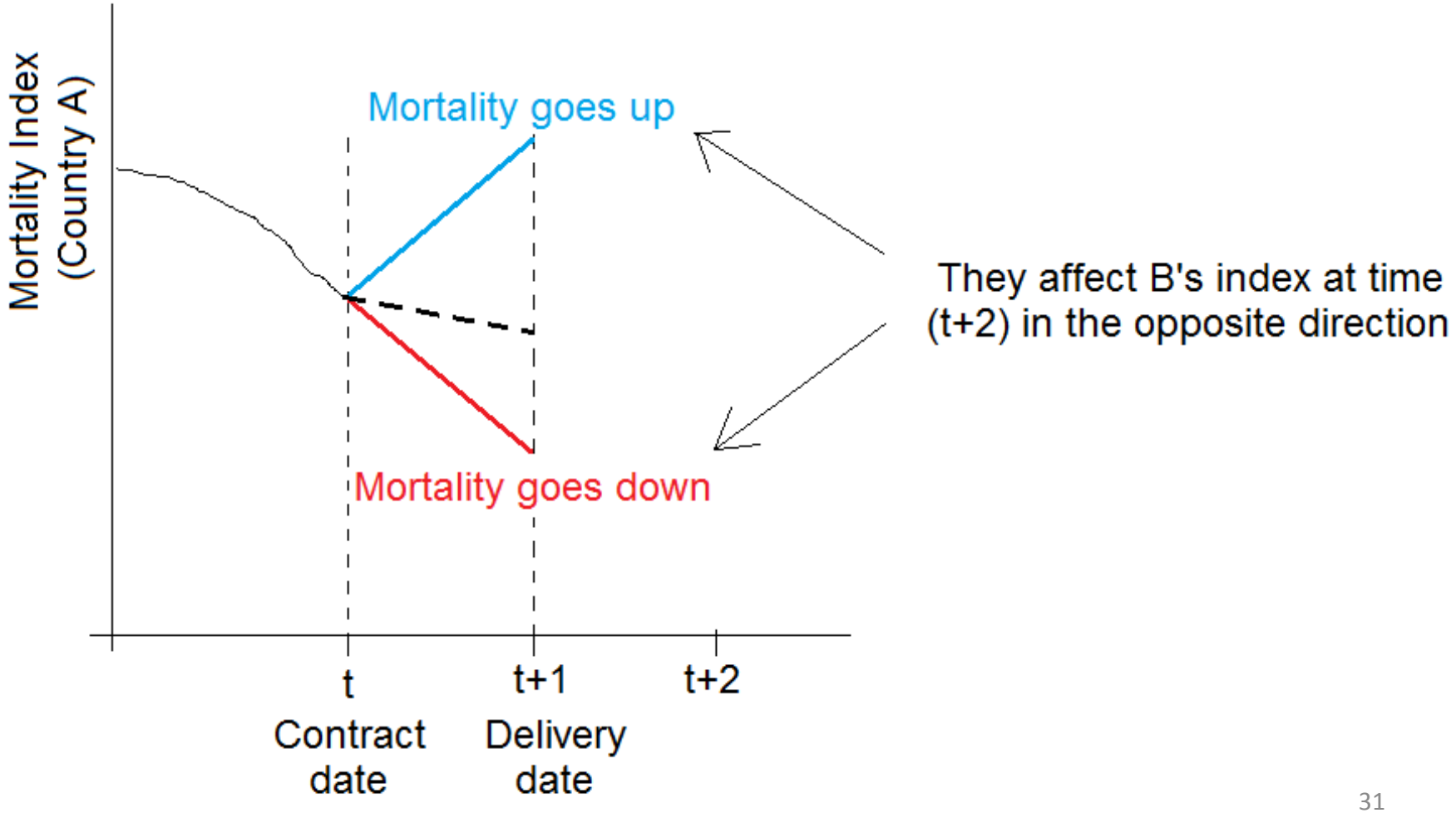
6. Why does Longevity Risk Transfer make sense?

- **Intuitive Example**:
  - Countries A and B want to hedge pension liability risk.
  - Forward contract on A's mortality index, one year ahead.
  - Hence, A and B agree at time ***t*** about a trade at time ***(t+1)***.
  - **B** promises **at *t*** to buy (long) the index at agreed price **q(t+1)**.
  - **A** promises **at *t*** to sell (short) the index at agreed price **q(t+1)**.
  - **A's q(t+1)** predicts **B's q(t+2)** with a negative coefficient.

6. Why does Longevity Risk Transfer make sense?

- **Intuitive Example:**



6. Why does Longevity Risk Transfer make sense?

A's Index	Instrument	B (long)	A (short)
Up	**Pensions:**	More at (t+2)	Less at (t+1)
	Forward:	Gain	Loss
Down	**Pensions:**	Less at (t+2)	More at (t+1)
	Forward:	Loss	Gain

For simplicity we assume 0% interest.

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7. Conclusion

- We use Granger-causality analysis in a multi-population setting.
- Data collection on APAC mortality resulted in a rich, unique dataset of 11 countries.
- Analysis conducted in relation to other western countries.
- Identified significant predictability relationships among pairs of countries.
- Proposed longevity risk forward contracts based predictability relationships established.

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Feedback welcome:

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Back-up Slides

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2nd Database: APAG Mortality Database

For ease of reference the following color representations are used:

- HMD
- HLT
- Bureau of Statistics
- Censuses
- Ministry of Health
- Sample registration system (India)

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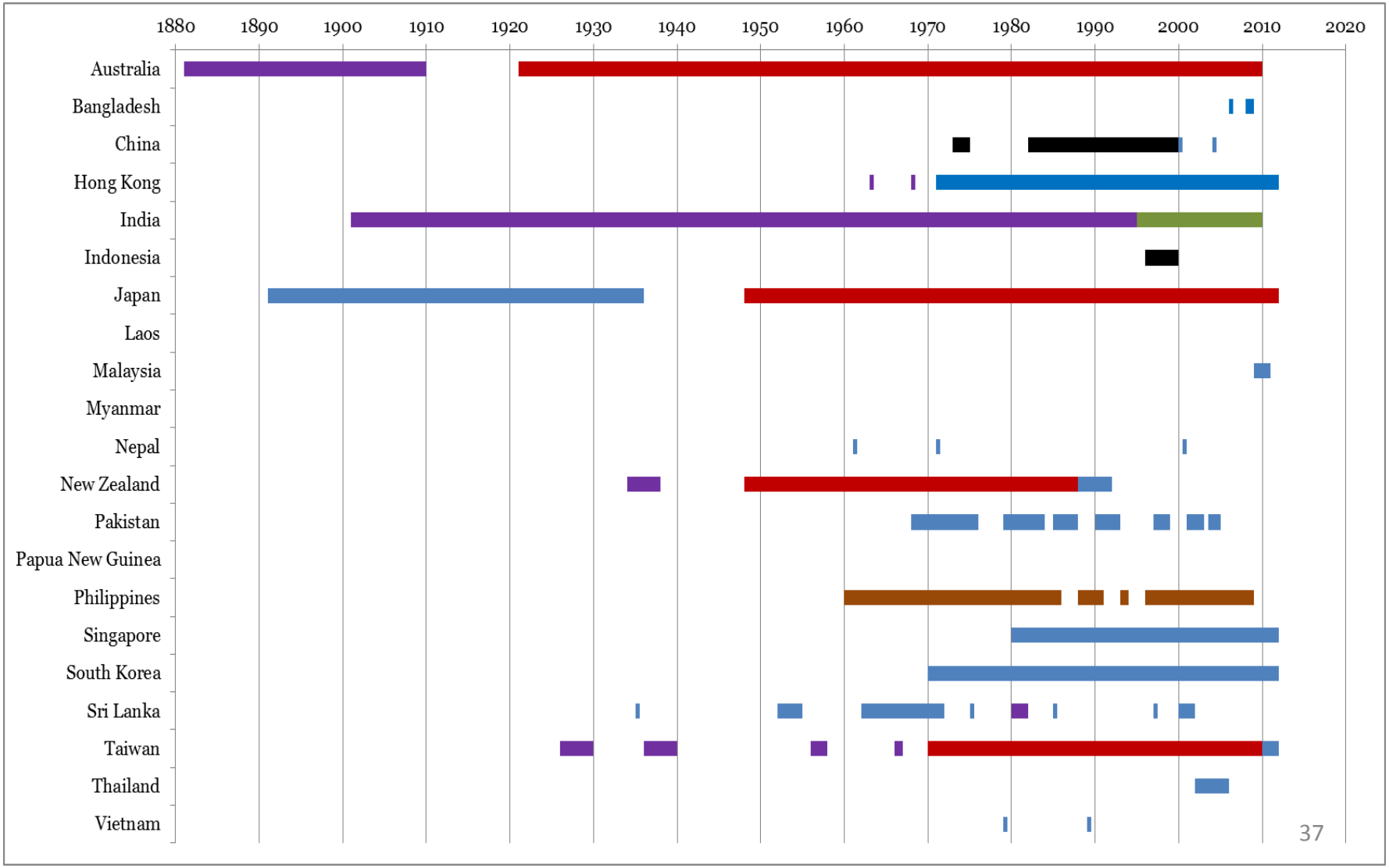
APAG Mortality Database



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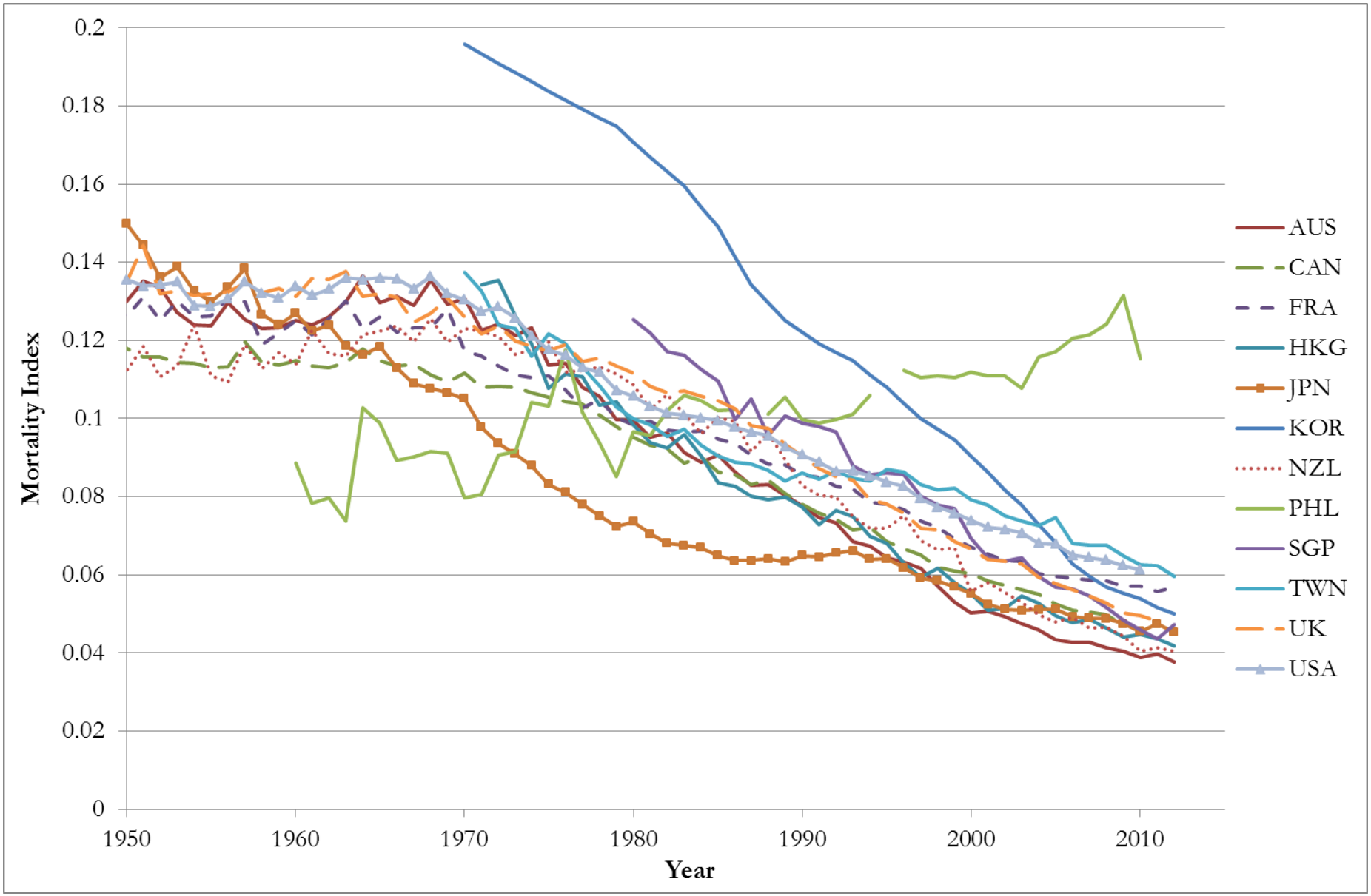
Mortality Indices-APAG (1950 - 2012)

Males 60-64



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Methodology - APAG

- To obtain stationarity we use
  - First difference: $q_t - q_{t-1}$

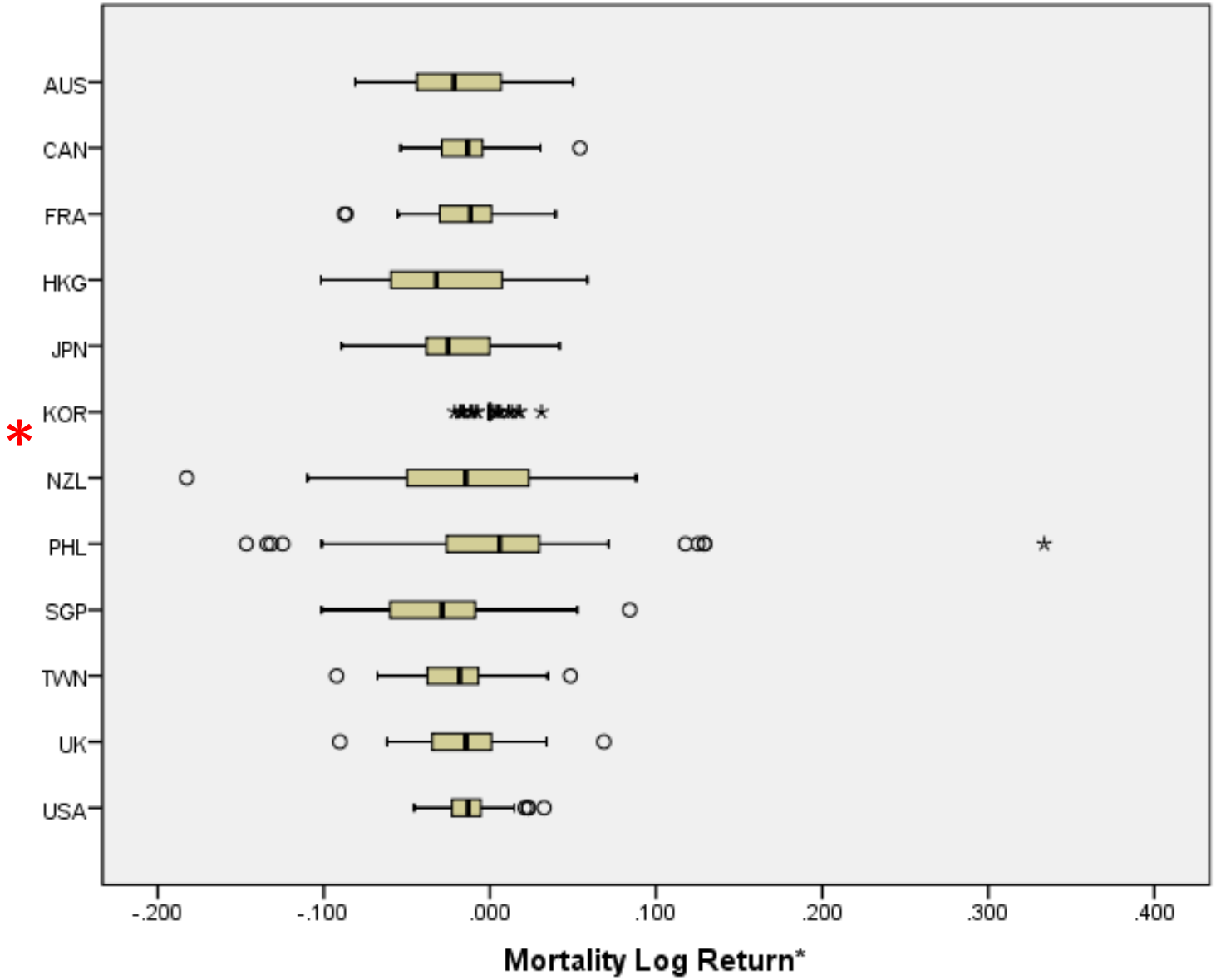
  - **Log of ratio of mortality rates:**

$$\log(q_t / q_{t-1})$$

  - **Exception of South Korea (2nd difference)**

$$\log(q_t) - 2\log(q_{t-1}) + \log(q_{t-2})$$

Log Mortality Returns* - APAG



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Spearman Correlations – APAG

	CAN	FRA	HKG	JPN	KOR	NZL	PHL	SGP	TWN	UK	USA
AUS	0.412	-0.015	-0.121	-0.012	-0.09	0.348	0.231	-0.129	-0.139	0.164	0.407
CAN		0.005	0.025	-0.007	-0.109	0.232	-0.01	-0.293	-0.102	0.116	0.343
FRA			-0.064	0.212	0.136	0.021	-0.039	0.318	-0.073	0.497	0.308
HKG				0.299	0.24	-0.277	0.084	0.121	-0.071	0.386	0.083
JPN					0.005	-0.072	0.224	-0.041	0.509	0.12	0.353
KOR						0.034	-0.329	0.163	0.166	0.027	-0.064
NZL							-0.11	0.063	0.053	0.308	0.115
PHL								-0.126	-0.003	-0.163	0.047
SGP									0.143	0.02	-0.009
TWN										-0.113	0.162
UK											0.437

Statistical Significance denoted at 5% (shaded).

Granger-Causality (APAG)
Country B predicts Country A

A	B	1 LAG			2 LAGS			3 LAGS			4 LAGS			5 LAGS		
		N	Test	P	N	Test	P	N	Test	P	N	Test	P	N	Test	P
AUS	CAN															
AUS	FRA	62	8.86	0.00	61	3.95	0.03	60	3.98	0.01	59	2.79	0.04	58	3.06	0.02
AUS	PHL							60	4.75	0.01	59	3.23	0.02	58	2.72	0.03
AUS	UK	61	4.95	0.03				59	3.14	0.03						
AUS	USA							58	4.02	0.01	57	3.35	0.02			
CAN	FRA	59	13.96	0.00	58	8.53	0.00	57	5.36	0.00	56	3.74	0.01	55	2.75	0.03
CAN	PHL															
CAN	UK	59	14.37	0.00	58	11.63	0.00	57	6.85	0.00	56	5.16	0.00	55	4.63	0.00
CAN	USA	59	9.14	0.00	58	4.83	0.01	57	3.30	0.03	56	2.99	0.03	55	2.50	0.05
FRA	PHL															
FRA	USA															

Granger-Causality (APAG)
Country A predicts Country B

A	B	1 LAG			2 LAGS			3 LAGS			4 LAGS			5 LAGS		
		N	Test	P	N	Test	P	N	Test	P	N	Test	P	N	Test	P
AUS	CAN				58	3.56	0.04									
AUS	FRA	62	13.85	0.00	61	10.72	0.00	60	8.52	0.00	59	7.16	0.00	58	7.61	0.00
AUS	PHL	62	4.51	0.04	61	8.60	0.00	60	5.04	0.00	59	2.81	0.04	58	2.51	0.04
AUS	UK															
AUS	USA				59	6.02	0.00	58	3.77	0.02	57	3.42	0.02			
CAN	FRA															
CAN	PHL				58	12.55	0.00	57	6.80	0.00	56	5.19	0.00	55	4.03	0.00
CAN	UK				58	7.03	0.00									
CAN	USA															
FRA	PHL				61	3.97	0.02	60	3.66	0.02						
FRA	USA													56	2.51	0.04

Parameter estimates – APAG
Example: USA predicts Canada

A	B	Variable	1 LAG		2 LAGS		3 LAGS		4 LAGS		5 LAGS	
			Est	P	Est	P	Est	P	Est	P	Est	P
CAN	USA	Intercept	-0.01	0.00	-0.01	0.01	-0.01	0.05	-0.01	0.21	-0.01	0.25
CAN	USA	CAN-1st lag	-0.28	0.05	**-0.36**	0.03	**-0.31**	0.05	-0.32	0.05	**-0.35**	0.05
CAN	USA	USA-1st lag	**0.50**	0.00	**0.53**	0.00	**0.47**	0.01	**0.36**	0.04	0.33	0.07
CAN	USA	CAN-2nd lag			-0.02	0.89	0.16	0.36	0.12	0.45	0.18	0.32
CAN	USA	USA-2nd lag			0.27	0.15	0.10	0.60	0.05	0.80	0.01	0.96
CAN	USA	CAN-3rd lag					**0.38**	0.01	**0.37**	0.03	**0.38**	0.03
CAN	USA	USA-3rd lag					-0.26	0.15	-0.30	0.11	-0.32	0.09
CAN	USA	CAN-4th lag							0.23	0.13	0.16	0.37
CAN	USA	USA-4th lag							0.23	0.23	0.26	0.20
CAN	USA	CAN-5th lag									-0.08	0.61
CAN	USA	USA-5th lag									0.24	0.24