

# LONG-RUN INCOME & PRICE ELASTICITIES OF ENERGY CONSUMPTION: THE SYLIZED FACTS

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# Income Elasticity of Energy Demand

- $E = Ap^{\beta_1}y^{\beta_2}$
- Project energy consumption for given economic growth rate
- Important parameter for IAM
- Several targets/goals intensity-based
  - Paris agreement: reduce carbon intensity
    - China, India, US (circa 2016)
  - APEC, ASEAN: reduce energy intensity
  - Indonesia: reduce income elasticity below unity

# Stylized Fact of Energy & Economic Growth:

- Energy intensity  $\left(\frac{E}{y}\right)$  declines with income
- True if income elasticity of energy demand less than unity
- $E = Ap^{\beta_1}y^{\beta_2}$
- $\frac{E}{y} = Ap^{\beta_1}y^{\beta_2-1}$

# Early Work

- Galli (1998): 10 developing Asian economies, 1973-1990
- Medlock & Soligo (2001): 28 countries (7 non-OECD), 1978-1995
- van Benthem & Romani (2009): 24 non-OECD countries, 1978-2003

- $\ln E_{i,t} = \alpha_i + \beta_1 \ln p_{i,t} + \beta_2 \ln y_{i,t} + \beta_3 (\ln y_{i,t})^2 + (1 - \gamma) \ln E_{i,t-1} + \varepsilon_t$

- $e_t = \beta_2 + 2\beta_3 \ln y_t$

- Energy intensity should rise and then fall
- Non-linearity in energy demand
  - Elasticity falls with income (G & M-S); Elasticity increases with income (vB-R)

# Recent Work

- Large group of countries, mostly cross-sectional
  - Csereklyei & Stern (2015); Csereklyei et al. (2016); Burke & Csereklyei (2016)
  - Energy-GDP elasticity is less than unity & stable over time
  - Energy intensity falls w/ economic growth
  - Energy-GDP elasticity is stable across GDP per capita levels
- Large, long (unbalanced) panel
  - van Benthem (2015)
  - No evidence that energy intensity of income lower for today's LDC than for IC at similar income levels—i.e., no energy leapfrogging
  - Not clear whether energy intensity of income is different for different income bands

# Questions

- I. How much will energy intensity fall in BAU economic growth scenarios?
- II. Do energy forecasting/IAM need dynamic energy elasticities?
- III. We know there's been technology transfer, but has there been energy leap-frogging?

# Dynamic Model

- $\ln E_{i,t} = \alpha_i + \beta_i^1 \ln p_{i,t} + \beta_i^2 \ln y_{i,t} + \beta_i^3 \ln p_{i,t-1} + \beta_i^4 \ln y_{i,t-1} + \beta_i^5 \ln E_{i,t-1} + \varepsilon_t$

- Long-run Elasticities:

- $GDP = \frac{\beta^2 + \beta^4}{(1 - \beta^5)}$

- $Price = \frac{\beta^1 + \beta^3}{(1 - \beta^5)}$

# Energy Price Data: Sources

- Real index
- IEA countries: IEA real index for industry & households
- Other countries: Enerdata used to create weighted index of residential, industry, and road (diesel & gasoline)
- 17 OECD countries extended to 1960 via Bade (1981)
- 10 Asian countries extended to 1973 via Pesaran et al. (1998)



# Energy Price Data: Coverage, 1960-2016

- 38 OECD/high-income countries, 53 non-OECD countries (min 13 obs)
- 37 OECD/high-income countries, 41 non-OECD countries (min 18 obs)
- 28 OECD/high-income countries, 15 non-OECD countries (min 29 obs)
- Unbalanced observations:

	OECD	Non-OECD
1960s	170	0
1970-80s	482	225
1990-2016	963	1114

# I. & II. Dynamic Common Correlated Effects Estimator

- $\ln E_{i,t} = \alpha_i + \beta_i^1 \ln p_{i,t} + \beta_i^2 \ln y_{i,t} + \beta_i^1 \ln p_{i,t-1} + \beta_i^2 \ln y_{i,t-1} + \beta_i^3 \ln E_{i,t-1} + Z_{i,t} + \varepsilon_t$
- $Z_{i,t} = \sum_{l=0}^2 \rho_i^l \overline{E_{t-l}} + \sum_{l=0}^2 \rho_i^l \overline{p_{t-l}} + \sum_{l=0}^2 \rho_i^l \overline{y_{t-l}}$
- Mean Group (MG) estimators (heterogeneous)
- Common Correlated Effects (CCE)
  - Adds cross-sectional averages of dependent & independent variables
- Dynamic Common Correlated Effects mean group estimator (DCCE)
  - Adds lags of those cross-sectional average terms
  - $L = \sqrt[3]{T}$  or 2 lags

# Long-Run Elasticities, DCCE, Long-T Panel: 28 OECD, 15 Non-OECD Countries

	Partial Adjustment	ARDL (111)	Error Correction
	OECD		
GDP			
Price			
	Non-OECD		
GDP			
Price			

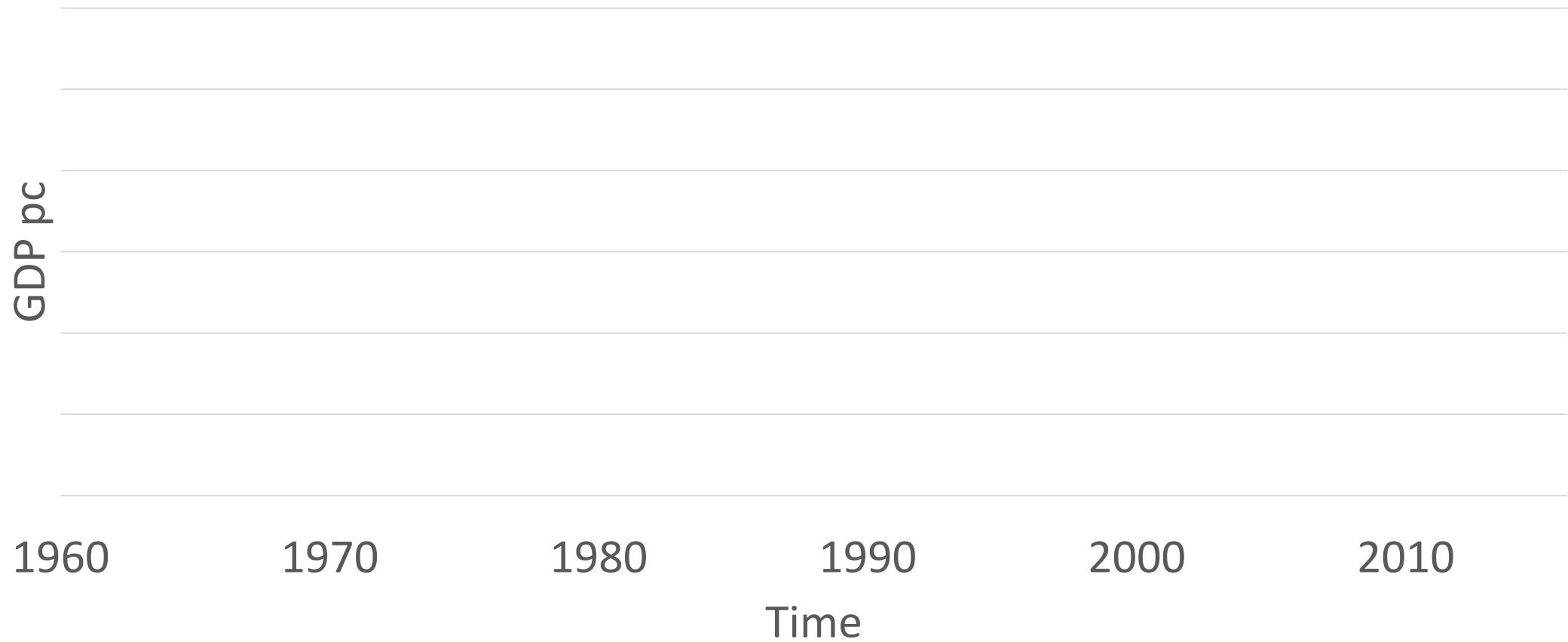
# Long-Run Elasticities, DCCE, Long-T Panel: 28 OECD, 15 Non-OECD Countries

	Partial Adjustment	ARDL (111)	Error Correction
	OECD		
<b>GDP</b>	0.62**** [0.43 0.82]	0.54** [0.08 1.01]	0.68**** [0.38 0.98]
<b>Price</b>	-0.27****	-0.26**	-0.21***
	Non-OECD		
<b>GDP</b>	0.76*** [0.33 1.19]	0.68** [0.06 1.29]	0.44* [-0.03 0.91]
<b>Price</b>	0.01	-0.02	-0.10

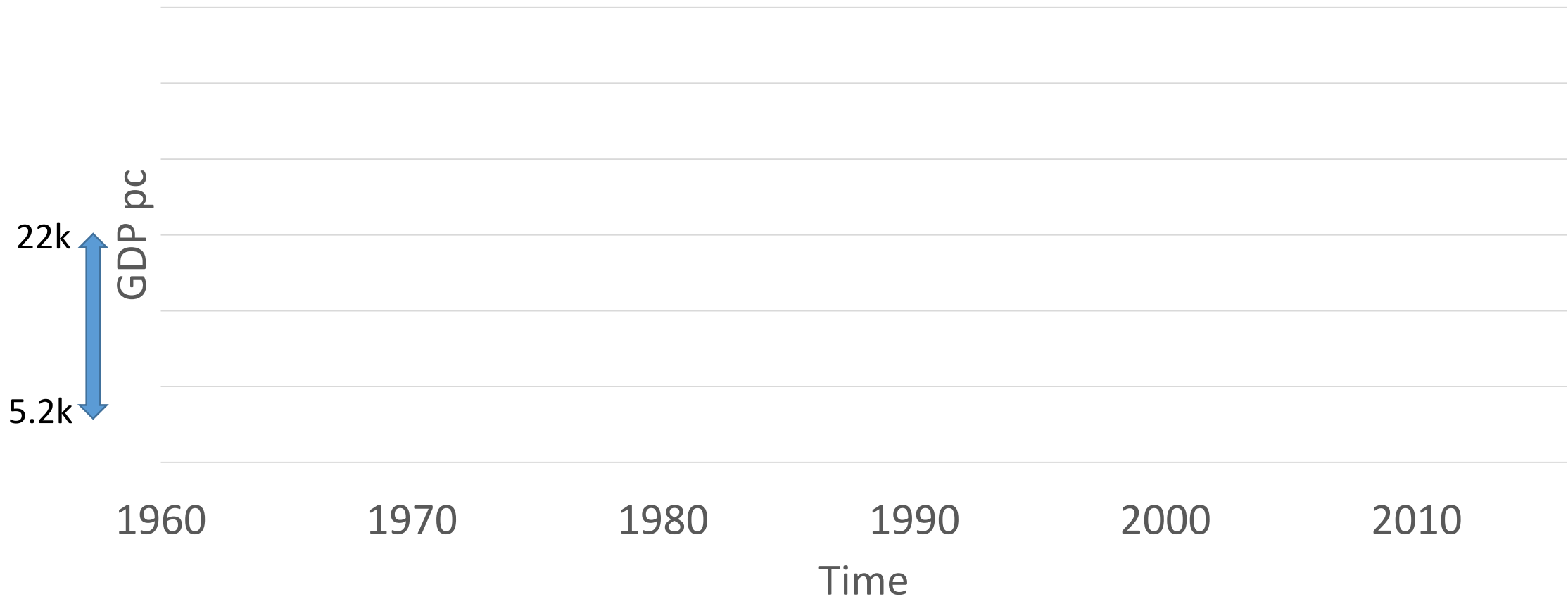
# Long-run Elasticity Summary

- Long-run GDP elasticity around 0.6 to 0.7
  - Not necessarily different from unity (95% confidence)
  - But, likely less than unity—particularly for OECD
- No evidence GDP elasticity is different across income/development level
  - Individual coefficients by average GDP p.c.
  - OECD vs Non-OECD
  - UMI vs LMI
- OECD long-run price elasticity around -0.2 to -0.3
- Price elasticity insignificant for non-OECD

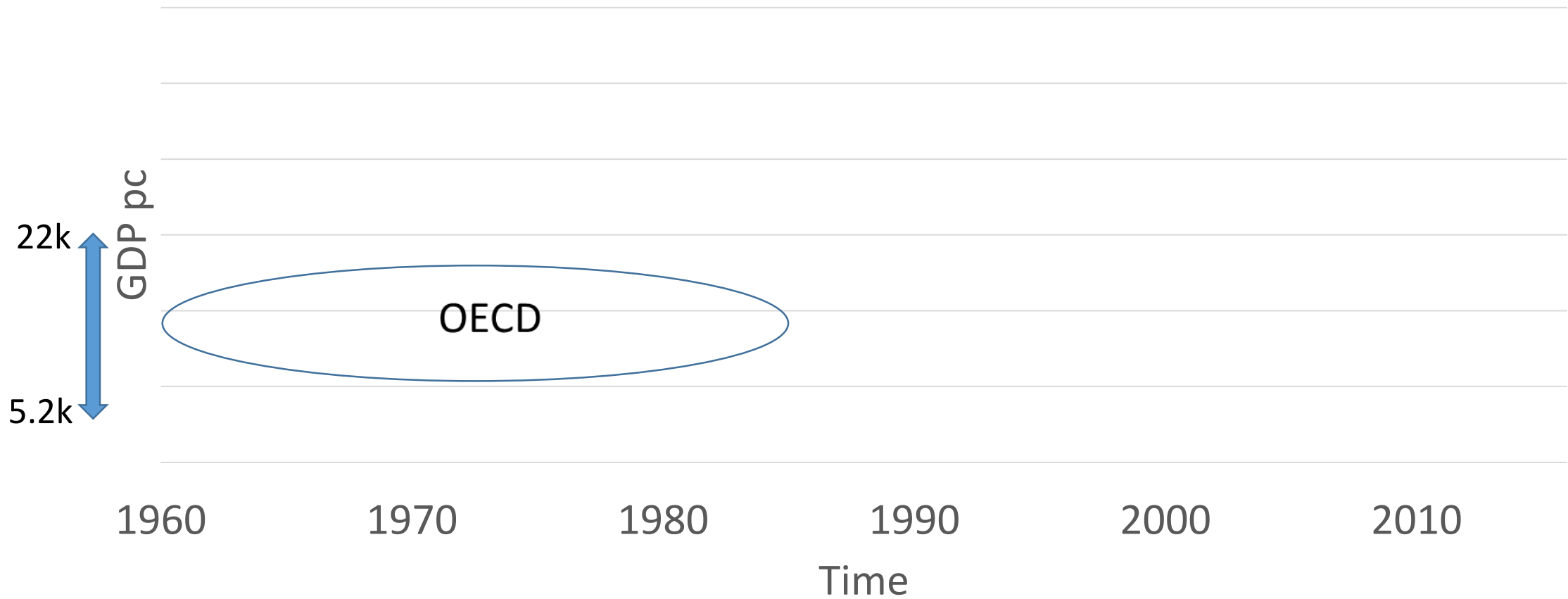
# III. Testing for Energy Leap-frogging



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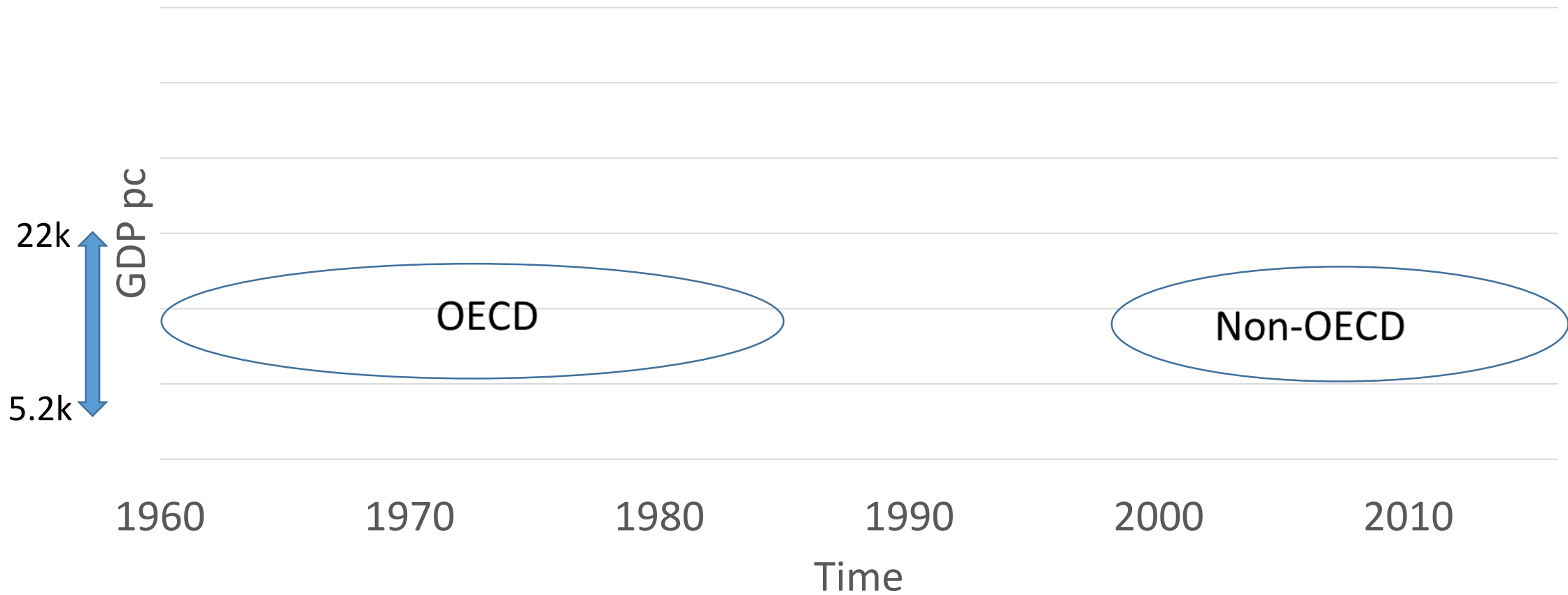


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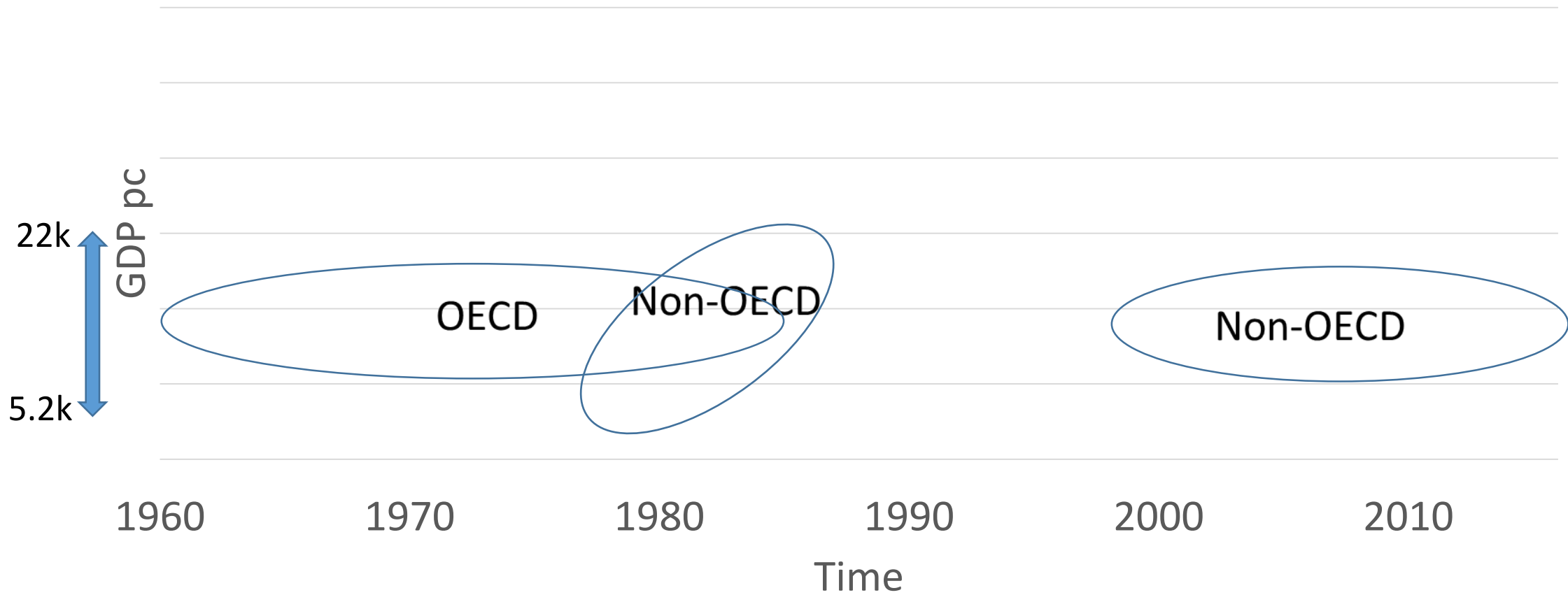




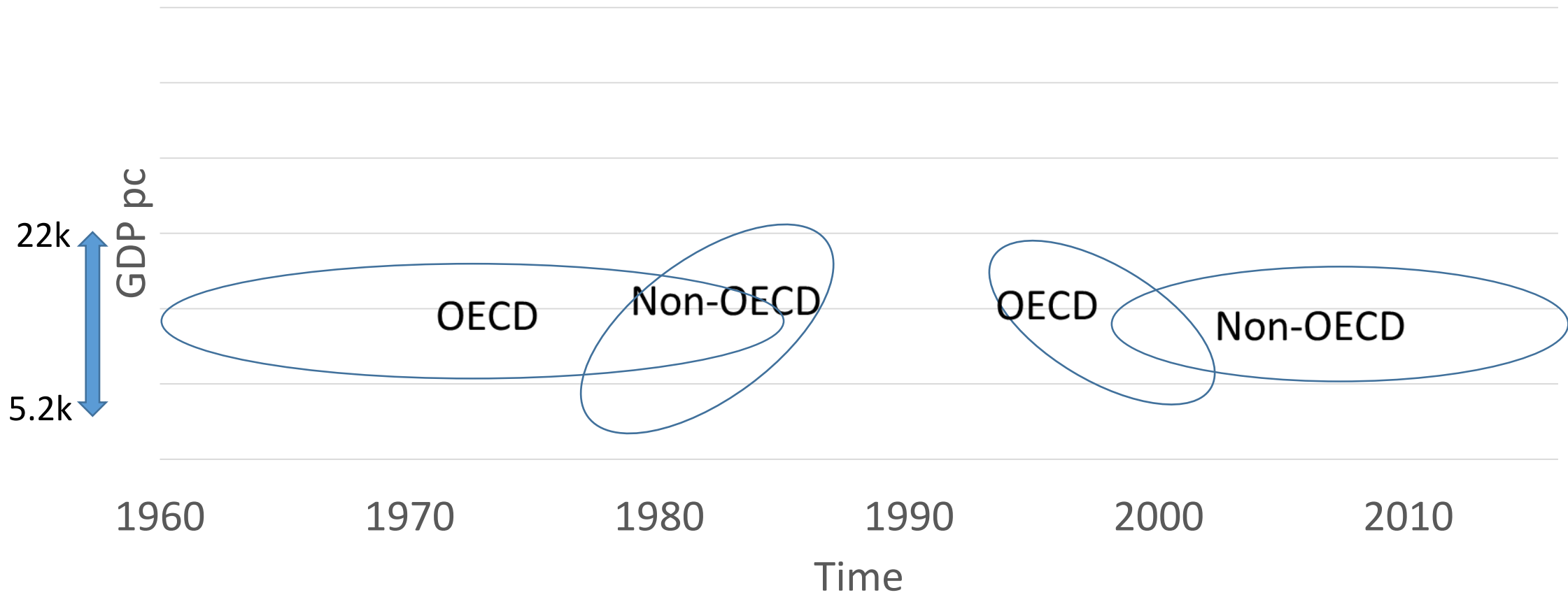
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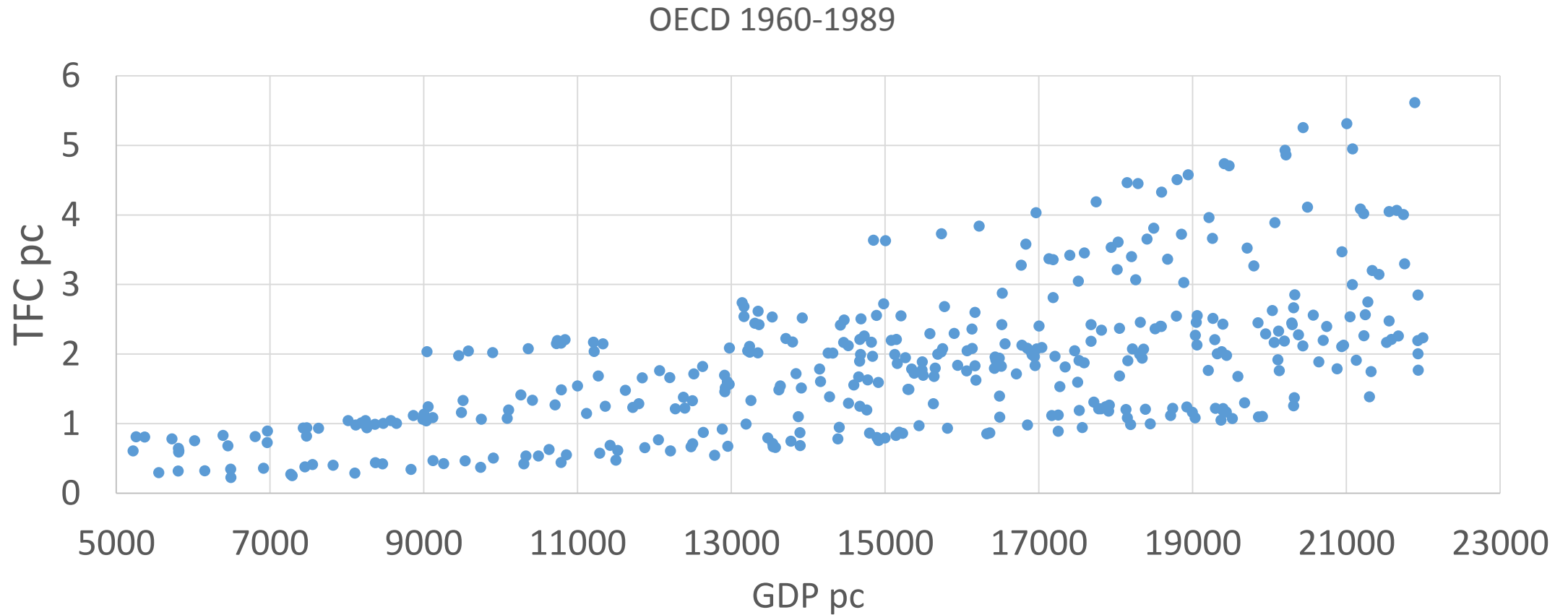
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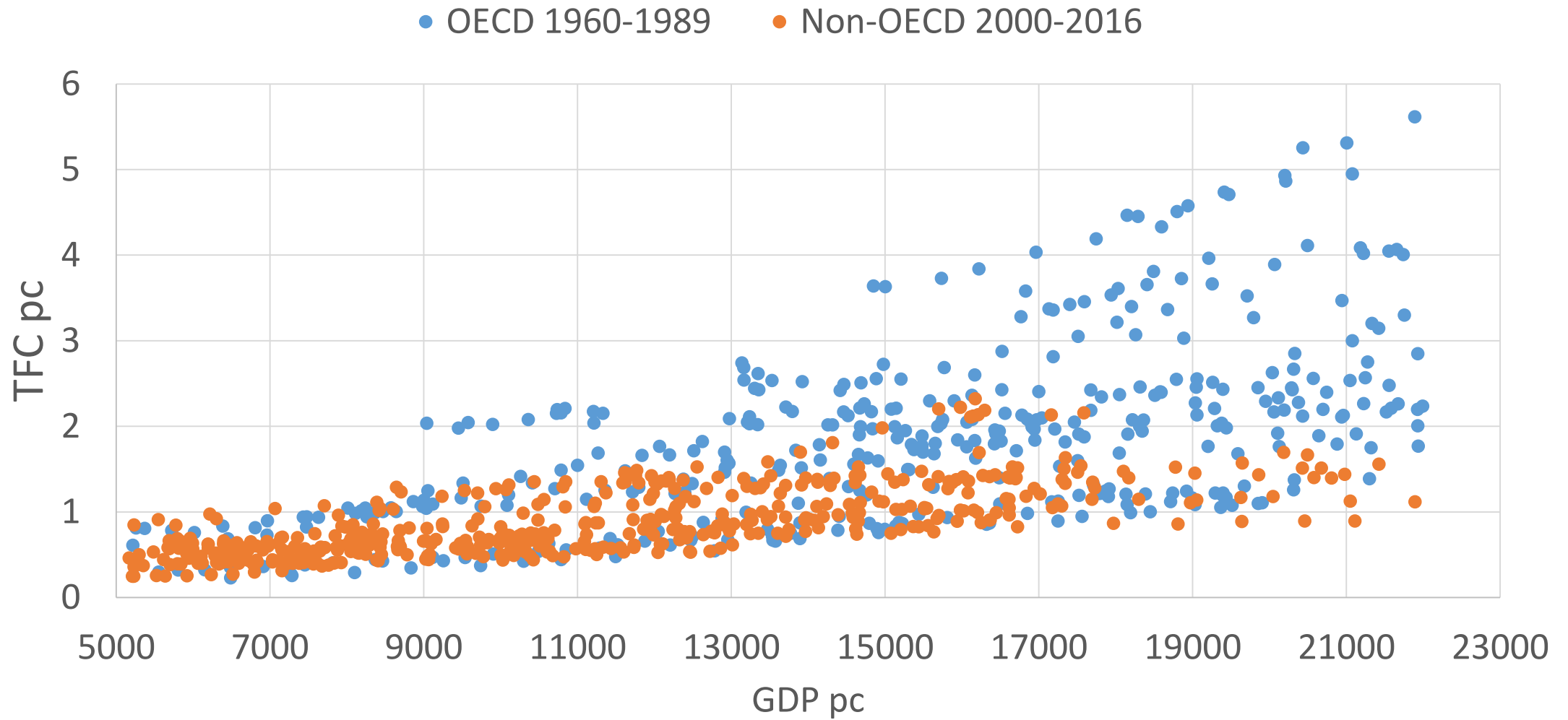
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# Leap-frogging? GDP: \$5,200-\$22,000



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OECD				Non-OECD			
AUT	1960-1976	NLD	1960-1971	ARG	2000-2016	LBN	2000-2016
BEL	1960-1975	NOR	1960-1970	BGR	2000-2016	LKA	2000-2016
CAN	1960-1972	NZL	1978-1983	BOL	2010-2016	MAR	2004-2016
CZE	1978-1989	POL	1978-1989	BRA	2000-2016	MEX	2000-2016
DNK	1960-1968	PRT	1960-1989	CHL	2000-2016	MYS	2000-2011
ESP	1960-1988	SVK	1978-1989	CHN	2005-2016	PAN	2000-2016
FIN	1978-1981	SWE	1960-1972	COL	2000-2016	PER	2000-2016
FRA	1960-1976	TWN	1973-1989	CRI	2000-2016	PHL	2008-2016
GBR	1960-1984	USA	1960-1965	DOM	2000-2016	PRY	2000-2016
GRC	1960-1989			ECU	2000-2016	ROU	2000-2016
HUN	1978-1989			GTM	2000-2016	SLV	2000-2016
IRL	1960-1989			HRV	2000-2016	SRB	2000-2016
ITL	1960-1978			IDN	2000-2016	THA	2000-2016
JPN	1960-1984			IND	2014-2016	TUN	2000-2016
KOR	1979-1989			JAM	2000-2016	TUR	2000-2014
				JOR	2000-2016	URY	2000-2016
				LAO	2014-2016	ZAF	2000-2016

Leap-frogging. LR Coefficients, CCEP, Income-band 5.2k-22k, OECD: 1960-1989 (388 obs, 24 countries), Non-OECD: 2000-2016 (499 obs, 34 countries)

		Static		ARDL (100)		ARDL (111)	
GDP	OECD						
	Non-OECD						
PRICE	OECD						
	Non-OECD						
Time FE							
P-value							
	Income						
	Price						

Leap-frogging. LR Coefficients, CCEP, Income-band 5.2k-22k, OECD: 1960-1989 (388 obs, 24 countries), Non-OECD: 2000-2016 (499 obs, 34 countries)

		Static		ARDL (100)		ARDL (111)	
GDP	OECD	1.3****	1.2****	1.7****	1.1****	1.7****	1.1****
	Non-OECD	0.9****	0.8****	0.9****	0.8****	0.9****	0.8****
PRICE	OECD	-0.3****	-0.3***	-0.6***	-0.6****	-0.6***	-0.3*
	Non-OECD	-0.0	-0.01	-0.01	0.00	-0.002	0.01
Time FE		Yes	No	Yes	No	Yes	No
P-value							
	Income	0.040	0.001	0.033	0.010	0.043	0.082
	Price	0.001	0.004	0.001	0.000	0.004	0.073



Leap-frogging. LR Coefficients, CCEP, Income-band 5.2k-22k, OECD: 1960-1994 (438 obs, 25 countries), Non-OECD: 1995-2016 (600 obs, 34 countries)

		Static		ARDL (100)		ARDL (111)	
GDP	OECD						
	Non-OECD						
PRICE	OECD						
	Non-OECD						
Time FE							
P-value							
	Income						
	Price						

Leap-frogging. LR Coefficients, CCEP, Income-band 5.2k-22k, OECD: 1960-1994 (438 obs, 25 countries), Non-OECD: 1995-2016 (600 obs, 34 countries)

		Static		ARDL (100)		ARDL (111)	
GDP	OECD	1.1*****	1.2*****	1.2*****	1.1*****	1.7*****	1.1*****
	Non-OECD	0.9*****	0.8*****	0.9*****	0.8*****	0.9*****	0.8*****
PRICE	OECD	-0.3*****	-0.2*****	-0.4*****	-0.4*****	0.2	-0.2
	Non-OECD	0.01	0.01	0.01	0.00	0.004	0.01
Time FE		Yes	No	Yes	No	Yes	No
P-value							
	Income	0.085	0.000	0.112	0.000	0.006	0.001
	Price	0.000	0.000	0.000	0.000	0.947	0.305

# No Leap-frogging. LR Coefficients, CCEP, Income-band 5.2k-22k, 1978-2006

		Static		ARDL (100)		ARDL (111)	
GDP	OECD						
	Non-OECD						
PRICE	OECD						
	Non-OECD						
Time FE							
P-value							
	Income						
	Price						

# No Leap-frogging. LR Coefficients, CCEP, Income-band 5.2k-22k, 1978-2006

		Static		ARDL (100)		ARDL (111)	
GDP	OECD	0.9*****	0.7*****	0.9*****	0.6*****	1.0*****	0.9*****
	Non-OECD	1.2*****	0.9*****	1.3*****	1.0*****	1.3*****	1.0*****
PRICE	OECD	-0.3*****	-0.4*****	-0.4*****	-0.5*****	-0.3**	-0.4**
	Non-OECD	-0.03*	-0.01	-0.05*	-0.02	-0.1*	-0.02
Time FE		Yes	No	Yes	No	Yes	No
P-value							
	Income	0.000	0.003	0.000	0.000	0.193	0.276
	Price	0.000	0.000	0.000	0.000	0.114	0.057

# Summary: Energy leap-frogging

- Current, non-OECD significantly lower income & price elasticities than early OECD (in contrast to van Benthem 2015)
- Keys to finding leapfrogging:
  - Observations from OECD circa 1960s & 1970s (more observations from early industrializers, e.g., BEL, CAN, FRA, ITL, NLD, SWE, USA)
  - Recent/current (2007-2016) observations from Non-OECD (more UMI countries, more time for tech to transfer)
  - Not including Non-OECD observations from 1980s (not much opportunity for leapfrogging/tech transfer)

# Future Work

- Sectoral analysis
  - Industry
  - Residential electricity
  - Road transport
- Make price data publically available

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# OECD vs Non-OECD, Long-Run Coefficients

	Static, CCEP	Dynamic, DCCE		
		Partial adjustment	ARDL (111)	Error Correction
	OECD			
<b>GDP</b>	0.72**** [0.59 0.84]	0.50**** [0.33 0.68]	0.64*** [0.18 1.10]	0.62**** [0.34 0.91]
<b>Price</b>	-0.14** [-0.26 -0.03]	-0.18*** [-0.29 -0.07]	-0.22** [-0.44 -0.0056]	-0.22**
	Non-OECD			
<b>GDP</b>	0.73**** [0.57 0.90]	0.63**** [0.35 0.92]	0.66*** [0.16 1.16]	0.54** [0.05 1.03]
<b>Price</b>	-0.05** [-0.09 -0.01]	-0.011 [-0.07 0.05]	0.011 [-0.12 0.14]	-0.08



# Dynamic Models, Non-OECD Countries, Long-Run Coefficients from DCCE

	Oil (6)	UMI (23)	UMI, non-Oil (19)	LMI (16)
<b>GDP</b>	-0.17	0.43	0.25	1.29***
LRA	(0.67)	(0.32)	(0.36)	(0.47)
<b>ALR</b>	0.34	0.72***	0.76***	0.86***
	(0.41)	(0.18)	(0.20)	(0.24)
<b>Price</b>	-0.13	0.058	0.090	-0.054
LRA	(0.26)	(0.083)	(0.096)	(0.13)
<b>ALR</b>	-0.19	-0.092	-0.059	-0.047
	(0.16)	(0.092)	(0.12)	(0.049)
Obs	143	576	473	424

# Non-OECD: UMI vs LMI, Long-Run Coefficients

	Static, CCEP	Dynamic, DCCE		
		Partial adjustment	ARDL (111)	Error Correction
	UMI (no Oil)			
<b>GDP</b>	0.82**** [0.77 0.86]	0.73*** [0.25 1.21]	0.25	0.84* [-0.02 1.71]
<b>Price</b>	0.03 [-0.04 0.11]	-0.02	0.090	0.01
	LMI			
<b>GDP</b>	0.60**** [0.41 0.78]	0.62*** [0.25 0.99]	1.29***	0.28 [-0.25 0.81]
<b>Price</b>	-0.08** [-0.15 -0.01]	-0.01	-0.054	-0.2**

# Static Models, Long-Run Coefficients from CCE

	OECD (37)	Non- OECD (41)	Oil (6)	Non- OECD, non-oil (35)	UMI (23)	LMI (16)	UMI, non-oil (19)
GDP	0.716**** [0.588 0.842]	0.731**** [0.568 0.897]	0.630** [0.090 1.17]	0.900**** [0.687 1.113]	0.836**** [0.561 1.112]	0.599**** [0.413 0.785]	0.816**** [0.767 0.864]
Price	-0.141** [-0.257 - 0.0252]	-0.048** [-0.086 - 0.01]	-0.144 [-0.374 0.086]	-0.032 [-0.072 0.007]	0.0055 [-0.080 0.091]	-0.0818** [-0.151 - 0.012]	0.0349 [-0.037 0.107]
Obs	1600	1149	160	989	630	470	519