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KIEL MARINE SCIENCES

The Impact of Temperature Changes on Global Residential Energy Demand

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Energy and
Temperature

Introduction

Model

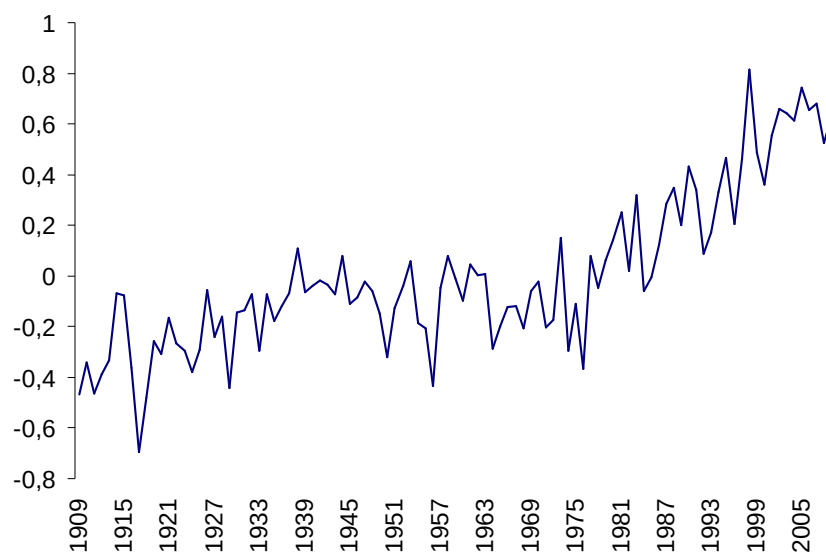
Data

Results

Conclusion

Temperature rise in the past...

Yearly global average temperature
(°C anomalies from 1961-90, 1909-2009)





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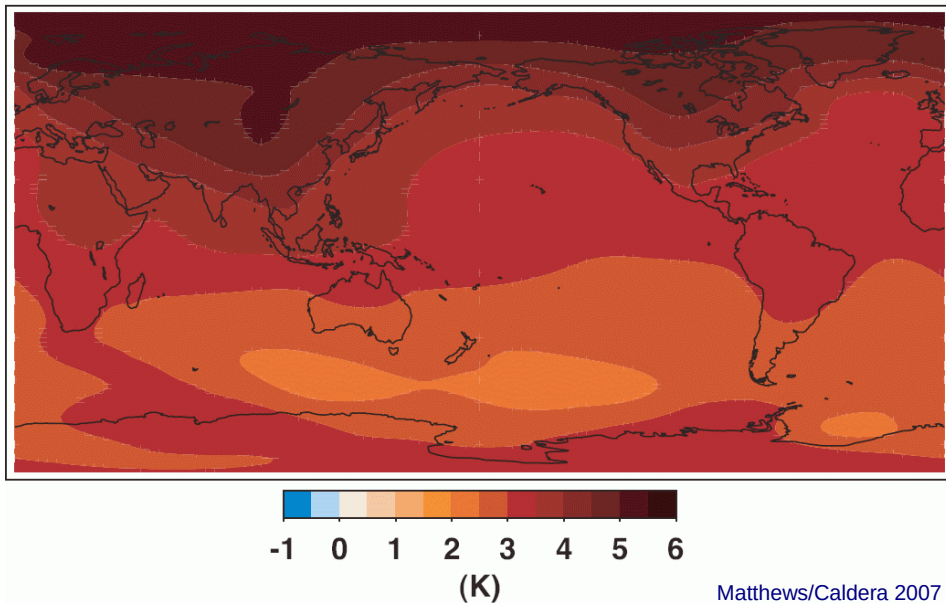
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...and in the future?

Surface Air Temperature (A2: 2100-1900)



Matthews/Caldera 2007





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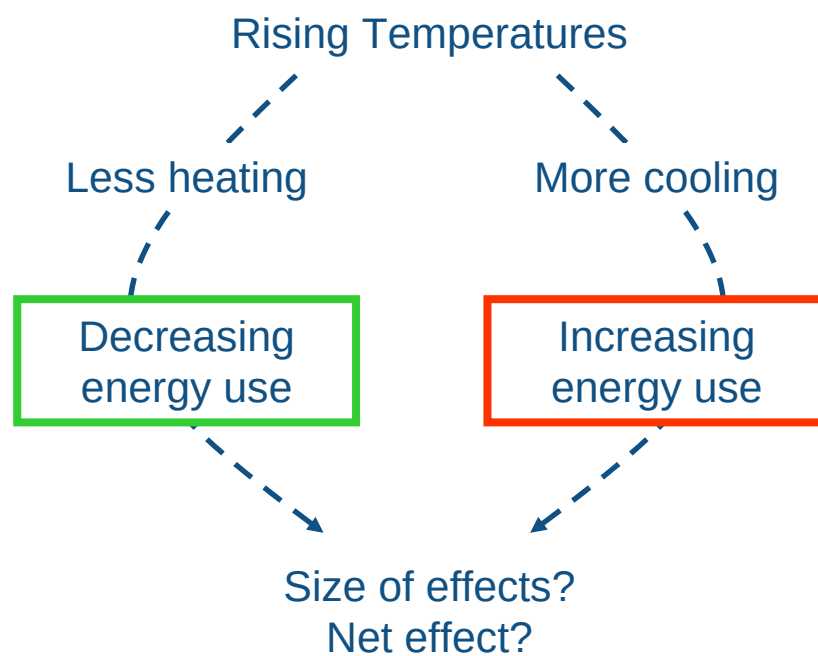
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Heating and cooling effect





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Outline

1. Introduction

2. Model

3. Data

4. Results

5. Conclusion

→ Discussion





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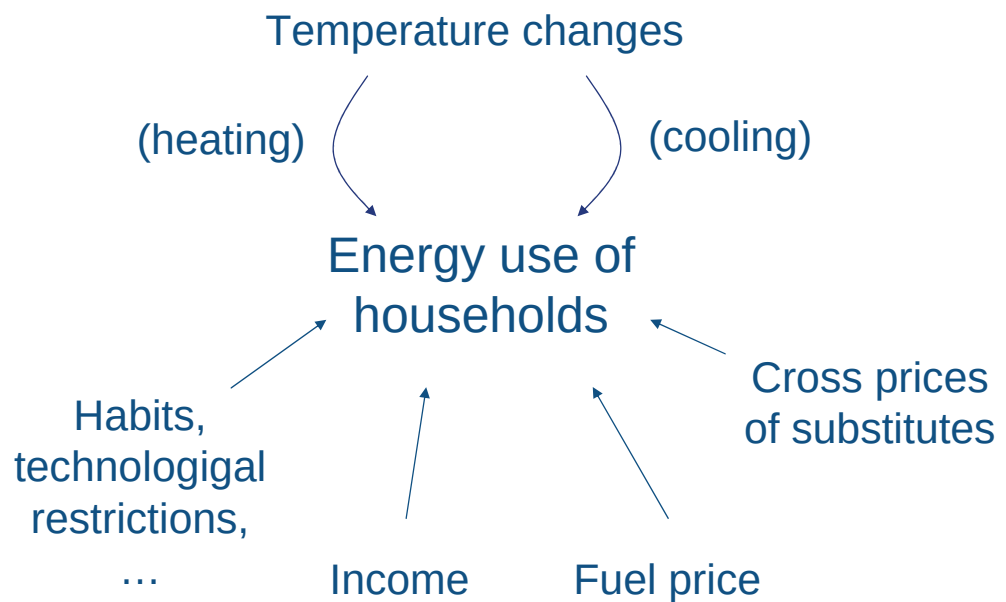
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Direct Influences on Energy Use



$$e_{i,t} = f(tmin_{i,t}, tmax_{i,t}, y_{i,t}, pe_{i,t}, ps_{i,t}, e_{i,t-1}, \delta_i)$$





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Non-linearities

- The *impact* of temperature changes differs depending on the temperature level
 - During a temperature rise, the heating effect might be larger for relatively colder countries
 - At the same time, the cooling effect might be smaller



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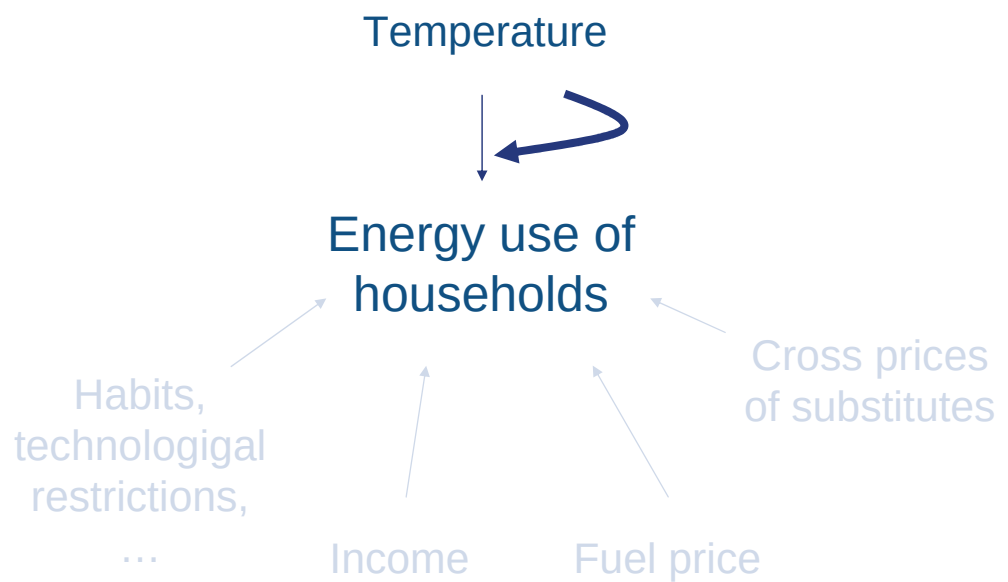
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Indirect Influences on Energy Use I





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Non-linearities in the literature

- Different (parametric) approaches to deal with this non-linearity:
 - Heating and cooling degree days
(e.g. Bigano et al. 2006 – use of electricity, oil, gas, coal in households, industry and service sectors of up to 29 countries, mostly OECD)
 - Country clusters and partial pooling for quarterly data, temperature enters directly
(De Cian et al. 2007 – use of electricity, oil, gas, coal in the household sectors of 31 countries, mostly OECD)
 - Threshold regression model with non-linear threshold function
(Bessec/Fouquau 2008 – electricity use in household sectors of the EU-15 countries)





Dealing with non-linearities

- In our study: Energy demand...
 - ... depends on the average temperature of the coldest (t_{min}) and hottest (t_{max}) month
 - heating and cooling effect
 - ... is a non-linear (but linearizable) function of temperature variable(s)
- Functional forms:
 - Quadratic
 - Logarithmic
 - Inverse
 - Linear (as benchmark)



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Interdependencies

- The impact of temperature changes depends not only on the temperature level, but potentially also on other explanatory variables
 - Income
 - Prices
 - ...?
- Higher (disposable) income
 - higher options for adaptation
 - higher response



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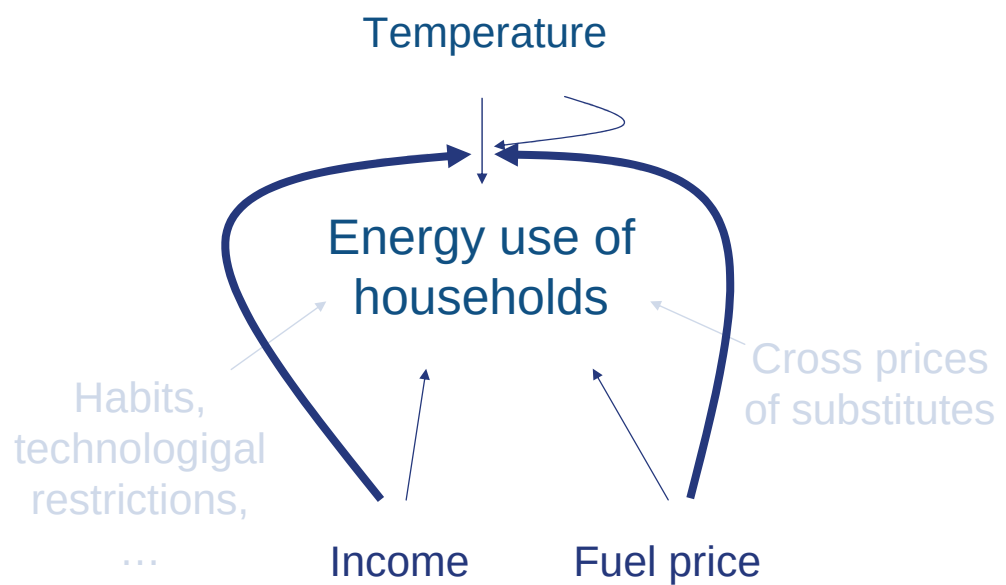
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Indirect Influences on Energy Use II





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Functional forms

Quadratic

$$e_{i,t} = \beta_1 tmin_{i,t} + \beta_2 tmin_{i,t}^2 + \beta_3 tmin_{i,t} \cdot y_{i,t} + \beta_4 tmin \cdot pe_{i,t} \\ + \beta_5 tmax_{i,t} + \beta_6 tmax_{i,t}^2 + \beta_7 tmax_{i,t} \cdot y_{i,t} + \beta_8 tmax \cdot pe_{i,t} \\ + \gamma_1 y_{i,t} + \gamma_2 pe_{i,t} + \gamma_3 ps_{i,t} + \gamma_4 e_{i,t-1} + \delta_i$$

Logarithmic

$$e_{i,t} = \beta_1 \log(tmin_{i,t}) + \beta_3 tmin_{i,t} \cdot y_{i,t} + \beta_4 tmin \cdot pe_{i,t} \\ + \beta_5 \log(tmax_{i,t}) + \beta_7 tmax_{i,t} \cdot y_{i,t} + \beta_8 tmax \cdot pe_{i,t} \\ + \gamma_1 y_{i,t} + \gamma_2 pe_{i,t} + \gamma_3 ps_{i,t} + \gamma_4 e_{i,t-1} + \delta_i$$

Inverse

$$e_{i,t} = \beta_1 tmin_{i,t}^{-1} + \beta_3 tmin_{i,t} \cdot y_{i,t} + \beta_4 tmin \cdot pe_{i,t} \\ + \beta_1 tmax_{i,t}^{-1} + \beta_3 tmax_{i,t} \cdot y_{i,t} + \beta_4 tmax \cdot pe_{i,t} \\ + \gamma_1 y_{i,t} + \gamma_2 pe_{i,t} + \gamma_3 ps_{i,t} + \gamma_4 e_{i,t-1} + \delta_i$$

Linear (benchmark)

$$e_{i,t} = \beta_1 tmin_{i,t} + \beta_3 tmin_{i,t} \cdot y_{i,t} + \beta_4 tmin \cdot pe_{i,t} \\ + \beta_1 tmax_{i,t} + \beta_3 tmax_{i,t} \cdot y_{i,t} + \beta_4 tmax \cdot pe_{i,t} \\ + \gamma_1 y_{i,t} + \gamma_2 pe_{i,t} + \gamma_3 ps_{i,t} + \gamma_4 e_{i,t-1} + \delta_i$$





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Four fuel types:



Images: Wikipedia users, StatoilHydro, Bureau of Land Management





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Global panel

- Global panel with more than 70 countries in all climate zones from 1978 to 2002
- Data coverage differs for the different variables:
 - 4055 observations from 174 countries for consumption of light fuel oil
 - Only 308 observations from 22 countries for coal price
 - 1679 observations from 73 countries for temperature variables
- Especially price data are scarce



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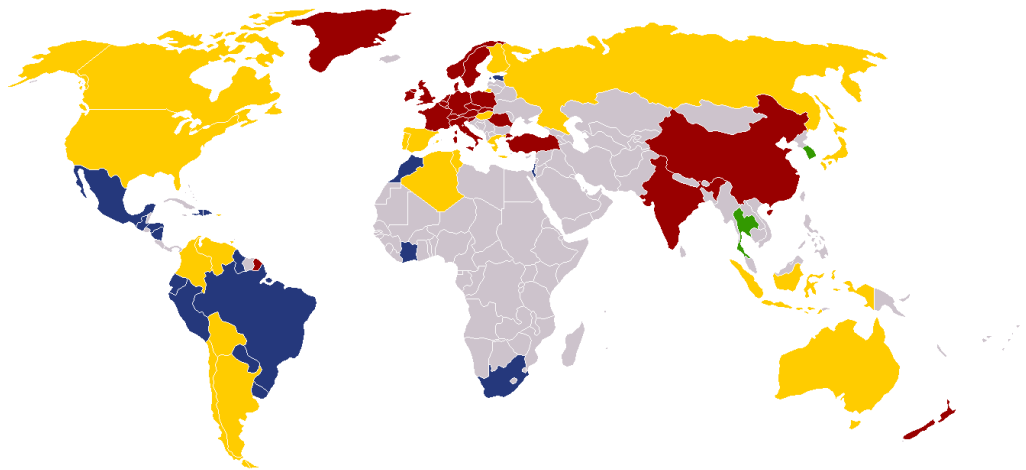
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Geographical coverage of price data



- ◆ Prices for electricity, oil, gas, coal
- ◆ Prices for electricity, oil, gas
- ◆ Prices for electricity, oil
- ◆ Prices for electricity





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No cooling effect (electricity)

(in brackets: p-values)	linear	quadratic	logarithmic	inverse
Electricity use in (t-1)	0.84(0)	0.84(0)	0.84(0)	0.84(0)
tmin	-0.12(0.9)	-1.32(0.64)		
tmin ²		0.02(0.42)		
log(tmin)			-27.27(0.34)	
tmin ⁻¹				356.51(0.32)
tmin-income	-0.05(0.17)	-0.06(0.09)	-0.03(0.38)	-0.05(0.05)
tmax	-0.07(0.94)	-1.77(0.6)		
tmax ²		0.01(0.53)		
log(tmax)			21.41(0.68)	
tmax ⁻¹				-44.39(0.98)
tmax-income	0(0.95)	0(0.95)	-0.02(0.67)	-0.01(0.88)
GDP (per capita)	3.23(0.01)	3.70(0)	3.31(0.01)	3.16(0.01)
Gas price	-0.01(0)	-0.01(0)	-0.01(0.01)	-0.01(0.01)
Constant	20.62(0.48)	78.69(0.12)	25.35(0.84)	2.51(0.93)
Adj. R ² (levels)	0.9854	0.9788	0.9851	0.9855
N	504	504	504	504





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Reasons for insignificant cooling effect

- Theoretical:
 - In developing countries, cooling devices are often not affordable
 - Potentially significant effects in developed countries are probably obscured
 - But: Analogue estimations for the OECD countries yield insignificant results as well
- Statistical
 - High collinearity: correlation coefficient between t_{min} and t_{max} is 0.96
 - Does the cooling effect show up in the t_{min} -coefficient?





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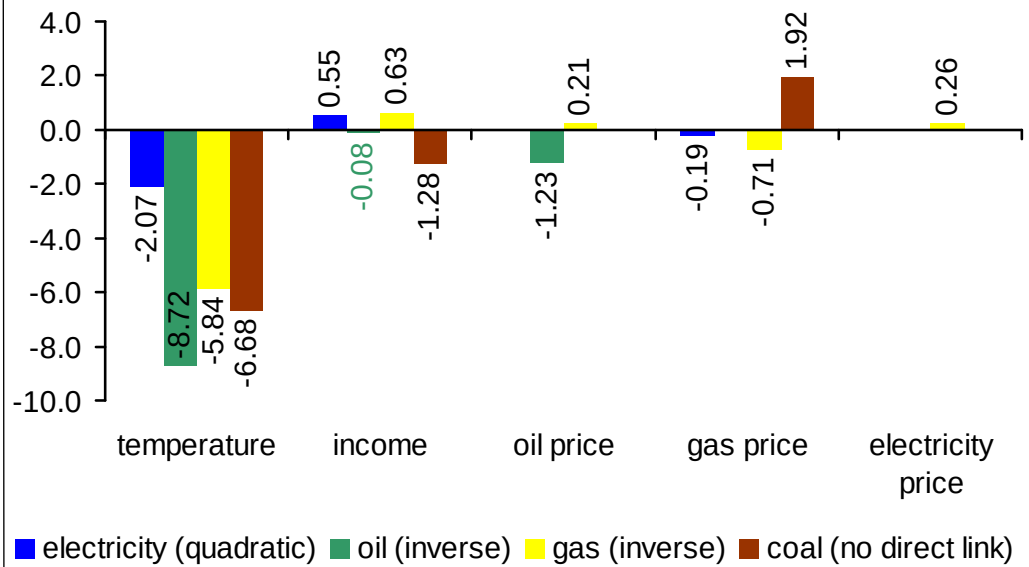
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Heating effect – estimation results

	electricity: quadratic	oil: inverse	gas: inverse	coal: no direct link
Fuel use in (t-1)	0.84***	0.86***	0.81***	0.78***
tmin	-2.45**			
tmin ²	0.03***			
tmin ⁻¹		2430.37***	1333.80***	
tmin·income	-0.07***	-0.33***	-0.25***	-0.10***
tmin·price		0.003***		
GDP (per capita)	3.70***	14.02***	11.38***	3.35*
Oil price		-0.21***	0.02*	
Gas price	-0.01***		-0.06***	0.05***
Electricity price			0.01**	
Constant	51.68**	-28.79	-9.9	2.41
Adj. R ² (levels)	0.98	0.8733	0.8876	0.9056
N	504	571	414	458



Long-run average elasticities





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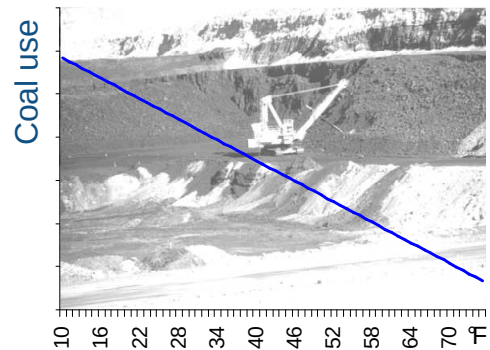
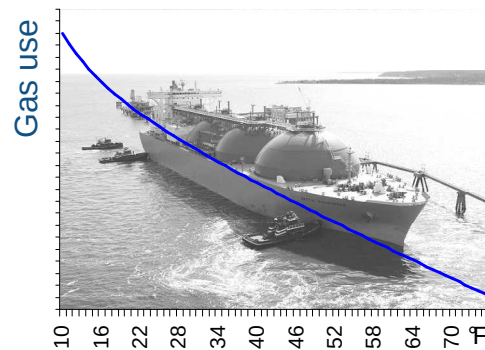
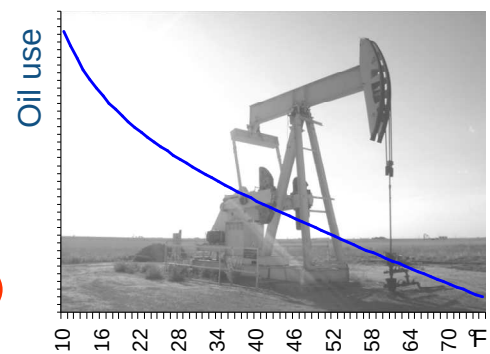
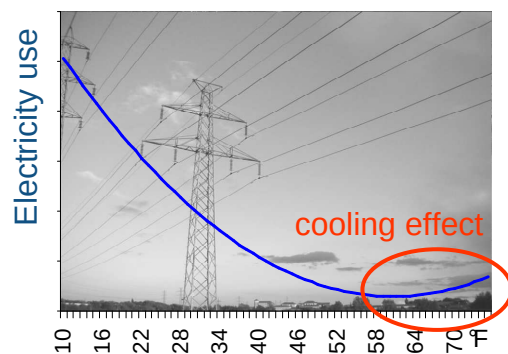
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Fuel use and temperature changes





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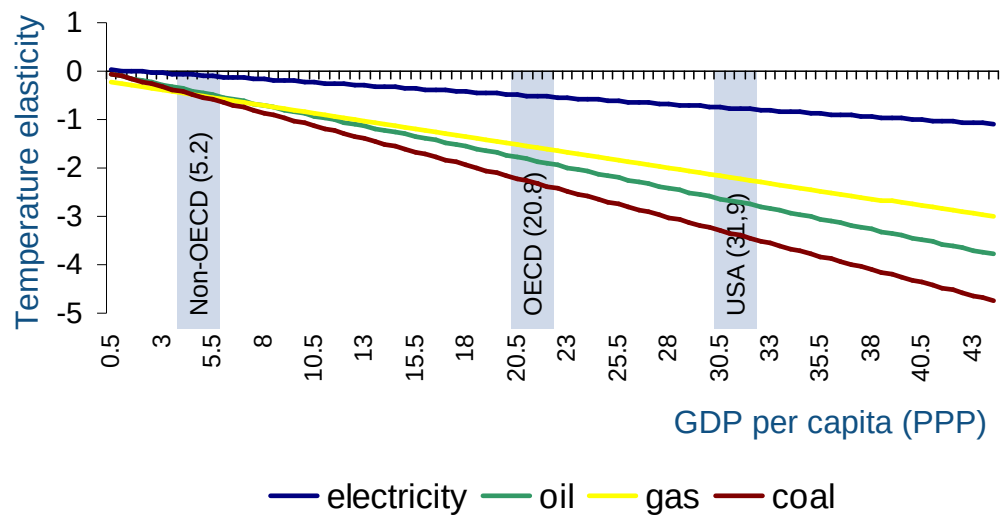
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Temperature elasticities and income





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Main findings

- Temperature influences energy use via the heating effect
- The existence of a cooling effect is arguable
- The link between temperature and energy use is non-linear
- Also income affects that link: The poorer a country, the more inert is its reaction



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Thank you!



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Some effects of temperature changes

- Higher probability of extreme weather events (floods, storms etc.)
 - Decreasing water availability
 - Stress on ecosystems (e.g. extinction of species)
 - Decreased agricultural productivity in low latitudes
 - Increased demand for cooling
- Increased agricultural productivity in high latitudes
 - Decreased demand for heating



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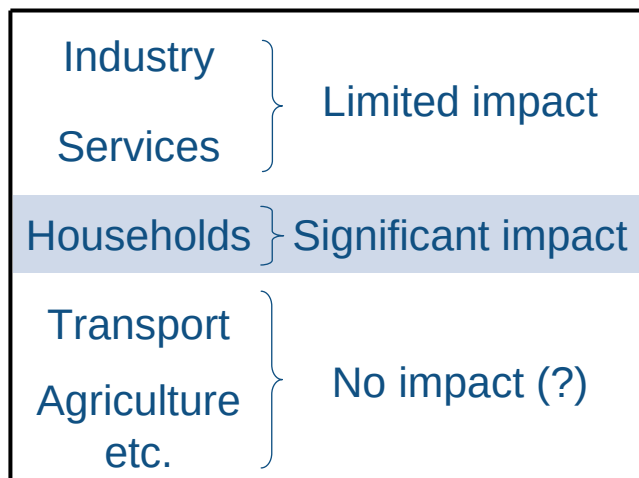
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Sectoral view

- Different importance for different economic sectors (cf. Bigano et al. 2006)
- Impact should increase with the share of use for heating purposes



Shares in
total energy
use
worldwide
2006
(IEA 2009)





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Non-linearities in the literature

“The negative relationship between [energy] demand and outside temperature becomes less steep as this temperature approaches the desired level of thermal comfort.”
(Henley/Peirson 1997)

“It is [...] very likely that not only the level of the temperature matters, but also the intensity of the change.” (Bigano et al. 2006)



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Additive vs. multiplicative models

- Using a linear regression model, one has the choice between two models:
 - Multiplicative model: estimated in logarithms (e.g. double-log)
 - Additive model: estimated without LHS-transformation
- The choice between the two models has theoretical implications!
- The estimation of interaction terms is not possible in the multiplicative model (perfect collinearity)



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Descriptive statistics (1978-2002)

	Mean	Min	Max	Observations	Countries	Years
Consumption per capita (toe)						
Electricity	58.6	0.1	692.7	4004	176	22.8
Oil	64.9	0.0	1170.3	4055	174	23.3
Gas	93.4	0.0	806.9	1462	71	20.6
Coal	42.9	0.0	632.5	1260	69	18.3
Price for residential sector (PPP(95USD) per toe)						
Electricity	1329.2	40.5	8835.4	1029	63	16.3
Oil	412.8	112.4	1352.7	662	33	20.1
Gas	163.5	13.4	305.2	308	22	14.0
Coal	429.1	5.1	1300.2	614	38	16.2
GDP per capita (PPP(95USD))						
	6.7	0.4	43.9	3993	162	24.6
Daily average temperature in the coldest/hottest month (°F)						
tmin	51.7	11.9	75.1	1679	73	23.0
tmax	69.1	29.0	91.2	1679	73	23.0



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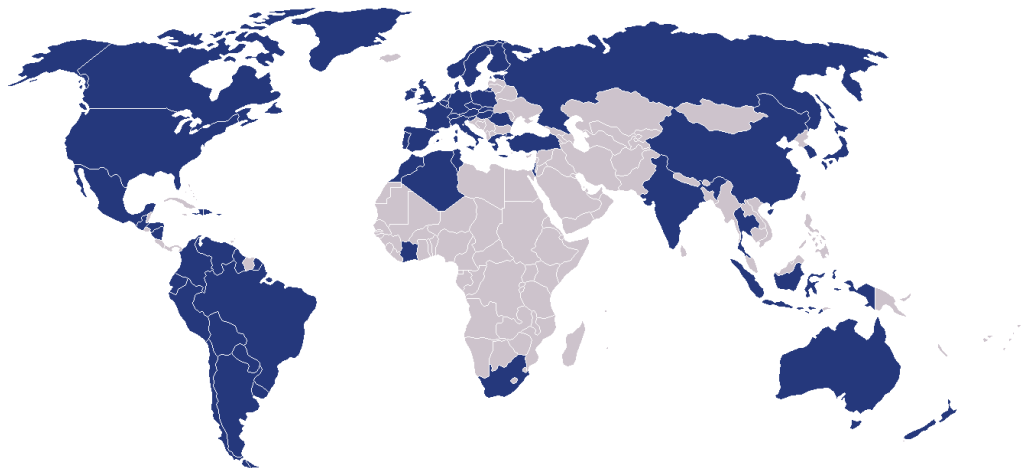
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Geographical coverage: Electricity prices





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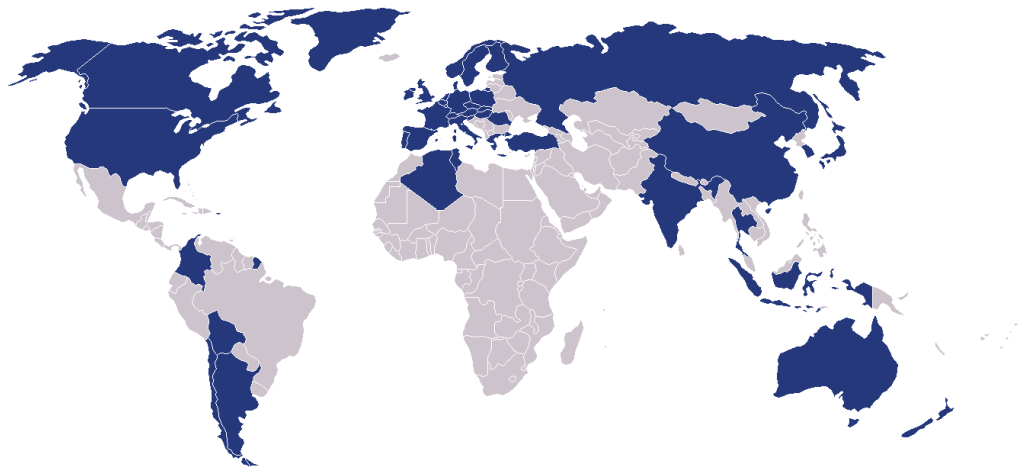
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Geographical coverage: Oil prices





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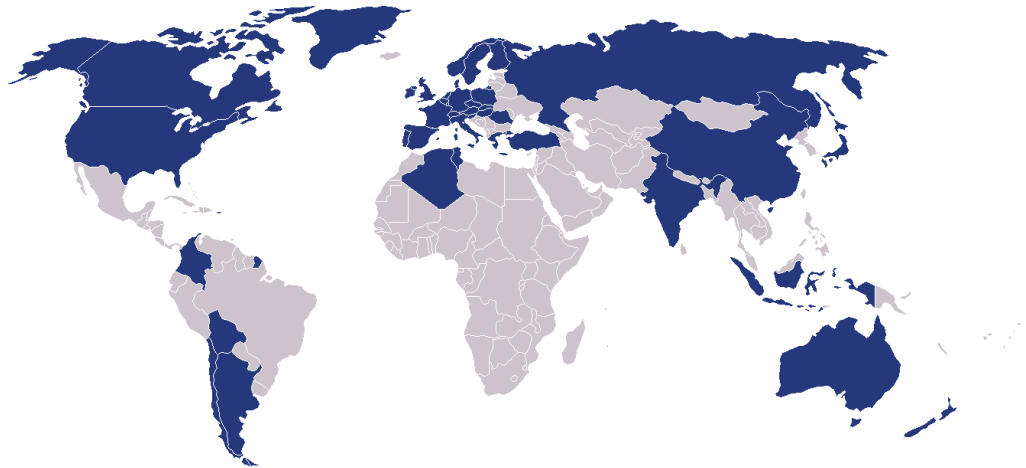
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Geographical coverage: Gas prices





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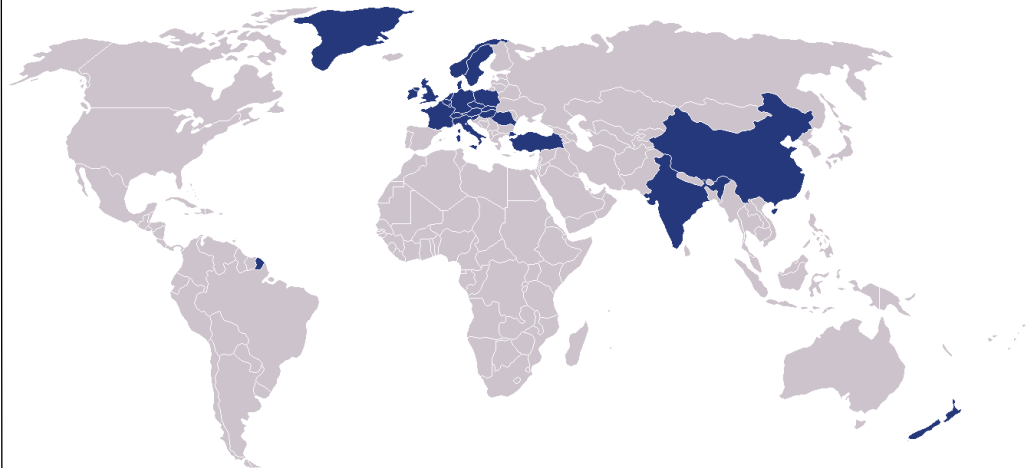
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Geographical coverage: Coal prices





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Correlations

		Consumption				Price				GDP per capita	tmin
		Electr.	Oil	Gas	Coal	Electr.	Oil	Gas	Coal		
C o n s	Electricity	1.00									
	Oil	0.30	1.00								
	Gas	0.18	0.16	1.00							
	Coal	-0.28	-0.29	-0.34	1.00						
P r i c e	Electricity	0.38	-0.01	0.10	-0.20	1.00					
	Oil	-0.57	-0.48	-0.37	0.06	-0.41	1.00				
	Gas	-0.23	-0.18	-0.50	0.48	-0.19	0.23	1.00			
	Coal	0.25	0.32	0.08	-0.19	0.07	-0.40	0.20	1.00		
GDP per capita		0.69	0.64	0.35	-0.46	0.42	-0.69	-0.28	0.53	1.00	
tmin		-0.19	-0.24	0.05	0.14	0.12	0.06	0.12	-0.16	-0.21	1.00
tmax		-0.38	-0.21	-0.04	0.01	0.00	0.31	-0.01	-0.32	-0.37	0.86





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Fisher's panel unit root test (Maddala/Wu 1999)

H_0 : All series are non-stationary

	chi ²	p-value	drift?
Consumption per capita			
Electricity	206.0	0.0	
Oil	648.4	0.0	
Gas	311.5	0.0	x
Coal	362.1	0.0	
Price			
Electricity	296.0	0.0	x
Oil	212.5	0.0	x
Gas	201.2	0.0	
Coal	113.4	0.0	x
GDP per capita	624.0	0.0	x
tmin	1007.1	0.0	
tmax	995.3	0.0	





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Estimation results – oil

	linear	quadratic	logarithmic	inverse
oil use in (t-1)	0.84***	0.84***	0.85***	0.86***
tmin	-8.97***	-11.12***		
tmin ²		0.03		
log(tmin)			-191.77***	
tmin ⁻¹				2430.37***
tmin·income	-0.08	-0.09	-0.22**	-0.33***
tmin·price	0.003***	0.003***	0.003***	0.003***
GDP (per capita)	3.79	3.94	9.14**	14.02***
Oil price	-0.27***	-0.27***	-0.25***	-0.21***
Constant	428.67***	461.18***	751.82***	-28.79
RSS (differences)	620782	618738	622106	629593
Adj. R ² (levels)	0.7798	0.7961	0.8457	0.8733
N	571	571	571	571



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Estimation results – gas

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	linear	quadratic	logarithmic	inverse
Gas use in (t-1)	0.82***	0.82***	0.82***	0.81***
tmin	-4.82***	-1.59		
tmin ²		-0.05		
log(tmin)			-95.80***	
tmin ⁻¹				1333.80***
tmin-income	-0.12**	-0.1	-0.20***	-0.25***
GDP (per capita)	5.96**	5.10**	9.17***	11.38***
Gas price	-0.05***	-0.05***	-0.06***	-0.06***
Electricity price	0.01**	0.01**	0.01**	0.01**
Oil price	0.02	0.02	0.02*	0.02*
Constant	220.06***	174.03***	376.77***	-9.9
RSS (differences)	213407	212135	215268	215240
Adj. R ² (levels)	0.8697	0.8687	0.8769	0.8876
N	414	414	414	414



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Estimation results – coal

	no direct temperature link	linear	quadratic	logarithmic	inverse
Coal use (t-1)	0.78***	0.78***	0.78***	0.78***	0.78***
tmin		-4.87**	3.36		
tmin ²			-0.12**		
log(tmin)				-52.89	
tmin ⁻¹					35.13
tmin-income	-0.10***	0.11	0.13	-0.04	-0.10***
GDP (pp)	3.35*	-5.13	-6.27**	0.77	3.30**
Gas price	0.05***	0.05***	0.05***	0.05***	0.05***
Constant	2.41	203.74**	71.38	197.36	1.47
RSS (diff.)	155986	151004	147904	156038	156029
Adj. R ² (lev.)	0.9056	0.8138	0.6612	0.8816	0.9048
N	458	458	458	458	458



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Estimation results – electricity

	linear	quadratic	logarithmic	inverse
Electricity use in (t-1)	0.84(0)	0.84(0)	0.84(0)	0.84(0)
tmin	-0.12(0.9)	-1.32(0.64)		
tmin ²		0.02(0.42)		
log(tmin)			-27.27(0.34)	
tmin ⁻¹				356.51(0.32)
tmin-income	-0.05(0.17)	-0.06(0.09)	-0.03(0.38)	-0.05(0.05)
tmax	-0.07(0.94)	-1.77(0.6)		
tmax ²		0.01(0.53)		
log(tmax)			21.41(0.68)	
tmax ⁻¹				-44.39(0.98)
tmax-income	0(0.95)	0(0.95)	-0.02(0.67)	-0.01(0.88)
GDP (per capita)	3.23(0.01)	3.70(0)	3.31(0.01)	3.16(0.01)
Gas price	-0.01(0)	-0.01(0)	-0.01(0.01)	-0.01(0.01)
Constant	20.62(0.48)	78.69(0.12)	25.35(0.84)	2.51(0.93)
Adj. R ² (levels)	0.9854	0.9788	0.9851	0.9855
N	504	504	504	504



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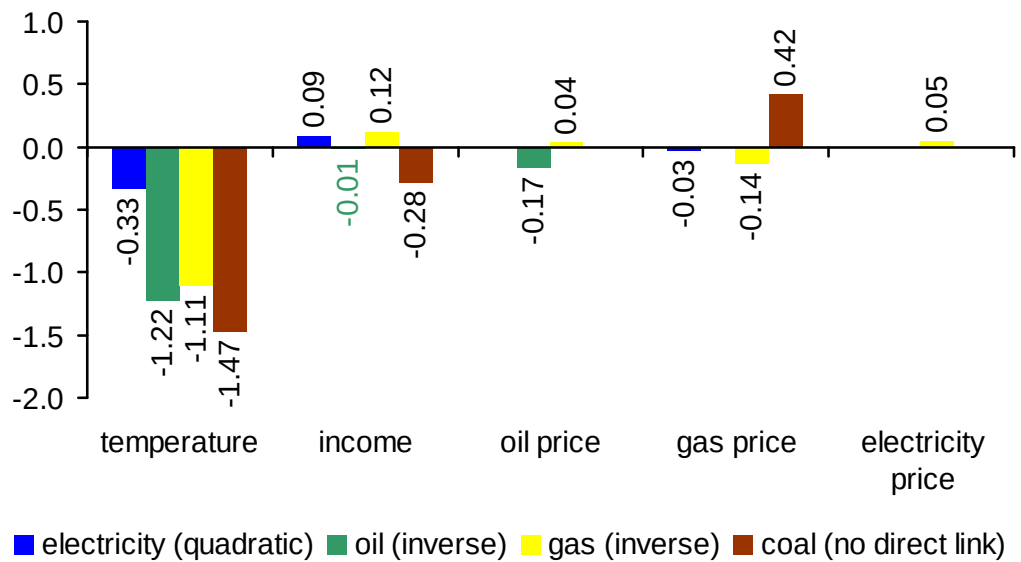
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Estimation results – electricity (no cooling)

	linear	quadratic	logarithmic	inverse
Electricity use in (t-1)	0.84***	0.84***	0.84***	0.84***
tmin	-0.18	-2.45**		
tmin ²		0.03***		
log(tmin)			-17.1	
tmin ⁻¹				349.59**
tmin·income	-0.05***	-0.07***	-0.04***	-0.05***
GDP (per capita)	3.19***	3.70***	2.72***	3.04***
Gas price	-0.01***	-0.01***	-0.01***	-0.01***
Constant	19.32	51.68**	74.50*	2.02
RSS (differences)	18896	18408	18813	18732
Adj. R ² (levels)	0.9859	0.98	0.9856	0.9859
N	504	504	504	504



Short-run average elasticities





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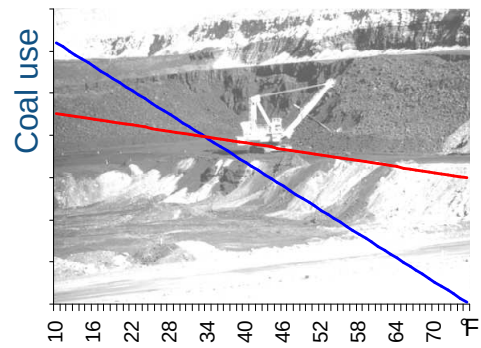
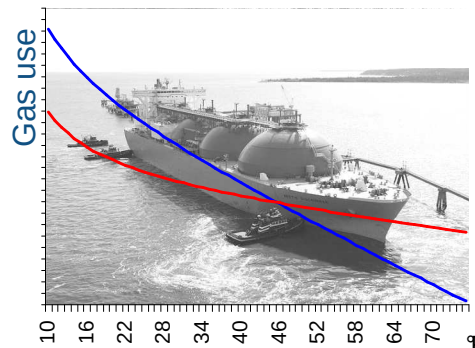
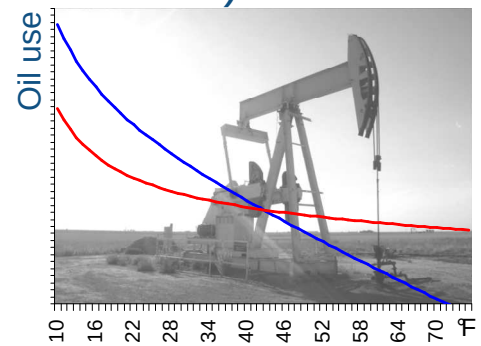
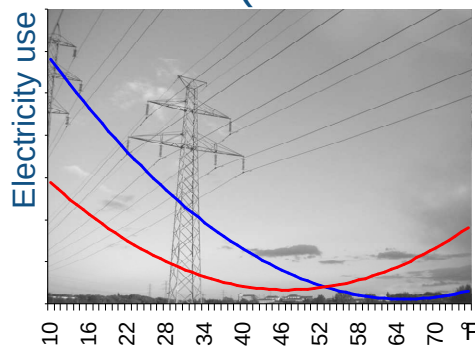
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Fuel use and temperature changes (OECD vs. non-OECD)



Curves for GDP of OECD (♦) vs. non-OECD (♦) countries (yr. 2000)





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Possible caveats

- Data
 - Countries may consist of different climate zones (China, Russia, US, ...)
 - Data reliability?
- Methodology
 - Choice of temperature variables susceptible to collinearity → not suitable for simultaneous evaluation of cooling and heating effect



Future Ocean



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