Rebound Effects in Europe

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Motivation

- Energy efficiency improvements allow to produce the same output with less energy input

- Full extent of energy savings are however not likely to materialize due to adjustments in production and consumption processes (rebound effects)

- Quantification of rebound effects is necessary to understand the impact of energy efficiency on energy demand and emissions

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Motivation

In this paper, we estimate rebound effects in five major EU countries (Germany, France, the U.K., Italy and Spain)

Preliminary results :

- **The lower bound estimate of rebound in productive sector of the economy is estimated between 45% and 60%, while the upper bound is well above 100%**
- **This suggests that (1) rebound in productive sectors is higher than in consumer sectors (2) accounting for dynamic efficiency increases estimates (3) rebound should not be disregarded**
- **This does not suggest that energy efficiency is not to be pursued, rather that it has to be matched with carbon pricing or other complementary measures**

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Outline

Motivation

1. Framing the research question

2. Literature

3. Methodology

4. Results

5. Energy only versus all Factors

6. Comments and next steps

7. Conclusions

1.

Framing the research question

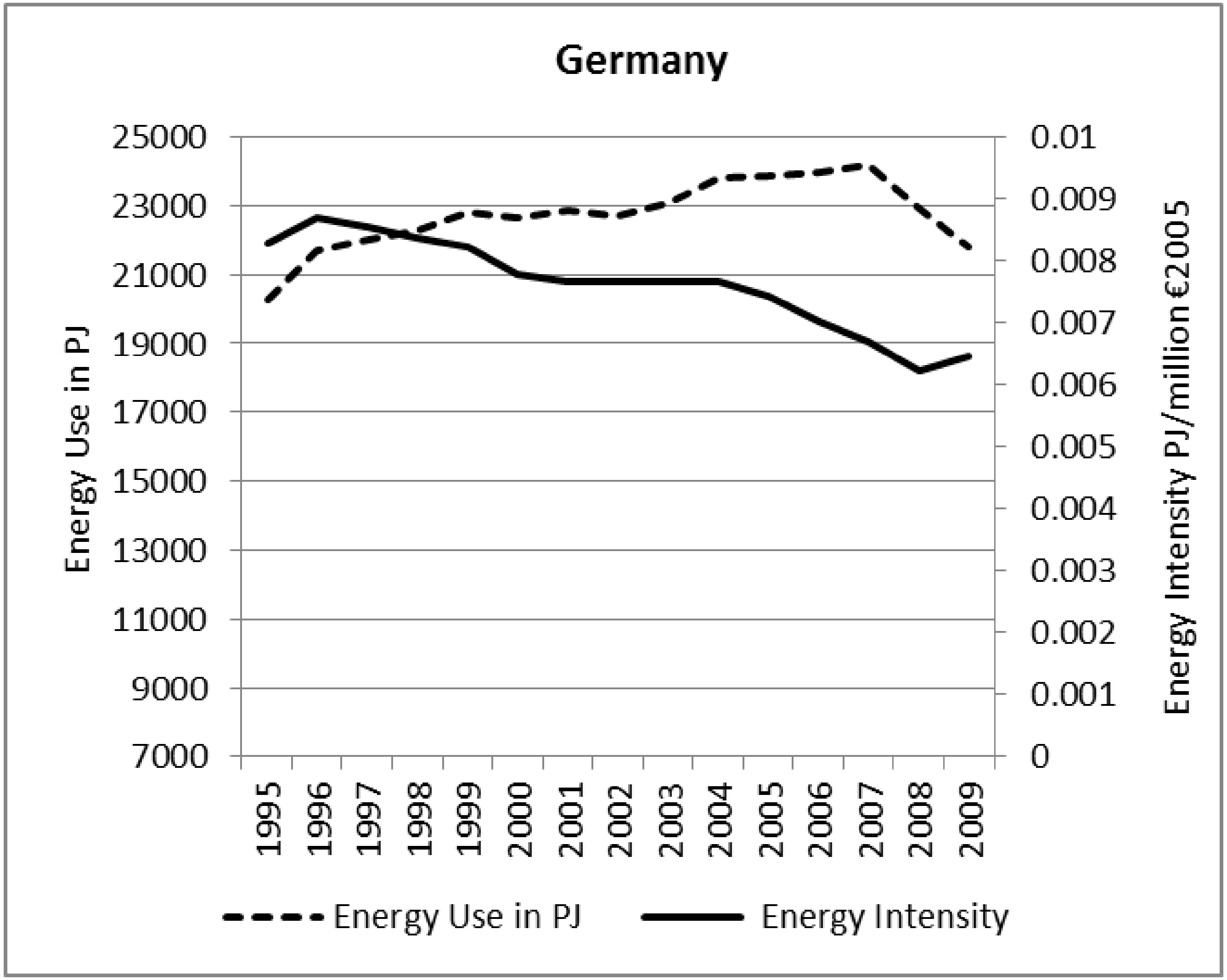
(Static and simplistic) View

X% improvements in (technical) «energy efficiency»

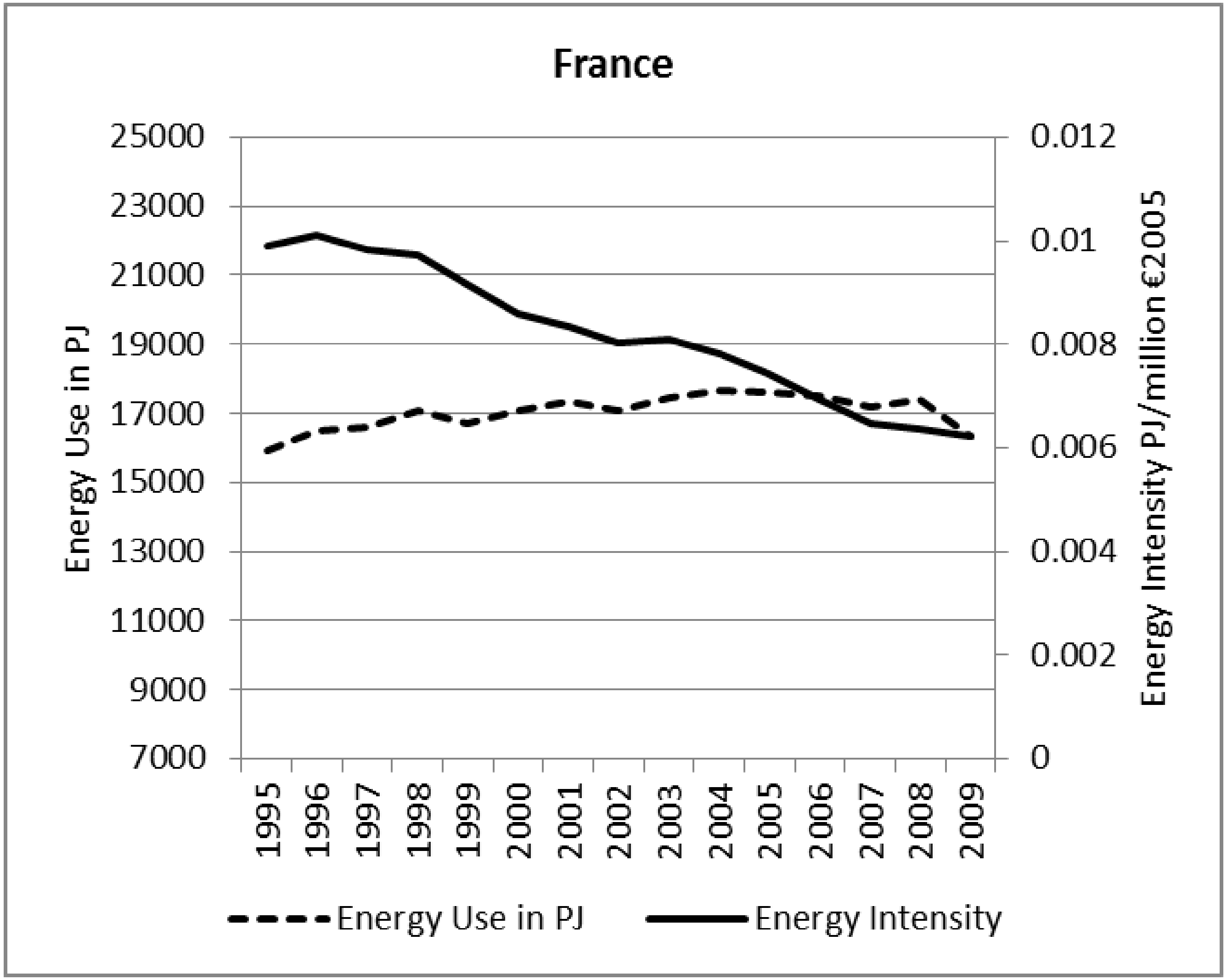
X% decrease in energy demand

Such correspondence not likely to hold

1. Framing the research question



1. Framing the research question



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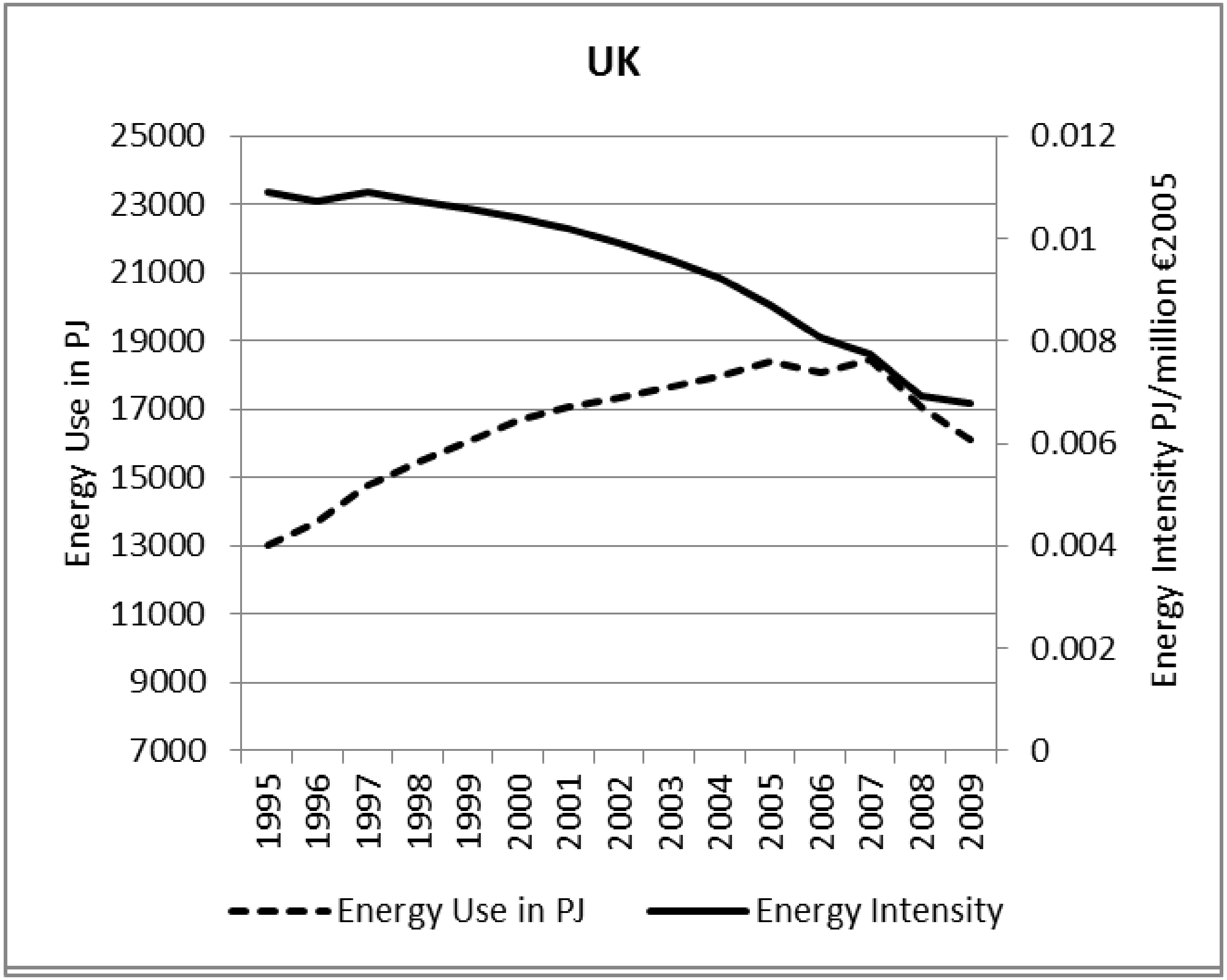

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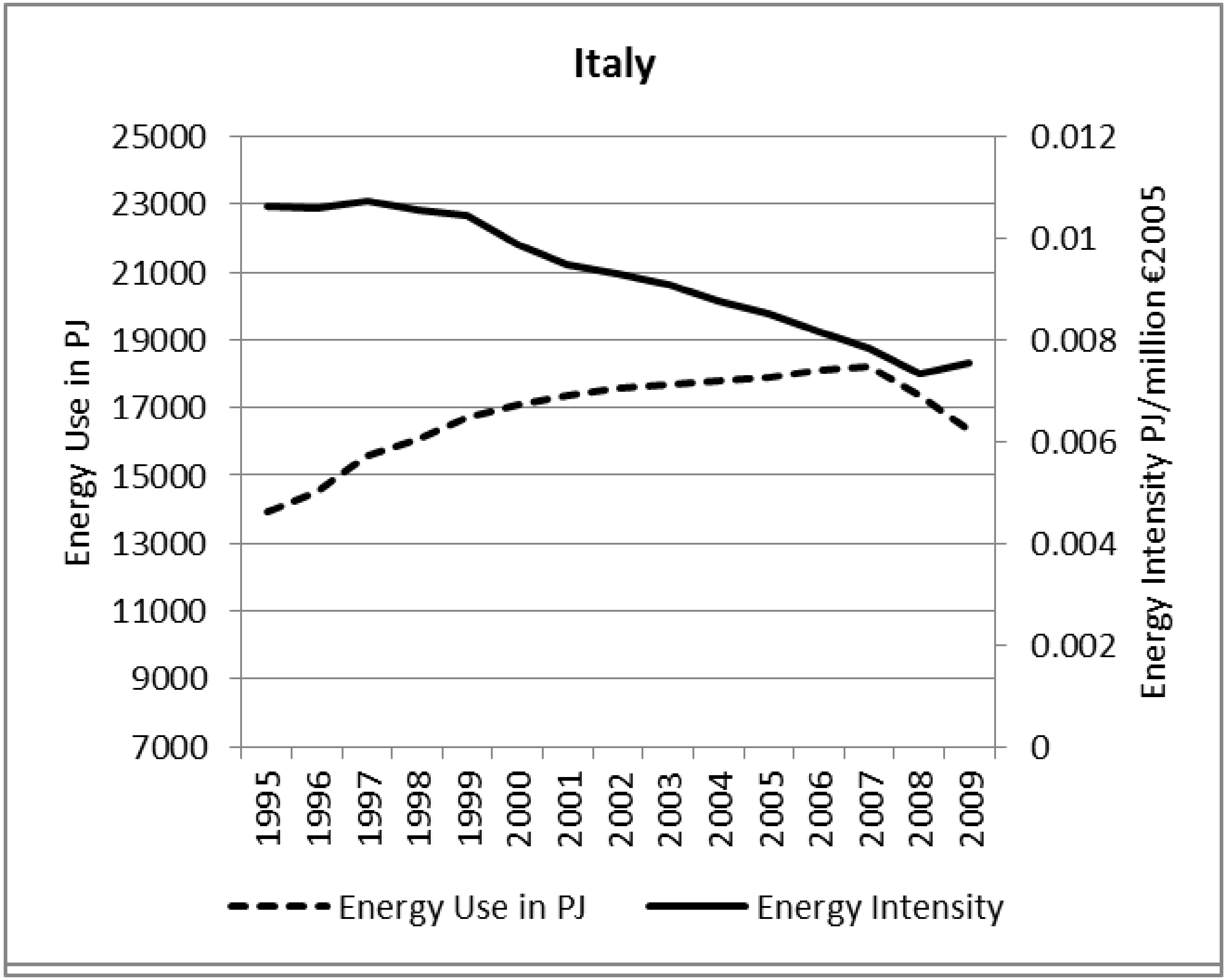

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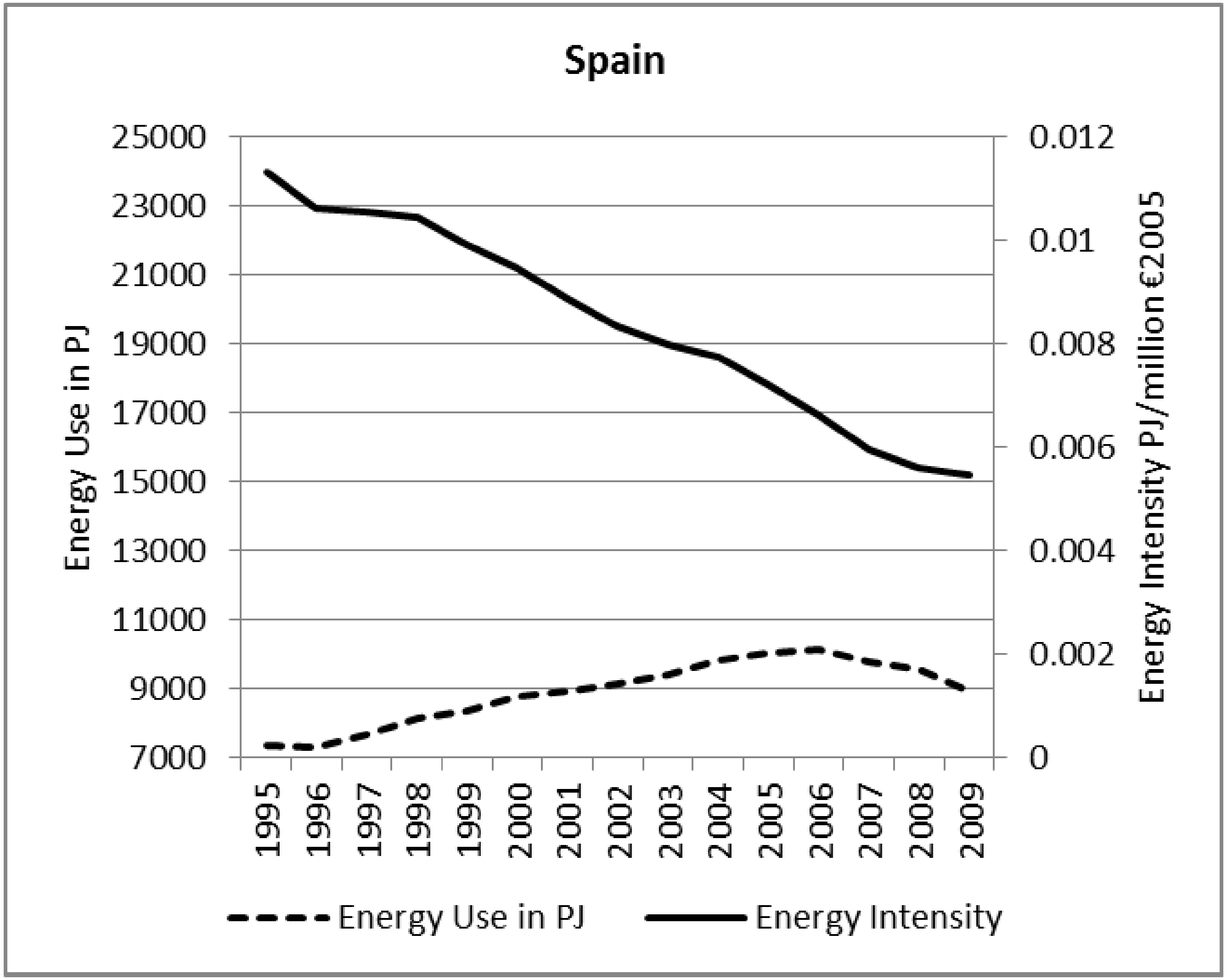


1. Framing the research question

(Static and simplistic) View

X% improvements in energy efficiency

X% decrease in energy demand

Such correspondence not likely to hold:

- ***output cannot be assumes constant over time***
- ***even if output were constant, energy efficiency improvements will almost certainly give rise to adjustments in production and consumption***

Framing the research question

Several economics forces/adjustments at work:

- **Income effect**

  Due to decrease in relative price of using energy, more income available to purchase other goods

- **Substitution effect**

  Energy (and energy intensive goods) are relatively more expensive than other (non-energy intensive) goods

- **General price effect**

  A reduction in energy demand in one sector (country) will have implications for the energy demand in other sectors (countries)

- **Dynamic efficiency**

  Since other factors are now relatively more expensive, consumers (producers) will innovate to economize such more expensive factors

1. Framing the research question

Rebound (Take back) effects

Percentage of engineering energy efficiency savings which are eroded due to the forces described above

$$R^E = \frac{EU - EU_{es}}{EU_{ne} - EU_{es}}$$

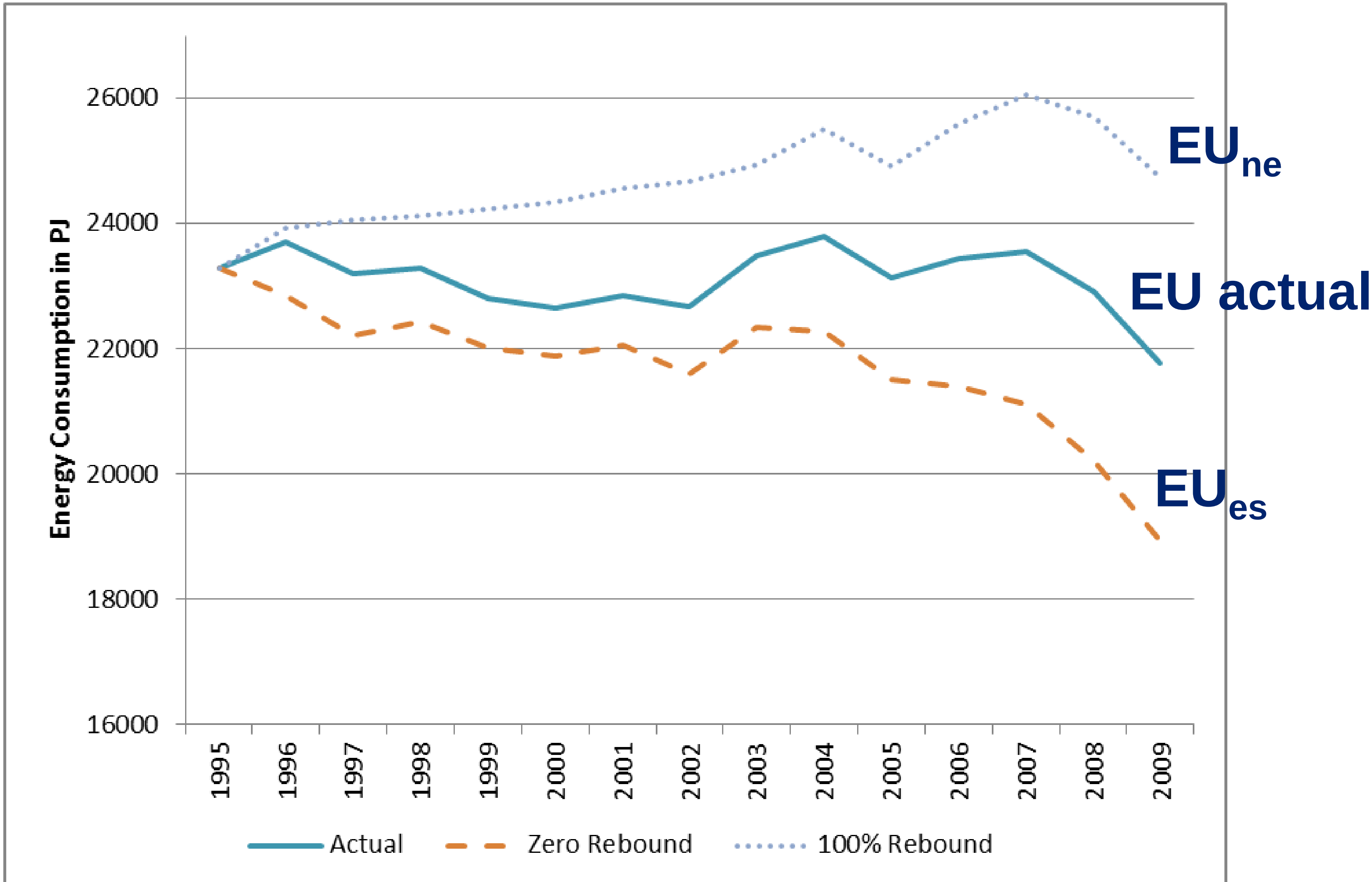
EU Actual Energy Demand

EU_{ne} Energy demand with no efficiency improvements

EU_{es} Energy demand under full engineering savings

1.

Framing the research question



2. Literature

Early literature: The concept of rebound effect can be traced back to Jevons (1865)

> *"….. the reduction of the consumption of coal, per ton of iron, to less than one third of its former amount, has been followed….by a tenfold increase in total consumption, not to speak of the indirect effect of cheap iron in accelerating other coal consuming branches of industry…" (Jevons, 1865)*

Few scholars provide some (indirect) evidence of rebound effects, which served as the basis for criticism of governments' energy efficiency policy (Brookes, Khazoom, Jorgenson).

1990s and 2000s: lively debate on the existence of rebound effects. Most analysis focuses on direct rebound effects in household services energy consumption (heating, transport). Concerns regarding differences between direct, indirect and economy wide rebounds

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2.

Literature

Recent contributions: rebound effect accepted, the question that is yet not settled is its quantification. Challenges linked with the estimation of the counterfactual energy demands.

Results are conflicting at best: Estimate of direct rebound in household consumption: from 0 to 50%, Indirect rebound effects not quantified but believed to be proportional to share of energy expenditures. Economy-wide rebound effects.

Shortcomings of the literature:

- **Mostly focused on consumption sector (1/3 of energy demand) and on one energy service only**
- **Econometric studies often fail to model input-augmenting technical change**
- **No consideration for dynamic efficiency, i.e. how energy efficiency improvements impacts the efficiency of other inputs**

2. Literature

We use a methodology proposed in Saunders (2013) to analyze the historic direct rebound effects in 30 productive sectors of five major EU economies

3. Methodology

In each sector, production choices are well described by the a four-factor (K,L,E,M) translog unit cost function, modified to include «efficiency gains» parameters characterizing how each vintage to increases input efficiency over time

↓

Use historical data to estimate the «efficiency gains» parameters

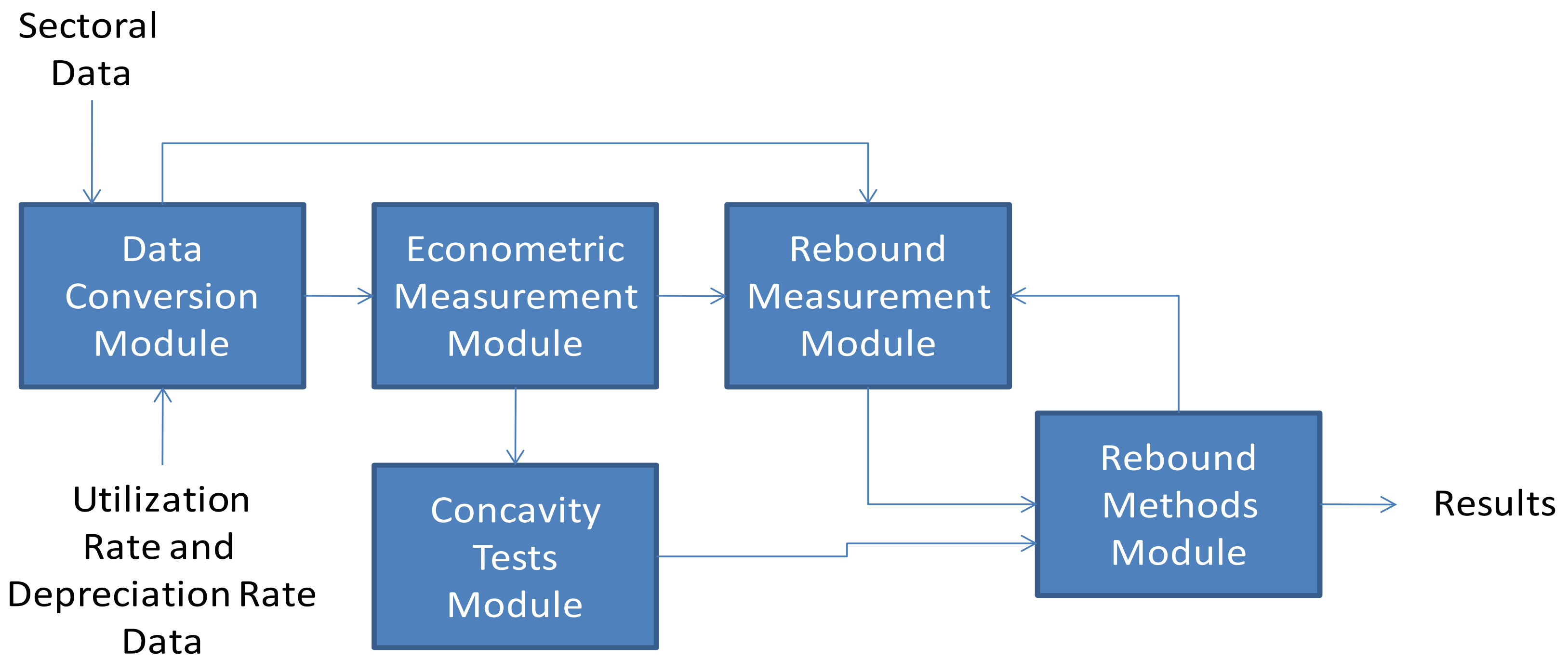
↓

Backcast different energy demands levels, by switching on and off the efficiency gains parameters (and constraining output levels)

↓

Sum up the sectoral level effects to obtain country-wide rebound estimate

3. Methodology



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In each sector, production choices are well described by the a four-factor (K,L,E,M) translog unit cost function modified to include «efficiency gains» parameters charachterizing how each vintage to increases input efficiency over time

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3.

Methodology

Countries	GDP/ EU28 GDP	POP/ EU28 POP	EN. USE/ EU28 EN. USE	MANUF/ EU28 MANUF	MANUF/ TOTAL GDP	ENERGY INT. 1995-2009	ENERGY USE 1995-2009
Germany	21.62%	16.72%	19.81%	13.19%	37.02%	-2.23%	0.51%
France	15.79%	12.56%	14.60%	6.99%	26.32%	-3.63%	-0.06%
United Kingdom	15.78%	12.12%	12.64%	5.43%	17.02%	-3.41%	1.33%
Italy	12.96%	11.77%	10.93%	6.81%	30.09%	-2.52%	0.96%
Spain	7.56%	8.53%	7.62%	4.01%	26.10%	-4.95%	1.63%
Average EU28	6.71%	4.97%	3.48%		27.68%	-2.61%	1.96%

3. Methodology

Number	Sector	Germany Energy Exp. Shares	Italy Energy Exp. Shares
1	AGRICULTURE, HUNTING, FORESTRY AND FISHING	4.40%	6.32%
2	MINING AND QUARRYING	10.20%	3.75%
5	LEATHER and FOOTWEAR	1.41%	0.94%
6	WOOD AND OF WOOD AND CORK	2.74%	3.23%
7	PULP, PAPER, PRINTING AND PUBLISHING	3.36%	4.32%
8	TEXTILES AND TEXTILE	2.41%	2.39%
9	CHEMICALS AND CHEMICAL	7.82%	9.68%
10	RUBBER AND PLASTIC	3.18%	4.21%
11	OTHER NON-METALLIC MINERAL	5.90%	7.19%
12	BASIC AND FABRICATED METALS	5.43%	5.47%
13	MACHINERY, NEC	0.81%	1.68%
14	ELECTRICAL AND OPTICAL EQUIPMENT	0.86%	2.00%
15	TRANSPORT EQUIPMENT	0.85%	1.21%
17	ELECTRICITY, GAS AND WATER SUPPLY	16.94%	16.79%
18	CONSTRUCTION	1.07%	0.54%
19	SALE AND MAINTENANCE OF MOTORS	2.45%	0.95%
22	HOTELS AND RESTAURANTS	1.81%	1.80%
23	INLAND TRANSPORT	9.26%	8.52%
24	WATER TRANSPORT	4.58%	15.09%
25	AIR TRANSPORT	14.48%	11.13%
26	SUPPORTING AND AUX. TRANSPORT ACTIVITIES	4.53%	1.76%
27	POST AND TELECOMMUNICATIONS	1.02%	1.64%
28	FINANCIAL INTERMEDIATION	0.39%	0.52%
29	REAL ESTATE ACTIVITIES	0.20%	0.37%
30	RENTING OF M&EEQ AND BUSINESS ACTIVITIES	0.59%	1.02%
33	HEALTH AND SOCIAL WORK	0.80%	1.27%
34	COMMUNITY, SOCIAL AND PERSONAL SERVICES	2.75%	1.30%

3. Methodology

Trasnlog cost function: work horse of production theory analysis, dual to a translog production function, has some advantages with respect to Cobb-Douglas and CES (for instance, handling separability and homogeneity)

Original formulation of translog cost function

$$\ln c = a_0 + \mathbf{a} \ln \mathbf{p}^T + \frac{1}{2} \ln \mathbf{p} \cdot \mathbf{B}_{pp} \cdot \ln \mathbf{p}^T$$

Is modified to allow for «efficiency gains» parameters (Saunders 2013)

$$\ln c = \ln c_0 \boxed{+ \mathbf{a}\boldsymbol{\lambda}^T t} + \mathbf{a} \ln \mathbf{p}^T + \frac{1}{2} \ln \mathbf{p} \cdot \mathbf{B} \cdot \ln \mathbf{p}^T \boxed{+ \boldsymbol{\lambda} \cdot \boldsymbol{B} \cdot \ln \mathbf{p}^T t + \frac{1}{2} \boldsymbol{\lambda} \cdot \mathbf{B} \boldsymbol{\lambda}^T t^2}$$

This formulation is consistent with assuming factor-augmenting technology gains of the form: $\tau_N = e^{\lambda t}_N$

(note that lambas are assumed constant)

3. Methodology

In each sector, production choices are well described by the a four-factor (K,L,E,M) translog unit cost function modified to include «efficiency gains» parameters charachterizing how each vintage to increases input efficiency over time

Use historical data to estimate the «efficiency gains» parameters

Backcast different energy demands levels, by switching on and off the efficiency gains parameters (and constraining output levels)

Sum up the sectoral level effects to obtain country-wide rebound estimate

3.

Methodology

$$\ln c = \ln c_0 \boxed{+ \mathbf{a}\boldsymbol{\lambda}^T t} + \mathbf{a} \ln \mathbf{p}^T + \frac{1}{2} \ln \mathbf{p} \cdot \mathbf{B} \cdot \ln \mathbf{p}^T \boxed{+ \boldsymbol{\lambda} \cdot \boldsymbol{B} \cdot \ln \mathbf{p}^T t + \frac{1}{2} \boldsymbol{\lambda} \cdot \mathbf{B} \boldsymbol{\lambda}^T t^2}$$

$\boldsymbol{\lambda}$ **vector of technology gains** $\lambda_K, \lambda_L, \lambda_E, \lambda_M$

Estimated at the sector level: 5 countries, 30 sectors*, 1995-2009

Using iterative procedure in TSP (full information maximul likelihood)

Main data source: WIOD database (2012, 2014)

for output and inputs quantities

Input prices, energy use, depreciations rates kindly provided by K. Kratena

- Excluded: refined petroleum and nuclear fuel, wholesale and commission and retail trade, household consumption

3. Methodology

Parameter	*Estimate*	*Error*	*t-statistic*	*P-value*
R_REV	1.76E-03	0.006131	2.86E-01	[.075]
R_CF	0.026161	0.036673	0.713359	[.076]

		t-statistics
d	7.26%	
r_rev	0.18%	0.29
r_cf	2.62%	0.71

Log likelihood = 222.673

Parameter	**Estimate**	**Standard Error**	**t-statistic**	**P-value**
DKK	0.120593	0.016629	7.25187	[.000]
DKE	0.032999	0.016668	1.97978	[.048]
AK	0.158471	0.003838	41.2946	[.000]
AE	0.093664	0.00958	9.7767	[.000]
DKL	0.034782	0.044196	0.786992	[.431]
AL	0.382436	0.03244	11.7889	[.000]
LK	0.016809	0.009485	1.77216	[.076]
LM	-0.0136	0.011262	-1.20757	[.227]
LL	0.045285	0.009166	4.94072	[.000]
LE	0.031086	0.012027	2.58474	[.010]
DLL	0.592987	0.055975	10.5937	[.000]
DLE	0.085159	0.025496	3.34015	[.001]
DEE	0.001003	6.16553	0.000163	[1.00]

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$$R^E = \frac{EU - EU_{es}}{EU_{ne} - EU_{es}}$$

EU Actual Energy Demand
EU_{ne} Energy demand with no efficiency improvements
EU_{es} Energy demand under full engineering savings

3. Methodology

EU_{ne} no efficiency improvements (100% rebound)

Energy efficiency gains do not lead to any reduction in energy demand (i.e. demand is the same as with no energy efficiency gains)

Simulation: constrain λ_E to zero, and **back-cast EU and Y**

EU_{es} full engineering savings (zero rebound)

Simulation: equivalent to assuming Leontieff production function, which leaves economic output, output costs and other factor uses **equal to those of the 100% rebound case**

EU actual energy demand

Uses estimated demand in econometric module, which is very close to actual demand

3.

Methodology

Agriculture					
	Energy			Output	
	Estimated Actual Rebound	Energy Only		Estimated Actual	λ_E=0
		Zero Rebound	100% Rebound		
1995	5,367	5,367	5,367	170,331	170,331
1996	6,542	6,423	6,490	171,677	168,625
1997	8,721	6,401	6,501	249,983	209,983
1998	7,546	6,338	6,525	271,240	166,399
1999	6,525	6,151	6,541	283,782	175,250
2000	6,485	5,841	6,778	288,923	176,678
2001	7,741	7,101	7,866	293,495	181,963
2002	5,491	4,882	6,000	292,505	179,797
2003	6,236	5,365	7,045	309,818	192,856
2004	6,674	5,495	7,793	339,068	215,264
2005	6,705	5,334	8,170	333,914	213,620
2006	6,544	5,008	8,317	338,015	213,928
2007	5,988	4,383	7,962	358,148	217,517
2008	6,705	5,334	8,170	398,289	213,620
2009	6,247	4,391	8,678	439,159	226,285

GERMANY	Sector	Energy Use Share of Economy in 1995	Output Share of Economy in 1995	Energy Intensity (E/Y) in 1995	Energy Intensity (E/Y) in 2009	Energy-specific Rebound		
						Short-term	Long-term	Trend (change in rebound)
		%	%	%	%	%	%	%/year
1	Agriculture	13.8%	3.9%	5.8%	3.6%	96%	43%	-5.2%
2	Metal Mining	1.8%	0.9%	7.2%	3.5%	171%	44%	-8.6%
5	Leather, leather and footwear	0.2%	0.2%	2.8%	2.1%	64%	31%	-4.7%
6	WOOD AND OF WOOD AND CORK	1.1%	0.9%	3.8%	2.1%	99%	29%	-7.9%
7	PULP, PAPER, PAPER , PRINTING AND PUBLISHING	3.5%	2.9%	3.4%	2.1%	152%	38%	-8.9%
8	Textiles and textile	1.8%	1.2%	4.3%	2.7%	141%	88%	-3.1%
9	Chemicals and chemical products	7.9%	4.3%	5.0%	3.3%	92%	36%	-6.1%
10	Rubber and plastics	2.8%	1.9%	4.4%	2.7%	147%	37%	-8.8%
11	OTHER NON-METALLIC MINERAL	3.4%	1.7%	5.1%	3.5%	156%	21%	-12.5%
12	BASIC METALS AND FABRICATED METAL	8.3%	5.0%	3.8%	3.0%	180%	23%	-12.8%
13	MACHINERY, NEC	4.1%	5.2%	1.5%	1.3%	163%	39%	-9.1%
14	ELECTRICAL AND OPTICAL EQUIPMENT	3.7%	5.1%	1.7%	1.3%	149%	29%	-10.3%
15	TRANSPORT EQUIPMENT	4.4%	6.0%	1.6%	1.3%	159%	54%	-6.9%
17	ELECTRICITY, GAS AND WATER SUPPLY	11.8%	1.7%	20.2%	12.9%	93%	61%	-2.8%
18	CONSTRUCTION	4.3%	10.0%	1.8%	0.8%	128%	28%	-9.6%
19	Sale, maintenance and repair of motor vehicles and motorcycles	1.2%	1.6%	1.8%	1.3%	127%	38%	-7.8%
22	HOTELS AND RESTAURANTS	2.8%	2.3%	2.2%	2.1%	124%	39%	-7.5%
23	Inland transport	4.5%	2.3%	5.8%	4.3%	158%	49%	-7.5%
24	Water transport	0.2%	0.3%	4.5%	1.6%	148%	42%	-8.0%
25	Air transport	1.2%	0.6%	14.2%	3.9%	139%	78%	-3.8%
26	Supporting and auxiliary transport activities	1.7%	2.2%	2.7%	1.4%	137%	40%	-7.8%
27	POST AND TELECOMMUNICATIONS	1.0%	2.1%	1.4%	0.9%	161%	83%	-4.4%
28	FINANCIAL INTERMEDIATION	1.9%	5.8%	0.7%	0.6%	92%	18%	-10.3%
29	Real estate activities	2.1%	10.5%	0.4%	0.4%	130%	80%	-3.2%
30	Renting of m&eq and other business activities	3.5%	10.6%	0.9%	0.6%	145%	15%	-14.1%
33	HEALTH AND SOCIAL WORK	4.3%	6.3%	1.6%	1.2%	172%	45%	-8.5%
34	Services	2.9%	5.0%	1.7%	1.0%	181%	44%	-9.0%
	OVERALL	100%	100%			137%	43%	

3. Methodology

In each sector, production choices are well described by the a four-factor (K,L,E,M) translog unit cost function modified to include «efficiency gains» parameters charachterizing how each vintage to increases input efficiency over time

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Sum up the sectoral level rebound effects

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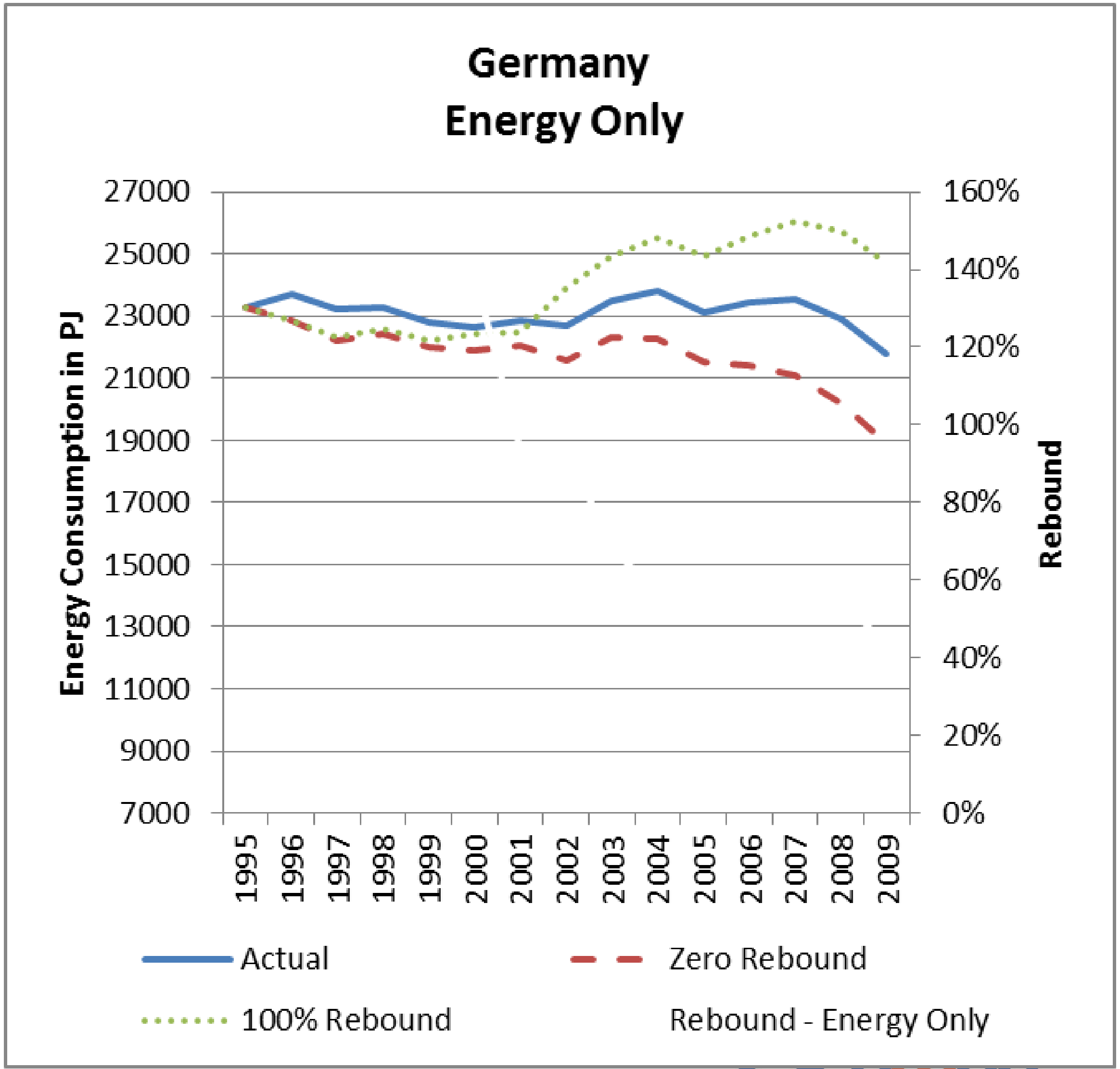
4. Results


Germany
Energy Only
27000
25000
23000
21000
19000
17000
15000
13000
11000
9000
7000
Energy Consumption in PJ
160%
140%
120%
100%
80%
60%
40%
20%
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Rebound
1995
1996
1997
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2008
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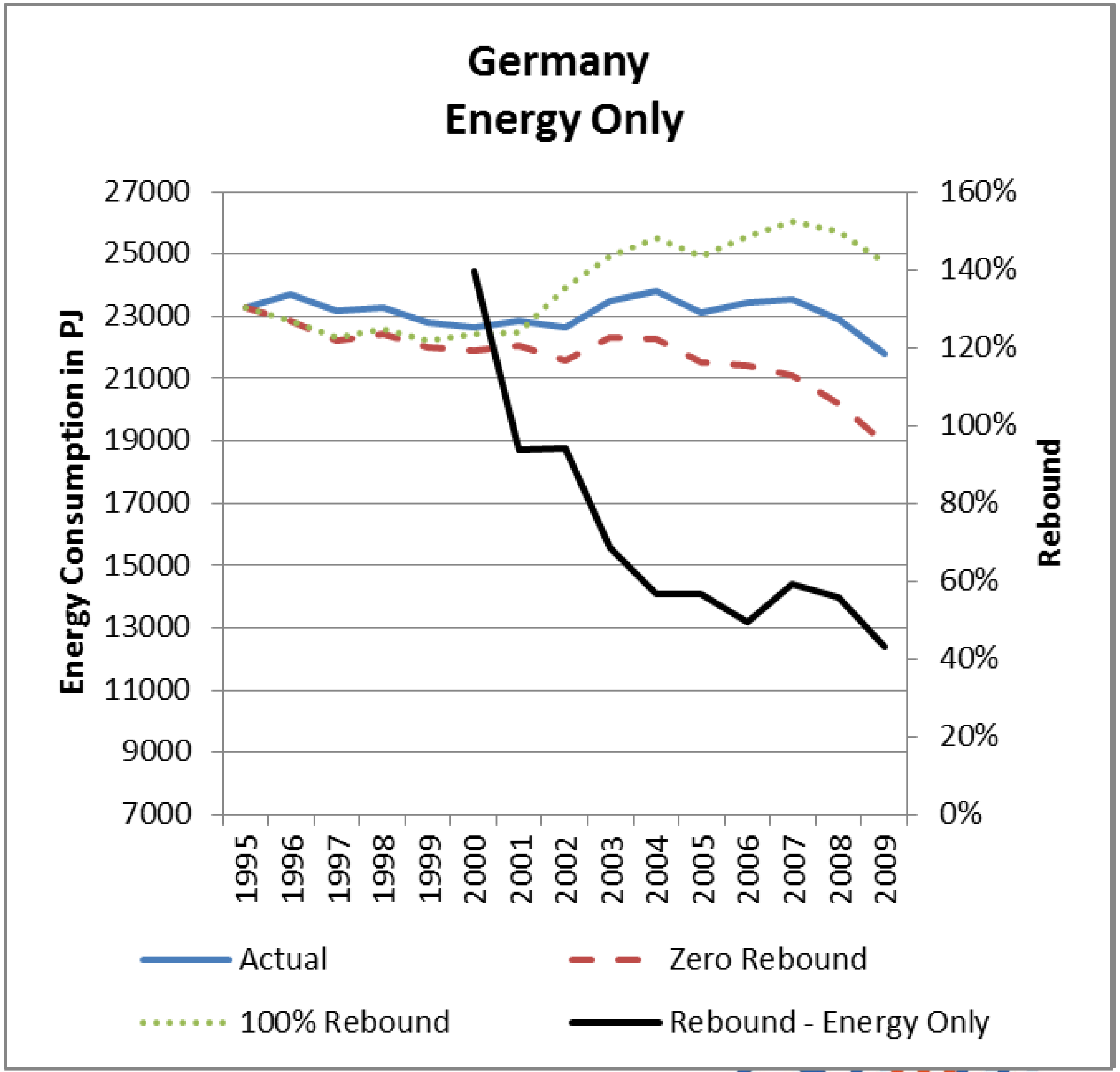
Actual
Zero Rebound
100% Rebound
Rebound - Energy Only

4. Results


Germany
Energy Only
Energy Consumption in PJ
27000
25000
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Rebound
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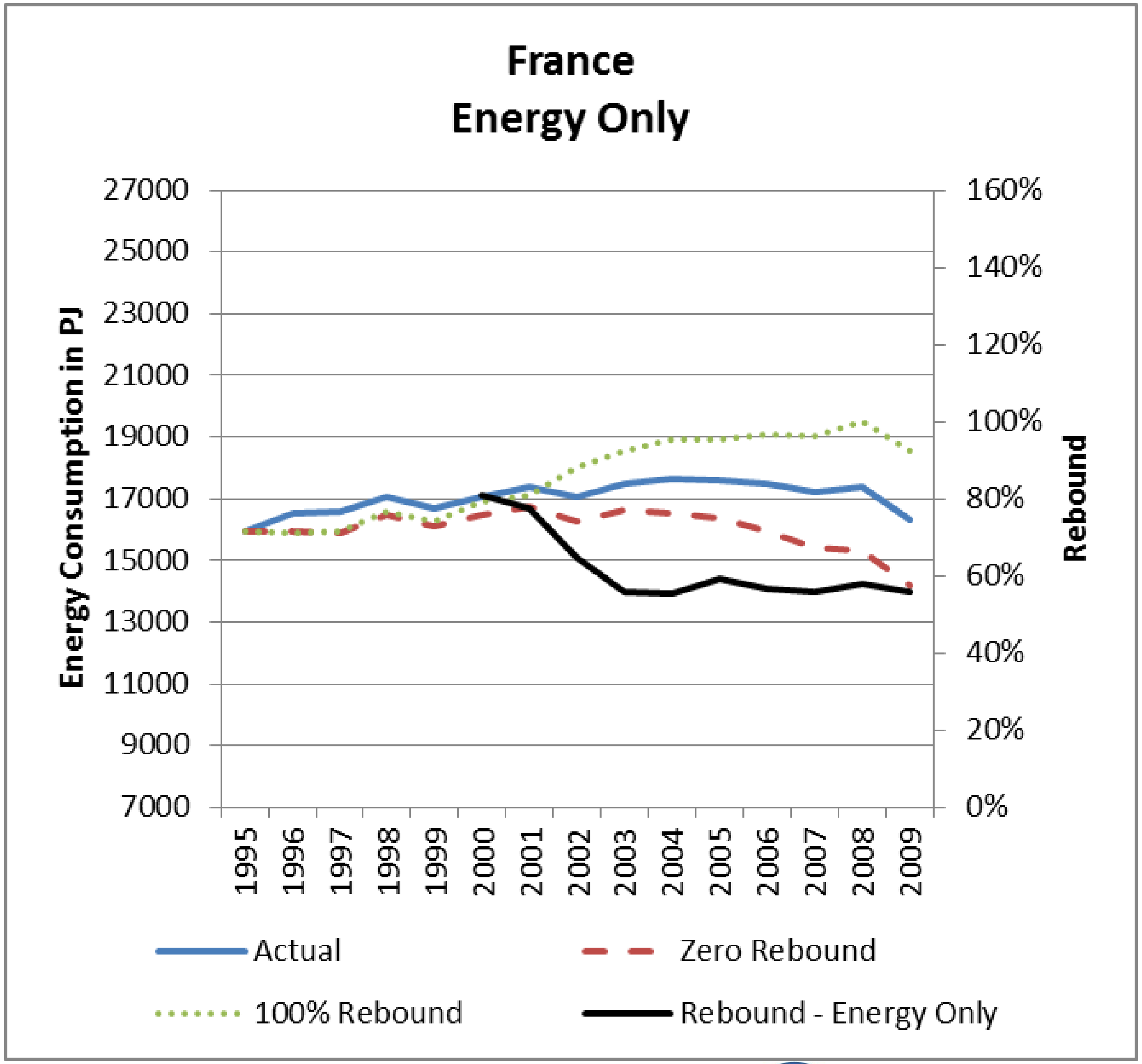
Actual
Zero Rebound
100% Rebound
Rebound - Energy Only

4. Results


France
Energy Only
Energy Consumption in PJ
Rebound
27000
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21000
19000
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7000
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140%
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100%
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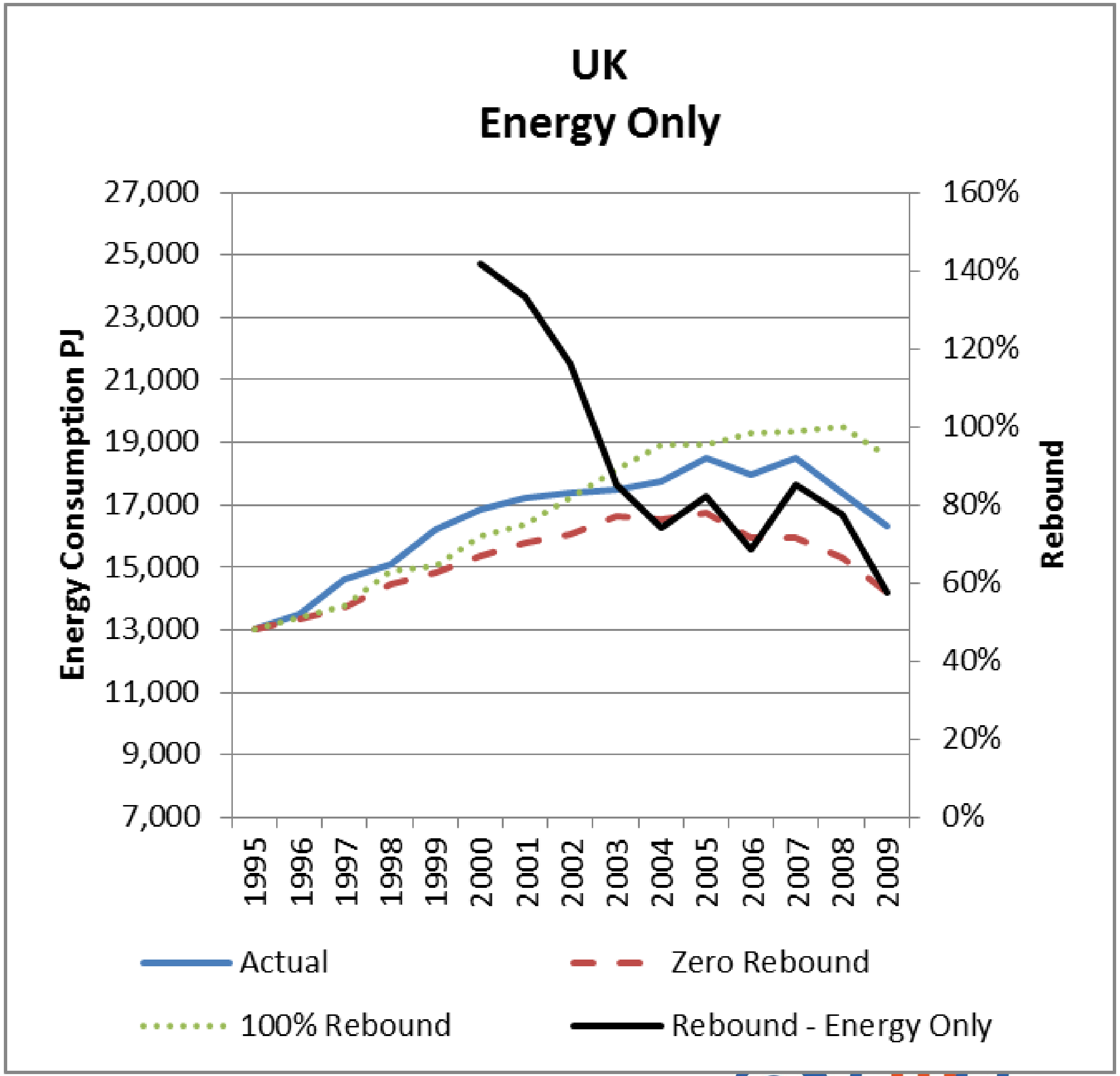
Actual
Zero Rebound
100% Rebound
Rebound - Energy Only

4. Results


UK
Energy Only
Energy Consumption PJ
27,000
25,000
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Rebound
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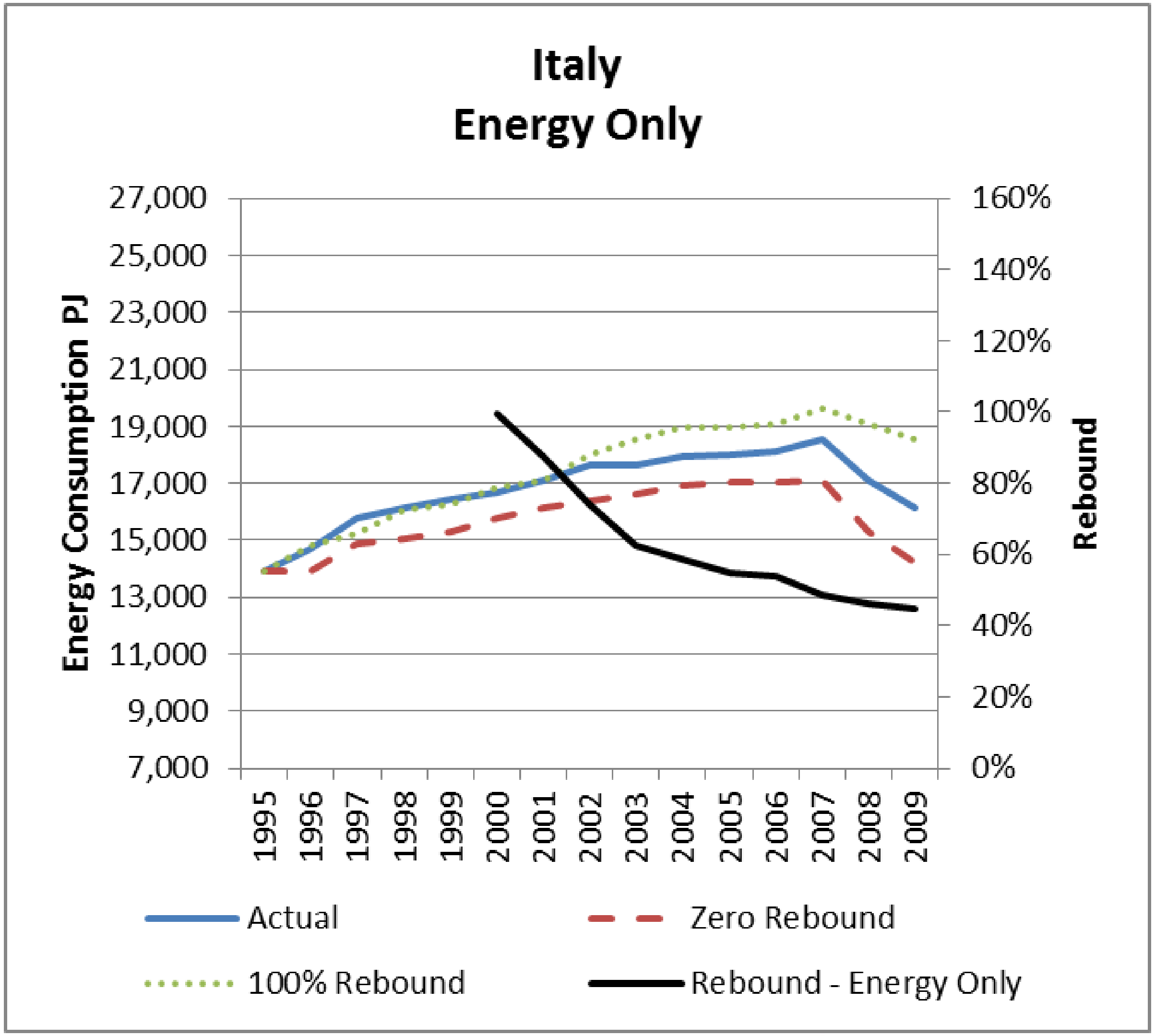
Actual
Zero Rebound
100% Rebound
Rebound - Energy Only

4. Results



Italy
Energy Only
Energy Consumption PJ
27,000
25,000
23,000
21,000
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13,000
11,000
9,000
7,000
160%
140%
120%
100%
80%
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20%
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Rebound
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Actual
Zero Rebound
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Rebound - Energy Only

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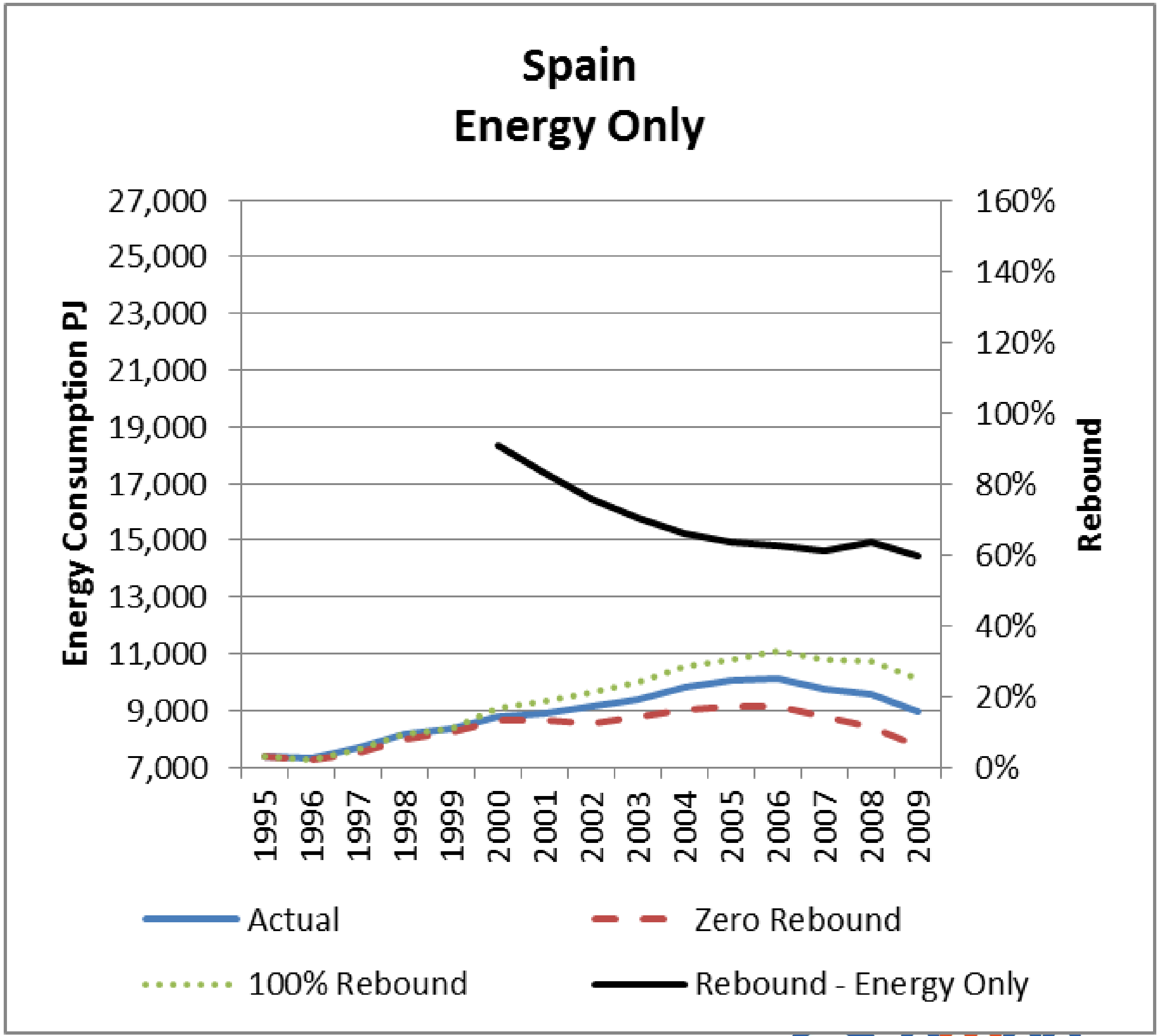
Spain
Energy Only
Energy Consumption PJ
Rebound
27,000
25,000
23,000
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140%
120%
100%
80%
60%
40%
20%
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2009
Actual
Zero Rebound
100% Rebound
Rebound - Energy Only

5. Energy only versus all factors

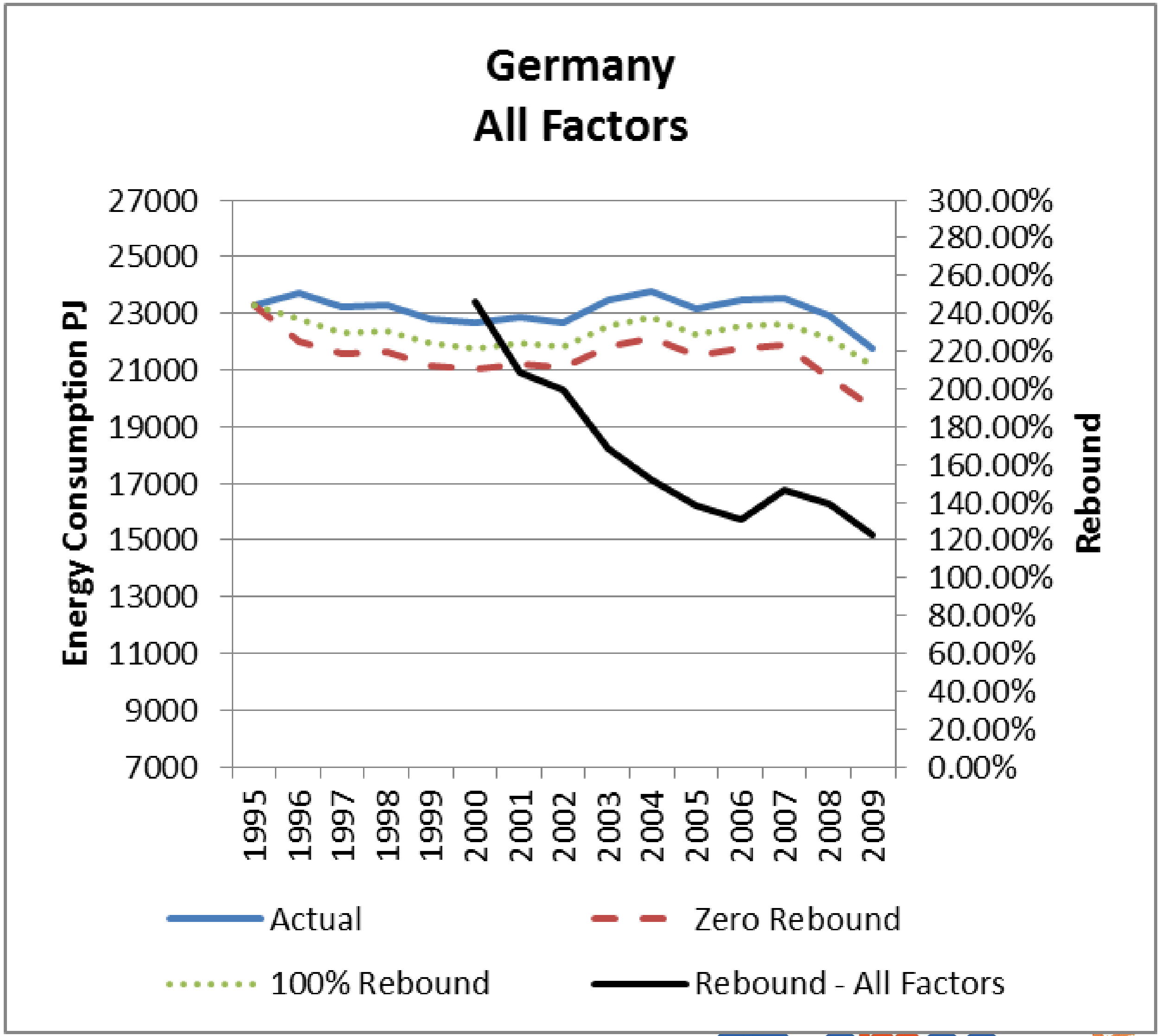
The rebound estimates presented so far are based on counterfactual energy demand assuming that energy technology gains did not happen, but allows efficiency gains in all other factors

Issue of dynamic efficiency, namely the fact that part of the efficiency gains in other factors of production (capital, labour, materials) may be due to energy efficiency improvements

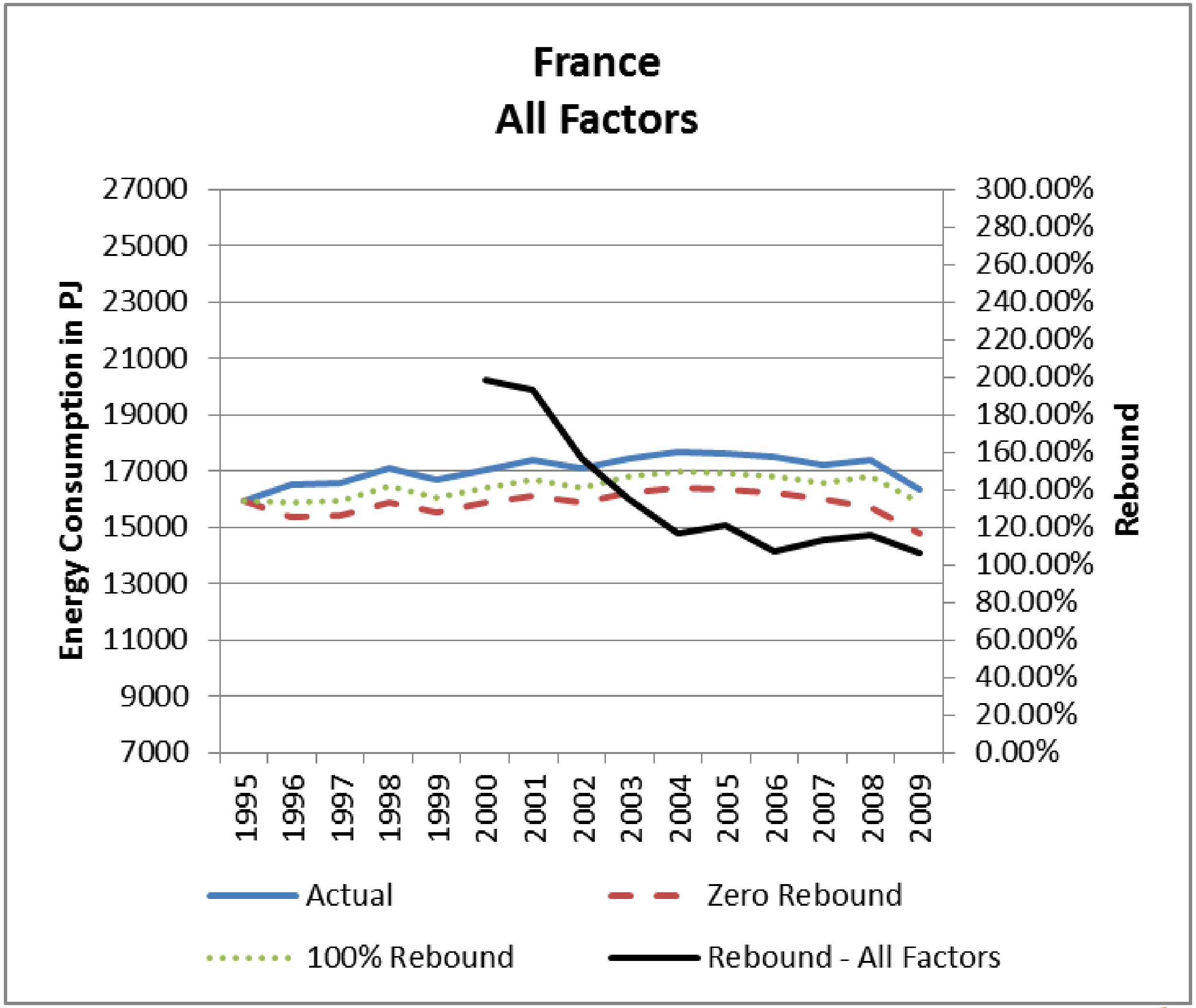
Hence, we repeat the back-casting to estimate rebound effects in case technology gains for all factors were equal to zero. This is an upper bound estimate of rebound

The result is consistent back-fire (rebound higher than 100%)

5. Energy only versus all factors

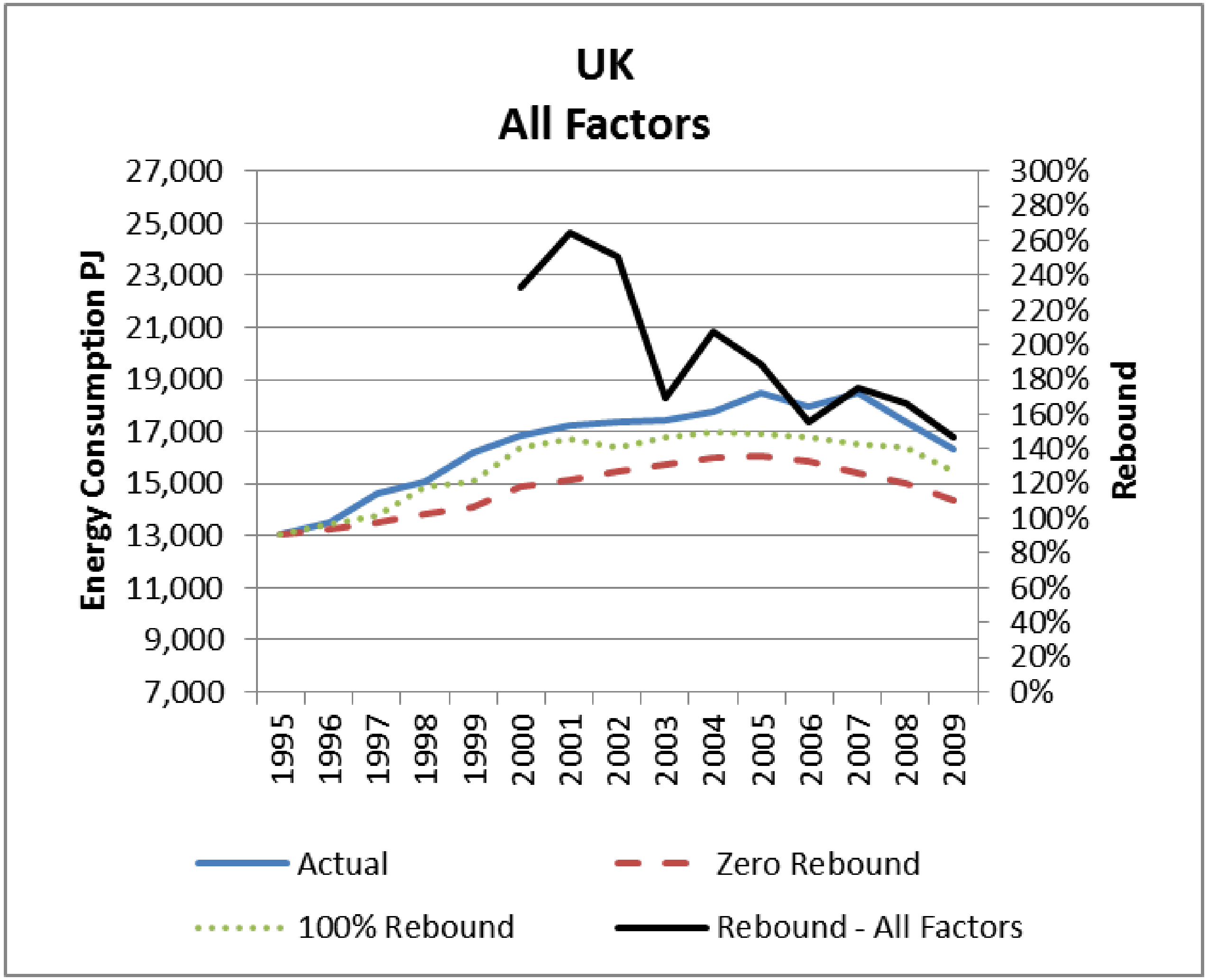


5. Energy only versus all factors



5.

Energy only versus all factors



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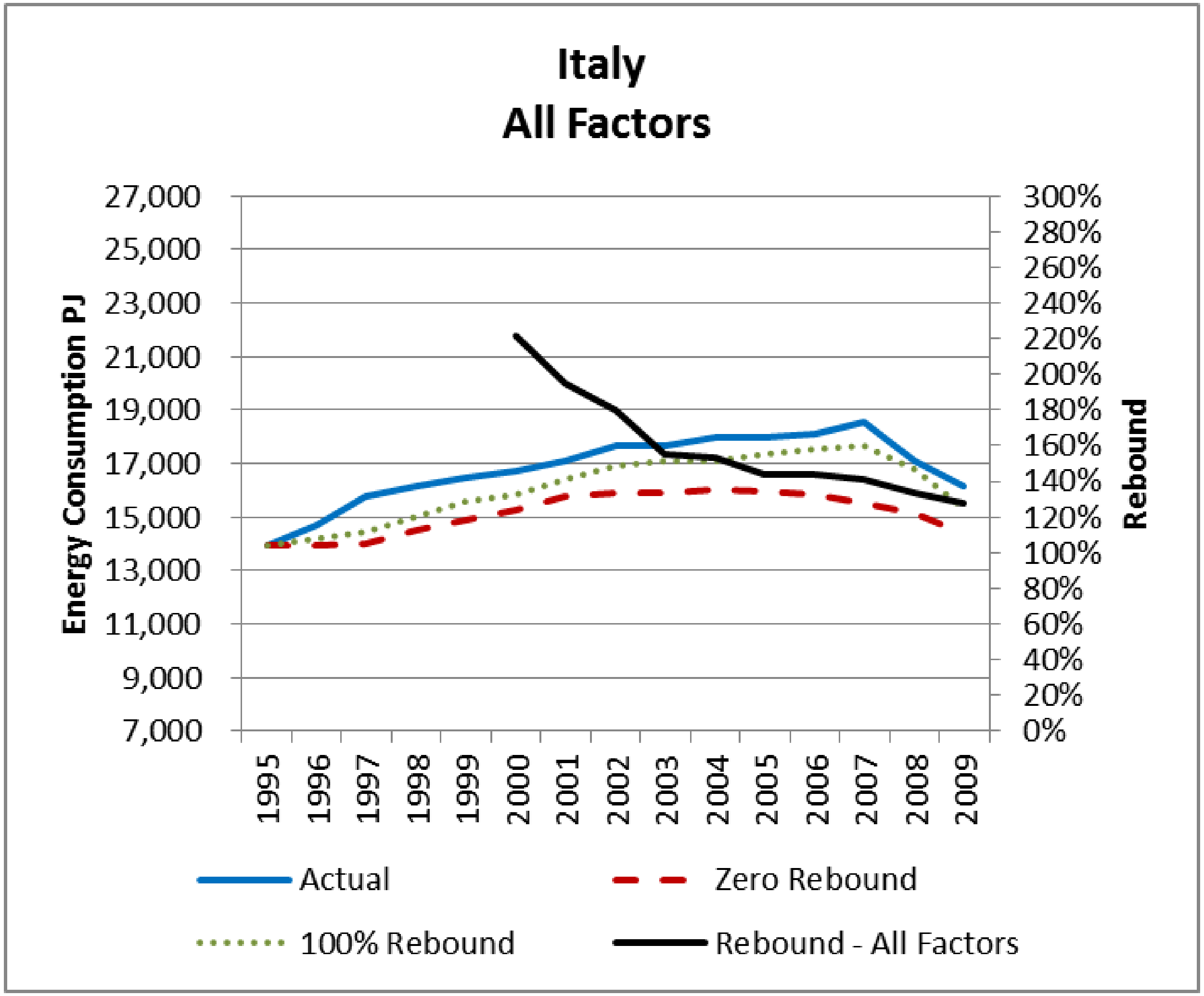
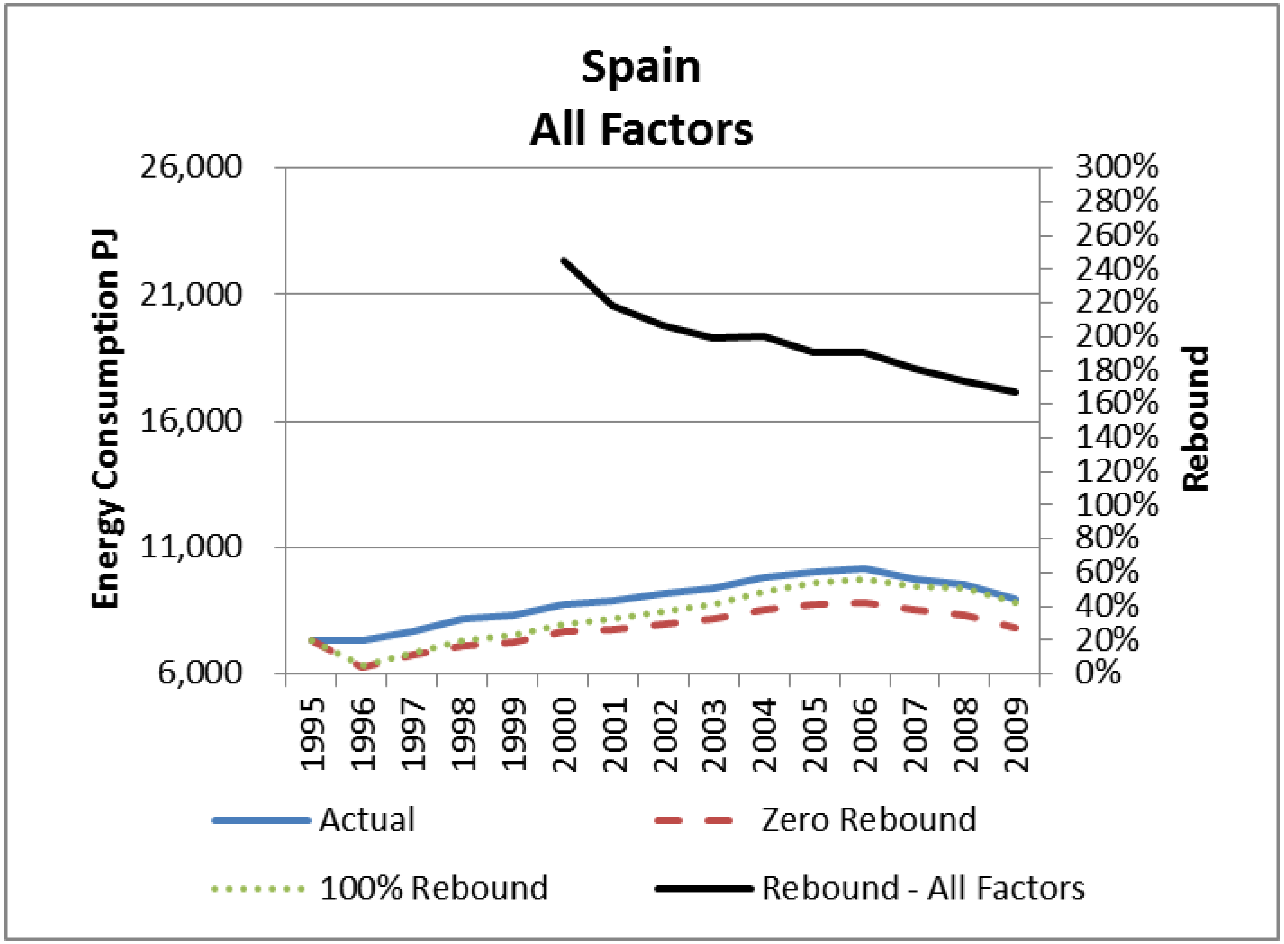
5. Energy only versus all factors



5. Energy only versus all factors



6. Comments and next steps

- Methodology rests on the assumption that economic choices are well described by a translog cost function. As such, it suffers from all shortcomings that characterize this literature (CRS, concavity tests, among others). Furthermore, lambdas are constant.
- Econometric estimation does not perform well in all sectors. Increasing the time coverage would be crucial to improve fit of the model.
- The simulations only include direct rebound effects (income and substitution effects) plus dynamic efficiency. No consideration for indirect rebound (general price effect), plus factors of production assumed elastic – which may be problematic for aggregation. This means that we are likely underestimating rebound effects

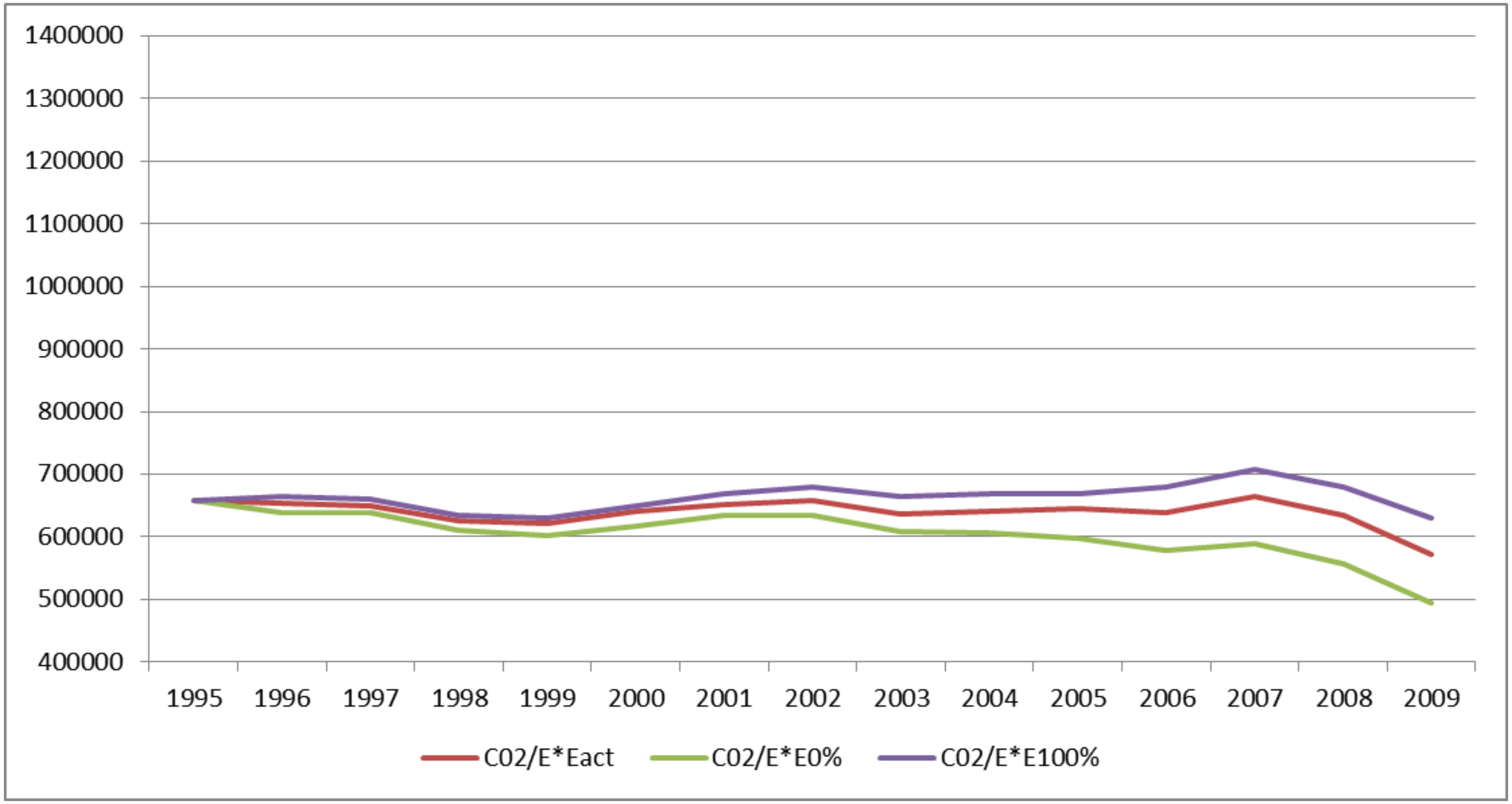
6. Comments and next steps

- Rebound effects are very different among the countries in our sample, indicating the importance to account for the sectoral composition of the economy, and for the fact that sectors may not behave in the same way in different countries. We are currently exploring this, and thinking of how to characterize it
- In all cases, the estimate of rebound decreases over time: this is due to the lower energy share which characterizes each new vintage installed
- Finally, issue of rebound is relevant only insofar as it affects CO_2 emissions (work in progress)

6.

Comments and next steps

Germany



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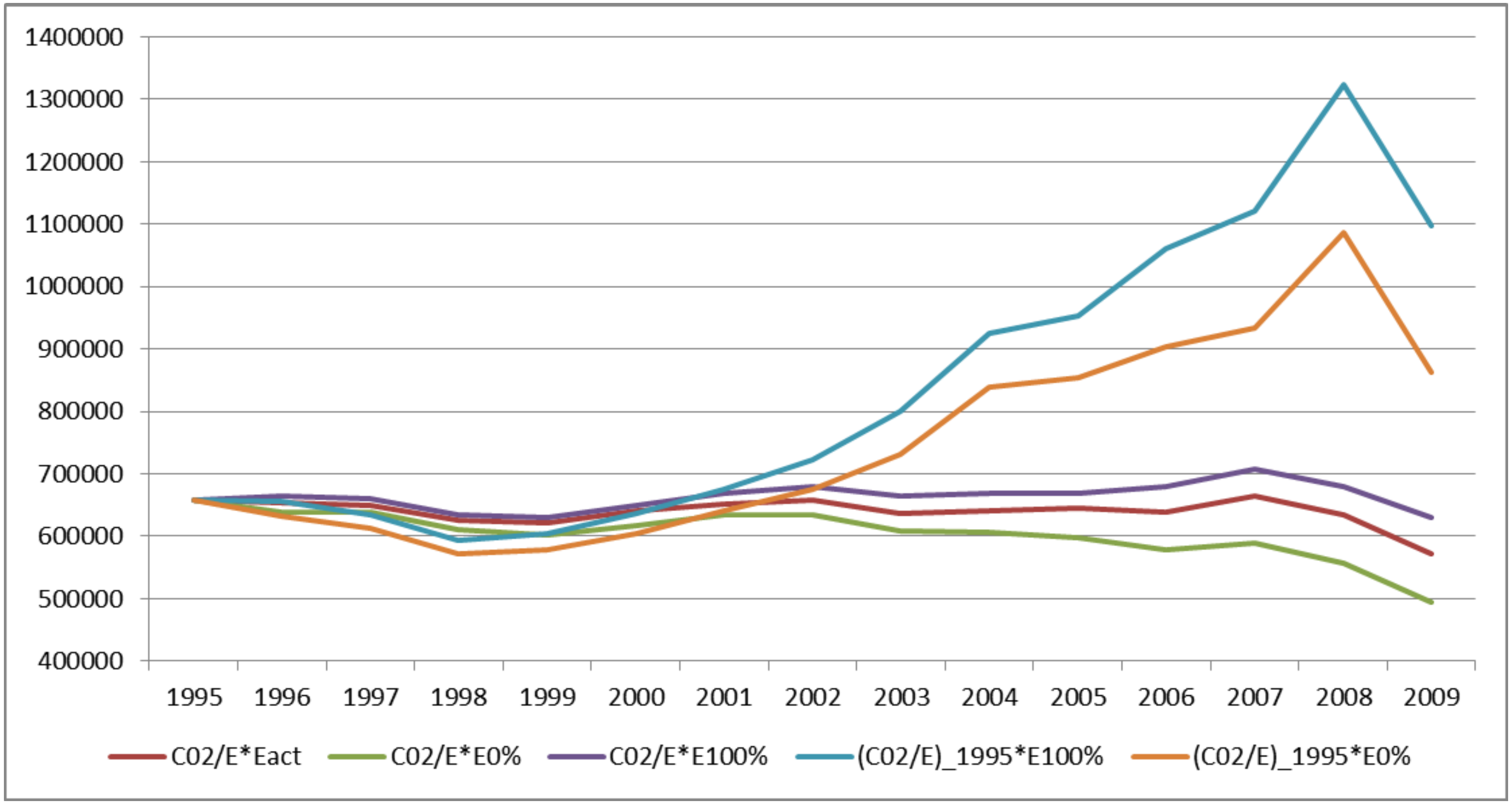
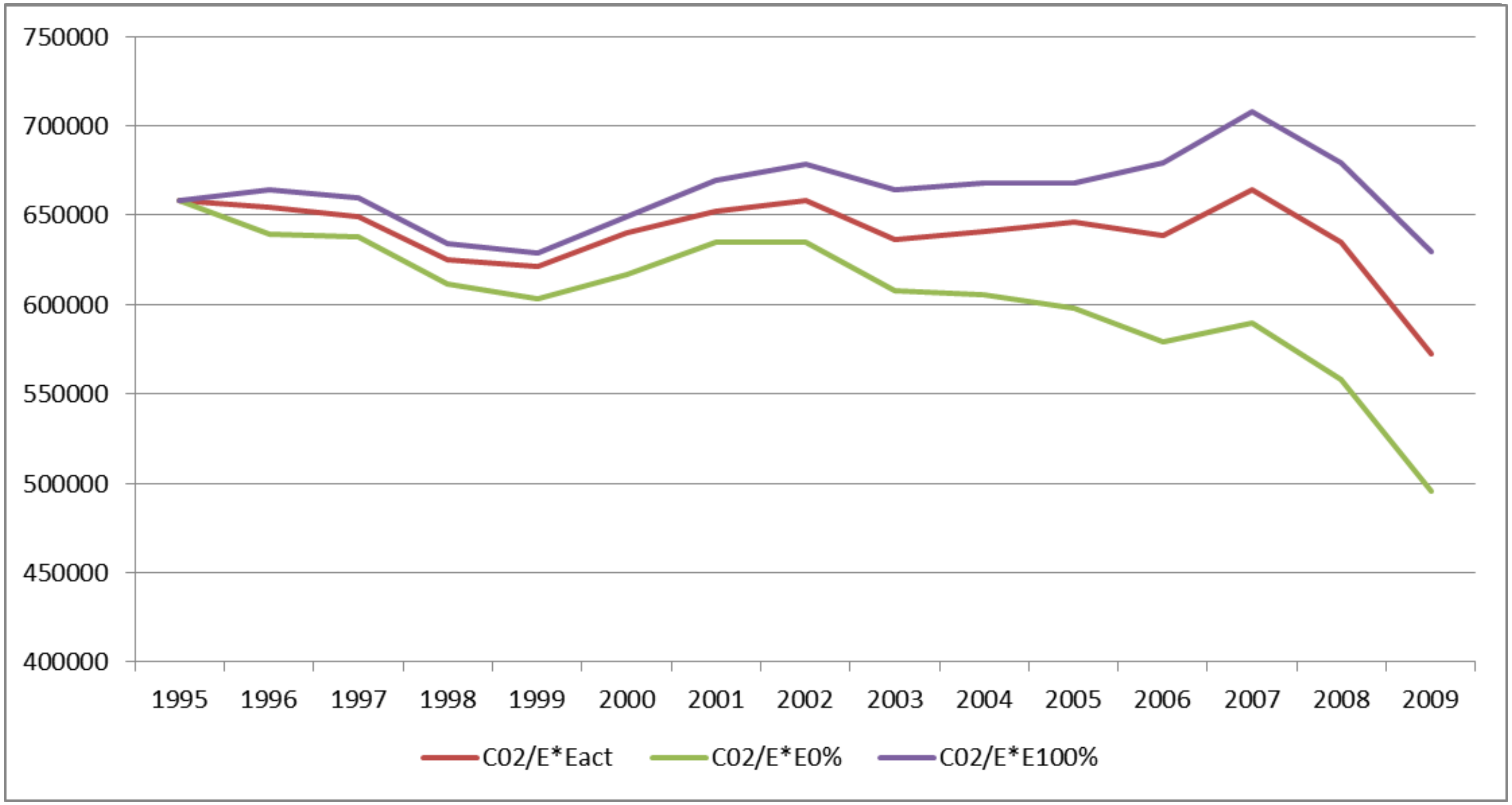
6. Comments and next steps

Germany



Comments and next steps

Germany



7. Conclusions and policy implications

- The estimation of input-augmenting technical change from historical data with the use of a more flexible cost (production) function leads to consistently higher estimates than those obtained from simulation studies
- Accounting for input-augmenting technical change in other factors amplifies the results
- For policy makers: caution in appropriately accounting for rebound effects. Note that these can be mitigated with a carbon tax. Hence, energy efficiency policy should not be pursued alone
- For the modelling community: CES production function is not flexible enough to give rise to precise estimates of the rebound effects (sensitivity to nesting)

Thank you

Comments/suggestions welcome

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