Study of the potential of fuel tax reforms to curb carbon emissions from road transport using the Value-Based DEA method

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Structure of presentation

1) Rationale for fuel taxation
2) Fuel taxation in EU
3) Methodology: Value-Based DEA with incorporation of preferences
4) The case study
5) Illustrative results
6) Conclusions/policy implications
7) Future Work
Rationale for fuel taxation

- **Why taxing fuel?**

  - Many countries tax road fuels primarily → to raise revenue.

  - Demand for these fuels tend to be relatively inelastic (price elasticity near 0) → fuel taxes tend to be a stable revenue source.

  - From an economic perspective taxes on road fuels may also be used to internalise environmental externalities or other social costs (congestion, traffic accidents, etc.) associated with their use.

  - Road fuel taxation could be seen as **Pigouvian tax** → imposing a tax on an activity with negative social costs in order to internalise these costs, ensuring that fuel users incorporate the full use costs into their decisions.

  - **Optimal taxation** postulates (Ramsey taxation) that higher taxation should be imposed on goods with relatively inelastic demand in order to minimize the reductions in welfare.

- Distributional concerns
The importance of fuel taxation in the EU: contribution to climate change

- Preventing climate change is a strategic priority for the EU.
- The EU has legislated to achieve a 20% reduction of GHG emissions by 2020 below 1990 levels.
- Different sectors will contribute differently towards achieving decarbonisation of the EU’s economy.
- The White Paper on Transport established that a reduction of at least 60% of GHGs by 2050 with respect to 1990 is required to achieve the overall target.
An overview of fuel taxation in the EU: the 2003 Energy Taxation Directive

- In October 2003 the Energy Taxation Directive (ETD - DIRECTIVE 2003/96/EC) became law.

- The Directive had some **key shortcomings** → no binding review clauses or automatic inflation adjustments were included → minimum taxation levels have not been updated

- In 2011 the European Commission proposed a revision of the ETD (**same taxes for both diesel and gasoline**, a CO2 element into energy taxation, etc.)

- On April 2012 the proposal was rejected (double burden for sectors already affected by the EU Emission Trading Scheme, economic crisis).

- The proposal was withdrawn by the Commission in 2015.

### Minimum rates for motor fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Rate expressed per</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaded petrol</td>
<td>Euro per 1000 litres</td>
<td>421</td>
</tr>
<tr>
<td>Unleaded petrol</td>
<td>Euro per 1000 litres</td>
<td>359</td>
</tr>
<tr>
<td>Gas Oil</td>
<td>Euro per 1000 litres</td>
<td>330</td>
</tr>
<tr>
<td>Kerosene</td>
<td>Euro per 1000 litres</td>
<td>330</td>
</tr>
<tr>
<td>LPG</td>
<td>Euro per 1000 kilograms</td>
<td>125</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>Euro per gigajoule</td>
<td>2.6</td>
</tr>
</tbody>
</table>
Methodological framework: Performance Evaluation using Value-Based DEA

• Data Envelopment Analysis (DEA) is a nonparametric approach for evaluating the relative efficiency of Decision-Making Units (DMUs).

• Each DMU uses multiple inputs to produce multiple outputs.

• Different DEA models seek to determine the DMUs that form the efficient frontier.

• DEA identifies benchmarks against which the inefficient units can be compared.

• The Value-Based DEA method is grounded on DEA and the input and output factors are converted into value functions, applying concepts from MAUT with imprecise information on weights.

• The DMUs take the place of alternatives of a multi-criteria evaluation model.

• Each criterion corresponds to a factor to be:
  
  i. minimized (input or undesirable output in a DEA model) or
  
  ii. maximized (output).
Value-Based DEA

• **Preparatory phase:**
  Convert inputs and outputs into value scales taking into account the preference information elicited from the Decision Maker.

• **Phase 1:**
  Compute the efficiency measure $d^*$ of each DMU and the corresponding weighting vector, excluding itself from the reference set, in the spirit of super-efficiency.

$$
\min_{d_k, w} d_k \\
\text{s.t. } \sum_{c=1}^{q} w_c v_c(\text{DMU}_j) - \sum_{c=1}^{q} w_c v_c(\text{DMU}_k) \leq d_k, j = 1, \ldots, n; j \neq k
$$

(1)

$$
\sum_{c=1}^{q} w_c = 1\\
w_c \geq 0, \forall c = 1, \ldots, q
$$

• $d^*$ = distance defined by the value difference to the best of all DMUs, excluding itself from the reference set.
  - If $d^* < 0$, the DMU is efficient.
Value-Based DEA method

• Phase 2:
  
  if $d^* \geq 0$ then solve the “weighted additive” model (2), using the weighting vector resulting from phase 1, and determine the corresponding projected point of the DMU under evaluation.

$$
\min_{\lambda, s} z_k = - \sum_{c=1}^{q} w_c^* s_c \\
\text{s.t. } \sum_{j=1, j \neq k}^{n} \lambda_j v_c(DMU_j) - s_c = v_c(DMU_k), \ c = 1, \ldots, q
$$

The variables $\lambda_j$, $j=1,\ldots,k-1,k+1,\ldots,n$ define a convex combination of the value score vectors associated with the $n-1$ DMUs. The convex combination corresponds to a point on the efficient frontier that is better than the DMU $k$ by a difference of value of $s_c$ (slack) in each criterion $c$. 
The Case Study

- The assessment of the potential of fuel tax reforms to curb carbon emissions from road transport in some EU countries using the Value-Based DEA method.

- The study considers different fuel pricing policy scenarios, which are inspired by the current political agenda:

  i. The adjustment of diesel excise tax levels towards gasoline taxation levels.

  ii. The potential effects of introducing a carbon content-based tax of 50€ per ton of CO\textsubscript{2} on both diesel and gasoline

    o The performance evaluation by means of the Value-Based DEA method → enables to identify the countries that exhibit the best practices defining an efficiency frontier.

    o Then measuring the gaps to best practices of the non-frontier countries → determines the benchmarks against which those inefficient countries should be compared with.
The Case Study

- The main principles usually underlining a tax design are:
  
  i. The potential of raising revenues
  ii. Their capacity to correct external cost
  iii. The distributive effects

- Fuel taxes might not originally have been designed for environmental purposes but they can make a significant contribution to environmental policy.

- Fiscal instruments such as fuel taxes may have some drawbacks as distributional effects that should be analysed preferentially using a lifetime income or an expenditure base.
The Case Study - Scenarios

In order to assess the gasoline and diesel taxation under these principles, the following Scenarios are considered:

I. Potential of fiscal revenue - The potential loss of revenue in 2013 as a percentage of total fiscal revenue in 2013 and the potential gain of fiscal revenue in 2020 as a percentage of total fiscal revenue in 2013 are considered as proxies.

II. Contribution to correct external costs (GHG emissions).

III. Distributive effects or fiscal equity

Data from:
- OECD and EU
- Zimmer and Koch (2016)
- Flues and Thomas (2015)
## Criteria

<table>
<thead>
<tr>
<th>Factors to <strong>minimize</strong> <em>(Input)</em></th>
<th>Factors to <strong>maximize</strong> <em>(Output)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1 - Assess a tax reform scenario of abandoning the diesel tax advantage</strong></td>
<td></td>
</tr>
<tr>
<td>$x_{\text{ADET}}$ - absolute distance between diesel and gasoline excise taxes.</td>
<td>$y_{\text{ATFT}}$ - average transport fuel taxes as percentage of pre-taxes expenditure by expenditure decile.</td>
</tr>
<tr>
<td>$x_{\text{PLR}}$ - potential loss of revenue in 2013 as a percentage of total fiscal revenue in 2013.</td>
<td></td>
</tr>
<tr>
<td>$x_{\text{DESD}2013}$ - distance from Effort Sharing Decision (ESD) target as a percentage of the achievement in 2013.</td>
<td></td>
</tr>
<tr>
<td><strong>Model 2 - Regarding 2020 target tax reform scenario</strong></td>
<td></td>
</tr>
<tr>
<td>$x_{\text{DESD}2013}$ - distance in 2020 from ESD targets as a percentage of the achievement in 2020.</td>
<td>$y_{\text{PGR}}$ - potential gain of revenue in 2020 as a percentage of total fiscal revenue in 2013.</td>
</tr>
<tr>
<td></td>
<td>$y_{\text{ATFT}}$ - average transport fuel taxes as percentage of pre-taxes expenditure by expenditure decile.</td>
</tr>
<tr>
<td><strong>Model 3 - Regarding 2020 with the introduction of a CO$_2$ content-based tax of 50€/tCO$_2$</strong></td>
<td></td>
</tr>
<tr>
<td>$x_{\text{DESD}2020_50\text{€}/tCO}_2$ - distance in 2020 from ESD targets as a percentage of the achievement in 2020 with a content-based tax of 50€/tCO$_2$</td>
<td>$y_{\text{PGR}_50\text{€}/tCO}_2$ - potential gain of revenue in 2020 as a percentage of total fiscal revenue in 2013 with a content-based tax of 50€/tCO$_2$.</td>
</tr>
<tr>
<td></td>
<td>$y_{\text{ATFT}}$ - average transport fuel taxes as percentage of pre-taxes expenditure by expenditure decile.</td>
</tr>
</tbody>
</table>
Value Functions

• The purpose of factors conversion into a value scale (linear and nonlinear value functions) is to reflect the preferences of the Decision Maker.

To construct the value functions we elicit:

• the difference in the DMU’s merit that corresponds to decreases in inputs or increases in outputs → rather than the value of having these inputs available or outputs produced.

• The problematical of factors that have negative or zero values is overpassed.
**Value functions**

**Absolute distance - excise taxes**

\[ y = -0.158 \ln(x) - 0.1658 \]

\[ R^2 = 1 \]

**Potential loss of fiscal revenue (%)**

\[ y = 0.1203 \ln(x) + 1.1822 \]

\[ R^2 = 1 \]

**Distance to ESD targets (%) 2020**

\[ y = -0.158 \ln(x) - 0.1658 \]

\[ R^2 = 1 \]

**Potential gain of fiscal revenue (%) 2020**

\[ y = 0.1203 \ln(x) + 1.1822 \]

\[ R^2 = 1 \]
Performances conversion for model 3

<table>
<thead>
<tr>
<th>DMUs</th>
<th>$y_{PGR; \text{\euro}/\text{tCO2}}$</th>
<th>$x_{DESD2020; \text{\euro}/\text{tCO2}}$</th>
<th>$y_{ATFT}$</th>
<th>$v_{PGR; \text{\euro}/\text{tCO2}}$</th>
<th>$v_{DESD2020; \text{\euro}/\text{tCO2}}$</th>
<th>$v_{ATFT}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>19.06%</td>
<td>-8.05%</td>
<td>96.88%</td>
<td>0.255</td>
<td>0.384</td>
<td>0.108</td>
</tr>
<tr>
<td>Belgium</td>
<td>20.35%</td>
<td>-13.99%</td>
<td>92.31%</td>
<td>0.291</td>
<td>0.483</td>
<td>0.084</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>18.50%</td>
<td>-157.29%</td>
<td>136.67%</td>
<td>0.238</td>
<td>0.993</td>
<td>0.319</td>
</tr>
<tr>
<td>Finland</td>
<td>19.66%</td>
<td>32.01%</td>
<td>143.48%</td>
<td>0.272</td>
<td>0.050</td>
<td>0.356</td>
</tr>
<tr>
<td>France</td>
<td>19.65%</td>
<td>-17.79%</td>
<td>93.94%</td>
<td>0.272</td>
<td>0.516</td>
<td>0.092</td>
</tr>
<tr>
<td>Germany</td>
<td>16.90%</td>
<td>38.07%</td>
<td>94.12%</td>
<td>0.189</td>
<td>0.012</td>
<td>0.093</td>
</tr>
<tr>
<td>Hungary</td>
<td>20.29%</td>
<td>-141.75%</td>
<td>264.71%</td>
<td>0.290</td>
<td>0.954</td>
<td>1.000</td>
</tr>
<tr>
<td>Italy</td>
<td>12.96%</td>
<td>-52.38%</td>
<td>76.60%</td>
<td>0.041</td>
<td>0.708</td>
<td>0.000</td>
</tr>
<tr>
<td>Netherlands</td>
<td>14.88%</td>
<td>10.73%</td>
<td>105.88%</td>
<td>0.118</td>
<td>0.183</td>
<td>0.156</td>
</tr>
<tr>
<td>Poland</td>
<td>72.47%</td>
<td>-10.71%</td>
<td>139.29%</td>
<td>0.996</td>
<td>0.429</td>
<td>0.333</td>
</tr>
<tr>
<td>Spain</td>
<td>20.70%</td>
<td>-66.99%</td>
<td>84.38%</td>
<td>0.301</td>
<td>0.767</td>
<td>0.041</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>13.11%</td>
<td>-2.50%</td>
<td>113.95%</td>
<td>0.048</td>
<td>0.292</td>
<td>0.199</td>
</tr>
</tbody>
</table>
## Results for model 3 without weight restrictions

<table>
<thead>
<tr>
<th>DMU</th>
<th>Phase 1</th>
<th></th>
<th>Phase 2</th>
<th></th>
<th>Peers ((\lambda))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(d^*)</td>
<td>(w^*_{\text{PGR,50€/tCO2}})</td>
<td>(w^*_{\text{DESD2020,50€/tCO2}})</td>
<td>(w^*_{\text{ATFT}})</td>
<td>(s^*_{\text{PGR,50€/tCO2}})</td>
</tr>
<tr>
<td>Poland</td>
<td>-0.695</td>
<td>1.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>-0.654</td>
<td>0.000</td>
<td>0.037</td>
<td>0.963</td>
<td></td>
</tr>
<tr>
<td>Czech Republic</td>
<td>-0.039</td>
<td>0.000</td>
<td>1.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>0.103</td>
<td>0.427</td>
<td>0.573</td>
<td>0.000</td>
<td>0.241</td>
</tr>
<tr>
<td>Italy</td>
<td>0.248</td>
<td>0.427</td>
<td>0.573</td>
<td>0.000</td>
<td>0.197</td>
</tr>
<tr>
<td>France</td>
<td>0.259</td>
<td>0.427</td>
<td>0.573</td>
<td>0.000</td>
<td>0.018</td>
</tr>
<tr>
<td>Belgium</td>
<td>0.270</td>
<td>0.427</td>
<td>0.573</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Finland</td>
<td>0.340</td>
<td>0.486</td>
<td>0.000</td>
<td>0.514</td>
<td>0.018</td>
</tr>
<tr>
<td>Austria</td>
<td>0.342</td>
<td>0.427</td>
<td>0.573</td>
<td>0.000</td>
<td>0.035</td>
</tr>
<tr>
<td>United Kingdom</td>
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<td>Netherlands</td>
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<td>0.000</td>
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</tr>
<tr>
<td>Germany</td>
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<td>0.486</td>
<td>0.514</td>
<td>0.240</td>
<td></td>
</tr>
</tbody>
</table>

Peers: CZE; POL

1. CZE (1)

2. HUN (1)

3. HUN; POL (0.998; 0.002)

4. HUN (1)
Results for model 3 without weight restrictions

• Only 3 countries are classified as efficient: Poland, Hungary and the Czech Republic:
  
i. Hungary remains efficient due to its priority on tax distribution concerns ($w_{ATFT}^* = 0.963$) 
ii. Czech Republic drive is mainly focused on the reduction of GHG emissions ($w_{DESD2020_50€/tCO2}^* = 1$) 
iii. Poland leads the chart just for revenue raising motives ($w_{PGR_50€/tCO2}^* = 1$).

• For the group of non-efficient countries (exception of Finland and Germany) the political priority appears to be the reduction of GHG emissions by assigning a higher weight to this criterion.

• Germany occupies the worst position → to emulate its peer (Poland) on the efficient frontier Germany should improve all the criteria.

• These results clearly suggest that taxing carbon would be severer for richer countries.

• Spain (benchmarks Czech Republic and Poland) has to focus both on potential revenue gains and distribution issues to become efficient.

• Italy (peer Czech Republic) has to pay attention to all criteria in order to become as efficient.
Weight restrictions

- Weight restrictions were elicited by asking the DM to compare the “swings” of value from 0 to 1.

<table>
<thead>
<tr>
<th>Value level</th>
<th>( y_{PGR_50€/tCO2} )</th>
<th>( x_{DESD2020_50€/tCO2} )</th>
<th>( y_{ATFT} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v(.)=0 )</td>
<td>13%</td>
<td>38%</td>
<td>77%</td>
</tr>
<tr>
<td>( v(.)=1 )</td>
<td>72%</td>
<td>-157%</td>
<td>265%</td>
</tr>
</tbody>
</table>

- The Decision Maker was asked to consider a unit with the performance level 0 for all factors and the question was: “if you could improve one and only one factor in the level 1, what would be?”:

- The Decision Maker answer was \( x_{DESD2020\_50€/tCO2} \).

- This allows the inference that \( w_{DESD2020\_50€/tCO2} \) is the highest scaling constant.

- By repeating this question successively for the remaining factors, we obtain the following ranking of the scale coefficients:

  \[ w_{DESD2020\_50€/tCO2} \geq w_{PGR\_50€/tCO2} \geq w_{ATFT} \]
Weight restrictions

- In order to avoid zero-value weights an indifference judgment question was asked to limit the ratio of the weights ranked in the first ($w_{\text{DESD2020} \_50\€/t\text{CO}_2}$) and last ($w_{\text{ATFT}}$) position:

  - The answer was $z = 0\%$ and allows to build the following inequality:

    $$w_{\text{ATFT}} v(265\%) + w_{\text{DESD2020} \_50\€/t\text{CO}_2} v(38\%) \geq w_{\text{ATFT}} v(77\%) + w_{\text{DESD2020} \_50\€/t\text{CO}_2} v(z).$$

  - Substituting $z$ in the previous expression yields:

    $$w_{\text{DESD2020} \_50\€/t\text{CO}_2} \leq 4 w_{\text{ATFT}}.$$
## Results for model 3 with weight restrictions

<table>
<thead>
<tr>
<th>DMU</th>
<th>Phase 1</th>
<th></th>
<th>Phase 2</th>
<th></th>
<th>Peers (λ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( d^* )</td>
<td>( w^* ) <em>PGR 50€/tCO₂</em></td>
<td>( w^* ) <em>DESD2020 50€/tCO₂</em></td>
<td>( w^* ) <em>ATFT</em></td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>-0.202</td>
<td>0.297</td>
<td>0.406</td>
<td>0.297</td>
<td></td>
</tr>
<tr>
<td>Poland</td>
<td>-0.006</td>
<td>0.444</td>
<td>0.444</td>
<td>0.111</td>
<td></td>
</tr>
<tr>
<td>Czech Republic</td>
<td>0.081</td>
<td>0.440</td>
<td>0.448</td>
<td>0.112</td>
<td>0.051</td>
</tr>
<tr>
<td>Spain</td>
<td>0.186</td>
<td>0.440</td>
<td>0.448</td>
<td>0.112</td>
<td>0.695</td>
</tr>
<tr>
<td>France</td>
<td>0.306</td>
<td>0.440</td>
<td>0.448</td>
<td>0.112</td>
<td>0.018</td>
</tr>
<tr>
<td>Belgium</td>
<td>0.313</td>
<td>0.440</td>
<td>0.448</td>
<td>0.112</td>
<td>-0.002</td>
</tr>
<tr>
<td>Italy</td>
<td>0.332</td>
<td>0.440</td>
<td>0.448</td>
<td>0.112</td>
<td>0.249</td>
</tr>
<tr>
<td>Austria</td>
<td>0.371</td>
<td>0.440</td>
<td>0.448</td>
<td>0.112</td>
<td>0.035</td>
</tr>
<tr>
<td>Finland</td>
<td>0.483</td>
<td>0.440</td>
<td>0.440</td>
<td>0.119</td>
<td>0.018</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.493</td>
<td>0.440</td>
<td>0.448</td>
<td>0.112</td>
<td>0.242</td>
</tr>
<tr>
<td>Netherlands</td>
<td>0.516</td>
<td>0.440</td>
<td>0.448</td>
<td>0.112</td>
<td>0.172</td>
</tr>
<tr>
<td>Germany</td>
<td>0.568</td>
<td>0.440</td>
<td>0.440</td>
<td>0.119</td>
<td>0.807</td>
</tr>
</tbody>
</table>
Results for model 3 with weight restrictions

• The analysis of these models enables the assessment of the impact on results of the priorities that policy makers judge pertinent in different economic contexts.

• Despite the relevance of the revenue criterion in the design of tax policies → this study assigned a high importance to the potential contribution of fuel taxes to environmental policies.

• Hungary is the only country that is consistently efficient with both political options.

• Germany is never well positioned in any of the models, in particular in model 3, without and with weight restrictions.
Results for model 3 with weight restrictions

- In order to become efficient and to reach the performance of its benchmark (Hungary) the Czech Republic is allowed to increase the difference of GHG emissions (DESD2020 targets as a % of the achievement in 2020 with a content-based tax of 50€/tCO2) → because the slack in this criterion is negative.

- Additionally, however, it is required to focus on the distributive effects of fiscal policy and to increase fiscal revenue.

- With Spain the improvements are similar → but this country chose Poland as its reference.

- Belgium (benchmark is Hungary) can reduce the values obtained with fiscal revenue (the slack of this factor to maximize is negative), but needs also to reduce the distance in 2020 from ESD targets as a percentage of the achievement in 2020 with a content-based tax of 50€/tCO2. Belgium also needs to increase the average transport fuel taxes as percentage of pre-taxes expenditure by expenditure decile.
Conclusions/Policy implications

• Fuel taxation accounts for around half of the pump price of fuel in EU member states.

• Historically, tax road fuels were primarily set to raise countries’ fiscal revenue → however, recent events such as the Paris Agreement on Climate Change and the diesel emission scandal have motivated a new interest in considering the fuel pricing policy as an important instrument to contribute to the reduction of GHG emissions.

• Inspired on the usual economic principles underlying efficient and fair tax design → we developed a multicriteria evaluation framework based on the Value-based DEA method to assess the impact of potential fuel tax reforms to reduce GHG (abandoning the diesel tax advantage and introducing a CO₂ content-based tax).
Conclusions/Policy implications

• Our main contribution is the possibility of considering multiple, conflicting and incommensurate evaluation criteria in a evaluation framework.

• The proposed approach indicates the countries (entities under evaluation) that can be taken as reference (peers) for non-efficient countries to improve and reach the efficiency frontier.

• The classical trade-off between equity and efficiency in the implementation of tax policies can be (partially) resolved in the framework of the proposed approach, since it offers the decision makers the possibility to incorporate their priorities in appraising fuel tax policies.
Future work

• Consider different criteria and preference parameters based on surveys conducted with the involved stakeholders.

• Extend the analysis to other complementary national policy measures to encourage fuel efficient lower-carbon vehicles → such as vehicle registration taxes, circulation taxes, fuel taxes, company car taxation and incentives for electric vehicles.

• These measures will strengthen the countries’ road fuel taxation systems and will contribute to a more efficient car fleet.