# Transport fuel demand responses to fuel price and income projections: Comparison of integrated assessment models

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# 1 Introduction

**Supply**

IAMs tend to represent **energy supply in more detail**, while presenting energy demand sectors in a rather stylized manner.

**Demand**

Energy demand sectors are complex: many **sub-sectors** with numerous technologies; **the heterogeneity of consumers** that use the services requiring energy.

Fuel price affects the benefits of energy efficiency of technologies used and of switching to alternative fuels — **Fuel price**

Income relates to the money available to spend on transport activities — **Income**

- Transport sector (freight and passenger)
    - Two-wheelers
    - Light-duty vehicles
    - Rail
    - Aviation
    - Shipping
- Residential and commercial sectors
- Industrial sector

# 1 Introduction

**Fuel price shock** **Income scenarios**

↓

| TIAM (UCL) | REMIND (PIK) | WITCH (CMCC) | IMAGE (PBL) | MESSAGE (IIASA) | POLES (JRC) |
|---|---|---|---|---|---|

↓

Demand responses to various fuel price and income trajectories

↓

Transport models’ implicit fuel demand elasticities for short-term (2030) and long-term (2060) trajectories

Understand model dynamics through a diagnostic experiment

Compare the model dynamics to empirical data as a validation test

# 2 Materials and Methods

Fuel demand elasticities measure the percentage change in demand due to a % increase in price (or income), with everything else remaining constant.

$$\eta_{Q,i} = \frac{log\mathbf{Q}_{i2} - log\mathbf{Q}_{i1}}{log\mathbf{P}_{i2} - log\mathbf{P}_{i1}}$$

$n_{Q,i}$ measures the price elasticity of quantity ***Q*** with respect to the price of fuel ***i***, with regards to fuel price ***P*** in scenarios 1 and 2.

| Scenario | | Price change per fuel type | | |
|---|---|---|---|---|
| | | Oil & Natural gas | Electricity | Biofuel |
| 1 | | Ref | Ref | Ref |
| 2 | | −50% | Ref | Ref |
| 3 | | Ref | −50% | Ref |
| 4 | | Ref | Ref | −50% |
| 5 | | +50% | Ref | Ref |
| 6 | | Ref | +50% | Ref |
| 7 | | Ref | Ref | +50% |
| 8 | | +100% | Ref | Ref |
| 9 | | Ref | +100% | Ref |
| 10 | | Ref | Ref | +100% |
| Scenario | Income change | | | |
| 11 | SSP1 GDP assumptions | | | |
| 12 | SSP3 GDP assumptions | | | |

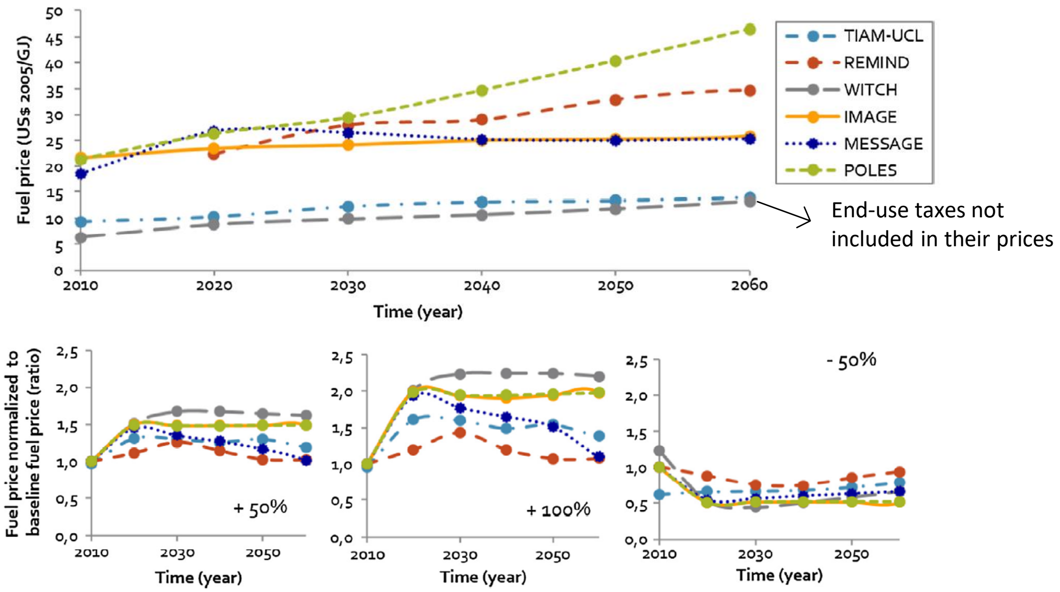
**Baseline**
**-50%**
**+50%**
**+100%**

# 2.1 Fuel price elasticity scenarios

The **fuel price is increased at the final energy level for all demand sectors**; even though the focus of this analysis is only on the transport demand response.

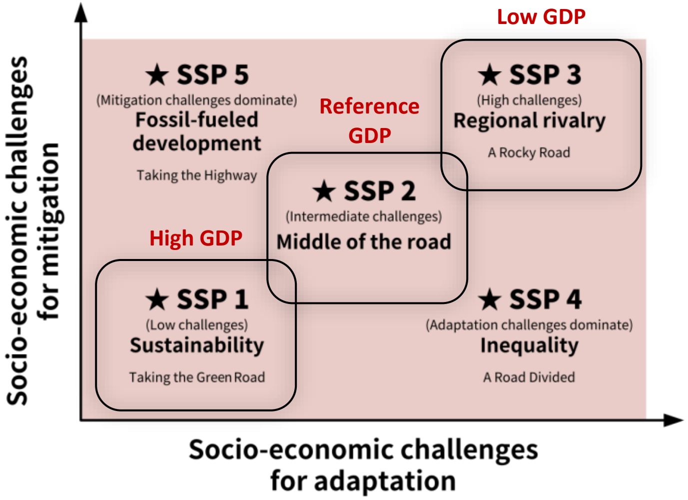
Where the fuel prices are not an exogenous input, final **energy prices tend to move away from the price shock** pathway towards the original price pathway (e.g., MESSAGE, TIAM-UCL and REMIND projections).

The perfect foresight (e.g. REMIND) feature leads to a reduction in the price change effect already by 2020 (when the shock is introduced).




**Global average price of transport oil in the baseline scenario (top) and the relative increase in oil price compared to this baseline (bottom), for the price shock scenarios of +50%, +100% and -50%**

# 2.2 Income elasticity scenarios

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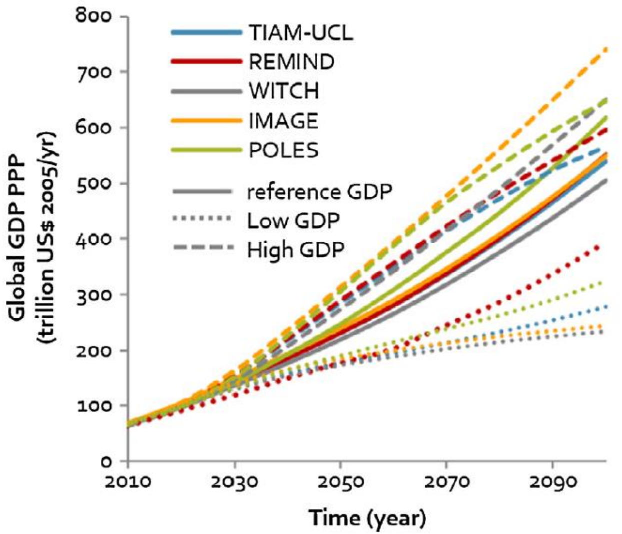



**GDP pathways implemented in the models**
**Reference x Low GDP x High GDP**

# 3 Results

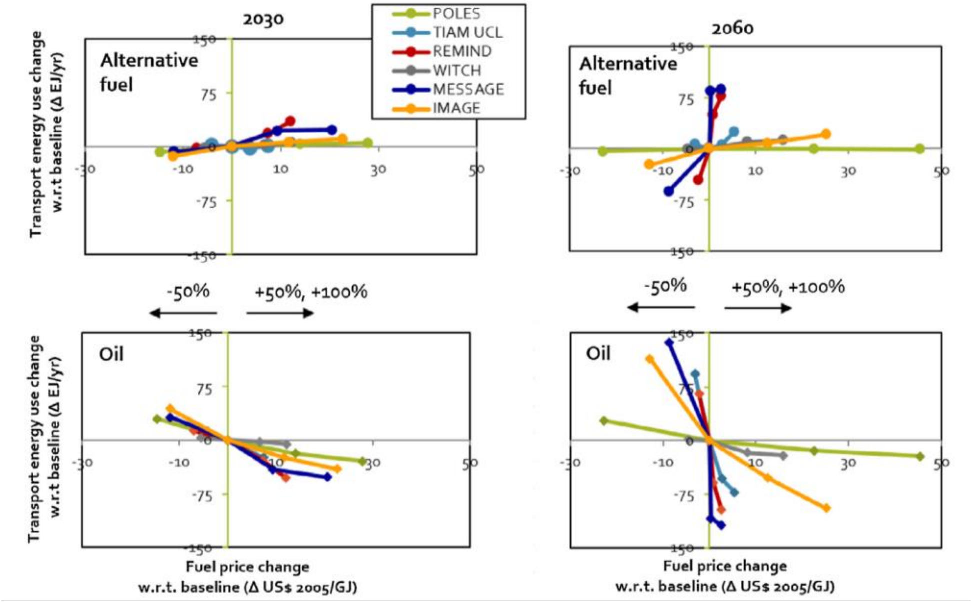
Oil and alternative fuel prices elasticities

Service and demand and fuel consumption elasticities

Market share elasticities of fuels

Income elasticities

# 3.1 Oil and alternative fuel prices




**The oil (bottom) and alternative fuel (top) energy demand response to oil and gas price shocks in 2030 (left) and 2060 (right). Alternative fuel is defined as any fuel other than oil**

- All models show a **decrease in oil demand and an increase in alternative fuel** under higher oil and natural gas prices, and vice versa.
- In all models, the decrease in oil is greater than the increase in alternative fuel demand, indicating **that increased fuel prices also lead to efficiency improvements.**
- MESSAGE, REMIND and WITCH show higher fuel substitution rates (48–83% of the oil change), while this is less the case in the more technology-rich models POLES, IMAGE and TIAM-UCL (2–34%).

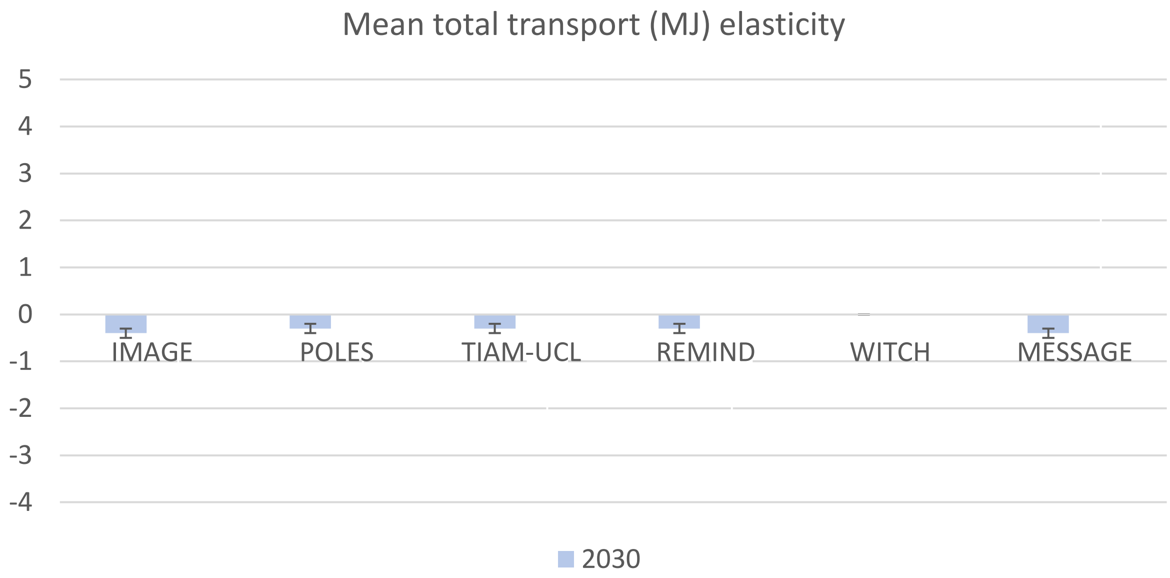
# 3.2 Service and demand and fuel consumption elasticities

| | | IMAGE | | POLES | | TIAM-UCL | |
|---|---|---|---|---|---|---|---|
| | | 2030 | 2060 | 2030 | 2060 | 2030 | 2060 |
| LDV | Pkm | −0.2 (0.1) | −0.1 (0.0) | −0.2 (0.0) | −0.1 (0.0) | 0.0 (0.0) | −0.1 (0.0) |
| | Efficiency | −0.3 (0.2) | −0.7 (0.6) | −0.3 (0.1) | −0.3 (0.0) | −0.2 (0.0) | −**2.0 (0.7)** |
| | Energy | −0.5 (0.2) | −0.8 (0.6) | −0.4 (0.2) | −0.4 (0.0) | −0.2 (0.0) | −**2.1 (0.7)** |
| Public transport | Pkm | −0.2 (0.0) | −0.2 (0.1) | −0.2 (0.0) | −0.1 (0.0) | −0.1 (0.0) | −0.1 (0.0) |
| | Efficiency | −0.1 (0.2) | −0.4 (0.5) | −0.3 (0.0) | −0.2 (0.0) | 0.0 (0.0) | −0.4 (0.2) |
| | Energy | −0.4 (0.2) | −0.6 (0.4) | −0.5 (0.0) | −0.4 (0.1) | 0.0 (0.0) | −0.4 (0.2) |
| Aviation | Pkm | −0.7 (0.1) | −0.6 (0.1) | 0.1 (0.0) | 0.0 (0.0) | −0.3 (0.0) | −0.4 (0.1) |
| | Efficiency | −0.1 (0.1) | −0.6 (0.2) | −0.2 (0.1) | −0.2 (0.1) | 0.0 (0.0) | 0.0 (0.0) |
| | Energy | −0.8 (0.1) | −1.2 (0.1) | −0.1 (0.1) | −0.1 (0.1) | −0.3 (0.0) | −0.5 (0.1) |
| Walking & cycling | Pkm | 0.1 (0.0) | 0.2 (0.0) | | | | |
| Total passenger | Pkm | −0.2 (0.0) | −0.2 (0.0) | −0.2 (0.0) | −0.1 (0.0) | −0.2 (0.0) | −0.3 (0.0) |
| | Efficiency | −0.3 (0.1) | −0.7 (0.4) | −0.2 (0.1) | −0.2 (0.0) | 0.0 (0.0) | −**1.0** (0.6) |
| | Energy | −0.5 (0.2) | −0.9 (0.4) | −0.4 (0.1) | −0.3 (0.0) | −0.2 (0.0) | −**1.3** (0.5) |
| Total freight | Tkm | −0.2 (0.1) | −0.1 (0.1) | | | −0.1 (0.0) | −0.1 (0.0) |
| | Efficiency | −0.1 (0.2) | −0.3 (0.3) | −0.2 (0.0) | −0.1 (0.0) | −0.3 (0.3) | −**2.0** (1.9) |
| | Energy | −0.3 (0.1) | −0.4 (0.2) | −0.2 (0.0) | −0.1 (0.0) | −0.4 (0.3) | −**2.1** (1.9) |
| Total Transport | Energy | −0.4 (0.1) | −0.7 (0.1) | −0.3 (0.1) | −0.2 (0.0) | −0.3 (0.1) | −**1.5** (0.7) |
| | | REMIND | | WITCH | | MESSAGE | |
| | | 2030 | 2060 | 2030 | 2060 | 2030 | 2060 |
| Total passenger | Pkm | −0.3 (0.1) | −0.5 (0.2) | | | | |
| | Efficiency | 0.0 (0.0) | −**1.7 (0.7)** | 0.0 (0.0) | −0.1 (0.2) | | |
| | Energy | −0.3 (0.1) | −**2.3 (0.9)** | 0.0 (0.0) | −0.1 (0.2) | | |
| Total freight | Tkm | −0.5 (0.1) | −**1.3 (0.5)** | | | | |
| | Efficiency | 0.0 (0.0) | 0.1 (0.1) | 0.0 (0.0) | 0.0 (0.0) | | |
| | Energy | −0.5 (0.1) | −**1.2 (0.5)** | 0.0 (0.0) | 0.0 (0.0) | | |
| Total transport | Energy | −0.3 (0.1) | −**1.9 (0.7)** | 0.0 (0.0) | −0.1 (0.1) | −0.4 (0.1) | 0.4 (3.8) |

**Mean and standard deviation of service demand (pkm or tkm), fuel efficiency (MJ/pkm or MJ/tkm) and fuel consumption (MJ) elasticities to oil price per mode of transport and aggregated for freight, passenger and total transport, comparing the oil & natural gas fuel-price shock to the baseline**

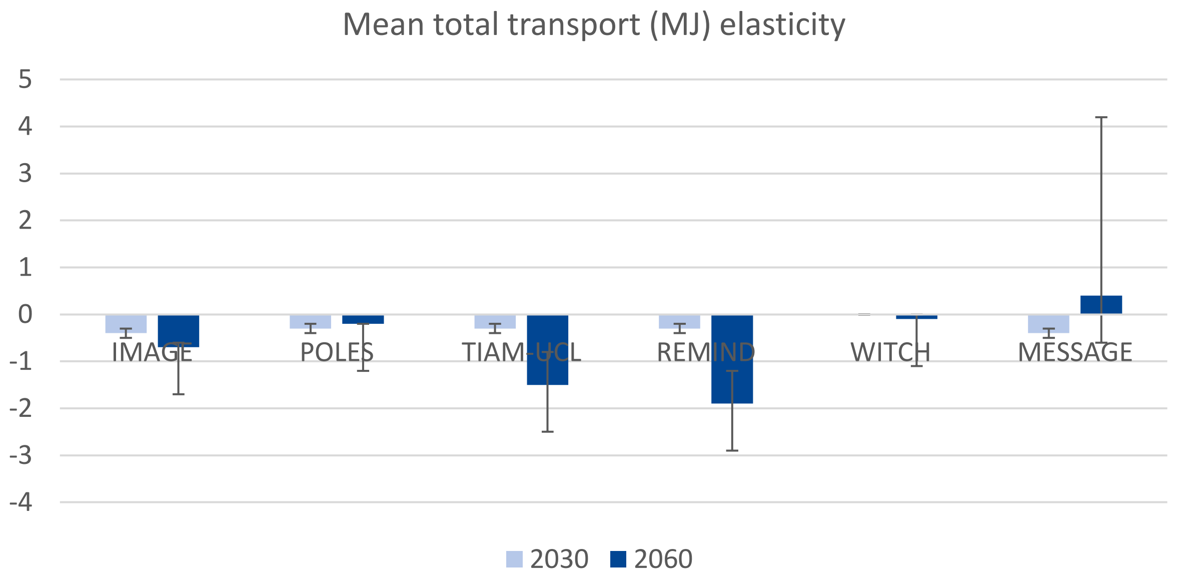
- The passenger service demand elasticity in 2030 varies between 0.2 and 0.3 across all models and in 2060 between 0.1 and 0.5.
- Freight service demand ranges from 0.1 to 0.5 in 2030 and from 0.1 to 1.3 in 2060.
- Price elasticities depend on income effects as well as substitution effects.

# 3.2 Service and demand and fuel consumption elasticities



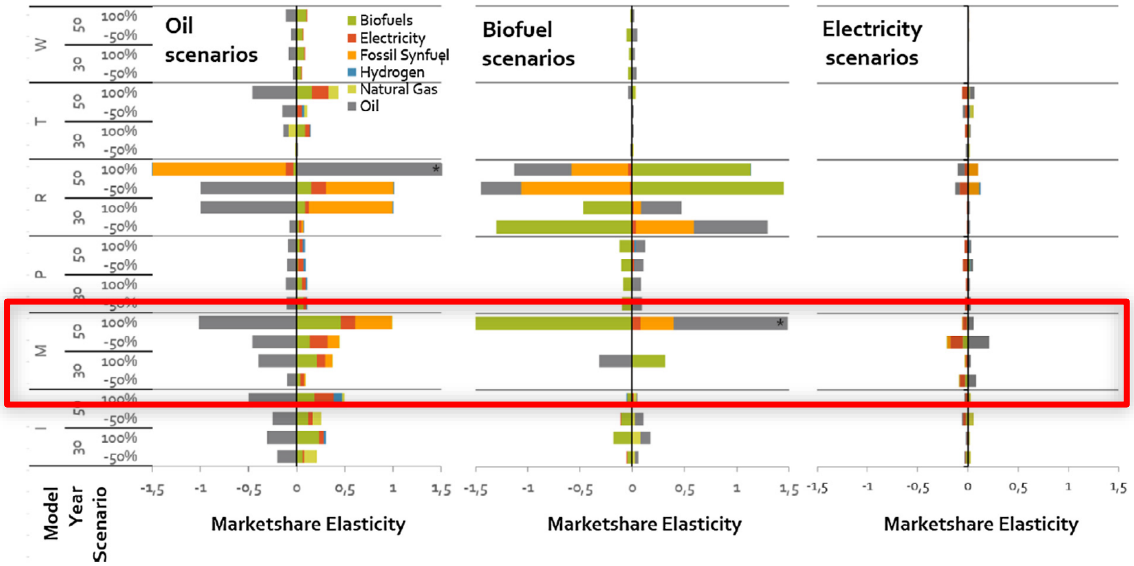

- The models show very **comparable elasticity values for the projected first 10–20 years.**
- Close to the range described in the empirical literature.

# 3.2 Service and demand and fuel consumption elasticities




- When looking at the **very long term (30–40 years), demand elasticity values widely vary** between models, between 0.4 and 1.9.
  - Long response time to fuel price shocks.
  - Availability of new technologies.
  - Feedback effects on fuel prices.

# 3.3 Market share elasticities of fuels



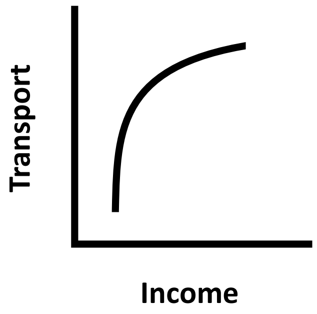

**Market share elasticities in response to changes in oil, biofuel and electricity prices from +100% to 50%. Elasticities indicate the shift in market shares, for all the different fuel types for which the sum of the elasticities is 0. Negative elasticities in the 50% scenario imply an increase in use, as the elasticity is relative to the price signal. * In two scenarios the market elasticity was larger than 1.5 – due to very high price feedbacks - the results were normalized to 1.5.**

- If market shares of alternative fuels are small, such as currently is the case for biofuel and electricity this results in difficult-to-compare **high elasticity responses to a slight change** in demand.
- POLES and WITCH show low response compared to the other models, projecting the sector to remain dependent on oil irrespective of fuel price changes.
- IAMs show that **fuel switching is an effective way** to mitigate the greenhouse gas emissions from the transport sector.
- Oil price increases are projected to lead to a switch **from oil to biofuel in 2030 and, in some models to fossil synfuel, while in 2050 electricity also becomes an attractive alternative**.

# 3.4 Income elasticities

- There have been suggestions that at higher income the per capita, kilometres travelled would saturate and that we are reaching peak travel (Millard-Ball and Schipper, 2011; Dargay et al., 2007).
- Transport is perceived as a ‘luxury’ product which is sensitive to income changes. As incomes continue to rise, saturation effects will reduce the income elasticity.

| | IMAGE | | POLES | | REMIND | | WITCH | | TIAM-UCL | |
|---|---|---|---|---|---|---|---|---|---|---|
| | low | high | low | high | low | high | low | high | low | high |
| *Passenger transport in 2030* | | | | | | | | | | |
| Pkm | 0.50 | 0.38 | 0.49 | 0.65 | 0.45 | 0.32 | 1.19 | 0.91 | | |
| Efficiency | 0.11 | 0.20 | −0.13 | −0.17 | −0.01 | −0.02 | −0.03 | −0.10 | | |
| Energy | 0.61 | 0.58 | 0.36 | 0.47 | 0.44 | 0.31 | 1.15 | 0.81 | | |
| *Freight transport in 2030* | | | | | | | | | | |
| Tkm | 0.87 | 0.35 | 0.43 | 0.83 | 0.42 | 0.30 | 1.17 | 0.93 | | |
| Efficiency | −0.26 | 0.18 | −0.01 | −0.42 | −0.06 | 0.00 | −0.03 | 0.04 | | |
| Energy | 0.61 | 0.54 | 0.42 | 0.41 | 0.36 | 0.31 | 1.14 | 0.97 | | |
| Total | 0.61 | 0.56 | 0.39 | 0.44 | 0.41 | 0.31 | 1.15 | 0.87 | 0.65 | 0.99 |
| *Passenger transport in 2060* | | | | | | | | | | |
| Pkm | 0.51 | 0.53 | 0.62 | 0.40 | 0.37 | 0.31 | 0.96 | 0.75 | | |
| Efficiency | 0.16 | 0.38 | −0.09 | −0.18 | 0.08 | 0.04 | −0.06 | −0.30 | | |
| Energy | 0.67 | 0.90 | 0.52 | 0.22 | 0.45 | 0.34 | 0.91 | 0.46 | | |
| *Freight transport in 2060* | | | | | | | | | | |
| Tkm | 0.78 | 0.50 | 0.53 | 0.59 | 0.41 | 0.25 | 0.99 | 0.79 | | |
| Efficiency | −0.08 | 0.03 | −0.14 | −0.15 | −0.02 | 0.00 | 0.02 | 0.04 | | |
| Energy | 0.70 | 0.52 | 0.40 | 0.44 | 0.39 | 0.25 | 1.01 | 0.83 | | |
| Total | 0.68 | 0.77 | 0.47 | 0.32 | 0.43 | 0.31 | 0.95 | 0.62 | 0.53 | 1.44 |







Dargay, J., Gately, D., Sommer, M., 2007. Vehicle ownership and income growth, worldwide: 1960–2030. Energy J., 143–170.
Millard-Ball, A., Schipper, L., 2011. Are we reaching peak travel? Trends in passenger transport in eight industrialized countries. Transp. Rev. 31 (3), 357–378.

# 4 Conclusions

- The proposed method in this paper to derive price and income elasticities as diagnostic indicators provides a **transparent environment to test model dynamics**.
- **Efficiency and service demand elasticities to fuel price are within the range of values found empirically**, and very close to each other in the medium term.
- A division can be made between the models that become more responsive in the long term (2060) than in the medium term (2030).
- Market share distribution responds more strongly to oil and biofuel price changes than to electricity prices.

  Oil will be substituted as the dominant fuel when oil prices increase. Biofuel price change sees in some models a strong effect but electricity price changes hardly have an impact on the projected shares. The models show that, in 2030, mainly biofuel is used as a substitute, and some models use fossil synfuel, while electricity shares increase as a result of higher oil prices in the long term.
- **Service demand projections are more responsive to income level than to fuel prices**, which corresponds to empirical findings.

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# Questions?