Modelling the Transport energy system towards implementing climate policies

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Outline

- Theory of the MDM-E3 Transport submodel
  - MDM-E3 model - theory of the model (Hybrid)
  - Transport submodel
    - data sources, classifications
    - theory of the submodel (passenger kilometres, vehicle efficiency, vehicle purchases and stock, hybrid estimation of fuel demand)
- Applications of the MDM-E3 Transport submodel
  - Comparison of the main energy MDM-E3 submodel with the MDM-E3 Transport submodel (UK Energy and the Environment 6-monthly forecast)
  - Further results of the MDM-E3 transport submodel
    - Green Fiscal Commission project analysis
- Next steps

Introduction

MDM-E3 is the UK's most detailed, integrated energy-environment-economy (E3) model

The model has been developed by the University of Cambridge and Cambridge Econometrics, a leading economic consultancy

MDM-E3 is one of a suite of E3 models:

- MDM-E3: Multisectoral Dynamic Model of the UK Economy, including energy-environment-economy (E3) interactions
- E3ME: E3 Model of Europe
- E3MG: E3 Model at a Global level
- E3M-GAIA: E4 Model of Gaia

All follow the same overall principles in their economics, construction and operation (Econometric, dynamic, structural, post-Keynesian, hybrid)

Hybrid modelling

The main energy submodel determines total secondary energy demand, fuel use, by user and prices of fuel use

- **Provides feedback to main economic framework**

In MDM-E3 this 'top-down' approach is supplemented by a set of 'bottom-up' submodels

- **the Electricity Supply Industry (ESI) submodel**
- **the CHP submodel**
- **the Household submodel**
- **the Transport submodel**
  - **transport will play a crucial role in climate change mitigation (25% of CO2 emissions)**
  - **incorporates much more detail than the existing top-down fuel equations:**
    - **the role of new technologies**
    - **distinction between efficiency gains and demand reduction**

Disaggregate Energy demand econometrics modelling

- **Transport econometrics modelling:**
  - **Traditional Energy demand econometric equations**:
    - Activity, fuel prices, technological progress indicator (investment in the Motor Vehicles sector, adjusted by R&D expenditure)
  - **Alternative Energy demand econometric equations**:
    - Demand for passenger travel, disaggregated by vehicle type (eg Cars and taxis, Bus/coach) and transport network (eg Urban A roads and Motorways)
    - Annual purchases of new vehicles, disaggregated by vehicle type and propulsion technology (eg petrol or diesel internal combustion engines)
    - Average fuel efficiency of new vehicles, disaggregated by vehicle type and propulsion technology
    - The above figures catch the effect of: personal disposable income, fuel prices, technology progress, transport vehicle availability, transport network availability, transport vehicle speed, transport vehicle safety, vehicle stock

Classifications in the Transport submodel

Modes

1. Rail
1. Road
2. Water
3. Air

Vehicle Types

1. London Underground
2. Light rail
3. InterCity
4. London & South East
5. Regional
6. Int'l Rail
7. Pipeline
8. Walk
9. Cycle
10. Motor cycles
11. Cars and taxis
12. Bus/coach
13. Light vans
14. HGV
15. Domestic boat – passenger
16. Domestic boat – freight
17. Int ship – passenger
18. Int ship – freight
19. Domestic Air –passenger
20. Domestic Air – freight
21. Int Air – passengers
22. Int Air - freight

Technology Types

1. Rail – electric
2. Rail – diesel
3. Rail – fuel cell
4. Pipeline
5. Road – ICE gasoline
6. Road – ICE diesel
7. Road – ICE other
8. Road – LPG
9. Road – CNG
10. Road – flex ethanol
11. Road – hybrid
12. Road – plug-in hybrid
13. Road –battery elec
14. Road –fuel cell
15. Water – diesel
16. Water – fuel cell
17. Air – kerosene
18. Air - hydrogen

Classifications in the Transport submodel

Fuel Types

1. Coal
2. Motor Spirit
3. Derv
4. Gas Oil
5. Fuel Oil
6. Other Refined Oil
7. Natural Gas
8. Electricity
9. Nuclear Fuel
10. Steam
11. Biodiesel
12. 2nd Gen Biodiesel
13. Ethanol
14. Battery
15. Methanol
16. Hydrogen

Network Types

1. Light Rail/Tube Track
2. Electric Railtrack
3. Non-Electric Railtrack
4. Pipeline
5. Pavement
6. Cycle Paths
7. Minor Roads
8. Rural A Roads
9. Urban A Roads
10. Motorway
11. Inland waters
12. Domestic sea
13. International sea
14. Domestic air
15. International air

Future model developments will consider further disaggregation:

11 Vehicle Age Types

8 Trip Length Types

20 Vehicle Age Types

Transport Submodel Data Sources

- **Sources**
  - BERR publications (DUKES, ECUK) for energy data
  - DfT publications (TSGB, NTS, PTSB, VLS)
  - various sources: ORR, NAEI, SMMT, ICAO, Sustrans…)
- **Data**
  - passenger km, vehicle km, vehicle occupancy, vehicle efficiency, vehicle survival rates, vehicle purchases, vehicle stock, network length, vehicle speed, reliability data, aircraft departures, emissions data…
- **Econometric technique**
  - Cointegration method with Error Correction Model

Transport Model for the UK (Green Fiscal Commission)

TPKE: Passenger travel demand

$$\ln(TPKE_{v,n,t}) = \alpha_1 + \beta_1 \ln(RPDH_t) + \beta_2 \ln(PROW_{v,t}) + \beta_3 \ln(PCE_t) + \beta_4 \ln(TPKW_{v,n,t}) + \beta_5 \ln(TVAV_{v,t}) + \beta_6 \ln(TNAV_{n,t}) + \beta_7 \ln(TSPD_{v,t}) + \beta_8 \ln(TSFT_{v,t}) + \varepsilon$$

(Long-run specification)

$$\Delta\ln(TPKE_{v,n,t}) = \alpha_2 + \beta_9 \Delta\ln(RPDH_t) + \beta_{10} \Delta\ln(PROW_{v,t}) + \beta_{11} \Delta\ln(PCE_t) + \beta_{12} \Delta\ln(TPKW_{v,n,t}) + \beta_{13} \Delta\ln(TVAV_{v,t}) + \beta_{14} \Delta\ln(TNAV_{n,t}) + \beta_{15} \Delta\ln(TSPD_{v,t})$$
$$+ \beta_{16} \Delta\ln(TSFT_{v,t}) + \beta_{17} \Delta\ln(TPKE_{v,n,t-1}) + \beta_{18} ECM_{v,n,t-1} + \varepsilon$$

(Short-run specification)

Where:

TPKE is demand for travel in billion passenger kilometres, RPDH is real personal disposable income per household

PROW is the price of travel, PCE is the consumer price index, TPKW is travel demand by competing modes of transport

TVAV is vehicle availability, TNAV is network availability, TSPD is transport speed, TSFT is transport safety

v = 1, …, 22 vehicle types (TV), n = 1, …, 15 network types (TN), t = time

TVPV: New vehicle purchases

Long-run specification: $\ln(TVPV_{v,e,t}) = \alpha_1 + \beta_1 \ln(RPDI_t) + \beta_2 \ln(PRPV_{v,t}) + \beta_3 \ln(TVSE_{v,t}) + \beta_4 \ln(PFR_{e,t}) + \beta_5 TIME_t + \varepsilon$

Short-run specification: $\Delta\ln(TTFN_{e,v,t}) = \alpha_2 + \beta_4 \Delta\ln(TYKE_{v,t}) + \sum_{i=0}^{L} \beta_5 \Delta\ln(PFR_{e,t-i}) + \beta_6 \Delta\ln(TTFN_{e,v,t-1}) + \beta_7 ECM_{e,v,t-1} + \varepsilon$

Where:

TVPV is new vehicle purchases in thousands, RPDI is real personal disposable income, PRPV is the price of new vehicles

TVSE is the size of the existing vehicle stock, PFR is the price of fuel, TIME is a time trend

v = 1, …, 22 vehicle types (TV), e = 1, …, 18 transport technology types (TT), t = time

TTFN: New vehicle efficiency

Long-run specification: $\ln(TTFN_{e,v,t}) = \alpha_1 + \beta_1 \ln(TYKE_{v,t}) + \beta_2 \ln(PFR_{e,t}) + \beta_3 TIME_t + \varepsilon$

Short-run specification: $\Delta\ln(TTFN_{e,v,t}) = \alpha_2 + \beta_4 \Delta\ln(TYKE_{v,t}) + \sum_{i=0}^{L} \beta_5 \Delta\ln(PFR_{e,t-i}) + \beta_6 \Delta\ln(TTFN_{e,v,t-1}) + \beta_7 ECM_{e,v,t-1} + \varepsilon$

Where:

TTFN is new vehicle efficiency in litres per hundred kilometres, TYKE is the technical progress indicator

PFR is the price of fuel, TIME is a time trend

e = 1, …, 18 transport technology types (TT), v = 1, …, 22 vehicle types (TV), t = time

Theory of the Model: passenger kms

- solved across network and vehicle type
  - cars on rural roads, buses on urban roads, etc
- passenger km is a function of:
  - income (or activity proxy for freight)
  - price (composition of running costs)
  - vehicle and network availability
  - speed, safety and reliability
  - competing passenger km demand
- vehicle km is formed across network types and vehicle type
  - based on average occupancy rates
  - n/a to freight

Theory of the Model: vehicle fuel efficiency l/km

- solved across vehicle type and technology type
  - cars ICE petrol, buses ICE diesel, int. air kerosene eng., etc,
- vehicle efficiency is a function of:
  - Investment
  - price of fuel
  - Time
  - dummy variable for New Vehicle Fuel efficiency Standards
- vehicle efficiency is solved for new vehicles and then the efficiency of the entire stock is taken

Theory of the Model: new purchases (thousands)

- solved across vehicle type and technology type
  - cars ICE petrol, buses ICE diesel, int. air kerosene eng., etc,
- vehicle purchases are a function of:
  - Income
  - price of vehicle
  - existing vehicle stock
  - dummy variable for Subsidies in specific transport vehicles
- new vehicle purchases from year 1 of the stock, year 1 ‘survivors’ go to year 2, etc

Previous Top-Down Treatment of fuel demand

- Econometric estimated cointegrating equation for road transport final energy demand – explanatory variables are:
  - economic activity
  - real weighted price of fuel (petrol/diesel)
  - technology indicator
- Split to petrol and diesel using econometric estimated cointegrating equations for fuel shares, explanatory variables are:
  - economic activity
  - own price
  - competitors price
  - technology indicator

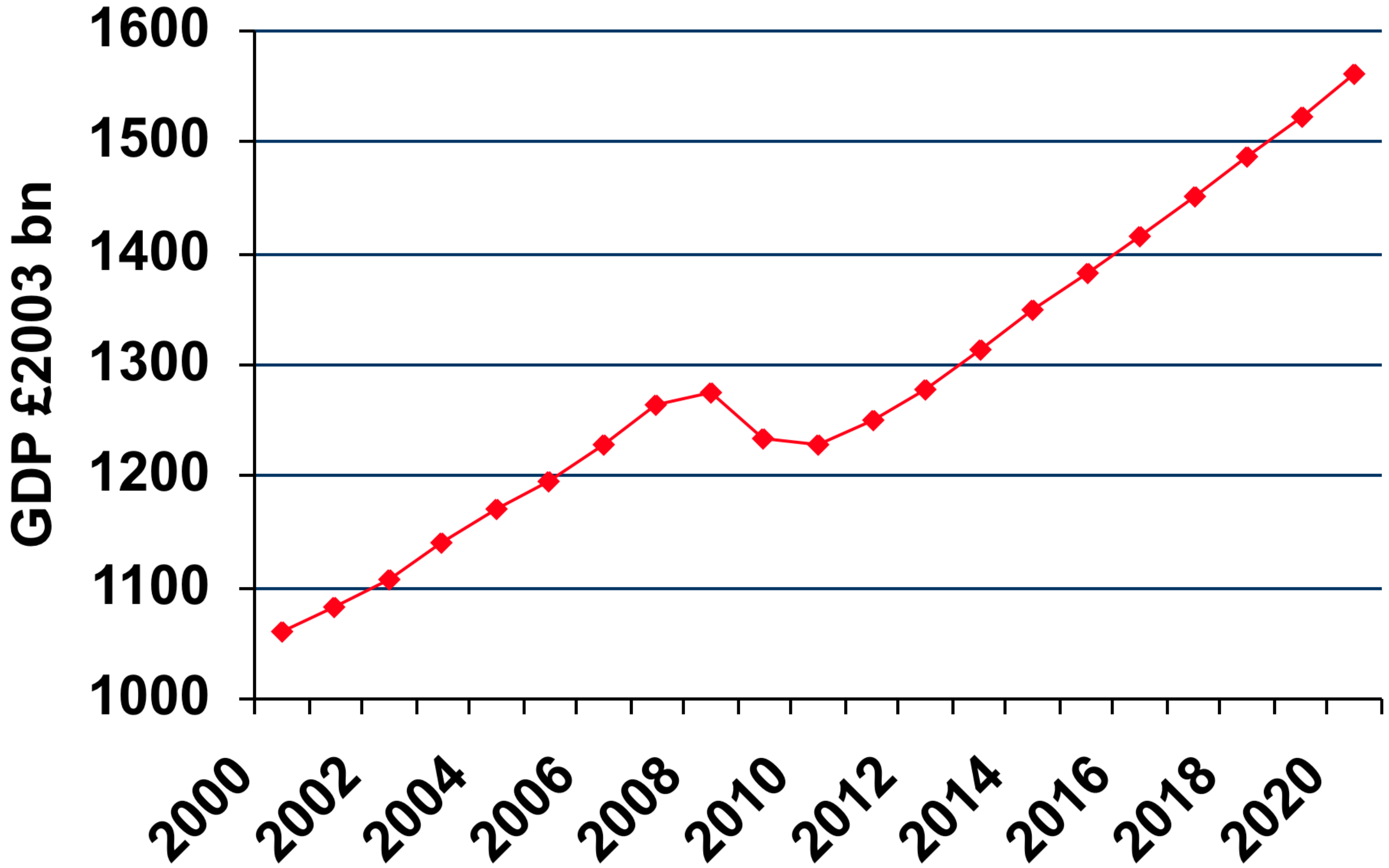
Theory of the Model: solving fuel demand and emissions

- fuel demand is solved for each fuel as a function of:
  - vehicle km
  - average stock efficiency
- emissions from fuels are solved as before based on implied coefficients for petrol and diesel, etc
- there is an alternative specification for emissions using full vehicle and technology emissions to capture end-of-pipe measures for NO_x, PM10s, etc

Comparison of Results

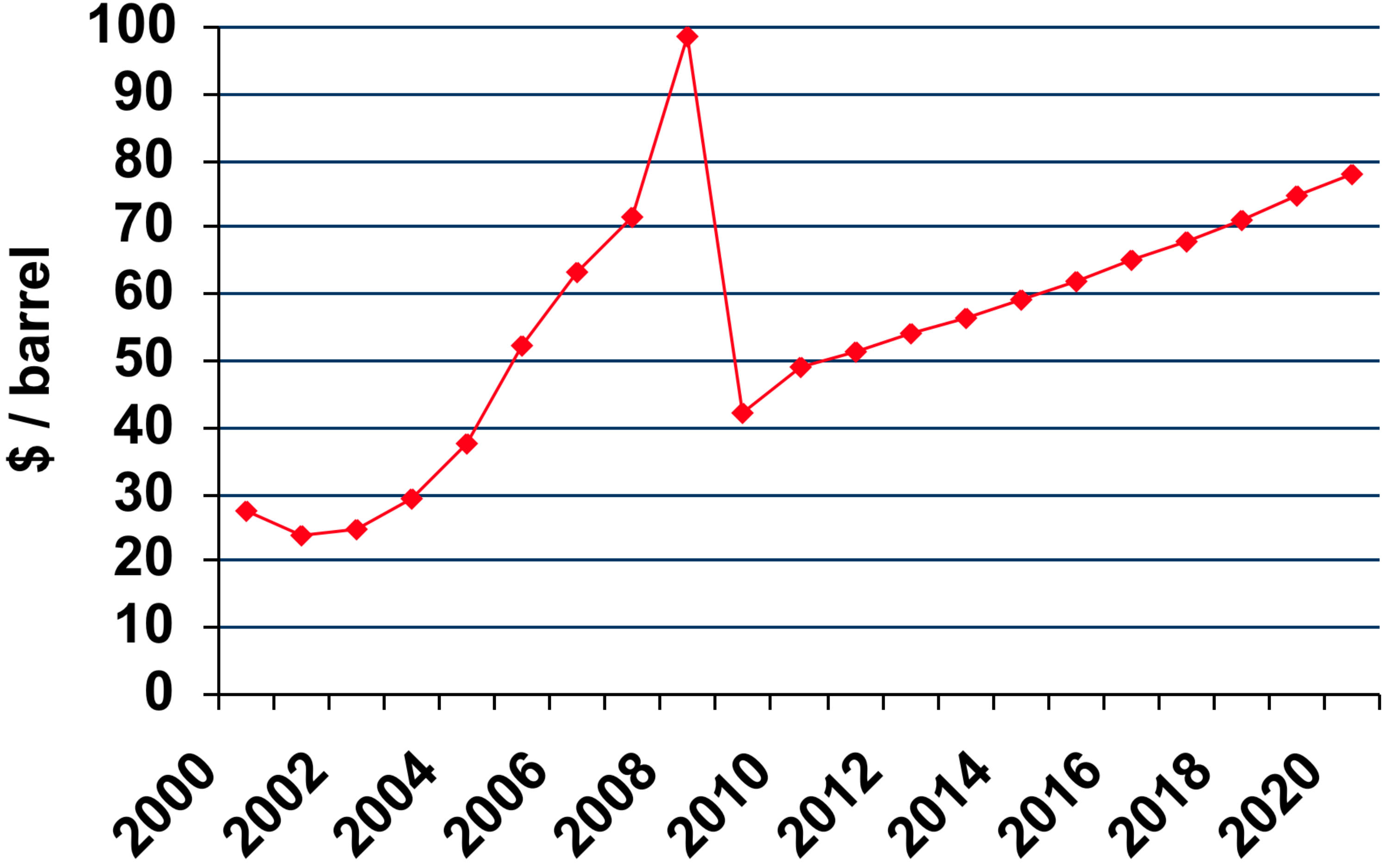
- parameters feeding into the two treatments;
  - economic activity, oil prices, etc
- energy demand comparisons
- fuel comparisons
- carbon emissions comparisons
- detailed results from the transport sub-model
- points for consideration
- transport sub-model applied to scenario analysis

GDP Profile

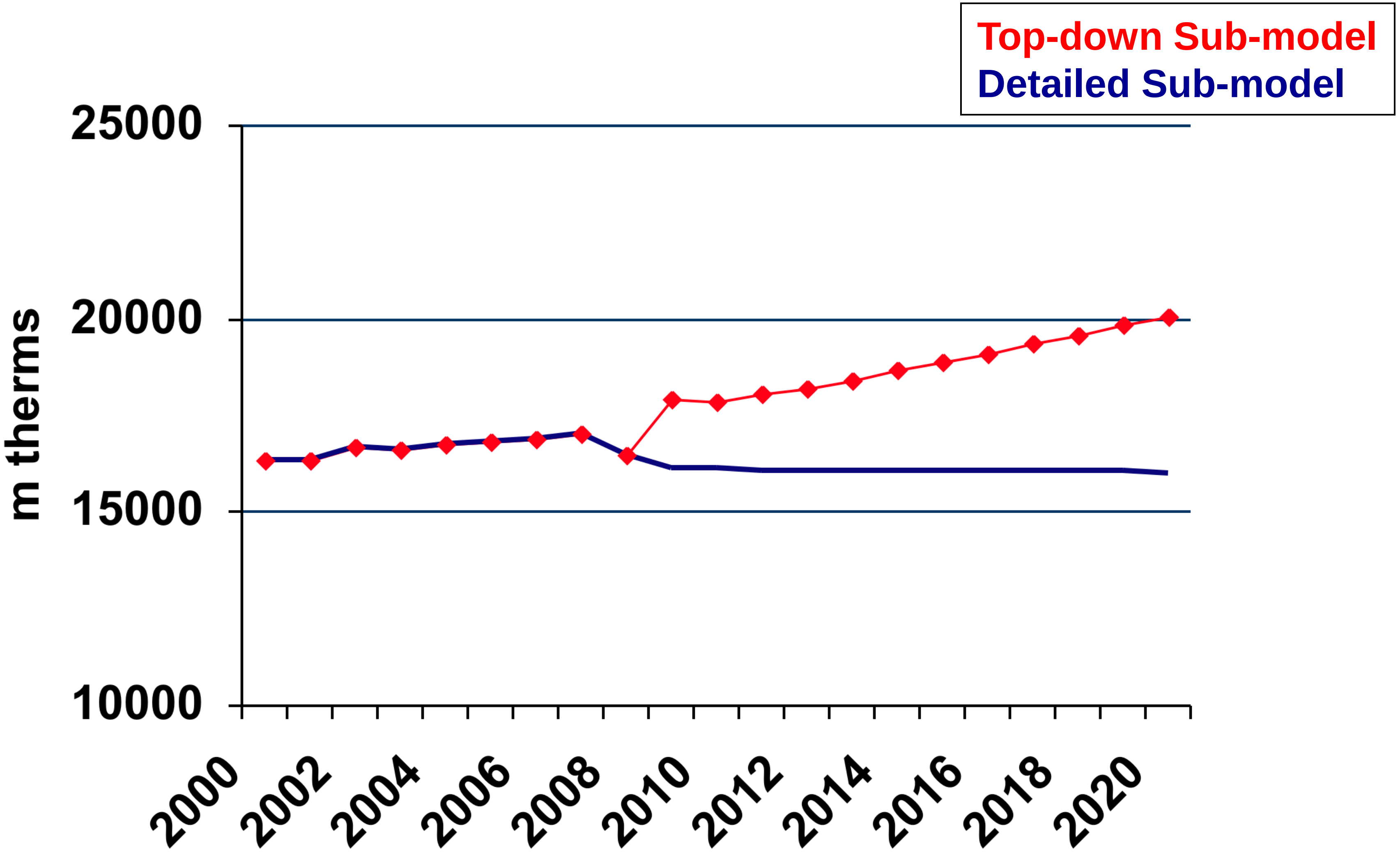


GDP £2003 bn
1600
1500
1400
1300
1200
1100
1000
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020

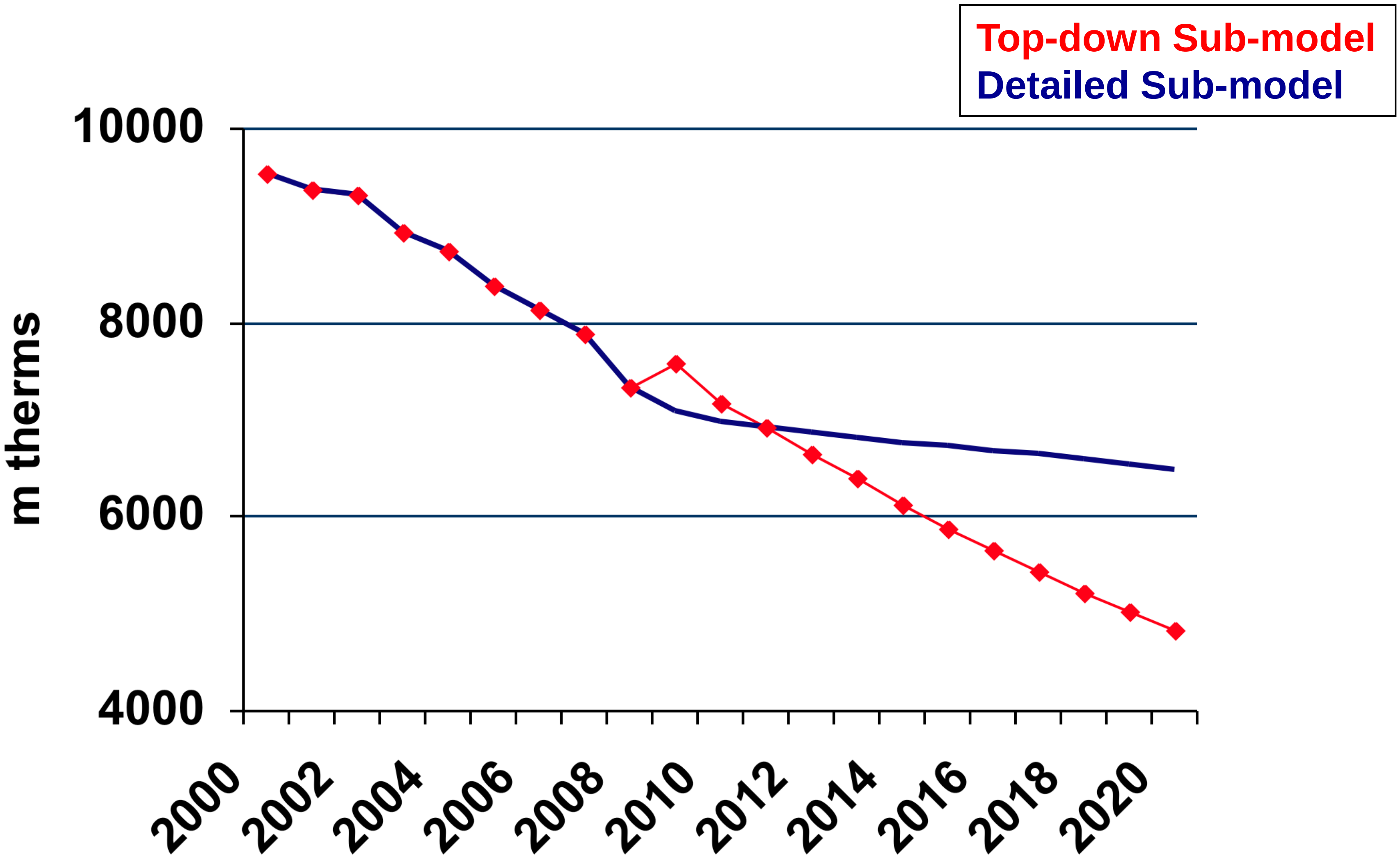
Nominal Oil Price Assumption



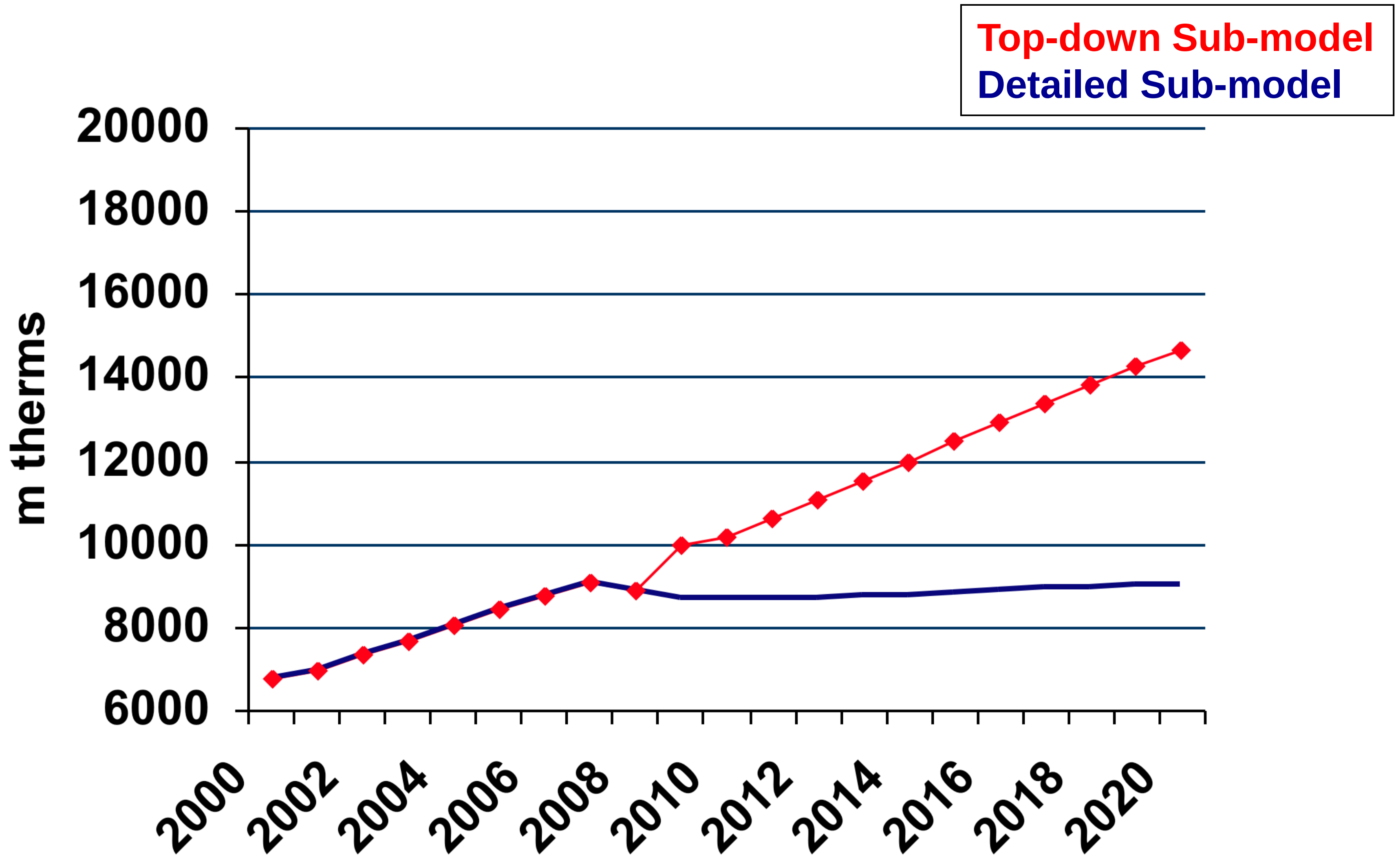
Road Transport Energy Demand



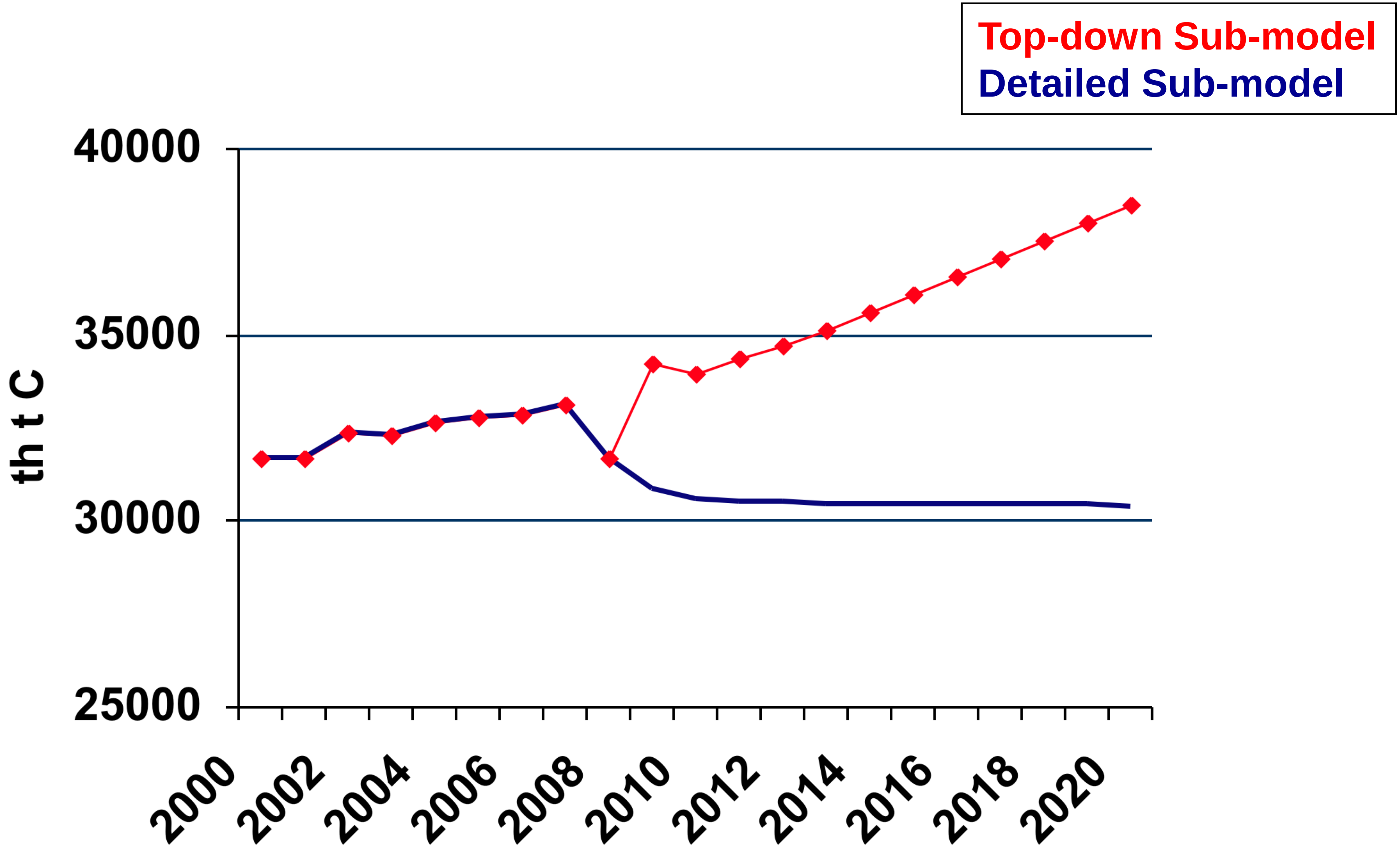
Petrol Demand



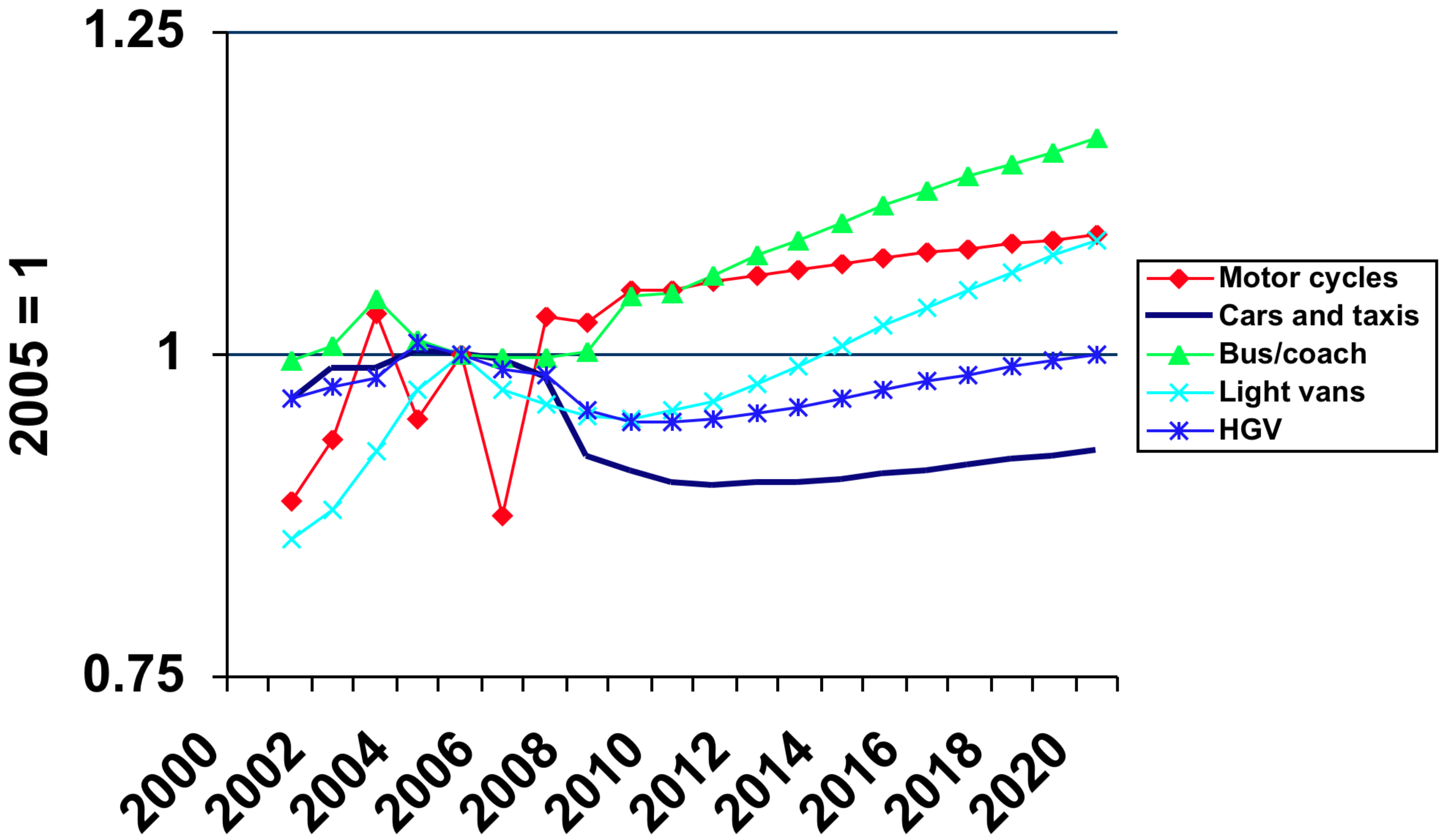
Diesel Demand



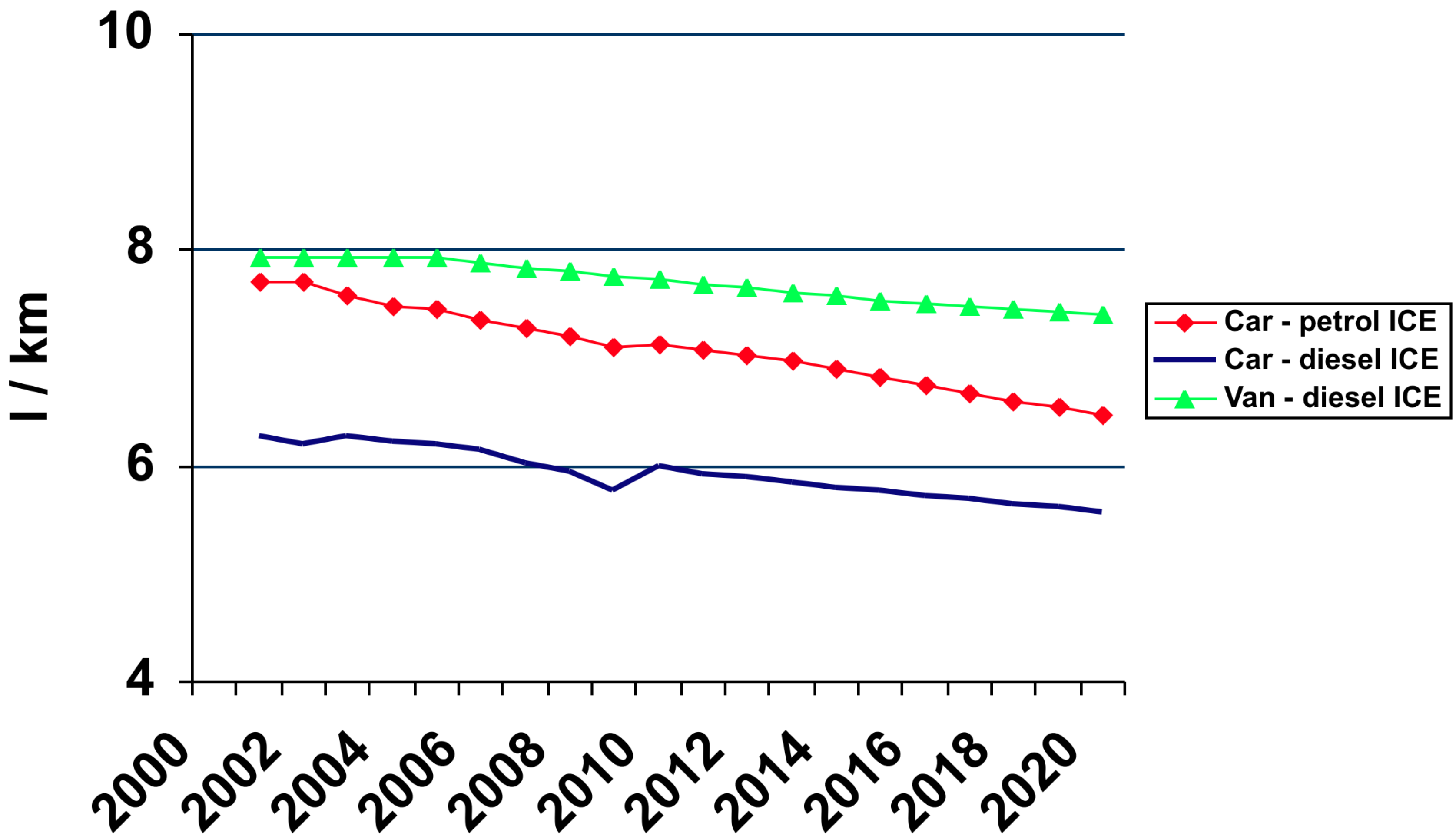
Comparison of CO2 projections



Vehicle km demand, by type from the Detailed Sub-model



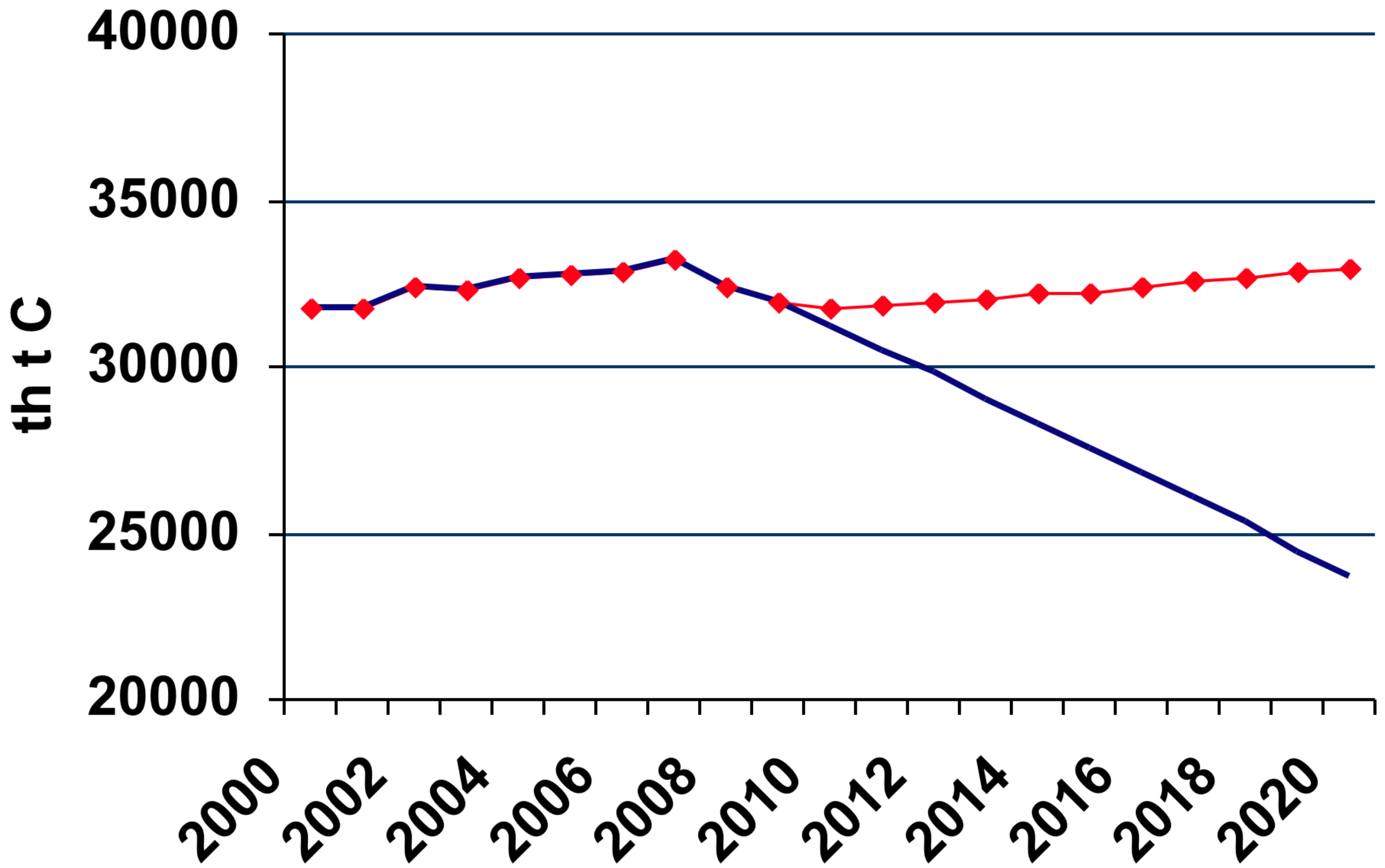
Vehicle stock efficiency improvements from the Detailed Sub-model



Green Fiscal Commission Analysis

- for the Green Fiscal Commission CE and 4CMR undertook a piece of research to understand the impacts of an environmental tax reform in the UK, the scenarios included:
  - a substantial increase in the fuel duty escalator
  - eco-innovation spending from green tax revenues
- as part of the eco-innovation spending we used the model framework to understand the implications of subsidising hybrid vehicles to the market value of the average petrol vehicle

GFC Partial Results – Road Transport Emissions



Overall comments on the results

- energy demand and CO_2 emissions actually seem more plausible from the detailed transport sub-model
    - the transport sub-model equations show a plausible shift between petrol and diesel demand
    - the bottom-up results give plausible results for:
        - vehicle fleet efficiency
        - vehicle km demand
- treatment for road freight could be reconsidered as recession has little effect in the sub-model – seems slightly implausible
- the oil price has a stronger impact on the top-down equations

Some considerations

- estimation period is shorter for detailed transport equations than top-down energy demand equations
  - top-down data is more robust
- detailed data gives us a better understanding of drivers of reduction in energy demand
  - freight vs passenger
  - demand or efficiency
- detailed results are therefore more useful in explaining the projections
- the transport sub-model is more useful in scenario analysis than in forecasting because we can examine the effects of a number of interesting policy interventions

Modelling Implications

- we can now investigate many more scenarios regarding transport policy options with respect to climate change mitigation
  - new vehicle technologies in the vehicle stock, eg plug-in hybrid
  - efficiency gains (improvements to existing technologies)
  - modal shift (switch from cars to buses)
  - demand reductions (behavioural changes)
  - varying fuel taxes (induced demand and efficiency effects)
  - vehicle purchases taxes
  - increased occupancy (max. use of air travel capacity)
  - varying income growth and the effect on the vehicle stock profile

Feedback Mechanisms & Next steps

- existing linkages with MDM-E3
  - only through fuel demand for road transport
- next steps
  - fuel demand for water, air and rail transport
  - further analysis on modal shift
  - linkage of modelling between supply and consumption side
    - electric plug-in vehicles increase the capacity factor of renewables
  - vehicle purchases to inform consumption
    - who is buying the vehicles (economic quintiles)?