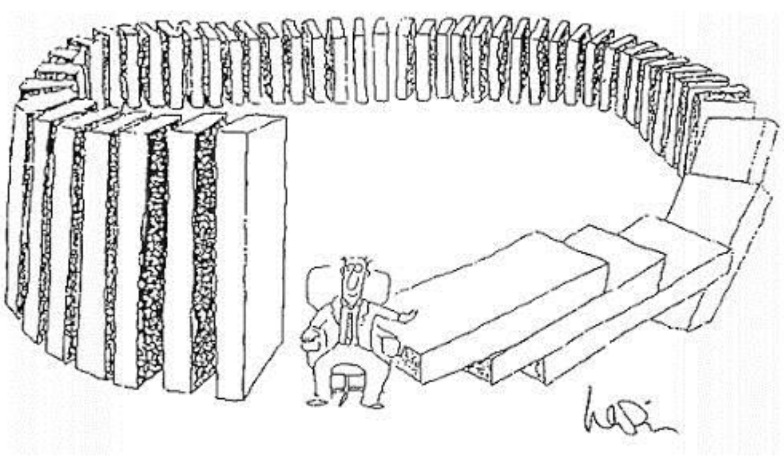
Rebound effects in GB road transport

Steve Sorrell and Lee Stapleton

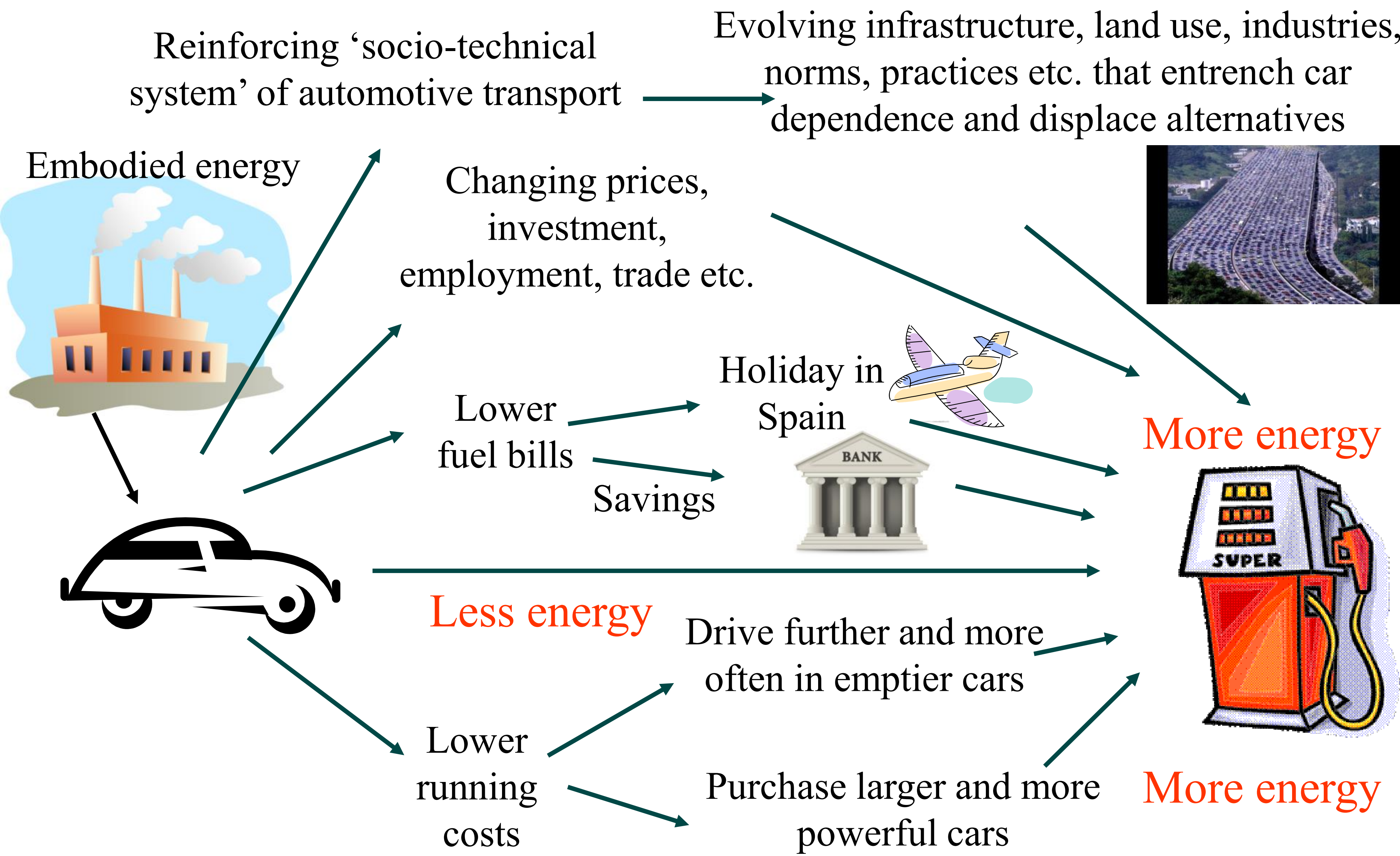
November 2015

Topics

- Project outline
- Methodological challenges
- Estimating direct rebound effects in GB personal automotive transport
- Next steps



Mechanisms



Reinforcing 'socio-technical system' of automotive transport
Evolving infrastructure, land use, industries, norms, practices etc. that entrench car dependence and displace alternatives
Embodied energy
Changing prices, investment, employment, trade etc.
Holiday in Spain
Lower fuel bills
Savings
BANK
More energy
SUPER
Less energy
Drive further and more often in emptier cars
Lower running costs
Purchase larger and more powerful cars
More energy

Implications

- Technical improvements reduce the energy cost of road transport, thereby encouraging increased transport activity and hence energy use
- More people travel further and more often in larger, faster, more powerful and emptier cars
- More goods are moved over greater distances in larger and more powerful trucks, encouraging more consumption of more and different types of goods
- The system of ‘automobility’ of people and goods is reinforced
- But establishing causality is difficult when data is limited, feedbacks abound and everything is endogenous

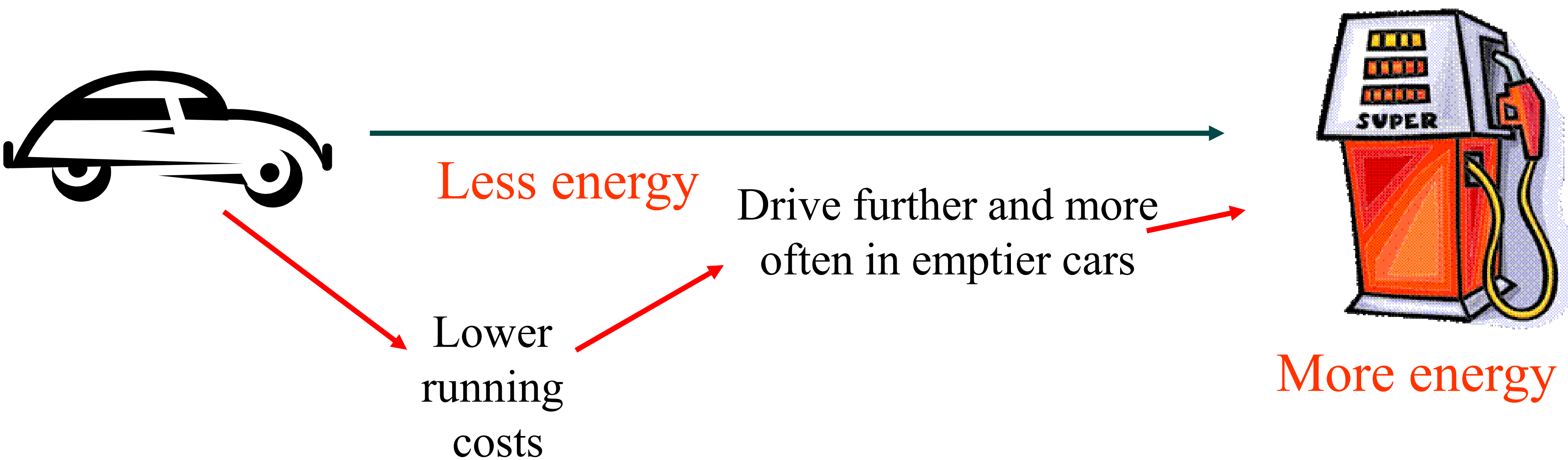
Questions

- What proportion of the potential energy and carbon savings from improved fuel efficiency in GB road transport have been taken back by various types of rebound effect over the last 45 years?
- What mechanisms have been responsible for these effects, what factors influence their operation and outcomes and how have these changed over time?
- How robust are our quantitative estimates of rebound effects and how can confidence in these estimates be improved?
- How may these rebound effects be expected to evolve in the future?
- What are the implications for UK energy and climate policy

Methodological issues when estimating direct rebound effects

Direct rebound for personal automotive transport

- Single energy service and single energy carrier
- Accounts for large proportion of total oil consumption and is relatively price-sensitive
- Good-quality, aggregate time-series data available *but* measurement errors, petrol/diesel, company cars etc.
- Disaggregate data sometimes available from surveys
- Growing number of studies with diverse methodologies
- **Most estimate direct rebounds in the range 10-30%**



Rebound as an efficiency elasticity

S = km travelled; ***E*** = Fuel use - GJ; ε = Fuel efficiency km/GJ

$$E = S / \varepsilon$$

Elasticity of fuel use with respect to energy efficiency :

$$\eta_{\varepsilon}(E) = \eta_{\varepsilon}(S) - 1$$

$$\boxed{\textbf{Rebound} = \ \eta_{\varepsilon}(S)}$$

Rebound may be defined as the elasticity of distance travelled with respect to fuel efficiency. But many datasets give only limited variation in (or don't measure) fuel efficiency.

Rebound as a price elasticity

$\boldsymbol{p_S}$ = fuel cost per km; $\boldsymbol{p_E}$ = Fuel price; ε = Fuel efficiency

$$p_S = p_E / \varepsilon \qquad\qquad E = \frac{s(p_E/\varepsilon)}{\varepsilon}$$

Elasticity of fuel use with respect to energy efficiency :

$$\eta_\varepsilon(E) = -\eta_{p_S}(S) - 1$$

$$\boxed{\textbf{Rebound} = -\eta_{p_S}(S)}$$

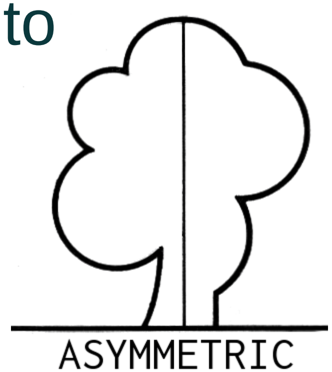
Rebound may be defined as the negative of the elasticity of distance travelled with respect to fuel cost per km.
Gives more variation in the explanatory variable.

Endogeneity and asymmetry

A core constraint:

everything depends on everything else

- Fuel efficiency may be endogenous:
  - influenced by fuel prices
  - influenced by expected travel demand
- Usually lack both a suitable instrumental variable for fuel efficiency and sufficient data for simultaneous equation model
- Fuel prices more likely to be exogenous, but response may be asymmetric and may differ from response to changes in fuel efficiency



Implications

- Efficiency elasticity of distance travelled is the natural measure, but data may not be available, there may be limited variation in this data and efficiency may be endogenous

Only a few studies have obtained significant estimates for efficiency elasticities

So which to believe??

- Fuel cost or fuel price elasticities of distance travelled typically give more precise parameter estimates, but these are only equivalent to the efficiency elasticity under certain assumptions

Lots of studies have obtained significant estimates for price elasticities

Our response

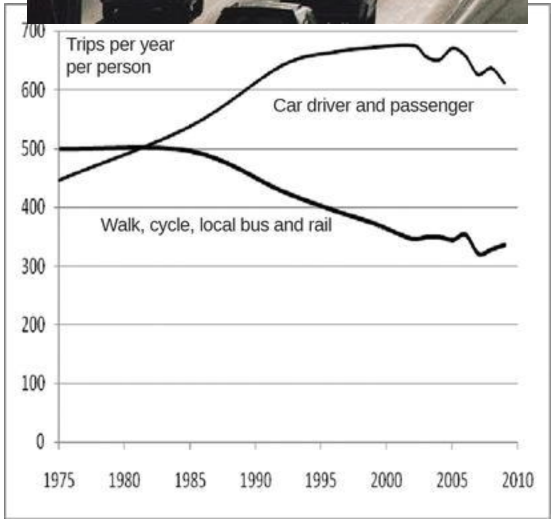
Estimate three different elasticities and compare the results

$$\eta_{\varepsilon}(S), \quad \eta_{p_E}(S), \quad \eta_{p_S}(S)$$

Estimating direct rebound effects in GB personal automotive transport

Summary of method

- Econometric analysis of aggregate time series data on GB car use, fuel use, household income, congestion etc. over the period 1970-2011
- Multiple specifications, different normalisations extensive robustness tests, weighted results
- Direct rebound effect estimated from elasticity of distance travelled with respect to:
    1. Fuel efficiency
    2. Fuel prices
    3. Fuel cost per kilometre



Model groups

- Different specifications of the **fuel cost of driving**:
  - Type A – fuel price and efficiency: $\eta_{\varepsilon}(S)$, $\eta_{p_E}(S)$
  - Type B – fuel cost per kilometre: $\eta_{p_S}(S)$
- Different specifications of **distance travelled**:
  - Vehicle kilometres
  - Passenger kilometres
- Different **normalisations**:
  - Per capita
  - Per adult
  - Per licensed driver

Model groups

Group	Explained variable	Normalisation of explained variable	Specification of the fuel cost of driving
1	VKM	Per capita	Type A
2	VKM	Per adult	Type A
3	VKM	Per driver	Type A
4	VKM	Per capita	Type B
5	VKM	Per adult	Type B
6	VKM	Per driver	Type B
7	PKM	Per capita	Type A
8	PKM	Per adult	Type A
9	PKM	Per driver	Type A
10	PKM	Per capita	Type B
11	PKM	Per adult	Type B
12	PKM	Per driver	Type B

Base models

Static model:

$$\ln S_t = \beta_0 + \beta_1 \ln Y_t + \beta_2 \ln p_{E_t} + \beta_3 \ln \varepsilon_t + \beta_4 X_t + \beta_5 C_t + u_t$$

Dynamic model:

Add a one period lag of the explained variable (S_{t-1})

Variables:

- Vehicle or passenger km by cars (S)
- Mean equivalised household income (Y)
- Mean fuel price in (£/GJ) (p_E)
- Fleet average fuel efficiency (km/GJ) (ε)
- Oil shock binary dummy (74 and 79) (X)
- Congestion proxy (e.g. road length/capita) (C)

Model variants

- *Quadratic income variants*:
  - Proxy for factors contributing to ‘peak car’
- *Asymmetric variants*:
  - Proxy for induced technical change, irreversible investments, habits etc.
- *Reduced variants*:
  - Remove insignificant variables
- *Co-integrated variants*:
  - Based on (low power) unit root tests; static specification, CCR method

Selection between models based on ‘robustness tests’

Diagnostic tests

- **Coefficients:** **do they behave?** [3 tests]
- **Residuals:** **do they behave?** [3 tests]
- **Stability:** **are predictions stable?** [2 tests]
- **Parsimony**: **is their a sound balance between model fit and model complexity?** [3 tests]
- **Functional form:** **is the model structure appropriate?** [2 tests]

Results used to create a composite 'robustness indicator' to guide model selection

A lot of models..

108 models

54 Type A
(fuel price and fuel
efficiency elasticities)

54 Type B
(fuel cost elasticity)

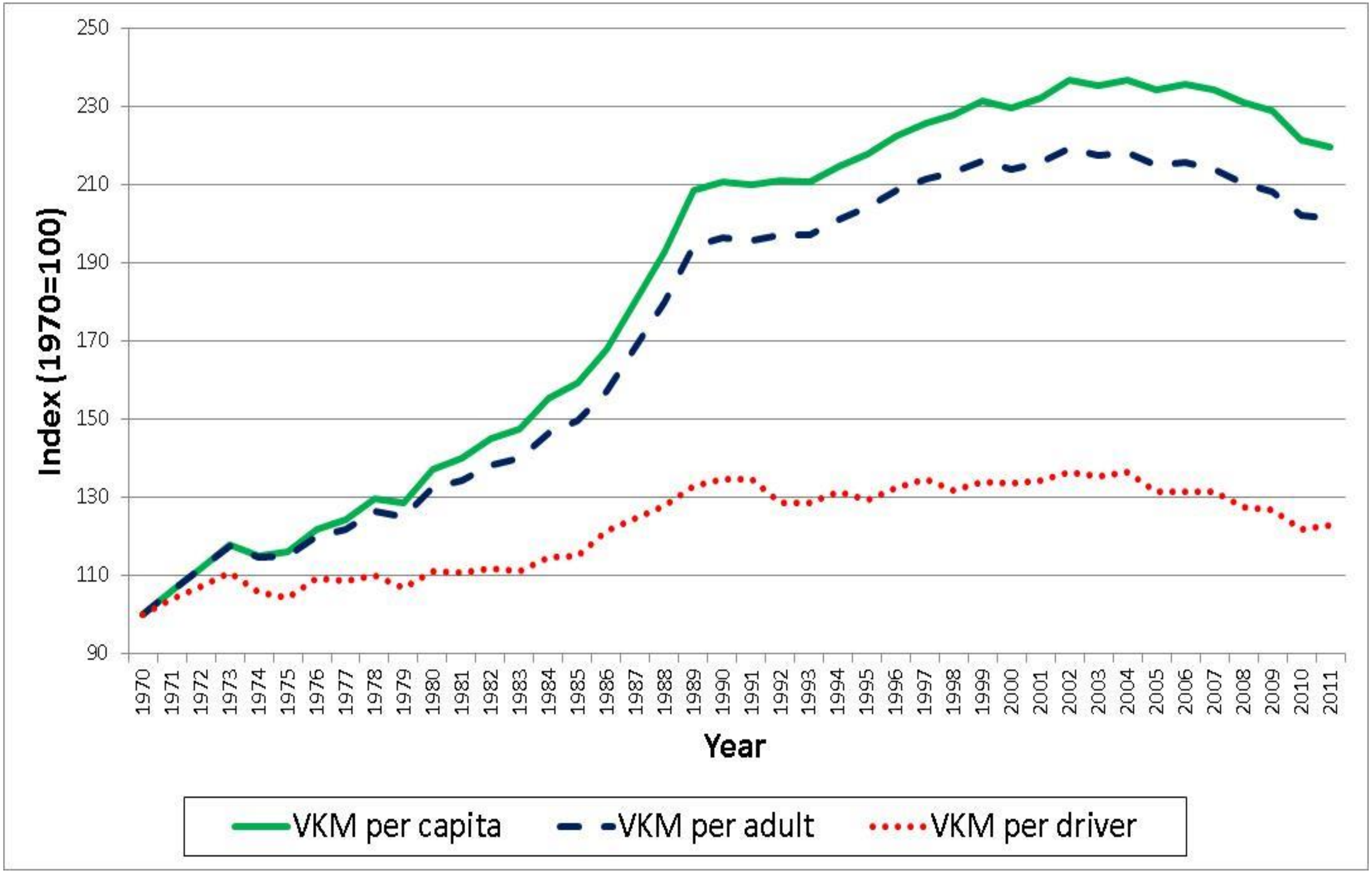
48 static models

48 dynamic models

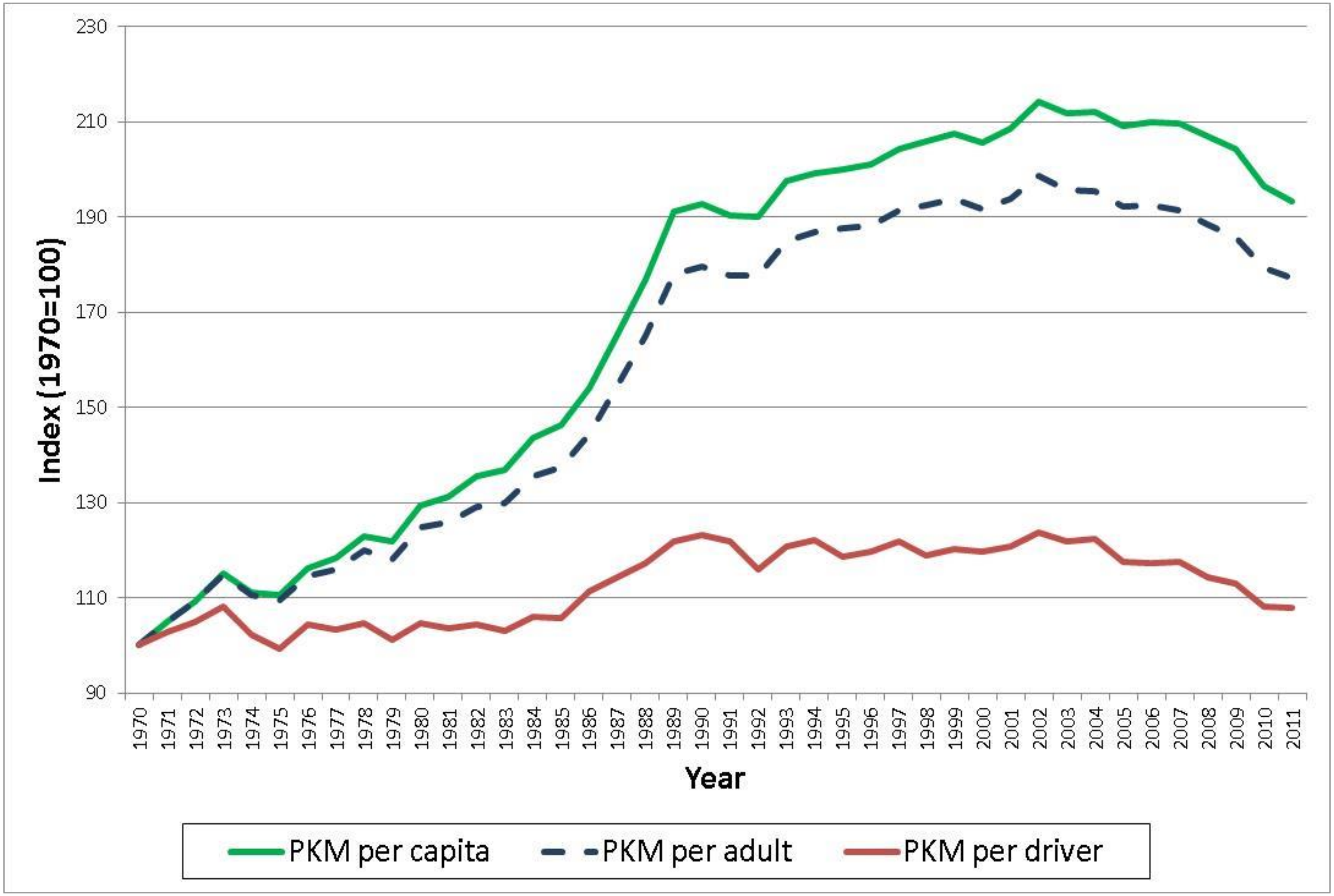
12 co-integrating models

1. **Simple mean of statistically significant estimates**
2. **Invariance weighted mean of all estimates**

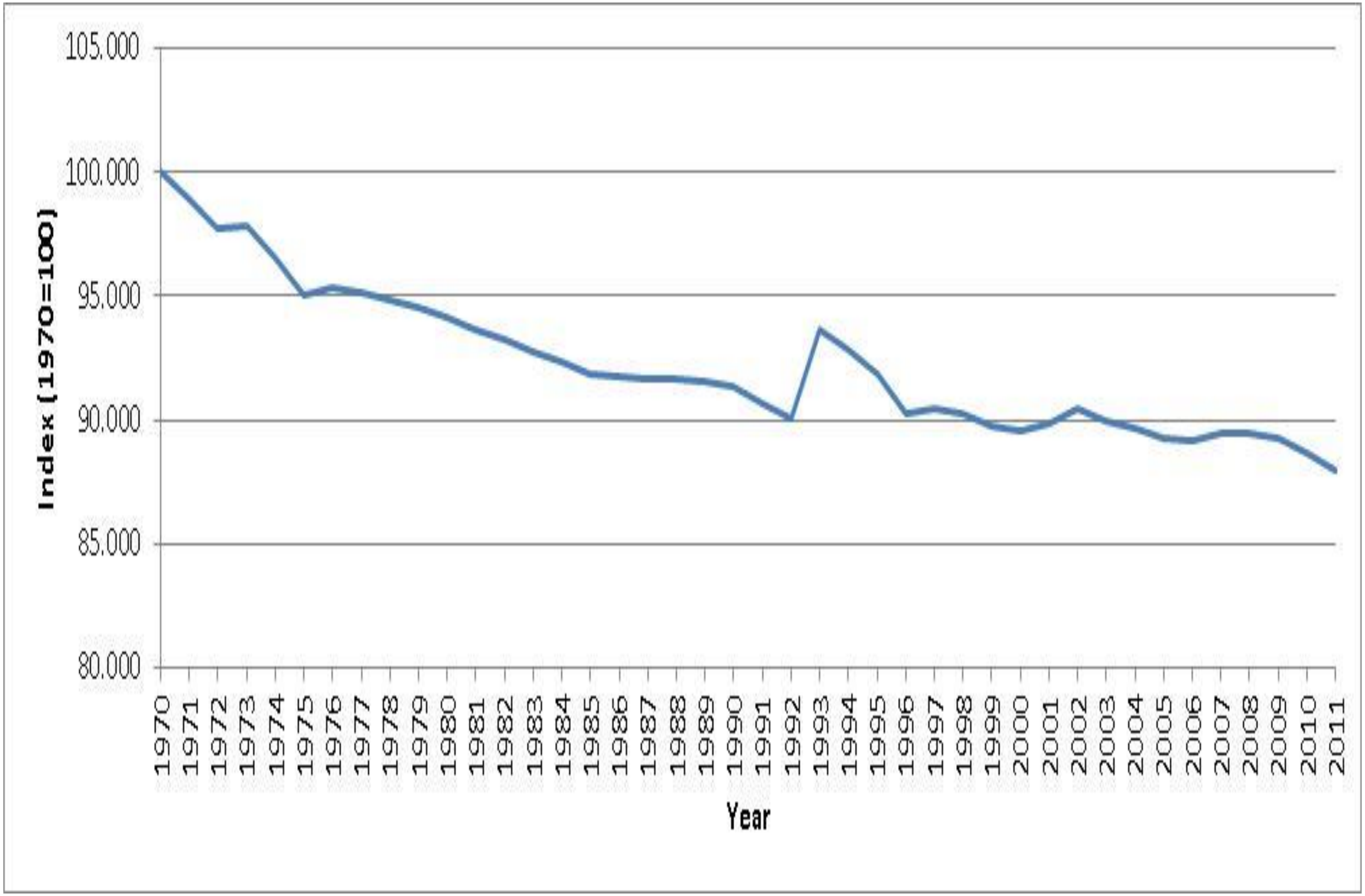
Vehicle kilometres



Passenger kilometres

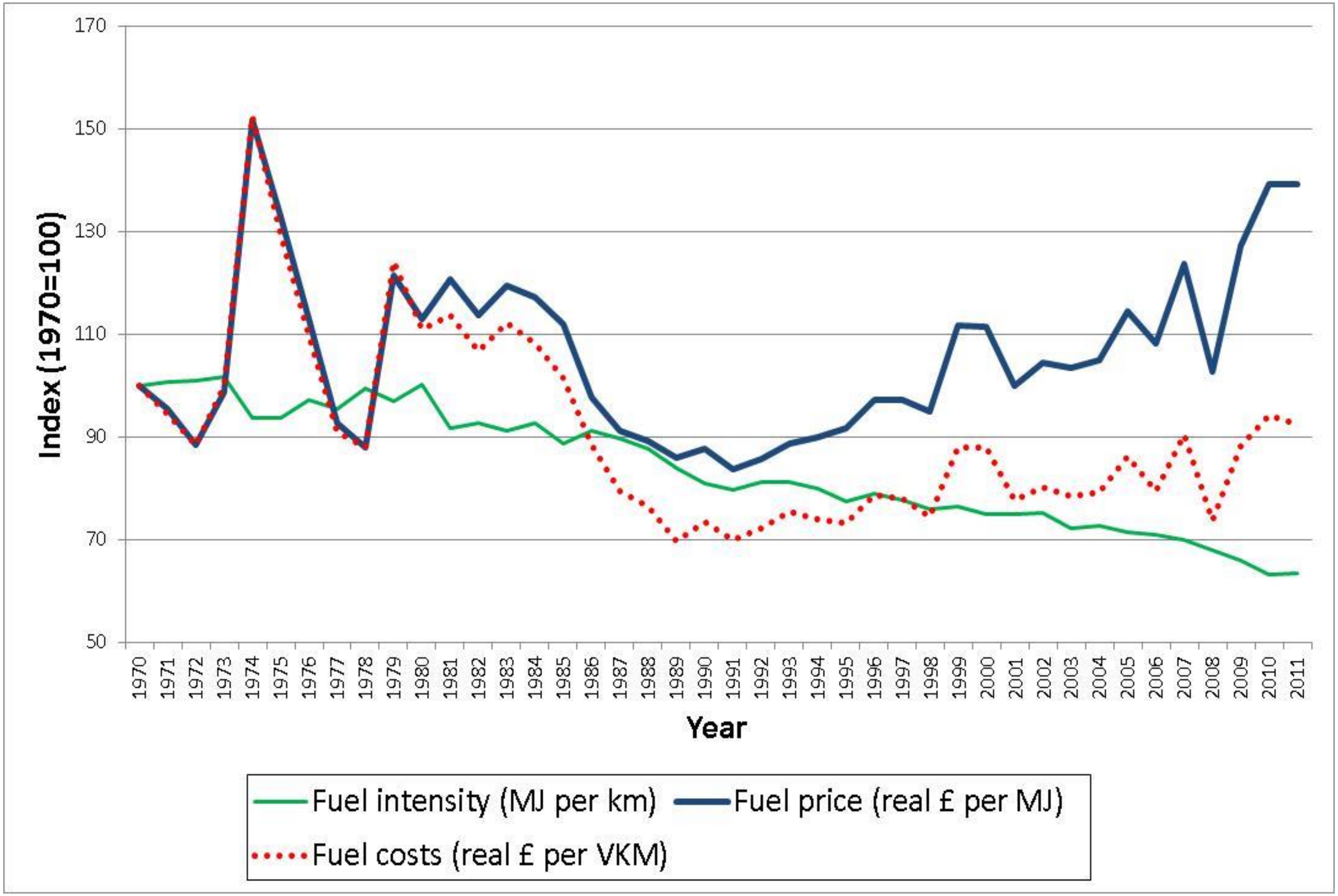


Occupancy

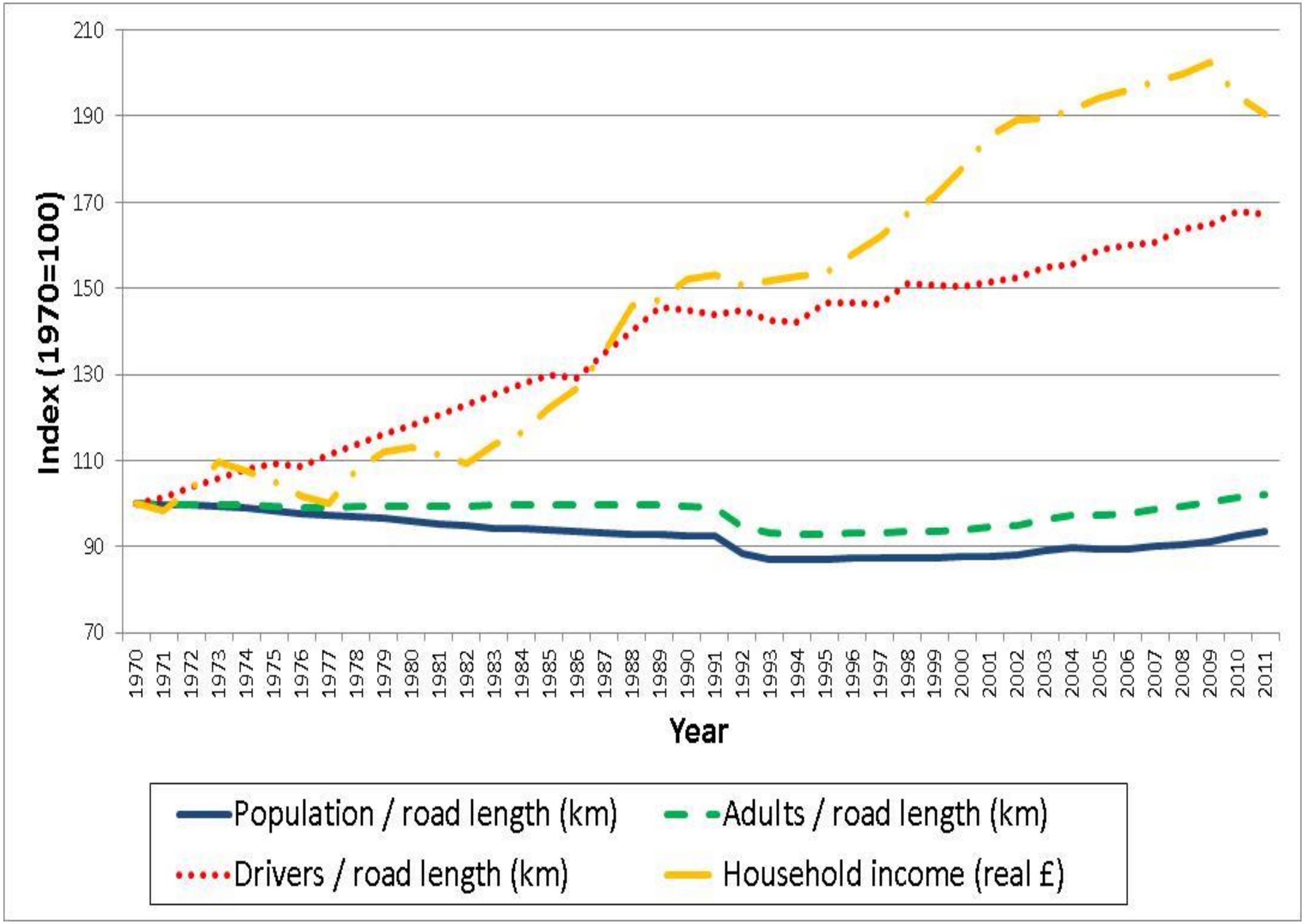


105.000
100.000
95.000
90.000
85.000
80.000
Index (1970=100)
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Year

Fuel cost of driving



Equivalised income and congestion proxies



Main Results - 1

- Using the fuel efficiency elasticity of distance travelled, we find **little** evidence of a long-run direct rebound effect over the last 40 years
- Using the fuel price and fuel cost elasticities of distance travelled, we find **good** evidence of a direct rebound effect in the range **9-36%**
  - *Half* of Type A models produced significant estimates of fuel price elasticity and *three quarters* of Type B models produced significant estimates of fuel cost elasticity
- Simple mean of statistically significant fuel price and fuel cost elasticities suggests a direct rebound of **~19%**
- Invariance–weighted mean of all fuel price and fuel cost elasticities suggests a direct rebound of **~16%**

Means of rebound estimates

Rebound measure	Simple mean of significant estimates	Invariance – weighted mean of all estimates	Average
Fuel prices – VKM	17.2%	15.2%	16.2%
Fuel prices – PKM	17.4%	15.2%	16.3%
Fuel costs – VKM	18.7%	15.2%	17.0%
Fuel costs – PKM	20.8%	17.7%	19.3%
Average	**18.5%**	**15.8%**	17.2%

Main Results - 2

- Estimates are slightly <u>lower</u> when distance travelled is normalised to the number of <u>drivers</u> rather than the number of adults or people
- Estimates are slightly <u>higher</u> when rebound is estimated with respect to fuel cost per kilometre, rather than fuel prices (expected)
- Estimates are slightly <u>higher</u> when using simple mean of statistically significant results, rather than invariance–weighted mean of all results
- But significant <u>overlaps</u> in the rebound estimates for each specification and measure
- Little evidence for <u>asymmetric</u> responses to price / efficiency changes
- Little evidence in favour of <u>dynamic</u> over static models
- Little evidence that consumers respond in the same way to lower (higher) fuel efficiency as to higher (lower) fuel prices (Wald tests)

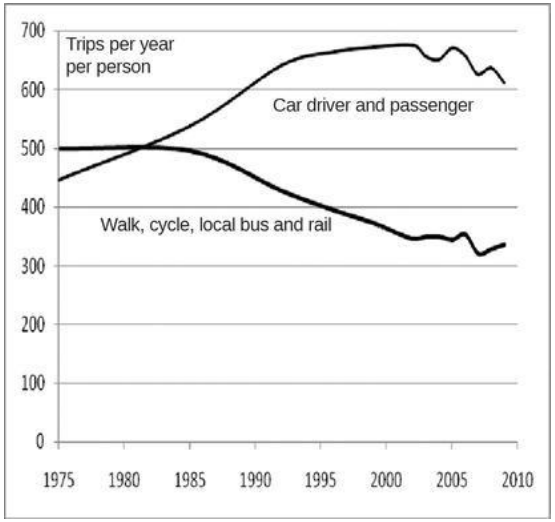
Implications

- Efficiency improvements have lowered the cost of car travel in GB over the last 40 years
- This has encouraged increased driving, which in turn has eroded around **one fifth** of the potential fuel savings
- Results are consistent with those from other studies
- *However*, the results also raise questions about the use of price elasticities to estimate rebound effects
- Multiple caveats and considerable scope for further work – but really need disaggregate data sources
- Also, direct rebounds are only one part of the picture

Next steps

1. Peak Rebound

- **Hypothesis:** rebound effects have fallen over time and with increasing incomes – implying greater potential for future energy savings
  - *Method*: Similar to earlier study
  - Identifying changes in elasticities over time and/or with increasing income
  - Covariates informed by literature on 'peak car' (e.g. urbanisation, internet use demographics etc.)

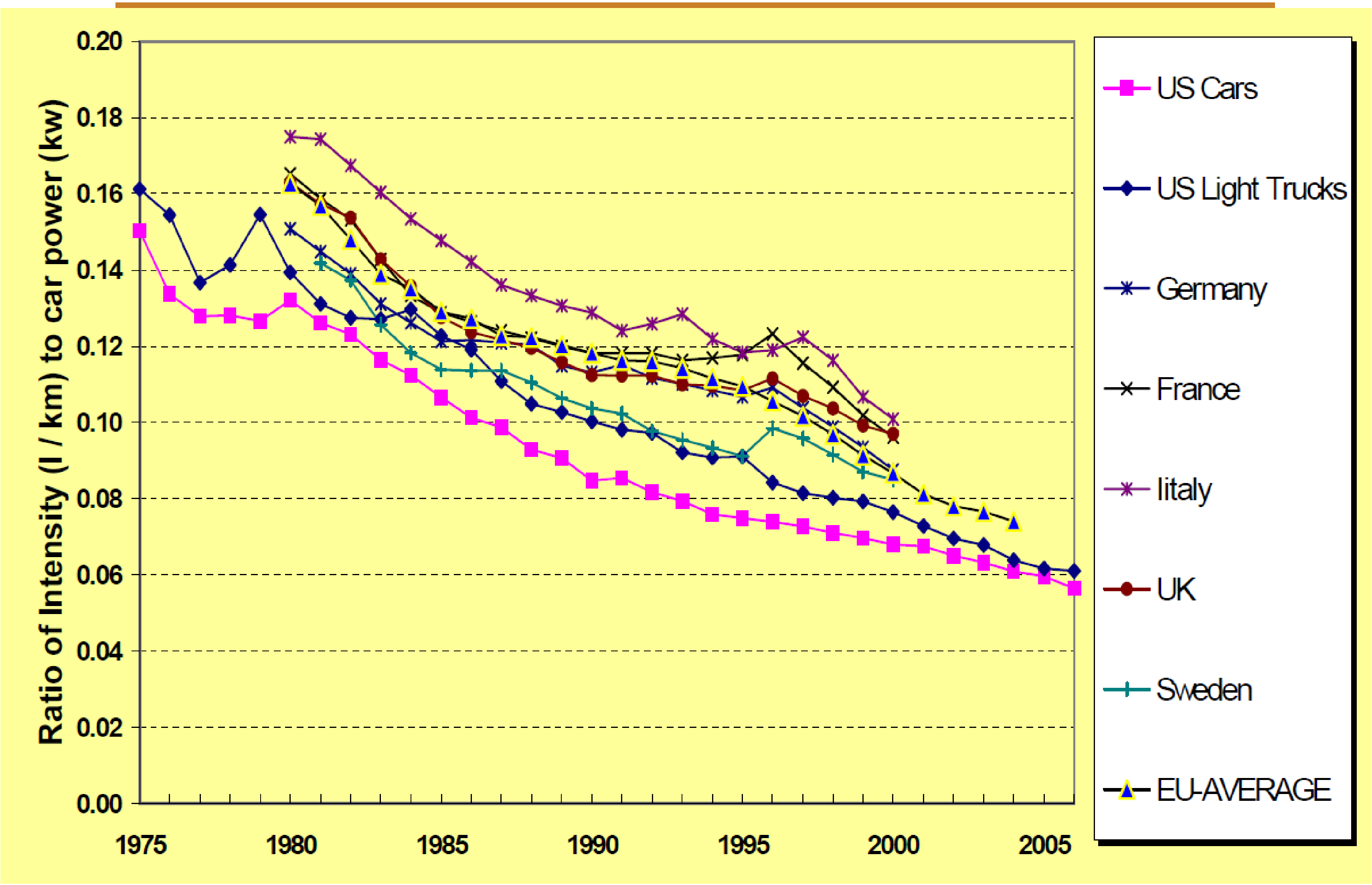


2. Service quality rebound

More driving in bigger and more powerful cars

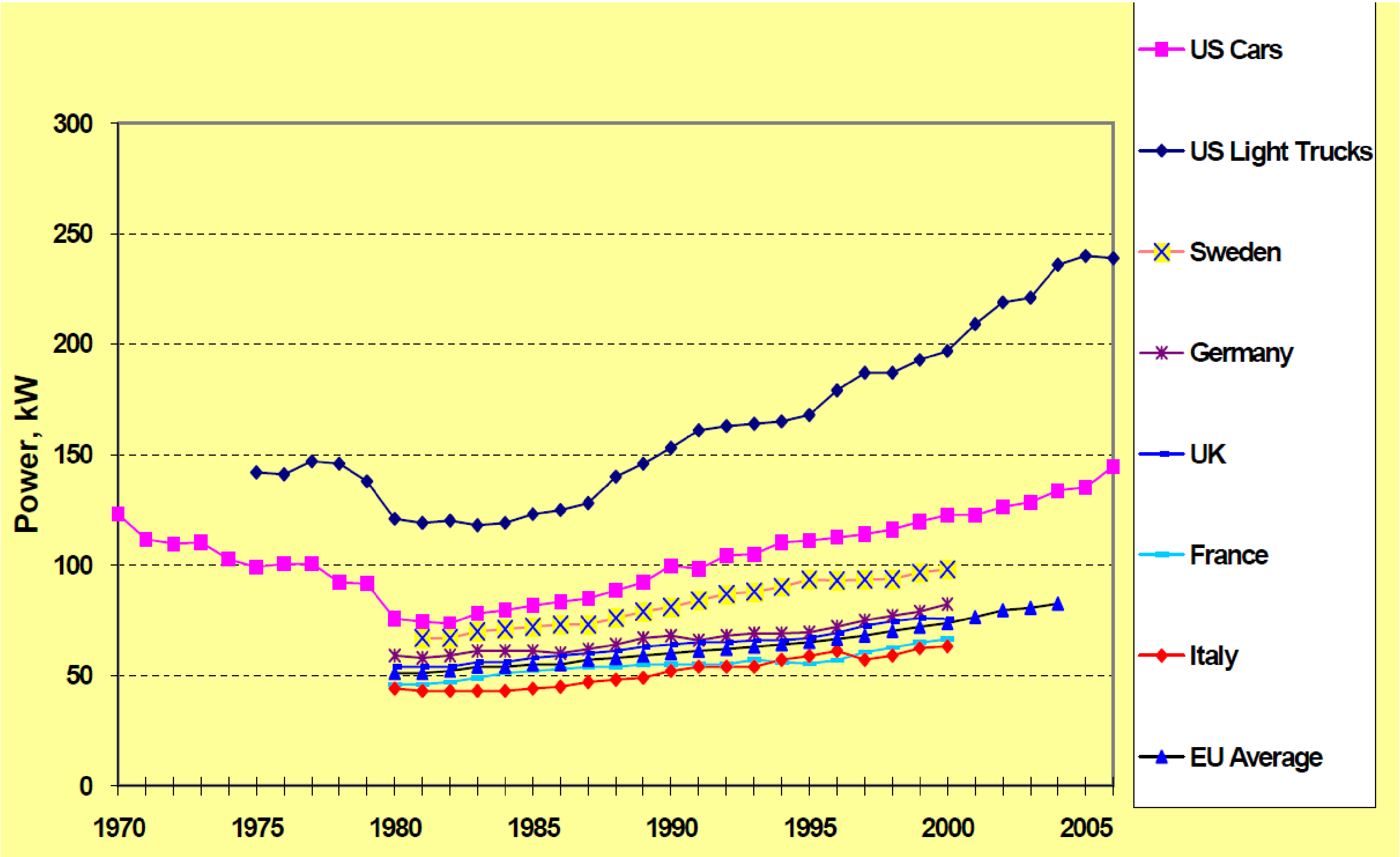
- *Method*: Construction and econometric analysis of aggregate time series of car use etc. including power and weight of vehicle stock.
- Rebound estimated from elasticities of ‘weighted’ service demand with respect to ‘technical’ efficiency or cost
- Weights could be power, weight or engine capacity (e.g. kW km)

Improvements in 'technical' efficiency of new cars (litres/km)/kW



Source: Schipper (2010)

Offset by increasing power of new cars (kW)

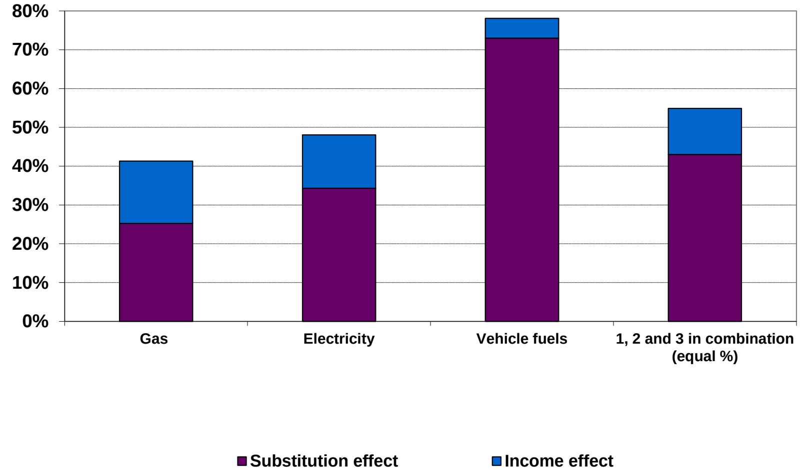


Source: Schipper (2010)

3. Indirect rebound

More driving and more money to spend on other stuff

- *Method*: Econometric analysis of household expenditures linked to multi-regional input-output modelling. Estimate system of demand equations and simulate energy/emission consequences of 're-spending' cost savings
- Four previous studies with Mona Chitnis
- Extensions: incorporate energy services directly within the demand model?



4. Freight rebound

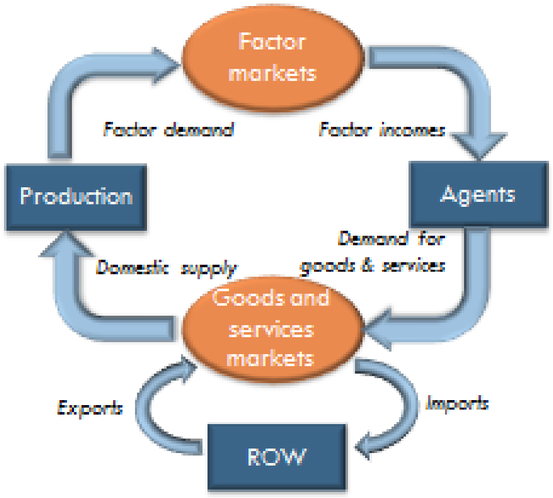
More and larger trucks carrying more stuff over longer distances

- *Method*: Econometric analysis of aggregate time series data on UK road freight, manufacturing output etc.
- Rebound estimated for different measures of efficiency and from different elasticities
- Builds upon earlier decomposition analysis

5. Economy wide rebound

More driving, more money, lower prices changed investments, changed trade patterns…

- Led by Karen Turner and colleagues, University of Strathclyde
- CGE modelling of UK economy linked to multi-regional input-output model. Allows economy-wide adjustments in expenditures, prices investment, trade patterns etc. to be explored
- Covers both road freight and passenger transport



6. Rebound and automobility…