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Mind the gap

The vicious circle of measuring automobile fuel use

Lee Schipper, Maria Josefina Figueroa, Lynn Price and Molly Espey

We review the circularity between estimates of automobile use, fuel consumption and fuel intensity. We find that major gaps exist between estimates of road gasoline, the quantity most often used to represent automobile fuel use in economic studies of transport fuel use, and the actual sales data of gasoline, diesel and other fuels used for automobiles. We note that significant uncertainties exist in values of both the number of automobiles in use and the distance each is driven, which together yield total automobile use. We present our own calculations for total automobile fuel use for a variety of OECD countries. We comment briefly on the impact of these gaps on econometric estimates of the price and income elasticities of automobile fuel use. We show that improper use of the circularity often leads to gross errors in estimating fuel intensity and other indicators of energy use for personal transport.

Keywords: Automobiles; Fuel use; Fuel intensity

Automobiles are significant sources of air pollution as well as CO_2, a major greenhouse gas. They use as much as two-thirds of the liquid fuels consumed by the transport sector. Not surprisingly, then, automobile fuel use is subject to scrutiny by a wide range of policy makers. Many policy measures to restrain automobile fuel use have been discussed, usually focusing on pricing and fiscal policies.[1] The question naturally arises, 'How much would change in automobile fuel prices change consumption?'

To answer this question, important insights can be gained through statistical studies of past gasoline use. Cross-country time series studies offer some of these insights. Since real fuel prices within any given country have changed so little over a period of decades, differences between countries may also offer some guidance as to the impacts of large price differences on consumption.[2]

Unfortunately, obtaining data that accurately reflect actual fuel consumed in transportation is one of the most serious problems in analysing energy use. The problem is particularly acute for international studies of energy use by automobiles. In this paper, 'automobiles' or 'cars' means automobiles and, for the USA and Denmark, personal light trucks and vans, which make up a significant portion of personal vehicles in those countries. 'Fuel intensity' means fuel use per kilometre; 'fuel economy' means kilometres per unit of fuel used. Improved/worsened fuel economy means greater/lesser fuel economy or, conversely, lower/higher fuel intensity respectively.

In the course of our project, The Future of the Automobile in an Environmentally Constrained World,[2] we devoted more than two person-years just to the collection of data on all aspects of transportation activity and energy use.[3] The structure of fuel use that we found was considerably different from that based on the traditional international sources of data. Thus, we believe that the lack of accurate and accessible national data has led to a major gap in our understanding of automobile fuel use.

Many problems cloud the determination of the structure of fuel use for automobiles. Among these are uncertainties over the actual number of vehicles in circulation, uncertainties over the definition of vehicle, ie whether light trucks, mopeds, motorcycles, or other vehicles are included in the popula-

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tion, uncertainties over how far these vehicles are driven, and uncertainties over how much gasoline, diesel fuel, and other fuel is actually consumed in transport (ie correctly counted fuel taxed as transport fuel and fuel that might have been consumed as such but not taxed). In this paper we discuss the most important problems inherent in measuring the fuel consumption of automobiles. The first problem we address is the result of the almost universal use of data on total gasoline consumption, as presented in national energy balances or published by the Organisation for Economic Co-operation and Development (OECD) as a proxy for fuel consumed by automobiles. We identify a difference between actual fuel consumed and that reflected in the data on total gasoline consumption most easily available to analysts. We then address the more general problem of measuring automobile fuel use and fuel intensity. We show that the circularity among fuel consumed, distance travelled, number of cars, and fuel use per car of kilometre travelled can hide serious errors in many analyses. We review some of the difficulties inherent in measuring these descriptors of automobile use. We then note some implications of these difficulties for previously published analyses. We review briefly the related problem of the gap between tests of fuel intensity of cars and actual on-road fuel intensity. From our review of major studies in OECD countries, however, we conclude that data exist from within most OECD countries that permit a reasonably accurate description of the number of cars, the distance they travel, their fuel economy and the fuel they use. In short, the gaps in our knowledge can be filled.

Measures of automobile fuel use

International analyses of automobile fuel use commonly use 'gasoline' listed under 'road fuels' in OECD balances or United Nations publications as their dependent variable.[4] While the OECD balances do not fully list their sources or definitions, our experience with OECD, IEA and national authorities suggests that national authorities send the OECD information from their own national balances, the same national sources we use in the present work. In virtually all of these national balances, 'road fuels' means fuel for automobiles, motorcycles, buses, trucks and other miscellaneous vehicles. These fuels are usually disaggregated into gasoline, diesel, liquid petroleum gases (LPG), and any other fuels actually used in road traffic. Data are supplied by fuel suppliers and marketers. Since all fuels for road use are taxed, often at many levels (federal, state or province, possibly even local), total sales of each tend to be reliably recorded.[5] Thus, 'gasoline' listed under 'road fuels' should be just that: an accurate picture of all gasoline sales for use on roads by all vehicles. While some gasoline bound for boats or agricultural vehicles may ultimately be used in road vehicles, this problem does not appear to be significant anywhere.

For diesel, however, the picture is more complicated. Road diesel can be used without road taxes for construction and agricultural uses. The fact that light heating oil and road diesel fuel are the same chemical can lead to *significant* leakage from industry or households to transportation or vice versa, depending on the relative taxation, as we found in a study of Denmark.[6] Thus diesel oil statistics must be viewed with caution.

Unfortunately, data reported for gasoline, which we will call 'total road gasoline', even if correctly representing road fuel, give a poor representation of total fuel consumed by automobiles alone, since this gasoline also fuels trucks, buses, and motorcycles. Thus, total road gasoline consumption overstates actual gasoline use for automobiles, which we will call 'automobile gasoline'. But automobiles also use diesel, and in a few cases (Denmark, Holland, Italy, the USA) they use LPG, CNG or even alcohol fuels. Thus, automobile gasoline understates 'automobile fuels'. Could these two problems cancel? We will show that the effects usually do not cancel. Indeed, we will show that total road gasoline consumption is a poor indicator of automobile fuel use.

Table 1 shows the figures for total road gasoline use listed under 'road gasoline' by each country's national balance. We use national sources and national conversion units from volumetric data (in tonnes or litres) to petajoules (PJ). Fuels are counted generally using the lower heating value for gasoline (31–32 MJ/l with the UK the most common exception to this convention) and 35.6 MJ/l for diesel fuel. Our sources, which use national energy balances directly, are Germany's *Verkehr in Zahlen*, the Japanese Agency for National Resources and Energy's *Comprehensive Energy Statistics*, AGIP (the Italian state oil company) and Italy's energy balances, the UK *Digest of Energy Statistics*, the French *Tableaux des Consummations d'Energie en France* (published by l'Observatoire d'Energie of the Ministry of Industry), the Norwegian Bureau of Statistics' *Energistatistikk*, the Danish Energy Agency's *Danmarks Energistrømme* and the Transport Ministry's *Transportstatistik*,[7] the Dutch Central Bureau of Statistics' *Manaadstatistiek verkeer en vervoer June 1991* and earlier years, the Swedish

Table 1. Automobile fuel use and prices 1970–1990.

		1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
United States																						
Road Gasoline	PJ	11306	11788	12574	13140	12888	13172	13828	14204	14693	13949	13064	13060	12989	13169	13293	13487	13899	14243	14500	14506	14324
Automobile Fuels	PJ	9499	10033	10781	11249	10840	11163	11813	12111	12434	11918	11138	11044	10761	10912	11026	11279	11751	11980	12233	12423	12439
Gasoline	PJ	9475	10008	10754	11221	10808	11119	11754	11990	12185	11501	10483	10321	10260	10610	10781	11091	11565	11811	12070	12271	12303
Diesel	PJ	24	25	27	28	33	45	59	121	249	417	655	723	501	303	245	188	186	169	163	162	137
Diesel, %	%	0.3	0.3	0.3	0.3	0.3	0.4	0.5	1.0	2.0	3.5	5.9	6.5	4.7	2.8	2 2	1.7	1.6	1.4	1 3	1 2	1 1
Fuel Prices																						
Gasoline (Nominal)	USD/litre	$0.10	$0.10	$0.10	$0.11	$0.15	$0.16	$0.16	$0.17	$0.18	$0.24	$0.33	$0.36	$0.34	$0.33	$0.32	$0.32	$0.25	$0.25	$0 25	$0.27	$0.31
Gasoline (Real)	80 PPP US$/l	$0.20	$0.20	$0.20	$0.20	$0.25	$0.24	$0.23	$0.23	$0.22	$0.27	$0.33	$0.33	$0.29	$0.27	$0.25	$0.24	$0.18	$0.18	$0.17	$0 18	$0 19
Diesel (Nominal)	USD/litre	$0.08	$0.09	$0.09	$0.09	$0.12	$0.13	$0.14	$0.14	$0.14	$0.20	$0.27	$0.32	$0.31	$0.32	$0.32	$0.32	$0.25	$0.26	$0.26	$0.27	$0 31
Diesel (Real)	80 PPP US$/l	$0.17	$0.17	$0.17	$0.17	$0.21	$0.20	$0.20	$0.20	$0.18	$0.23	$0.27	$0.29	$0.26	$0.26	$0.25	$0.25	$0.19	$0.19	$0.18	$0.18	$0.20
Wtd Avg (Real)	80 PPP US$/l	$0.20	$0.20	$0.20	$0.20	$0.25	$0.24	$0.23	$0.23	$0.22	$0.27	$0.32	$0.33	$0.29	$0.27	$0.25	$0.24	$0.18	$0.18	$0.17	$0 18	$0.19
Japan																						
Road Gasoline	PJ	723	789	858	939	939	1005	1062	1104	1187	1210	1211	1235	1239	1266	1265	1288	1319	1348	1393	N/A	N/A
Automobile Fuels	PJ	515	597	635	725	740	801	841	880	968	1011	1021	1039	1079	1147	1158	1197	1244	1286	1355	1492	1614
Gasoline	PJ	506	588	625	714	728	788	825	859	945	983	988	1001	1034	1093	1099	1128	1166	1191	1250	N/A	N/A
Diesel	PJ	9	9	10	12	12	13	16	21	23	28	33	38	45	55	49	68	78	95	105	N/A	N/A
Diesel, %	%	1.7	1.5	1.6	1.6	1.6	1.6	2.0	2.4	2.4	2.8	3.2	3.7	4.2	4.8	5.1	5.7	6.3	7.4	7 8	N/A	N/A
Fuel Prices																						
(262 Yen = 1980 PPP US$1)																						
Gasoline (Nominal)	JYen/litre	44.3	47.0	47.6	54.1	86.3	95.0	96.6	110.5	99.0	121.0	147.0	152.0	164.0	151.0	145.0	140.0	123.0	121 0	116 0	119 0	125 0
Gasoline (Real)	80 PPP US$/l	$0.40	$0.40	$0.38	$0.39	$0.51	$0.50	$0.46	$0.49	$0.42	$0.50	$0.56	$0.55	$0.58	$0.52	$0.49	$0.47	$0.41	$0.40	$0.38	$0.38	$0 39
Diesel (Nominal)	JYen/litre	27.44	27.95	27.51	30.04	45.39	46.84	56.05	59.76	57.00	73.00	102.00	107.00	118.00	108.00	104.00	100.00	84.00	72 00	68.00	69.00	74 00
Diesel (Real)	80 PPP US$/l	$0.25	$0.24	$0.22	$0.22	$0.27	$0.25	$0.27	$0.27	$0.24	$0.30	$0.39	$0.39	$0.42	$0.38	$0.35	$0.33	$0.28	$0.24	$0 22	$0 22	$0 23
Wtd Avg (Real)	80 PPP US$/l	$0.40	$0.40	$0.38	$0.39	$0.50	$0.50	$0.46	$0.49	$0.42	$0.49	$0.55	$0.55	$0.57	$0.52	$0.48	$0.46	$0 40	$0.39	$0.37	$0 38	$0.39
France																						
Road Gasoline	PJ	N/A	N/A	N/A	692	N/A	699	N/A	745	772	777	779	795	796	798	802	788	811	811	824	809	799
Automobile Fuels	PJ	455	479	506	563	540	570	605	626	661	671	726	743	760	773	784	780	809	823	852	863	877
Gasoline	PJ	441	463	488	543	515	542	572	585	611	611	662	670	677	682	685	672	690	694	707	695	686
Diesel	PJ	13	16	19	20	24	28	33	41	51	60	64	73	82	91	99	108	118	129	145	168	191
Diesel, %	%	2.9	3.3	3.7	3.6	4.5	5.0	5.5	6.5	7.7	8.9	8.9	9.9	10.9	11.8	12 6	13.9	14.7	15 7	17 0	19 5	21 8
Fuel Prices																						
(6 FF = 1980 PPP US$1)																						
Gasoline (Nominal)	FF/litre	1.06	1.07	1.11	1.12	1.61	1.69	1.76	2.09	2.55	2.88	3.38	3.87	4.43	4.77	5.16	5.59	4 72	4 85	4 82	5 18	5 35
Gasoline (Real)	80 PPP US$/l	$0.44	$0.42	$0.41	$0.39	$0.49	$0.46	$0.44	$0.48	$0.53	$0.54	$0.56	$0.57	$0.58	$0.57	$0.58	$0.59	$0.49	$0 48	$0 47	$0 49	$0 48
Diesel (Nominal)	FF/litre	0.72	0.74	0.78	0.78	1.04	1.16	1.25	1.34	1.54	1.86	2.35	2.83	3.26	3.52	3.76	3.96	3.10	3.05	2 90	3 00	3 09
Diesel (Real)	80 PPP US$/l	$0.30	$0.29	$0.29	$0.27	$0.32	$0.32	$0.31	$0.31	$0.32	$0.35	$0.39	$0.42	$0.43	$0.42	$0.42	$0.42	$0.32	$0 30	$0.28	$0 28	$0 28
Wtd Avg (Real)	80 PPP US$/l	$0.44	$0.42	$0.41	$0.38	$0.48	$0.45	$0.43	$0.46	$0.51	$0.52	$0.54	$0.55	$0.56	$0.54	$0.54	$0.55	$0.45	$0 44	$0 42	$0 43	$0 44

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Table 1 continued.

		1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Germany																						
Road Gasoline	PJ	663	737	777	795	775	849	889	942	994	1007	1025	961	981	995	1021	999	1044	1082	1125	1122	1160
Automobile Fuels	PJ	666	742	785	797	780	849	889	934	990	1018	1052	992	1029	1064	1095	1088	1159	1215	1271	1281	1327
Gasoline	PJ	631	705	745	754	735	799	838	879	929	946	968	897	917	936	957	939	987	1025	1068	1071	1108
Diesel	PJ	35	36	40	43	45	50	51	55	61	73	84	94	112	128	138	150	173	190	204	210	219
Diesel, %	%	5.5	5.2	5.3	5.7	6.2	6.3	6.1	6.3	6.6	7.7	8.7	10.5	12.2	13.6	14.4	16.9	17.5	18.5	19.1	19.6	19.8
Fuel Prices																						
(2.72 DMK = 1980 PPP US$1)																						
Gasoline (Nominal)	FF/litre	0.55	0.57	0.58	0.61	0.76	0.82	0.89	0.88	0.93	1.00	1.17	1.42	1.39	1.37	1.40	1.44	1.08	1.05	1.02	1.23	1.28
Gasoline (Real)	80 PPP US$/l	$0.33	$0.33	$0.32	$0.31	$0.36	$0.37	$0.38	$0.36	$0.37	$0.39	$0.43	$0.49	$0.46	$0.44	$0.44	$0.44	$0.33	$0.32	$0.31	$0.36	$0.36
Diesel (Nominal)	DM/litre	0.54	0.59	0.59	0.63	0.78	0.86	0.89	0.89	0.79	0.86	1.00	1.13	1.16	1.12	1.15	1.18	0.87	0.82	0.77	0.83	0.87
Diesel (Real)	80 PPP US$/l	$0.33	$0.34	$0.32	$0.32	$0.37	$0.39	$0.38	$0.37	$0.32	$0.33	$0.37	$0.39	$0.38	$0.36	$0.36	$0.36	$0.27	$0.25	$0.23	$0.24	$0.25
Wtd Avg (Real)	80 PPP US$/l	$0.33	$0.33	$0.31	$0.31	$0.36	$0.37	$0.38	$0.36	$0.37	$0.38	$0.42	$0.48	$0.44	$0.42	$0.42	$0.42	$0.31	$0.30	$0.29	$0.34	$0.34
Italy																						
Road Gasoline	PJ	392	409	443	482	436	465	450	438	465	506	510	503	500	484	490	488	496	504	512	N/A	N/A
Automobile Fuels	PJ	N/A	N/A	N/A	400	N/A	N/A	N/A	N/A	N/A	499	520	540	566	568	581	606	627	655	691	728	N/A
Gasoline	PJ	N/A	N/A	N/A	395	N/A	N/A	N/A	N/A	N/A	460	471	471	474	463	458	474	476	484	505	528	N/A
Diesel	PJ	N/A	N/A	N/A	5	N/A	N/A	N/A	N/A	N/A	38	49	69	924	104	122	132	151	171	186	200	N/A
Diesel, %	%	N/A	N/A	N/A	1.2	N/A	N/A	N/A	N/A	N/A	7.7	9.4	12.7	16.3	18.4	21.1	21.8	24.0	26.1	26.9	27.5	N/A
Fuel Prices																						
(862 Lire = 1980 PPP US$1)																						
Gasoline (Nominal)	Lire/litre	130	130	152	152	190	287	300	480	500	541	700	887	1030	1172	1290	1321	1280	1300	1360	1376	N/A
Gasoline (Real)	80 PPP US$/l	$0.56	$0.53	$0.59	$0.53	$0.56	$0.72	$0.64	$0.87	$0.81	$0.76	$0.81	$0.86	$0.86	$0.85	$0.85	$0.79	$0.73	$0.70	$0.70	$0.87	N/A
Diesel (Nominal)	Lire/litre	75	75	75	80	113	135	146	150	144	175	275	332	427	505	555	608	517	553	603	676	N/A
Diesel (Real)	80 PPP US$/l	$0.32	$0.31	$0.29	$0.28	$0.33	$0.34	$0.31	$0.27	$0.23	$0.25	$0.32	$0.32	$0.36	$0.37	$0.36	$0.37	$0.29	$0.30	$0.31	$0.33	N/A
Wtd Avg (Real)	80 PPP US$/l	$0.55	$0.53	$0.58	$0.53	$0.56	$0.72	$0.64	$0.87	$0.81	$0.72	$0.77	$0.79	$0.78	$0.76	$0.74	$0.70	$0.62	$0.60	$0.60	$0.57	N/A
UK																						
Road Gasoline	PJ	668	702	746	794	773	756	792	813	861	876	898	878	903	918	949	957	1007	1040	1090	1122	1140
Automobile Fuels	PJ	538	571	646	688	670	656	684	703	745	759	773	759	780	793	837	845	892	946	996	1052	1071
Gasoline	PJ	535	567	643	685	666	652	680	699	741	755	769	755	776	789	825	832	876	926	970	N/A	N/A
Diesel	PJ	3	4	4	4	4	4	4	4	4	4	4	4	4	4	11	12	16	20	25	N/A	N/A
Diesel, %	%	0.6	0.6	0.6	0.5	0.5	0.6	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.5	1.4	1.5	1.8	2.1	2.6	N/A	N/A
Fuel Prices																						
(0.522 = UK£ = 1980 PPP US$1)																						
Gasoline (Nominal)	pence/litre	0.07	0.07	0.07	0.07	0.09	0.15	0.16	0.17	0.17	0.22	0.28	0.34	0.37	0.39	0.41	0.43	0.37	0.38	0.37	0.40	0.447
Gasoline (Real)	80 PPP US$/l	$0.46	$0.45	$0.42	$0.40	$0.40	$0.58	$0.53	$0.48	$0.43	$0.50	$0.54	$0.58	$0.58	$0.59	$0.58	$0.58	$0.49	$0.48	$0.45	$0.45	$0.45
Diesel (Nominal)	pence/litre	0.07	0.07	0.07	0.08	0.09	0.12	0.14	0.17	0.17	0.21	0.25	0.29	0.31	0.33	0.33	0.37	0.31	0.30	0.30	0.315	0.352
Diesel (Real)	80 PPP US$/l	$0.48	$0.45	$0.42	$0.40	$0.40	$0.58	$0.53	$0.48	$0.43	$0.50	$0.54	$0.58	$0.58	$0.59	$0.58	$0.58	$0.49	$0.47	$0.45	$0.45	$0.45
Wtd Avg (Real)	80 PPP US$/l	$0.46	$0.45	$0.42	$0.40	$0.40	$0.58	$0.53	$0.48	$0.43	$0.50	$0.54	$0.58	$0.58	$0.59	$0.58	$0.58	$0.49	$0.47	$0.45	$0.45	$0.45

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Table 1 continued.

		1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Norway																						
Road Gasoline	PJ	46	43	46	48	45	50	54	58	59	62	61	61	62	63	66	70	75	77	78	78	79
Automobile Fuels	PJ	31	34	36	38	37	43	47	51	52	54	54	54	56	57	59	62	65	67	68	68	68
Gasoline	PJ	31	34	36	38	36	42	46	50	51	53	53	53	54	55	57	60	63	65	66	66	66
Diesel	PJ	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2
Diesel, %	%	0.8	0.7	0.7	0.8	1.0	1.1	1.1	1.2	1.4	1.7	2.0	2.6	3.0	3.2	3.3	3.2	3.1	2.9	2.9	3.0	3.2
Fuel Prices																						
(743 NKr = 1980 PPP US$1)																						
Gasoline (Nominal)	NOK/litre	1.27	1.48	1.49	1.56	2.09	2.01	2.13	2.20	2.62	2.83	3.71	4.35	4.59	4.92	5.20	5.23	4.74	5.12	5.36	5.78	6.38
Gasoline (Real)	80 PPP US$/l	$0.38	$0.42	$0.39	$0.38	$0.47	$0.40	$0.39	$0.37	$0.41	$0.42	$0.50	$0.51	$0.49	$0.48	$0.48	$0.46	$0.39	$0.38	$0.38	$0.39	$0.41
Diesel (Nominal)	NOK/litre	0.37	0.48	0.44	0.51	0.88	0.78	0.92	0.94	0.88	1.03	1.60	2.00	2.19	2.29	2.33	2.36	1.73	1.77	1.79	1.94	2.38
Diesel (Real)	80 PPP US$/l	$0.11	$0.14	$0.12	$0.13	$0.20	$0.16	$0.17	$0.16	$0.14	$0.15	$0.21	$0.24	$0.23	$0.22	$0.21	$0.21	$0.14	$0.13	$0.13	$0.13	$0.15
Wtd Avg (Real)	80 PPP US$/l	$0.38	$0.42	$0.39	$0.38	$0.47	$0.40	$0.39	$0.37	$0.41	$0.42	$0.49	$0.51	$0.48	$0.47	$0.47	$0.45	$0.38	$0.38	$0.37	$0.38	$0.40
Sweden																						
Road Gasoline	PJ	119	121	126	134	123	138	145	151	155	154	149	147	148	151	157	158	166	173	179	186	176
Automobile Fuels	PJ	105	110	117	123	116	128	133	137	140	140	140	139	141	143	147	148	154	159	163	166	161
Gasoline	PJ	100	105	112	118	111	123	128	132	134	134	133	133	133	134	139	139	146	152	156	160	155
Diesel	PJ	4	5	5	5	5	5	6	6	6	6	7	7	8	8	9	8	8	7	7	6	6
Diesel, %	%	4.0	4.3	4.1	4.2	4.2	4.1	4.3	4.1	4.3	4.5	4.7	5.0	5.4	5.6	5.8	5.6	5.1	4.6	4.2	3.7	3.4
Fuel Prices																						
(6.97 SKr = 1980 PPP US$1)																						
Gasoline (Nominal)	SKr/litre	0.87	0.98	1.01	1.01	1.15	1.36	1.58	1.58	1.86	2.20	2.95	3.53	3.96	4.19	4.22	4.66	4.15	4.19	4.47	4.81	6.48
Gasoline (Real)	80 PPP US$/l	$0.30	$0.32	$0.31	$0.29	$0.30	$0.32	$0.34	$0.30	$0.33	$0.36	$0.42	$0.45	$0.47	$0.45	$0.42	$0.43	$0.37	$0.36	$0.36	$0.37	$0.45
Diesel (Nominal)	SKr/litre	0.63	0.76	0.78	0.78	0.83	0.55	0.62	0.64	0.74	0.93	1.47	1.81	2.34	2.56	2.89	3.07	2.33	2.57	2.65	2.84	3.48
Diesel (Real)	80 PPP US$/l	$0.22	$0.25	$0.24	$0.22	$0.22	$0.13	$0.13	$0.12	$0.13	$0.15	$0.21	$0.23	$0.28	$0.28	$0.29	$0.29	$0.21	$0.22	$0.22	$0.22	$0.24
Wtd Avg (Real)	80 PPP US$/l	$0.30	$0.31	$0.30	$0.29	$0.29	$0.31	$0.33	$0.30	$0.32	$0.35	$0.41	$0.44	$0.46	$0.44	$0.42	$0.43	$0.36	$0.35	$0.36	$0.36	$0.44
Denmark																						
Road Gasoline	PJ	N/A	N/A	68	N/A	N/A	68	71	72	74	70	64	60	59	61	63	65	68	69	70	70	72
Automobile Fuels	PJ	N/A	N/A	62	66	N/A	62	65	66	68	66	61	59	59	61	61	63	67	68	70	70	73
Gasoline	PJ	N/A	N/A	61	65	N/A	60	63	63	65	64	59	56	56	58	57	59	61	61	62	62	64
Diesel	PJ	N/A	N/A	2	2	N/A	2	2	2	2	2	2	2	3	3	4	4	6	7	8	8	9
Diesel, %	%	N/A	N/A	2.4	2.3	N/A	2.7	2.9	3.2	3.5	3.1	3.7	4.0	4.3	4.8	6.3	7.1	8.6	10.5	11.5	11.8	11.8
Fuel Prices																						
(8.69 DKK = 80 PPP US$1)																						
Gasoline (Nominal)	DKK/litre	3.30	3.23	3.10	2.98	3.14	3.54	3.27	3.59	3.39	3.80	4.54	4.75	4.82	4.61	4.29	4.19	4.23	4.20	3.96	3.96	3.54
Gasoline (Real)	80 PPP US$/l	$0.38	$0.37	$0.36	$0.34	$0.36	$0.41	$0.38	$0.41	$0.39	$0.44	$0.52	$0.55	$0.55	$0.53	$0.49	$0.48	$0.49	$0.48	$0.46	$0.46	$0.41
Diesel (Nominal)	DKK/litre	0.90	1.08	1.04	1.02	1.43	1.53	1.47	1.42	1.12	1.42	1.84	2.05	2.18	2.03	1.89	1.92	1.21	1.11	1.02	1.08	1.07
Diesel (Real)	80 PPP US$/l	$0.10	$0.12	$0.12	$0.12	$0.16	$0.18	$0.17	$0.16	$0.13	$0.16	$0.21	$0.24	$0.25	$0.23	$0.22	$0.22	$0.14	$0.13	$0.12	$0.12	$0.12
Wtd Avg (Real)	80 PPP US$/l	N/A	N/A	$0.35	$0.34	N/A	$0.41	$0.37	$0.41	$0.38	$0.43	$0.52	$0.55	$0.56	$0.53	$0.48	$0.47	$0.46	$0.45	$0.42	$0.42	$0.38

Bureau of Statistics' *Energiförsörjning* (fourth quarter and yearly reports), and the US Department of Energy *State Energy Data System* national tables.

Table 1 also shows automobile gasoline consumption as derived in our study or compiled from leading national energy and transport authorities. For example, the German, Dutch and French figures come from the same sources as the energy balance data. The US figures come from the *Transportation Energy Data Book*.[8] Figures for Denmark were worked out by the Ministry of Transportation for a forthcoming data book;[9] those for Norway worked out by Esso of Norway and the Institute for Transport Economics;[10] those for Sweden by LBL based on material published by the former Transportrådet (Transportation Council) from 1980 and the National Board of Industry for 1970–76.[11] Italian figures were developed by A. Liberati of Agip, based on data supplied by Agip and the Ministry of Transportation. Figures for the UK were published by the Energy Technology Support Unit and communicated by Martin, as well as by P. Hughes of the Open University and Sorrell.[12] Figures for Japan come from the Japanese Ministry of Transportation and the Japanese Institute of Energy Economics.[13] Dutch figures from 1984 are published by the Central Bureau of Statistics, which also supplied estimates of figures for fuel use by type and vehicle type 1970–84.[14] Each source is considered the most authoritative in its respective country.

Finally, we show the share of automobile fuel (by energy content) that is diesel fuel. For Denmark and Italy, a small amount of LPG is included with gasoline. For Italy, a small amount of CNG is also included. For Holland, LPG made up as much as 10% of total fuel use for automobiles. These third and fourth fuels are included with gasoline. As our data base of Holland is still under study, we omit these figures from Table 1. By the late 1980s diesel assumed a significant share of automobile fuel. Whereas figures for total gasoline far overestimated auto fuel use in the early 1970s, the two tended to converge or even cross by the late 1980s. Clearly there is a fuel use gap represented by these often striking divergences.

The fuel use gap

The phrase 'fuel use gap' refers to the differences between various measures or estimates of automobile fuel use (total road gasoline, automobile gasoline and automobile fuel) in analyses of automobile fuel consumption. For example, using total road gasoline to infer automobile gasoline overestimates fuel consumed by passenger automobiles (and personal light trucks) by various amounts. In 1973, the difference was a full 47% in Japan and between 12% and 27% in every other country we studied except Germany, where the error was only 6%. By 1988, the overestimation had declined in every country except in Germany, although the rates of decline varied considerably. The excess in the eight other countries in 1988 lay between 10% and 26%. In Germany the excess remained nearly the same. Thus, total road gasoline clearly overstated automobile gasoline for every country we examined during the period 1970–89.

The share of automobile gasoline in total automobile fuel has also varied. Here the trend is clear everywhere: the share of automobile gasoline has fallen, largely being replaced by diesel fuel. In the early 1970s, diesel was used mostly in taxis and a few private cars with high yearly driving distances. By the end of the 1980s, diesel vehicles in many countries had made significant inroads into the world of the family car. As noted above, LPG and even CNG have appeared as third or even fourth fuels in a few countries. However, the penetration of these alternative fuels is very uneven. For example, in 1988 diesel was around 1% of all fuels used by automobiles in the USA (diesel fuel peaked at approximately 5% in 1980, according to references cited by ORNL) and was less than 5% in Sweden, Norway and the UK. But by 1988, diesel had risen to around 20–25% of all automobile fuel in Germany and France, and well over 26% in Italy. Finally, 4% of the automobile fuel use in Italy in 1988 was LPG or CNG. By 1988, therefore, use of automobile gasoline figures clearly underestimated the fuel use by motorists in many of the countries we have studied.

Since the quantity of total road gasoline is always greater than automobile gasoline, while the amount of automobile gasoline consumed underestimates total automobile fuels, we might presume that these effects cancel. However, this is not the case. Instead, the effects combine in a perverse way: the difference between total road gasoline and automobile gasoline was greatest in the early 1970s, when the use of gasoline for vehicles other than cars was highest and the use of fuels other than gasoline for automobiles was small. In the late 1980s, by contrast, the difference between total road gasoline and automobile gasoline was much smaller, but automobile gasoline held an increasingly smaller share of automobile fuels. This means that the growth in total road gasoline use almost always understates the growth in automobile fuel use.

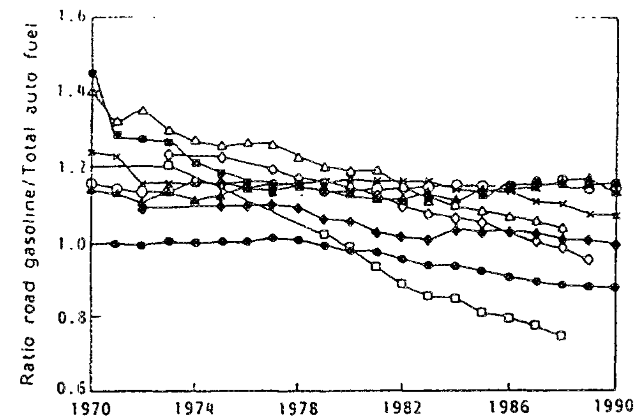

Figure 1. OECD automobile fuel: 'total road gasoline' and all auto fuels.
Key: -O-O- USA; -□-□- Italy; -△-△- Japan; -●-●- Germany; -■-■- Norway; -▲-▲- Sweden; -◊-◊- France; -♦-♦- Denmark; -×-×- UK

Source: Road gasoline from national balances.

Figure 1 shows the ratio of total road gasoline to automobile fuels consumed for the 1970–90 period. It can be seen that for almost every country shown the ratio falls significantly over time. Figure 2 compares average growth rates in total road gasoline and automobile fuels over the entire period. In eight of nine countries, automobile fuel use grew more rapidly than that of total road gasoline. The differences in growth rates ranged from as little as 0.4% per year (UK) to as much as 3.3% per year (Italy). Because of the importance of diesel fuel in France, Germany and Italy, total road gasoline underestimates automobile fuel after 1979 (after 1987 in France). The error widens to as much as 26% for Italy in 1988. Only in Sweden is the reverse true, and the difference there is small, 0.1% per year.[15] In general, then, we can conclude that total road gasoline does not accurately represent the fuel used by automobiles and personal light trucks in the OECD countries we studied.

The rise of diesel fuel use bears further comment. As Table 1 shows, the share of this fuel in several countries became significant in the late 1980s. This diesel fuel is almost always priced significantly lower than gasoline.[16] This means that the average price paid for automobile fuel in Italy, Germany and France was significantly lower than the average price for gasoline only. These price differences must have played an important role in encouraging the spread of diesel. The result is that consumers paid less for their *fuel*, on average, than for gasoline alone.

Table 1 also shows the real price of gasoline (regular) and the real price of diesel, both expressed

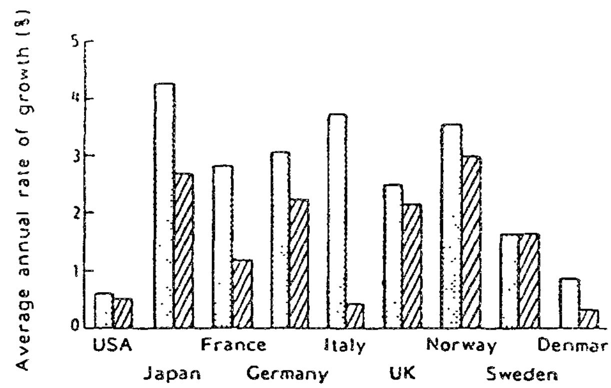

Figure 2. Road gasoline and auto fuels use in the OECD: growth rates 1973–90.
Key: ▒ Auto fuel; ▨ Total road gasoline

Source: The ratios for Italy, Japan and UK correspond to 1973–88.

in US$/l. We used the consumer price index of each country, base 1980, to convert to real local currency, then the purchasing power parity conversion rate to convert to 1980 US$. Additionally, the table shows the average price of motor fuel weighted by the quantities consumed (in litres) and the actual energy content of a litre of fuel, which is higher for diesel. This price is then expressed as the energy equivalent of a litre of gasoline. These weighted average fuel prices are also shown in Figure 3. In some countries, the differences between the price of gasoline and the weighted prices of gasoline and diesel are large.[17] This means that the shift to diesel leads to a lower weighted average price, all else equal, than if the share of diesel and gasoline had remained constant. Thus the price of gasoline alone overstates the price drivers pay for fuel in every country, and the amount

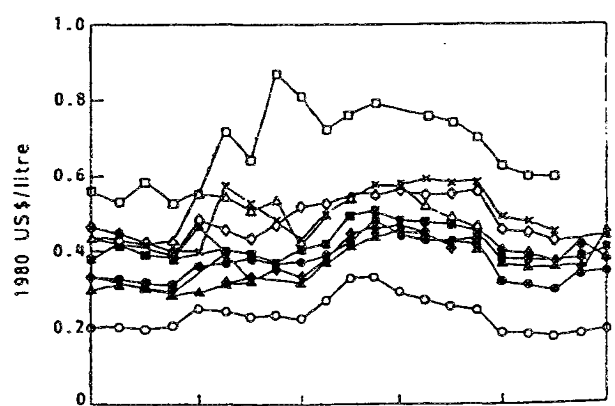

Figure 3. Real average fuel prices, weighted for gasoline and diesel.
Key: -O-O- USA; -□-□- Italy; -△-△- Japan; -●-●- Germany; -■-■- Norway; -▲-▲- Sweden; -◊-◊- France; -♦-♦- Denmark; -×-×- UK

of that overstatement increases over time. This shift to diesel also contributes to the fact that the real price of 'fuel' in 1988 or 1989 was close to its 1973 value in every country except Italy.

One final distortion affects any calculations that rely on the price of fuel actually paid. A significant (ie greater than 15%) number of drivers in Sweden, Holland, Germany and the UK have company car privileges, paying only income tax for the use of the car that falls far short of the real costs of acquisition and ownership.[18] These cars are used like private cars, as distinct from cars that companies have in their own fleets for employees' use during actual work. First-time users keep these cars for relatively short times, typically two years, hence company cars occupy a higher share of new car purchases than they do in the stock as a whole. In Sweden and the UK the new car markets are virtually driven by company cars, and these cars are heavier and driven farther than are truly private cars. Also, drivers rarely pay for their fuel directly, which extends this distortion. Since there is ample evidence that these cars are both larger or more powerful than 'private' cars and driven significantly farther,[19] their existence has a measurable impact on fuel consumption and total travel. This should be considered in econometric modelling of automobile use and fuel consumption. We will investigate this important distortion in forthcoming work.

Our brief analysis of gasoline and fuel use for automobiles and other vehicles has clear conclusions. First, total road gasoline is an inaccurate proxy for the fuels used by personal automobiles and light trucks. Only in the USA and Germany are the errors roughly constant, ie within 2 percentage points above a mean value for the period of 1970–90. For other countries, the error differs among countries and varies over time with differing rates between countries. The rate of growth in use of automobile fuels was greater than that of total road gasoline in eight of the nine countries we studied. Second, gasoline provides a decreasing share of automobile fuels, particularly in France, Germany and Italy. This trend means that the price of gasoline gives a poor representation of the price motorists pay for fuels. Alternatively, ignoring the impact of alternative fuels in these countries ignores an important response to changing fuel prices in these countries.

The degree to which total road gasoline overstates automobile fuel use decreases over time. That is, the use of gasoline for vehicles other than automobiles, which is the source of the error, has declined in relative importance. In addition, the size of the error differs across countries at any one time. Thus, total road gasoline gives neither a good representation of automobile fuel use in any one country over time, nor a consistent indication of automobile fuel use across countries

Measures of fuel use and activity: impact on econometric calculations

Given the data problems we have described above, it should not be surprising that these distortions might have an impact on economic modelling of the demand for automobile fuel. In an accompanying paper we found that using 'gasoline' rather than 'automobile fuel' and 'gasoline prices' rather than 'automobile fuel prices' tends to overestimate short-term price elasticities of fuel demand and underestimate income elasticities of fuel demand.[20] Our analysis covered only the period 1970–88; had we included data for the 1960s, during which 'total gasoline' use exceeded 'total automobile fuel' by as much as a factor of two, the distortion would be even larger. And inclusion of more recent years (now underway) should increase the differences in results, because the extension increases the weight of years in which the use of diesel fuel (with its lower price) has been important. Since the role of diesel fuel (and quite likely many other fuels) as automobile fuel is increasing, it is clearly important to model each fuel separately, or at least to recognize the different prices and market shares in studying future automobile fuel demand. And since the prices of different fuels may vary substantially (with the possibility of fuels like natural gas that may have high initial costs but lower variable costs), the demand for travel may also be dependent on the choice of fuel.

The vicious circle

The fuel use gap arises because of a larger difficulty that has daunted researchers, namely the measurement of a group of parameters that describe automobile use.[21] These additional parameters include the total number of automobiles, the distance travelled per vehicle, and the fuel used per kilometre of travel. These parameters are key to understanding automotive fuel use. Wheaton gives the following identity:[22]

$$\text{Total gasoline use} = \text{fuel use/km} \times \text{total km driven}$$

He then notes that finding any two permits determination of the third. This is potentially misleading and incorrect, unless the first two quantities are

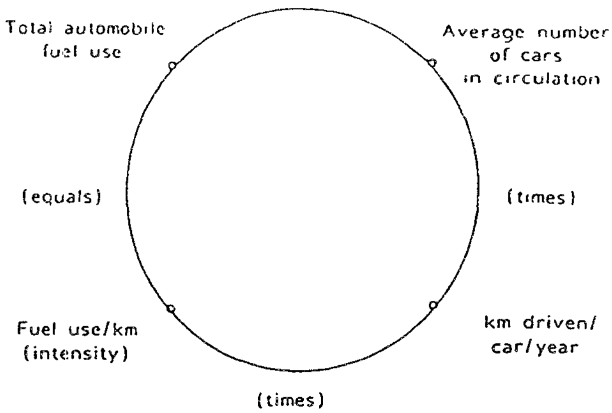

Figure 4. Squaring the circle: automobile fuel use components.

independently determined or any correlation between them or circular derivation is clearly exposed. Indeed, Wheaton divides total road gasoline use by a synthetic figure for gasoline use/km (a figure itself open to question) to derive total kilometres driven. He further divides this result by the number of cars to obtain total distance travelled per car per year. Clearly his results are in serious error if total road gasoline misrepresents the fuel used by the vehicles he is studying, if his estimates for fuel intensity (energy/km) are wrong, or if the number of cars itself is incorrect.

The problem lies in the fundamental circularity of the measurement process (Figure 4). Total automobile fuel use per year, fuel use per kilometre and kilometres driven per car per year form a trio of numbers that should be distinguished by fuel. When the number of cars in circulation is included in the analysis, the vicious circle illustrated in Figure 4 is complete. We will show that all the elements of this circle are subject to errors in analysis.

Total automobile fuel use

As we have shown, measuring total automobile fuel is not a simple task because the commonly used proxy (total road gasoline) is inaccurate. Thus, we must turn to more detailed data on both automobile gasoline and diesel use.

Total automobile gasoline consumed is not really known, but can be estimated rather closely by using surveys of car users or judgement to eliminate the small share of gasoline not used by cars.[23] Unfortunately, this share was much larger in the past – as much as 50% in the early 1960s – indicating great data uncertainties in these early years.[24] Nevertheless, we can estimate total use of gasoline for automobiles and, because surveys usually cover the use of the other fuels, this can be extended to all automobile fuel use.

In practice, experts in all countries appear to follow the same procedure: gather bits and pieces of information about distance, vehicle characteristics and unit consumption (often supplied by trade associations); estimate gasoline use for buses, commercial trucks (mostly light trucks), motorcycles and mopeds, boats and even lawn-mowers; assign the residual to automobiles. In some cases this procedure is done quite carefully, with iterations to provide a satisfactory and self-consistent accounting of gasoline use among the various users.[25]

Total automobile diesel fuel can be estimated in the same way. Information on consumption of road diesel by buses (from operators or authorities) and larger trucking companies (often regulated) chips away at much of the fuel. Estimates of the diesel use in taxis come from authorities as well. What remains is to split the fuel use of light trucks used for freight from that used as private automobiles. This procedure presumes there is not a great deal of leakage between the heating sector, where diesel is used as 'heating oil', and the transport sector. Unfortunately, great differentials in taxation of these fuels according to purpose, particularly in Italy and Denmark, have led to some leakage.

Fuel intensity, or fuel use/kilometre

The second element of the vicious circle is automobile fuel intensity, calculated as fuel use/km. Figure 5 shows the on-road fuel intensity of automobiles (including diesel vehicles) in nine countries

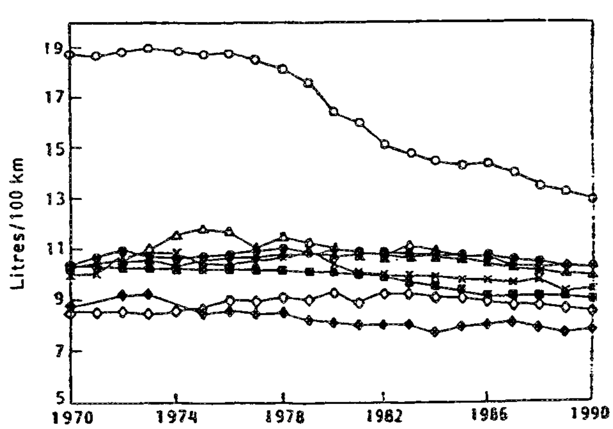

Figure 5. Automobile fuel intensities: on road (actual) fleet averages (includes diesels, personal light trucks. Litres of gasoline equivalent).
Key: -O-O- USA; -△-△- Japan; -●-●- Germany; -■-■- Norway; -▲-▲- Sweden; -◇-◇- France; -◆-◆- Denmark; -×-×- UK

Source: LBL-IES transport study.

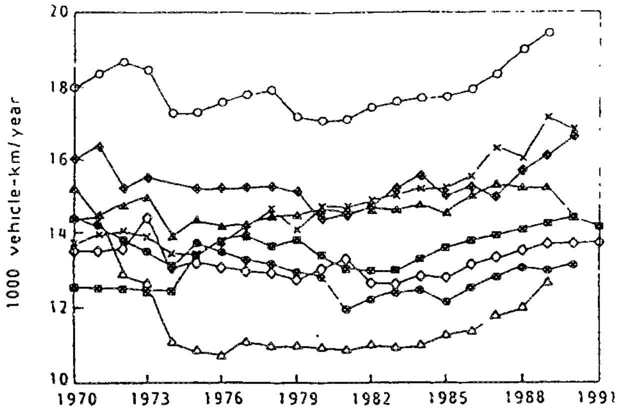

Figure 6. Distance travelled per automobile.
Key: -O-O- USA; -Δ-Δ- Japan; -●-●- Germany; -■-■- Norway; -▲-▲- Sweden; -◊-◊- France; -♦-♦- Denmark; -x-x- UK

Source: National authorities.

over time. Aside from theoretical models of fuel use, there are three ways to measure fuel intensity (fuel use per kilometre) of vehicles:

- estimates of consumption for the stock, built from tests of consumption for each vehicle type;
- direct surveys of users of cars, asking for fuel consumed and distance driven;
- comparison of total fuel used with total distance driven, yielding a 'top-down' estimate of fuel intensity.

Each of these calculations must be carried out for each fuel. In the end, most experts apply fragments of the first two methods in order to validate their estimates derived from the third method.

The first method, estimating fuel intensity from test values for the individual cars in the stock, is very inaccurate since the test values represent only those for new cars sold (see 'The fuel intensity gap' below). Given that the estimates of fuel use of new cars based on tests is prone to error, Wheaton's attempt to synthesize a figure for fuel intensity for entire stocks therefore must be viewed with great suspicion.[26]

The second method, using various surveys directed at auto users, provided a more accurate measure of intensity. The US RTECS for 1985, French, Swedish and Canadian surveys ask drivers to note both how far they drive *and* how much fuel they purchased.[27] Sample size must be very large to reduce the errors to suitable levels, say, an interval smaller than the expected change in fuel intensity from year to year. Surveys should include socio-economic information on the owners, since information on the link between sociodemographic characteristics and driving patterns is often important for forecasting. In particular, the survey should give valuable information on characteristics of car ownership and driving distance. From these surveys, aggregation yields a measure of fuel economy for the entire fleet.[28]

The third method for estimating fuel intensity relates total distance driven by automobiles to total fuel used. This works if the quantity of each fuel used for automobiles is well known and the numbers of cars and distances driven by fuel types are also well known, and clearly separable from the driving of other vehicles. This method appears to be the one applied by most authorities. Independent checks on this calculation can be done using the first two methods described above.

Our own experience with Denmark and Sweden, as well as anecdotal evidence from Germany, suggests that there are uncertainties in the number of vehicles and in the distance driven per vehicle.[29] In these cases we suspect that overcounting the rise in kilometres driven leads to an underestimate of fuel intensity, since the product of the two gives total fuel (of a given kind), which in turn is often believed to be fixed for a given year. Thus we conclude that only the surveys provide accurate information on fuel intensity. With proper weighting for vehicle types and driving conditions (including seasonality), these can give a good measure of fuel intensity.

Kilometres driven

The third element of the vicious circle is total kilometres driven. Total distance driven is important because of its relationship to many problems (noise, accidents, road wear etc). This figure is obtained in two ways, through traffic counts or through surveys of individual vehicle users. Figure 6 shows our best estimates of the yearly driving distance for all automobiles (and personal light trucks in Denmark and the USA) over time. The upward trend during the late 1980s appears widespread. The rather higher values for the USA in the late 1980s, obtained by dividing total automobile travel by the number of cars in use on 1 July is confirmed by both the EIA surveys and the Nationwide Personal Transportation Survey (NPTS).[30] For every other country the values shown are confirmed by one or more personal transportation surveys or other information that is independent of traffic counts.

In principle, total driving can be measured from traffic surveys that note vehicle-kilometres through electronic or manual counting of vehicles. For the USA, the main source is 'The VM-1', published yearly by the Federal Highway Administration, based on state-by-state data.[31] Unfortunately, such data cannot be disaggregated among cars by fuel, nor can such counts easily differentiate between cars and trucks or buses. In addition, the state data sources themselves are open to suspicion.[32] In a major study of energy use in Hawaii, for example, figures for travel per car were given for each of the Hawaiian islands.[33] When these were divided into total gasoline sales on each island (as a proxy for automobile fuel use, there being relatively few heavy trucks as Hawaii), the resulting figures for fuel/km turned out to be identical to two decimal places for all the islands! Clearly the state derived total distance driven by dividing gasoline by some average figure for fuel use per km. Thus the sources of data on automobile usage must be examined carefully.

The fundamental problem with traffic counts is the uncertainty over how many vehicles are really counted, and how these counts are related to traffic on all roads. Wall explains the Swedish method.[34] First, the number of axle impressions from road counters is recorded. These are multipled by 0.92 to give vehicles, and by 0.88 to give cars. The results, which are counted for the intercity network in Sweden, are then multiplied by 1.54 to give total car traffic. Wall notes sceptically (ie without endorsing the procedure) that these coefficients are considered as constants over time, yet Swedish data show that the relative numbers of vehicles with two axles increased over time, and that the traffic of two-axled light trucks itself has increased more than that of cars. Also the multiplication of counts by a fixed number assumes traffic patterns and the distribution of activities within regions have been constant. While we cannot refute this assumption, we find it dubious that the basic patterns of traffic have been stable over so many years, with only the scale changing. The US study tends to produce scepticism of US data as well.[35]

There are other, indirect methods for tabulating kilometres driven. Odometer data recorded when cars are sold, or from insurance companies, show the distance a car of a given age has been driven. Regular safety or emissions inspection data, which almost always include the odometer reading of the car, are also useful. Distance data may often be obtained for vehicles in regulated commerce (taxis, trucks, buses). For Sweden and Norway, additional information is available for diesel automobiles, which are subject to a yearly tax on distance driven. However, these sources provide only data on driving, not on drivers or other variables that may be central to explaining kilometres driven.

A much preferred method for measuring distance, then, is to survey individual vehicle users. If these surveys include information on car characteristics and the socioeconomic status of the owners, it is relatively straightforward to generalize the results to the entire household car population, using both socioeconomic and demographic data for the population *and* data on the vehicle fleet. For example, it is widely known that wealthier drivers generally travel longer distances than poorer drivers, that new cars are driven farther than used cars, that second cars in households with two cars are driven less than cars in households with only one car, that driving distance depends on the location and characteristics of the household owning the car, and that driving distance depends on whether the owner pays for the fuel or not. Given all of these variations, it is crucial that any survey of car use be weighted by the characteristics of the survey population to the wider distribution in the population as a whole.

Once the individual car users are surveyed, the challenge is to generalize from the sample of household vehicles to the total automobile population that includes taxis, fleet vehicles, rental cars, etc. In practice, these other cars are driven more than ordinary private vehicles raising the average distance a car is driven, as estimated by national experts and surveys, by roughly 5–10%.[36] This problem is acute for diesel cars in Europe. While the fleet of diesels in the 1970s was dominated by taxis, which had very high yearly distances, the fleet is now dominated by personal vehicles, with much lower driving distances. The average distance a diesel car is driven has thus dropped considerably because of this change in the structure of the fleet, not out of any consideration related to energy efficiency among diesel cars *per se*. It is important to include the effect of these vehicles because it is almost impossible to exclude the fuel they consume.

One way to approach this problem is to use national travel surveys such as the NPTS in the USA, a similar survey in Denmark or the National Travel Survey in the UK, which measure total travel by all modes.[37] Carefully designed, such surveys capture distances individuals' travel as drivers, as passengers, in taxis etc. These can be used to check other measures of total travel. Interestingly, the NPTS for 1990 and FHWA Table VM-1 do agree on the total number of vehicle-kilometres cars are driven in the USA when the NPTS data on work-related driving are included.[38]

The stock of automobiles

The last element of our vicious circle is the number of cars in actual use. Estimating the stock of cars correctly is important for judging the impact of ownership itself on travel and fuel use. From comparisons carried out in Sweden, the USA and France, we know that the total number of cars registered during a year is an overestimate of the real number in use.[39] The problems are threefold. First, car use is seasonal, particularly in colder countries. Thus, a better measure is the average number of cars in use during the year. This figure can be taken from many kinds of consumer expenditure surveys if they are taken throughout the year, but these surveys will miss the important fleets (10% of vehicles owned and used directly by businesses, taxis, rental cars, government cars etc) mentioned above. Second, there is a clear danger in using 'total registrations' to represent fleets in use. Both new cars and cars that 'expired' during the year are counted for the whole year, representing an overcounting of roughly 5%. Cars under repair and cars awaiting resale, cars garaged and not driven, are also counted, as are cars that have effectively 'died' but are not removed from registration rolls. Temporary deregistration of cars to save fees, particularly during winter months, as is common in Sweden, adds a seasonal variation of another 5%, but this should be ignored, as it will be reflected in driving surveys that show lower driving per car. Finally, cars for which registration is transferred from one jurisdiction to another (in the USA, for example, between states) may be counted in both places. In all, the comparisons of registrations and 'in use' data in both the USA and Sweden suggest that total registrations overcount the real number of cars in actual use by about 10–15%. As a rule, we find that using the average number of cars in use during the year or the average number in use on a particular day (even if there is a slight systematic over- or underestimate of the average number during the year) is a most reliable measure of car use.[40] For the USA, for example, we use the R.L. Polk data reported in Davis and Morris that reflect registrations on 1 July of the year in question.[41]

Making the problem more complicated, however, is the definition of 'car'. In the USA, nearly 20% of the personal vehicles are light trucks or pickup trucks (ie vehicles with cabs and flat beds), campers, vans (ie delivery type vehicles with windows that may have three or four rows of seats) or other two-axled vehicles not always counted as cars in surveys. Motorcycles are common, too, but far less important to fuel consumption and easy to exclude by assumptions. In the Scandinavian countries small vans have risen in importance as personal vehicles. These are counted as cars in Denmark, but as light trucks in Norway and Sweden, where their numbers are still too small to have an important impact on personal travel. In the UK, too, vans are significant but clearly identified in surveys. Citing difficulties in removing gasoline-fuelled light vans, Sorrell presents calculations for the UK that include these vans.[42] In other countries in Europe, light trucks, vans and campers make up a very small portion of the personal vehicle fleet and tend to be counted as trucks. Part of the difficulty we face here is that the definition of light truck or van is sometimes based only on gross weight, sometimes on net capacity, and sometimes on the way the vehicle is registered. So far, ignoring the activity of these vehicles has not seriously distorted our observations of energy use or activity for personal vehicles, except as noted above for the USA and Denmark.[43] As we found, however, growth in the popularity of these vans and other light trucks has a fundamental upward impact on energy use for truck freight that deserves further study.[44]

Closing the fuel use gap: squaring the vicious circle?

Thus we see that all of the elements of the vicious circle are open to errors. Only surveys can independently determine these elements for the various classes of cars (ie by fuel and possibly distinguishing cars, light trucks, vans etc). Fortunately, the gap can be closed and the circle squared.

In practice, a combination of survey data and good judgement often resolves the problem so that the errors that remain are smaller than the very real effects that are being observed. Such results can be seen from the material published by sources we used for our automobile fuel-use calculations. All of these efforts produce reasonable values for the elements of the vicious circle. The US, German, and Japanese sources published all of the elements of the circle from 1970, the Dutch from 1984. The French sources published most, but not all, of the requisite data from 1973–75, but surveys prepared in that country by transport authorities square the circle and fill in the years 1970–73 adequately.[45]

The information from the other countries is less certain. Authorities in Denmark (the Ministry of Transport and the National Energy Agency) use more rough estimates of each of these parameters, but they provide all of the elements of the circle. Authorities in Sweden published one set of data for the 1970–76 period;[46] a different authority prepared data for 1980 and 1983–89.[47] More recently, the Swedish Road and Traffic Research Institute in Linköping, Sweden (VTI), began revising Swedish data to cover much of the period 1970–89, but the method is uncertain and the results still unpublished[48] Authorities in the UK (the Department of Transport) and Norway (Transportøkonomisk Institutt, Statistisk Sentalbyrå), have made fewer efforts to assemble regularly all the required data to permit study of long-term trends of the parameters that determine automobile fuel use, although reasonable 'official' estimations appear from time to time.[49] For this reason we relied on private or academic sources for these two countries. And while the Canadian government supported a quarterly automobile use and fuel consumption survey for a long period (1979–88), there has been virtually no attempt to measure or deduce the elements at the national level, which is why Canada is not included in the present work.

Unfortunately, little of this information is published in any international form. Even the International Energy Agency's recent analyses of energy use in transportation contain conflicting information.[50] Figures for gasoline use/car are presented in one place, figures for fuel use/km in another, and for km/car/year still elsewhere. In addition, these data were only collected for a particular set of studies. Consequently, most analysts understandably fall back on the data published by the OECD in their energy balances, or by the United Nations. As we have seen, using these data is problematic.

Given all the problems reviewed up to this point, we believe that the data shown in Table 1 can be used by researchers and policy makers interested in comparing fuel consumption and other characteristics of automobile use. In the future we will endeavour to add countries to this list, and we will expand our published data to include the characteristics of fuel consumption for trucks and buses as well.

Implications for analysis and policy

The fuel-use gap has important implications for analysis. Many of the misunderstandings that arise occur because either the analysts or their readers are unaware of the 'gaps' that exist in treatment of automobile use. Since the size of these gaps can be comparable to the size of the effects purportedly being measured, misleading conclusions or implications arise from even the simplest of analyses. Since many transport and energy policies aim at affecting all the elements of the vicious circle (possibly including automobile ownership), good survey instruments must be devised to determine all of the elements and their subsequent changes. In the following sections we review some of the policies' goals, whose measures of success will be affected by such determinations

Indicators of fuel use and efficiency

Consider how those data problems affect some of the more commonly used indicators of automobile fuel use and fuel economy. Sterner, for example, noted that total gasoline use/car fell significantly in many countries in the 1960s.[51] The reason is not energy conservation, but rather the increasing share of fuel for automobiles (*vis-à-vis* trucks and buses) in total gasoline consumption. While we have not studied the 1960s in great detail, we found that the distortions noted above in Japan, Germany and the USA were significantly greater in 1965 than in 1970, and even worse in 1960. The IEA used the same indicator in one place (their Table 3) but limited the time frame to the late 1970s and 1980s, hence the errors from miscounting gasoline are smaller.[52]

Von Weizäcker and Jesinghaus chose to represent gasoline per capita *vs* GDP per capita as an indicator of energy efficiency.[53] They claimed that 'Holland was an efficient country' because the Dutch have a low value of automobile gasoline relative to GDP. Yet figures from the Dutch Bureau of Statistics show clearly that while 92% of total gasoline in 1989 was consumed by automobiles, 34% of automobile fuel was either diesel or LPG.[54] Energy use/km, energy use/car/year, and energy use/per capita for cars for the Dutch fleet did not differ significantly from the values for neighbouring European countries. Thus, it is in large part the accounting of fuels, not energy efficiency *per se*, that gives rise to the effect von Weizäcker and Jesinghaus report.

Fuel switching

Fuel switching is an important element of the dynamic market for automobile fuels. The switch from gasoline to diesel in some European countries (Germany, Italy and France most markedly, but also Denmark and Holland) appears as a drop in gasoline use that overstates any change in automobile fuels. As can be seen, the gasoline share of automobile fuel in 1988 or 1989 was close to 1 in the USA, Sweden and Norway, fell to 0.92 in Japan and 0.87 in Denmark, and reached as low as 0.73 in Italy and 0.84 in Germany.

It is this change that gives rise to the strange results shown for Italy in 1988–89 in Figure 1. Recall that for Italy, total road gasoline understates automobile fuel use significantly in recent years. The shift away from gasoline to diesel (and other minor fuels) was so important that even total road gasoline

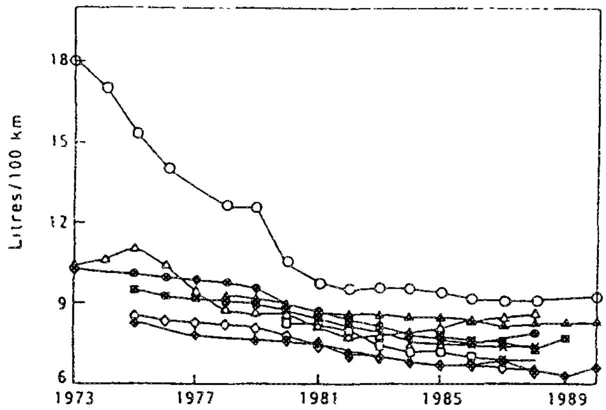

Figure 7. New car fuel economy: sales-weighted test values.
Key: -O-O- USA; -□-□- Italy; -Δ-Δ- Japan; -●-●- Germany; -■-■- Norway; -▲-▲- Sweden; -◊-◊- France; -♦-♦- Denmark; -x-x- UK

understated total automobile fuel use. Indeed, between 1973 and 1988, the growth in automobile fuels in Italy was 1.72 times the growth rate in 'gasoline' in that country. This works out to 3.7% per year!

Understanding the dynamics of fuel switching is important as nearly every country is now experimenting with incentives to encourage lead free fuel, alcohol fuels, or some other alternative fuels. Both differences in fuel prices and differences in new-car and yearly taxation, as well as differences in vehicle efficiency, drove the switch from gasoline to diesel.

The fuel intensity of the automobile stock

Much interest by policy makers today centres over the degree to which fuel prices or other factors affect fuel economy of the entire fleet.[55] Since fuel economy in any year is largely a function of decisions made in the year when each car in the stock was purchased, relating stock-wide fuel economy to price is not straightforward, but this problem can be handled using lagged variables. Using total road gasoline to represent the energy used by automobiles, and total vehicle kilometres driven, or only total number of automobiles, will give a very misleading estimate of the real change in fuel economy of cars because of the inaccuracy of total road gasoline discussed above. As Figure 1 suggests, the effect will be to overstate the increase in fuel economy (ie decline in fuel/km) over time. In general, difficulties arise because of uncertainties in the other three figures in the vicious circle: number of cars by fuel, fuel use and distance driven per vehicle. For the USA (and probably Canada), changes in fleet fuel intensity have been considerably larger than uncertainties in the other parameters. Changes in Italy (due largely to the increase in diesel cars) also portend real improvements larger than the uncertainties in data. Since diesels tend to use less energy/kilometre, failure to include them directly affects the gauging of fuel intensity. The French surveys pin down fuel intensity satisfactorily. In the UK there is a small uncertainty, perhaps 5%, somewhat larger than the likely change in real fuel economy.[56] But for Sweden, Norway and Germany, where few measurements of stockwide fuel economy have been undertaken, it is clear that changes in fuel intensity remain somewhat uncertain because the other elements of the vicious circle are also uncertain.

The fuel intensity of new cars

Figure 7 shows the sales-weighted new car intensities for a variety of OECD countries. Changes in new-car fuel economy are an important indicator of future fuel economy. They should reveal the short-term reactions of car manufacturers and buyers to changes in fuel prices. Since a change in new-car fuel economy may be a policy goal stimulated by changes in fuel prices, new car taxation, or standards such as the CAFE standards in the USA, observers want to see the change soon to judge the effectiveness of the policies.[57]

The problem of measuring fuel economy is particularly difficult for new cars. The reason is the gap between test and actual fuel economy. The test is carried out on a pre-determined driving cycle (for the EEC) or indeed on a machine (USA, Germany). A figure is then calculated by weighting the results for various parts of the cycle representing different speeds and driving conditions. It is widely known that new-car fuel economy tests, while using indicators of the relative fuel economy of different new cars, are a poor measure of actual fuel use.[58] Our survey of international literature suggests that real consumption/kilometre is 15–25% more that test consumption as reported by national authorities.[59] We summarize our findings here.

The gap between test fuel economy and actual use arises for several reasons:

- The formulae used to construct the 'real' cycle from road tests misrepresent the proportions of city (ie congested and stop-and-start) and urban (ie uncongested, steady) driving.
- The actual conditions of use in either of these parts of the cycle, including hills, weather, etc are themselves worse than modelled, leading to an increase in actual fuel consumption.

- Driver behaviour (ie speed, acceleration, cold start) reflects patterns that are themselves more fuel-intensive than the patterns used in tests.
- The test values do not represent cars actually sold, either because the cars tested are somehow doctored, or because cars actually bought contain more fuel-intensive features (larger engines, turbogeneration, more accessories) than are reflected in either the tests or the sales-weightings.
- Standards of maintenance vary so that even relatively new vehicles soon fail to perform as designed.

Additionally, the gap may be large if the vehicles counted in the weightings do not accurately represent the entire new-car fleet. In Denmark, for example, authorities publish values based on only the top 10 models, formerly the top 20. Our tabulation of the entire new-car fleet in 1990 shows that this practice introduces a small inaccuracy. The top 10 cars sold had a weighted fuel intensity of 7.67 l/100 km, the top 20 sold one of 7.47 l/100 km, and the entire run of models 7.61 l/100 km, based on analyses of sales data supplied by the Ministry of Finance. Switching from 20 to only 10 models (between 1988 and 1990) to make the weightings introduced inaccuracies that were as large as the actual changes in weighted fuel economy over several years. And the Swedish practice of performing the weightings by brand names, not by individual model, allows for the influence of large engines or fuel-intensive options that raise fuel intensity to escape the figures calculated using 'base models'. Thus even the weighting procedures can be inaccurate. Since power, size and performance has increased in recent years, these problems will tend to increase the gap between actual and test fuel economy.

There are other good reasons to believe that this gap may be growing.[60] Increases in the size of the gap make this problem even more contentious: the real-world achievement, a certain level of fuel economy, diverges from what was promised. This actually occurred in Germany, where the manufacturers' pledges of improved fuel economy, based on the static tests, diverged increasingly from what was obtained in real road tests (and on the road). By contrast, the pledges of the auto industry in Sweden to bring the weighted average fuel intensity down to 8.5 l/100 km were more closely achieved, since the sales weighted average in the late 1980s lay in the interval 8.2–8.3 l/100 km and the Swedish test values themselves lay close to 'reality', according to consumer surveys.[61] On the other hand, the overall stock in Sweden showed only about a 10% improvement. Was this because the tests and surveys were incorrect indicators of fuel economy, or because the approach taken to estimate real fuel economy of the fleet was flawed? In the UK, the existence of the gap has been known for some time, with tests underestimating the published fuel intensity values by 10–20%.[62] Unfortunately, the UK authorities do not provide a yearly sales-weighted average of estimated fuel economy.[63] Finally, an important and increasing gap appeared in France.[64] This gap increased over time, and was found to be larger for larger and more powerful cars than for smaller cars.

The conclusion is clear: using test values of new car fuel intensity to represent either actual values of new car intensity or, by building a model of the stock by vintage, estimating stock vintage, is clearly fraught with dangers. Resolving this uncertainty over the fuel economy gap is particularly important for Germany and France, where overall improvement in fleet fuel economy between 1973 and 1989 appears to be small, under 15%, although the changes in new car fuel economy as published by national authorities are apparently much larger. Which version is correct? In Sweden and the UK, by contrast, the changes in reported new car fuel intensity figures between 1978 and 1990 are small, under 18%, but the apparent changes in the intensity of the fleet are even smaller. What really happened? Clearly, if the elements of the quartet used to determine actual fuel economy are fraught with uncertainties, the changes in fuel economy might have to accumulate in the stock over several years before anything definite can be said about the real impact of changes in new car fuel economy on fleet fuel economy. Since the stock fuel economy itself is uncertain, this leads to even more delays for sound analysis.

Directions for future analyses

Analysts must take a second look at the data presented and assumptions used, as Sorrell does.[65] Are the data in the 'vicious circle' at least self-consistent? How many of these elements are likely to have been independently determined? Are driving distances independently confirmed by driving surveys? Are fuels broken down by type? Are definitions of vehicles and distinctions by fuel type clear? Where alternative fuels are important, particularly diesel, are their prices properly represented? If these questions can be answered in the affirmative, then the modeller can probably shed light on important questions of relevance to today's energy and environmental policy making.

Gately's 1990 review of automobile fuel use in the

USA meets many of the criteria named above.[66] He chose a time series for automobile fuel use that, despite some imperfections, has been 'cleaned' of non-automobile gasoline use. Automobile diesel fuel use in the USA has been insignificant for most of the period Gately studied, except for a brief period in the late 1970s and early 1980s when there were several million diesel vehicles, so that factor is not important. His parameters describing both total distance travelled and numbers of vehicles come from the same source. It is important for the reader to bear in mind that roughly 15% of US gasoline use is *not* covered by Gately's calculations.

Sterner, Dahl and Franzen present an alternative approach.[67] They studied the implications of taxation and prices in general for CO_2 emission from gasoline use. In so far as their analysis is in fact only applied to gasoline, their work makes useful predictions for what might happen to gasoline use. But the components of gasoline or fuel use (including use for trucks and buses) in most countries are significantly different in the 1990s than in the early 1980s or before, ie the period covered by most of the estimation. Therefore, applying their conclusions to automobile fuel use must be done with caution, since their historical analysis is not based on automobile fuel use.

The problem for analysts is to learn how changes in different fuel prices might affect the use of gasoline and other fuels in different components of the vehicle stock. Our own work shows that a reasonably accurate breakdown of automobile fuel use and fuel price can be obtained for almost any country. Our simple modelling exercise shows that obtaining a better measure of fuel use is important to the statistical results. Good results can be obtained from data that respect the problems of the vicious circle.[68] Such results can then be applied to the current discussion of how fuel use affects the environment.[69] The challenge is to combine all three approaches, something we hope to present in the near future.

Conclusion: closing the gap and squaring the circle

Clearly, this report shows that the uncritical use of 'total road gasoline' from OECD balances or UN publications as a measure of automobile fuel use can lead to serious errors. If this independent variable is used, the implications of modelling fuel use for automobiles, trucks, buses and motorcycles to derive conclusions regarding fuel use in automobiles should be explored. The likely result, however, will be confusion, if the modeller then has to explain how the results might differ between different vehicles Otherwise, the modeller should formulate her hypothesis with full regard to the errors of measurement when total road gasoline is taken as the independent variable. As we have shown, researchers can obtain good data for almost any country from national sources, but researchers should avoid data from different international sources. National sources must explain their methods, data and assumptions. Most important, the national sources must explain how the problem of the vicious circle has been resolved and where the 'gaps' remain Given all these problems, we believe that the data we present in Table 1 offer a good representation of the fuel used by automobiles in a variety of OECD countries.

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[43] For Denmark, we follow official practice and count all of these with cars. For the USA we used surveys of various years, (*op cit*, Ref 23); EIA; *op cit*, Ref 31. FHWA (NPTS) EIA, *op cit*, Ref 31, various years, also ORNL, various years) to determine the number of light trucks used as private vehicles and the distance they were driven We estimated fuel intensity as 10% greater than that for private automobiles.
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