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On the depreciation of automobiles: An international comparison

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Abstract. Since older automobiles are less efficient and technologically obsolete, over-aged capital stocks are associated with higher environmental burden. Given the rapid growth of over-aged car stocks in many poor countries, the knowledge of depreciation data, depreciation patterns, and their determinants in developing countries becomes increasingly important for effective environmental policies. This paper refers to used automobile prices and generates depreciation data for a sample of 54 car models from 30 countries. We found the following results: (1) Overall, geometric depreciation appears to be a good approximation to real depreciation rates. (2) Depreciation rates are significantly lower in developing countries than in industrialized countries. (3) When using corrected prices the depreciation rates increase substantially. The average depreciation in OECD countries is 31%, whereas in non-OECD countries it is about 15%. Besides prices for new cars, the economic life of automobiles is particularly dependent on real income. In the long-run, an income increase by $1000 is likely to increase the annual depreciation rate by 2.7% in OECD countries and 3.6% in non-OECD countries.

1. Introduction

Fuel consumption and, therefore, pollution and CO_2 emissions of automobile travel are a "derived demand" and are calculated as the product of three factors: the number of cars, miles driven per car, and their fuel economy (1/mpg or l/100 km) or specific emissions per mile driven. Thus, reduction strategies may include reducing the car stock, lowering its utilization (e.g. change the modal split), or improving the technical traits of the vehicles. This article will focus on the latter.

From an environmental policy point of view, particularly the age distribution of the automobile stock seems to be of paramount interest. Since older vehicles are less efficient and technologically obsolete, all other things being equal, an over-aged capital stock is associated with higher environmental burden. Case studies in OECD and UNEP (1999) show a significant influence of a car stock's age distribution on CO, CO_2, HC and NO_x emissions. Hence, an environmental policy aimed at reducing traffic pollution will attempt to keep the fraction of old and fuel inefficient cars as low as possible. In other words: The economic life of cars should be shortened, i.e. their depreciation should be accelerated.

Recent examples of that kind of policy are scrappage schemes and accelerated vehicle retirement programs. Owners of older vehicles are provided with financial incentives if they replace their car with a new, modern car. Scrappage schemes have been offered in many countries. A survey of the different programs is given in ECMT (1999a).

Despite the importance of the age distribution of capital assets with respect to environmental policies, there is little empirical knowledge about the average economic life of automobiles in emerging and developing countries. Since one relies on more or less accurate estimates, even for many industrialized countries, cross-sectional analyses often assume a flat, uniform economic life of, for example, 15 years (e.g. Johanssen & Schipper 1997). This may be justified for developed countries since their economic frame is similar. From a global point of view this seems to be more problematic since the fundamentals are different in developing countries. As for developing countries, there are virtually neither data nor estimates on the economic life of automobiles.

This paper sets out to shed some light on this issue and will attempt to determine depreciation rates for automobiles in an international comparison. After the data are generated, we will focus on the main long-run determinants of depreciation rates and will quantify their effect by employing a cross-sectional analysis.

2. Depreciation: Theoretical considerations

The value of an asset, such as an automobile, changes as a result of depreciation and revaluation. Depreciation is the loss in value associated with the aging of the asset. The value of an asset is determined by the utility it is expected to generate over the remainder of its useful life. In principle this value is equal to the net present value of all future rentals plus the remaining scrap value (Wykoff 1973; Jorgenson 1994; Hulten & Wykoff 1996; Blades 2001). Assuming a constant discount rate and a scrap value of zero the remaining present value of an s-year old asset in t is equal to

$$P_{t,s} = \sum_{\tau=0}^{T} \frac{f_{t+\tau,s+\tau}}{(1+r)^{\tau+1}}. \tag{1}$$

with $P_{t,s}$ is the value of an s-year old asset in t, f is the utility generated, T is the lifetime of the asset, r is the discount rate.

Since the efficiency of an asset, i.e. its productive capacity (Hulten & Wyckoff 1996), plays a crucial role in the process of depreciation Equation (1) can also be expressed as:

$$P_{t,s} = \sum_{\tau=0}^{T} \frac{\varphi_{s+\tau} f_{t+\tau,0}}{(1+r)^{\tau+1}}, \tag{2}$$

where φ_s stands for the efficiency of an s-year old asset as a fraction of the productive capacity of a new asset. Since φ_0 is normalized at $\varphi_0 = 1$ and efficiency is assumed to be declining with age $\varphi_{s\succ 0}$ will be lower than 1. Equation (2) expresses the remaining present value of the asset in terms of the rental price of a new asset weighted with its efficiency.

As an asset ages, its price changes because it declines in efficiency in the current and in all future periods. Depreciation reflects the change in net present value over time.

Revaluation, on the other hand, is the change in value or price of an asset that is caused by everything other than aging. This includes price changes due to inflation, obsolescence, and any other change not associated with aging.

Depreciation and revaluation can be distinguished as follows. The total change in the price of an asset over time can be written as

$$\Delta P = P(t,s) - P(t+1,s+1), \tag{3}$$

where s denotes the age of the asset.

By inserting $P(t,s+1)$, Equation (3) can be rewritten as

$$\Delta P = [P(t,s) - P(t,s+1)] - [P(t+1,s+1) - P(t,s+1)]. \tag{4}$$

The term in the first set of brackets holds time constant and denotes depreciation, the change in price of the asset resulting from a change in age. The term in the second set of brackets denotes price changes due to inflation and other reasons not associated with aging.

When working with pooled data Equation (3) is appropriate to decompose the change in the asset's value into the depreciation and revaluation effect. However, since this paper deals with cross-section data only, that is, prices of automobiles of different vintages at one point in time, the revaluation effect is excluded automatically. We, therefore, will keep t constant and refer only to the term in the first set of brackets. Defining δ as the depreciation rate total annual depreciation year can also be expressed as

$$\delta_{t,s}P_{t,s} = P_{t,s} - P_{t,s+1} = \sum_{\tau=0}^{T} \frac{(\varphi_{s+\tau} - \varphi_{s+\tau+1})f_{t+\tau,0}}{(1+r)^{\tau+1}}. \tag{5}$$

Equation (5) shows that it is the erosion of the efficiency of the asset due to aging which causes the decline in the asset's value. Accordingly, efficiency patterns will determine the path of economic depreciation. We distinguish the one-hoss shay pattern, the straight-line pattern and geometric pattern decay.

According to the theory of Böhm-Bawerk (1884) and Wicksell (1893) a chair will do its service constantly over its entire lifetime, the annual stream of service will always be the same. Similar, a light bulb provides constant rentals over time. But when the filament burns through the stream of service stops abruptly. The Böhm-Bawerk-Wicksellian approach to capital theory assumes certainty and proposes constant rentals over the entire lifetime of a capital good, that is,

$$\varphi_0 = \varphi_1 = \cdots = \varphi_{T-1} = 1, \varphi_{T+t} = 0 \quad \text{with} \quad t = 0, 1, 2, \ldots \tag{6}$$

This in economic analysis popular approach is known as *one-hoss shay*[1] or *light bulb* model. With a discount rate of zero the one-hoss shay pattern implies straight-line depreciation, with any other positive discount rate it will lead to a concave pattern: absolute depreciation and depreciation rate increase with aging (Table 1).[2]

Even though the simplicity of this approach appears to be fairly attractive it is associated with some major issues: First, future rentals are rarely certain; mostly economists have to deal with uncertainty (Dixit & Pindyck 1994). Second, we can assume that most capital goods provide decreasing rentals over time. Repair and maintenance cost as well as obsolescence increase with age, at the same time reliability goes down. Third, it is argued that *one-hoss shays*, such as light-bulbs, lose their value because the failure point gets closer with aging. This suggests that the annual rentals will decrease as the asset ages. In Table 2 linear and geometric declines of annual rentals and their impact on depreciation are shown. As opposed to the one-hoss shay model, decreasing rentals lead to straight-line or convex depreciation pattern.

The straight-line decay pattern assumes that efficiency falls off linearly over the asset's service life:

Table 1. Relation between rentals and capital value in the one-hoss shay model (discount rate 10%).

Year	Rental	Value of discounted rental at beginning of year									
		1	2	3	4	5	6	7	8	9	10
1	10	10									
2	10	9.09	10								
3	10	8.26	9.09	10							
4	10	7.51	8.26	9.09	10						
5	10	6.83	7.51	8.26	9.09	10					
6	10	6.21	6.83	7.51	8.26	9.09	10				
7	10	5.64	6.21	6.83	7.51	8.26	9.09	10			
8	10	5.13	5.64	6.21	6.83	7.51	8.26	9.09	10		
9	10	4.67	5.13	5.64	6.21	6.83	7.51	8.26	9.09	10	
10	10	4.24	4.67	5.13	5.64	6.21	6.83	7.51	8.26	9.09	10
Value of asset		67.59	63.35	58.68	53.55	47.91	41.70	34.87	27.36	19.09	10.00
Normalized value		100.00	93.73	86.82	79.23	70.88	61.69	51.59	40.47	28.25	14.80
Depreciation			6.27	6.90	7.59	8.35	9.19	10.11	11.12	12.23	13.45
Depreciation rate			6.27	7.36	8.74	10.54	12.96	16.38	21.55	30.21	47.62

Table 2. Rentals, capital value, and depreciation of different models (discount rate 10%).

Rental type	Year	1	2	3	4	5	6	7	8	9	10
One-hoss shay	Rental/year	10	10	10	10	10	10	10	10	10	10
	Value[a]	100	93.73	86.82	79.23	70.88	61.69	51.59	40.47	28.25	14.80
	Depreciation	–	6.27	6.90	7.59	8.35	9.19	10.11	11.12	12.23	13.45
	Dep. rate %	–	6.27	7.36	8.74	10.54	12.96	16.38	21.55	30.21	47.62
Linear decay	Rental/year	10	9	8	7	6	5	4	3	2	1
	Value[a]	100	83.98	69.06	55.23	42.62	31.33	21.51	13.30	6.85	2.36
	Depreciation	–	16.02	14.92	13.82	12.61	11.29	9.82	8.21	6.44	4.50
	Dep. rate %	–	16.02	17.77	20.02	22.84	26.48	31.35	38.19	48.46	65.63
Geometric decay	Rentals/year	10	9	8.10	7.29	6.56	5.90	5.31	4.78	4.30	3.87
	Value[a]	100	90.00	81.00	72.90	65.61	59.05	53.14	47.83	43.05	38.74
	Depreciation	–	10.00	9.00	8.10	7.29	6.56	5.90	5.31	4.78	4.30
	Dep. rate %	–	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

[a] Asset's value normalized at 100.

$$\varphi_0 = 1, \varphi_1 = 1 - (1/T), \varphi_2 = 1 - (2/T), \ldots, \varphi_{T-1} = 1 - [(T-1)/T], \\ \varphi_{T-\tau} = 0 \text{ with } \tau = 0, 1, 2, \ldots \tag{7}$$

In this form, the efficiency will decrease by the same total amount every year. Like with the one-hoss shay depreciation pattern, efficiency is determined by T. This is not to be confused with linear depreciation. In general, linear decay will lead to a decreasing depreciation. However, with an increasing discount rate the straight-line decay will approximate a linear depreciation.

The best known pattern of decreasing depreciation is the geometric decay, in which the asset's efficiency declines at a constant rate δ:

$$\varphi_0 = 1, \varphi_1 = (1-\delta), \varphi_2 = (1-\delta)^2, \ldots, \varphi_t = (1-\delta)^t, \ldots \tag{8}$$

This pattern is not determined by the asset's lifetime but solely by the depreciation rate δ. In fact, according to this pattern the asset's life is infinite. The geometric form has the self-dual property that the value of the asset declines at the same rate as the annual rentals. This leads to a constant depreciation rate.

3. Data

The price data used in this study consist of market prices of used automobiles. Price information is publicly available and provided by newspapers, magazines, and on the internet. Since all prices are solely suggestions by sellers, they do not represent the equilibrium price but rather an upper limit of the market value. Nevertheless, we can assume them to be a fairly good approximation and, therefore, an adequate proxy variable for the market equilibrium price. We took advantage of the market information available and compiled price-age data series comprised of 54 car types from 31 countries. To ensure the comparability, all data were taken within a defined short period of time (January–April 2001). Thus, we collected prices of vehicles of different ages at one point in time. As for new cars, we referred to the list price. In contrast to Peles (1988) we did not refer to the average price per vintage but included all prices for one car type which were available in spring 2001. This procedure may entail an increase in the sum of squared errors. In addition, the error variance might vary systematically with the age of the car, i.e. the model has to account for heteroscedasticity.

Considered were only vehicles that were drivable and were not equipped with any extras. We chose car types which are frequently traded in the respective countries and which model series has existed for more than 10 years (e.g. Toyota Corolla, VW Golf).

However, used automobile prices may lead to biased estimates of the depreciation of assets. There are two arguments suggesting the possibility of such a bias. First, asset samples normally only represent surviving assets. Second, surviving asset-samples and thus their prices may not represent the stock of all surviving assets.

If asset samples represent only surviving assets, the age-price profiles of used asset samples can overestimate the value of the asset considerably. Since retirements are not included depreciation for the entire population will be underestimated. This is known as the "censored-sample bias". For example, the sample might indicate that the price of a one year old car is $12,000 whereas the price of a 20 year old car is $2000. This does not take into account that the majority of the older car has already been retired while almost the entire population of the newer car is still in service. Therefore, the average value of the entire population of 20 year old cars has to account for the large fraction of retired cars with a value of zero and thus will be considerably lower than $2000. While most studies on depreciation ignored this issue, Hulten and Wykoff (1981) suggested a censored-sample adjustment which accounts for the cohort of capital assets which already has been retired. Like in Hulten and Wykoff (1981) it is assumed that retired automobiles have a value of zero.[3] Then the adjusted price P^* is to be calculated as a weighted average of the observed prices and the unobserved zero prices. The respective weights reflect the probability of remaining in service at a given age. That is,

$$P^* = \theta_t P_{\text{observed}} + (1 - \theta_t) P_{\text{unobserved}}, \tag{9}$$

where θ_t is the probability of survival at age t. Since the unobserved prices were assumed to be zero the adjusted prices are $P^* = \theta_t P_{\text{observed}}$.

There are different curves to calculate survival probabilities. While Hulten and Wykoff (1981) used the Winfrey L-0 curve to calculate survival probabilities and retirement pattern of structures this paper will refer to the much shorter Winfrey L-3 curve (Winfrey 1935). The L-3 curve is an asymmetrical distribution with heavy discards before the mean service life. It implies that only 43.8% of the population survive the mean asset life. The entire population will be retired after 240% of the mean service life.[4] These patterns are consistent with retirement tables for automobiles in Germany provided by RWI (2002).

Yet another issue is the choice of the appropriate mean service life. For countries such as the U.S. or Germany one can refer to information provided by the Bureau of Economic Analysis which assumes a mean service life for passenger cars of 10 years (Fraumeni 1997). This squares with the data given for Germany (BMV 2000). However, this mean lifetime in combination with the L-3 Winfrey curve entails that the entire automobile population will be retired after 24 years. This would exclude a considerable number of survivors in

Table 3. OLS estimates of nonlinear depreciation for OECD countries – observed prices.

Country	Car model	n	a_0	β_1*(10^2)	β_2*(10^2)	β_3*(10^3)	R^2	SSE (SSE/n)	White's test[a]
Australia	Toyota Camry	346	0.04	−5.70	−0.51	0.05	0.87	6.51	89.91
			(0.8)[0.8]	(−2.2)[−2.0]	(−1.2)[−1.0]	(0.2)[0.2]		(0.02)	
Australia	Honda Civic	15	−1.22	69.95	−12.82	5.97	0.87	0.33	0.21
			(−2.4)	(2.5)	(−3.0)	(3.0)		(0.02)	
Denmark	VW Golf	326	−0.18	−13.15	−0.23	0.17	0.92	6.29	40.81
			(−8.2)[−7.1]	(−11.9)[−8.3]	(−1.6)[−1.0]	(3.4)[1.9]		(0.02)	
Germany	VW Golf	218	−0.05	−5.71	−2.10	0.72	0.92	14.89	41.92
			(−0.8)[−1.2]	(−1.5)[−1.7]	(−3.5)[−3.4]	(2.7)[2.6]		(0.07)	
Germany	Opel Astra	262	−0.13	−2.87	−3.38	1.35	0.86	50.06	30.57
			(−1.1)[−2.1]	(−0.6)[−0.8]	(−6.3)[−7.1]	(7.5)[7.9]		(0.19)	
Germany	Opel Omega	129	−0.23	−6.16	−2.61	0.92	0.92	14.98	21.97
			(−2.0)[−5.2]	(−1.6)[−2.5]	(−7.0)[−9.0]	(9.2)[11.3]		(0.12)	
Germany	BMW 316	259	−0.11	−16.56	0.28	−0.63	0.93	9.85	91.51
			(−0.0)[−0.0]	(−5.6)[−3.3]	(0.5)[0.3]	(−2.4)[−1.1]		(0.04)	
Germany	BMW 520	1435	−0.14	−6.99	−1.73	0.67	0.91	53.95	209.31
			(−5.3)[−4.8]	(−4.2)[−3.0]	(−5.9)[−3.5]	(4.4)[2.3]		(0.04)	
France	VW Golf	94	0.05	−18.01	0.15	0.05	0.91	2.44	15.03
			(1.0)[1.1]	(−4.4)[−4.2]	(0.2)[0.2]	(0.2)[0.1]		(0.03)	
Ireland	VW Golf	61	−0.04	−0.79	−3.76	2.66	0.90	1.05	2.40
			(−0.4)	(−0.1)	(−2.0)	(2.1)		(0.02)	
Italy	BMW 318	110	−0.04	−14.40	−0.38	−0.05	0.92	3.75	19.89
			(−0.5)[−1.0]	(−3.9)[−4.0]	(−0.5)[−0.6]	(−0.2)[−1.0]		(0.03)	
Mexico	VW Jetta	39	−0.09	−29.32	3.38	−1.81	0.86	0.86	2.96
			(−0.5)	(−2.4)	(1.6)	(−1.7)		(0.02)	
New Zealand	Toyota Corolla	326	−0.06	−27.25	2.55	−1.18	0.65	13.78	18.86
			(−0.6)[−0.6]	(−4.9)[−4.6]	(3.0)[2.6]	(−3.0)[−2.3]		(0.04)	
Norway	VW Golf	447	−0.11	−10.66	−0.02	−0.10	0.95	9.21	74.76

			(−4.3)[−4.5]	(−8.2)[−6.8]	(−0.1)[−0.1]	(−1.7)[−1.2]		(0.02)	
Austria	VW Golf	247	−0.11	−7.71	−0.96	0.18	0.90	19.89	30.16
			(−2.1)[−2.6]	(−2.5)[−1.9]	(−2.2)[−1.3]	(1.1)[0.5]		(0.08)	
Poland	VW Golf	96	−0.07	−10.43	−0.34	0.10	0.95	2.36	7.68
			(−0.8)[−0.8]	(−3.5)[−2.8]	(−1.1)[−0.8]	(1.2)[0.9]		(0.02)	
Poland	Toyota Corolla	86	−0.17	−6.62	−1.03	0.48	0.89	2.19	1.49
			(−1.9)	(−1.3)	(−1.3)	(1.3)		(0.03)	
Poland	VW Passat	115	−0.04	−13.63	−0.24	0.05	0.95	2.42	21.59
			(−0.5)[−0.6]	(−4.4)[−4.3]	(−0.6)[−0.6]	(0.4)[0.4]		(0.02)	
Sweden	VW Golf 1.6/1.8	466	−0.25	−6.79	−0.91	0.27	0.92	8.72	59.28
			(−8.5)[−8.5]	(−4.1)[−3.6]	(−3.6)[−2.7]	(2.5)[1.7]		(0.02)	
Switzerland	VW Golf 1.6/1.8	171	−0.17	−3.47	−1.43	0.37	0.88	20.29	20.97
			(−2.0)[−3.1]	(−0.7)[−0.8]	(−2.4)[−2.0]	(1.8)[1.3]		(0.12)	
UK	VW Golf 1.6/1.8	205	−0.25	−11.01	−1.71	0.65	0.90	28.50	32.59
			(−2.0)[−3.2]	(−2.6)[−2.9]	(−4.0)[−3.7]	(5.1)[4.2]		(0.14)	
UK	Toyota Corolla	87	−0.59	23.65	−5.29	1.88	0.84	10.61	14.37
			(−1.8)[−2.6]	(1.9)[2.3]	(−3.9)[−4.2]	(4.2)[3.9]		(0.12)	
UK	BMW 318i	154	−0.82	14.71	−3.67	1.09	0.87	20.34	10.20
			(−2.6)[−2.9]	(1.4)[1.5]	(−3.6)[−3.4]	(3.6)[3.2]		(0.13)	
USA	Cadillac Seville	233	−0.11	−11.07	−1.42	0.66	0.89	18.16	63.35
			(−1.5)[−1.6]	(−3.4)[−2.9]	(−3.7)[−2.7]	(5.4)[3.9]		(0.08)	
USA	Toyota Camry	375	−0.13	−12.07	−0.37	0.05	0.93	10.49	66.91
			(2.8)[−3.2]	(−4.9)[−5.0]	(−1.0)[−1.0]	(0.3)[0.3]		(0.03)	
USA	Honda Accord	567	−0.10	−5.49	−1.95	0.79	0.89	31.76	38.80
			(−1.8)[−2.3]	(−1.9)[−2.0]	(−4.5)[−4.1]	(4.1)[3.6]		(0.06)	
USA	Honda Civic	486	−0.25	−9.42	−1.41	0.66	0.87	26.93	24.75
			(−4.7)[−6.7]	(−3.7)[−4.3]	(−4.0)[−4.0]	(4.6)[4.2]		(0.06)	

[a] White's test without cross terms, the critical value of χ^2 (2) at the 5% level is 5.99; t-statistics in parenthesis, heteroscedasticity consistent t-statistics in brackets.

Table 4. OLS estimates of nonlinear depreciation for non-OECD countries – observed prices.

Country	Car model	n	a_0	β_1*(10^2)	β_2*(10^2)	β_3*(10^3)	R^2	SSE (SSE/n)	White's test[a]
Egypt	Honda Civic	21	0.31	−30.02	1.75	−0.43(−1.1)	0.88	0.25	2.01
			(0.7)[0.9]	(−2.3)[−2.3]	(1.4)[1.8]	[−1.5]		(0.01)	
Brazil	VW Gol	193	−0.12	−16.97	0.86	−0.30(−3.9)	0.93	2.75	31.89
			(−2.8)[−2.3]	(−9.0)[−8.5]	(3.8)[3.9]	[−4.3]		(0.01)	
Brazil	Ford Escort	97	0.23	−12.04	−0.03	0.00	0.92	1.44	16.97
			(1.7)[2.6]	(−1.9)[−2.9]	(−0.0)[−0.0]	(0.0)[0.0]		(0.01)	
India	Hindustan	161	−0.00	−25.33	1.19	−0.19(−4.8)	0.68	24.86	29.63
	Ambassador		(−0.0)[−0.0]	(−8.3)[−8.4]	(5.7)[5.2]	[−4.1]		(0.15)	
India	Maruti 800	607	0.24	−20.63	1.21	−0.38(−3.3)	0.81	20.88	95.83
			(4.3)[5.0]	(−8.6)[−8.6]	(4.0)[3.5]	[−2.7]		(0.03)	
Indonesia	Toyota	185	0.16	−28.81(−10.4)	2.61	−1.09(−5.0)	0.90	1.37	7.80
	Corolla		(2.9)[2.4]	[−8.7]	(5.8)[5.0]	[−4.5]		(0.01)	
Kenya	Nissan Sunny	174	0.02	−20.79	0.63	−0.07(−0.2)	0.70	7.99	14.80
			(0.1)[0.1]	(−2.5)[−3.2]	(0.7)[0.9]	[−0.3]		(0.05)	
Kenya	Peugeot 504	128	−0.52	0.07	−1.19	0.41	0.68	7.38	5.12
			(−2.2)[−3.1]	(0.0)[0.0]	(−1.5)[−2.1]	(1.7)[2.5]		0.06)	
Kenya	Toyota Hilux	77	−0.72	10.07	−1.82	0.57	0.71	2.52	3.10
			(−3.9)[−5.4]	(1.5)[1.8]	(−2.5)[−2.9]	(2.5)[2.9]		(0.03)	
Colombia	Mazda 323	24	0.81	−47.89	3.79	−1.13(−1.2)	0.83	0.54	2.07
			(0.8)[0.9]	(−1.5)[−1.7]	(1.2)[1.5]	[−1.5]		(0.02)	
Malaysia	Honda Accord	122	−0.07	−12.14	0.28	−0.32(−2.0)	0.94	2.83	12.52
			(−0.8)[−1.3]	(−3.3)[−4.0]	(0.6)[0.6]	[−1.9]		(0.02)	
Malaysia	Proton Saga/Wira	189	−0.14	−2.71	−1.07	0.39	0.98	0.64	6.37
			(−5.6)[−8.5]	(−2.0)[−2.5]	(−4.8)[−5.7]	(3.8)[4.3]		(0.00)	
Malawi	Toyota Corolla	44	−0.81	49.14	−8.32	3.52	0.83	0.37	7.07
			(−0.5)[−0.6]	(0.9)[1.1]	(−1.4)[−1.7]	(1.7)[2.0]		(0.01)	

Namibia	Toyota Hilux	52	0.18	−35.41	3.63	−1.28	0.60	3.19	6.65
			(1.0)[1.0]	(−4.0)[−4.1]	(3.0)[3.0]	(−2.7)[−2.7]		(0.06)	
Namibia	VW Golf	38	0.11	−22.83	0.89	−0.16	0.85	2.09	2.70
			(0.8)[1.1]	(−3.5)[−4.1]	(1.1)[1.3]	(−0.5)[−0.7]		(0.06)	
Philippines	Toyota	213	−0.35	−6.85	−0.42	0.13	0.76	12.81	11.67
	Corolla		(−3.9)[−2.6]	(−2.0)[−1.1]	(−1.3)[−0.6]	(1.2)[0.6]		(0.06)	
Philippines	Mitsubishi Lancer	285	−0.06	−19.17	0.82	−0.19(−2.6)	0.84	11.11	4.86
			(−0.9)[−1.0]	(−7.7)[−7.6]	(3.3)[3.0]	[−2.2]		(0.04)	
Philippines	Mitsubishi	148	−0.18	−6.41	−0.74	0.22	0.94	4.68	50.96
	Galant		(−1.6)[−1.4]	(−1.8)[−1.3]	(−2.1)[−1.5]	(2.3)[1.5]		(0.03)	
Romania	VW Golf	117	−0.11	−5.13	−1.15	0.40	0.89	6.65	19.18
			(−1.7)[−2.7]	(−1.5)[−1.6]	(−2.5)[−2.5]	(2.5)[2.3]		(0.06)	
Romania	Opel Vectra	102	−0.12	−13.97	0.47	−0.40(−0.7)	0.90	1.56	7.41
			(−1.6)[−2.4]	(−2.7)[−3.4]	(0.5)[0.6]	[−0.8]		(0.02)	
Zimbabwe	Mazda 323	161	−0.39	−7.33	−0.14	0.05	0.76	8.76	11.03
			(−2.3)[−1.9]	(−1.2)[−0.9]	(−0.2)[−0.2]	(0.3)[0.2]		(0.05)	
South Africa	VW Golf	127	0.21	−17.97	0.04	0.16	0.71	12.47	0.11
			(0.9)[0.9]	(−2.3)[−2.3)	(0.0)[0.1]	(0.7)[0.8]		(0.10)	
South Africa	Toyota	101	0.09	−24.32	1.09	−0.26(−1.2)	0.91	2.89	0.40
	Corolla		(0.7)[0.8]	(−4.5)[−4.5]	(1.7)[1.7]	[−1.1]		(0.03)	
Swaziland	Nissan 1400	61	−0.17	−11.94	0.02	0.10	0.78	1.94	16.77
			(−1.1)[−0.8]	(−1.7)[−1.1]	(0.0)[0.0]	(0.4)[0.2]		(0.03)	
Swaziland	Toyota	92	−1.54	44.51	−6.41	2.28	0.62	4.36	3.17
	Corolla		(−3.7)[−4.6]	(2.8)[3.5]	(−3.5)[−4.5]	(3.5)[4.6]		(0.05)	
UAE[a]	Toyota	35	0.22	−36.46	3.40	−1.35(−3.1)	0.94	0.52	0.58
	Corolla		(1.8)[2.2]	(−5.1)[−6.8]	(3.2)[−4.2]	[−3.9]		(0.01)	
Uruguay	VW Gol	147	0.11	−33.38	3.33	−1.22	0.93	3.07	8.01
			(1.7)[2.6]	(−13.2)[−15.4]	(10.9)[11.5]	(−11.8)[−12.2]		(0.02)	

[a] White's test without cross terms, the critical value of χ^2 (2) at the 5% level is 5.99; t-statistics in parenthesis, heteroscedasticity consistent t-statistics in brackets.

developing countries. For instance, 20% of the Hindustan Ambassador sample in India is older than 24 years. Therefore, different mean service lives for each country were to be estimated. Taking the geometric depreciation rates based on unadjusted prices as given in Tables 7 and 8, we assumed the mean service life to be reached when the car value equaled 5% of the per capita private consumption. When several models for one country were available the country average was calculated. Decimals were rounded; values under 10 years and over 20 years were not allowed (see also Tables 5 and 6). Thus all requirements to calculate adjusted prices were fulfilled.

Another problem associated with vintage asset prices is that surviving-asset samples and their prices may not represent the population of surviving assets. This problem is mainly associated with the lemons hypothesis by Akerlof (1970). Due to asymmetric information buyers will assume that assets for sale are lemons and will, therefore, offer lower prices for used assets. Sellers have an incentive to offer lemons, since they will receive lemons prices regardless of whether the asset is a lemon or not; superior vehicles will be sold otherwise. Thus, used asset prices will be below the average of the stock of assets and depreciation would be overestimated. However, Hulten and Wykoff (1981) tested for the existence of a lemons bias by comparing the depreciation profiles of assets with a potential lemons bias (e.g., automobiles) and assets that arguably do not (e.g., heavy construction equipment). They found that both depreciation profiles were approximately the same and the lemon bias is unimportant in depreciation estimates. Akerlof himself pointed out that sellers have an incentive to help buyers to overcome the information asymmetry problem. If this were not so, the logic of the lemons argument itself would imply only a tiny used automobile market.

Data on private consumption, exchange rates, and purchasing power parities (PPP) were taken from World Bank (2001). Information on gasoline prices came from the International Energy Agency (IEA 2001) and the "Gasoline Price Database" of the World Bank (Metschies 1999).

4. Depreciation data: Results

In general, the price of a used asset (P) sold at a certain time (t) depends on its age (s) and a vector $\mathbf{z}$ of other characteristics of the asset.

$$P_t = P_t(s, \mathbf{z}). \tag{10}$$

For automobiles, the latter – aside from other traits – especially encompasses the mileage driven. In order not to unnecessarily restrict the form of the depreciation function, flexible forms are estimated. For instance, Hulten and Wykoff (1981) used the Box–Cox power transformation as a flexible representation of Equation

(10). This function nests several popular hypothesis for the form of the depreciation function, including one-hoss shay, linear, and geometric forms. However, the Box-Cox function is highly nonlinear in its parameters, which complicates its estimation. This paper follows a simpler approach already employed by Oliner (1996) for machine tools and regresses the natural logarithm of P for each automobile model in each country on third-order polynomials in age. Since we have no information about the particular condition and especially the mileage of the car at the date of sale, the vector $\mathbf{z}$ could not be controlled for and was omitted from the regression. Hence, the equation to be estimated is:

$$\ln P = \alpha + \sum_{i=1}^{3} \beta_i s^i + \varepsilon, \qquad (11)$$

where α denotes the intercept and ε the stochastic error term.

This equation allows for a wide range of depreciation patterns. In the special case of $\beta_2 = \beta_3 = 0$, the equation will reflect the geometric depreciation pattern, i.e. $\delta = \beta_1$. The depreciation function is computed as the percentage change in price due to a unit change in age. Given estimates of the parameters of Equation (11), the depreciation rate can be calculated as

$$-(\beta_1 + 2\beta_2 s + 3\beta_3 s^2). \qquad (12)$$

Tables 3 and 4 show the results for unadjusted price data, Tables 5 and 6 represent the results for retirement adjusted price data (see Equation (9)).

First, the White's test reveals the existence of heteroscedasticity for most of the car models, suggesting a strong correlation between the age of the car and the error term. Since the variance in the car's condition and the miles driven increases with the car's age, this is not surprising. Distinguishing OECD and non-OECD countries, it appears that this problem is more severe in the developed world: The null hypothesis of no heteroscedasticity was not rejected for only four out of 27 automobiles in OECD countries; compared to 10 out of 27 in non-OECD countries. This may suggest that the usage of cars in developing countries is more homogenous, i.e. equally intense. In contrast, in rich countries the variability in usage seems to be considerably higher. For instance second cars are used less intensely and have a lower mileage than first cars. Garage cars are in better condition than cars parked outside. The inclusion of mileage values would have helped to reduce the heteroscedasticity issue. However, these data were not readily available for our sample. Hence, heteroscedasticity consistent t-values were calculated.

Second, depreciation rates are significantly lower in developing countries than they are in the developed world. Figure 1 shows the change in the normalized value of an automobile model in the United Kingdom and in Malaysia. Particularly within the first decade of a car's life depreciation rates

Table 5. OLS estimates of nonlinear depreciation for OECD countries – adjusted prices.

Country	Car model	Avg life	a_0	β_1*(10[2])	β_2*(10[2])	β_3*(10[3])	R^2	SSE (SSE/n)	White's test[a]
Australia	Camry	12	0.01	−4.22	−0.45	−0.54	0.95	6.71	79.02
			(0.1)[0.1]	(−1.6)[−1.6]	(−1.1)[−1.0]	(−2.9)[−2.7]		(0.02)	
Australia	Honda Civic	12	−1.18	66.47	−11.78	4.84	0.95	0.33	0.17
			(−2.3)	(2.4)	(−2.7)	(2.4)		(0.02)	
Denmark	VW Golf	12	−0.24	−8.78	−0.79	−0.08	0.97	7.51	32.54
			(−9.7)[−8.0]	(−7.3)[−4.9]	(−5.0)[−2.9]	(−1.5)[−0.8]		(0.02)	
Germany	VW Golf	10	−0.15	2.23	−3.47	0.58	0.97	15.92	41.18
			(−2.2)	(0.6)[0.6]	(−5.6)[−5.3]	(2.1)[1.9]		(0.07)	
Germany	Opel Astra	10	−0.38	17.66	−6.70	2.01	0.95	51.16	34.26
			(−2.8)[−3.7]	(2.7)[2.6]	(−7.8)[−6.5]	(6.1)[4.6]		(0.20)	
Germany	Opel Omega	10	−0.28	−0.70	−3.39	0.43	0.98	15.63	18.22
			(−2.2)[−4.5]	(−0.1)[−0.2]	(−5.9)[−5.9]	(2.4)[2.3]		(0.12)	
Germany	BMW 316	10	−0.07	−9.17	−0.94	−0.87	0.97	10.92	102.98
			(−1.8)[−1.3]	(−2.9)[−1.5]	(−1.7)[−0.7]	(−3.2)[−1.2]		(0.04)	
Germany	BMW 520	10	−0.19	−2.74	−2.21	−0.01	0.96	52.98	214.64
			(−7.5)[−7.3]	(−1.7)[−1.3]	(−7.6)[−4.9]	(−0.0)[−0.0]		(0.04)	
France	VW Golf	10	0.04	−16.49	0.08	−0.43	0.96	2.50	15.66
			(0.6)[0.7]	(−4.0)[−3.8]	(0.1)[0.1]	(−1.3)[−1.1]		(0.03)	
Ireland	VW Golf	10	−0.02	−3.67	−2.52	0.87	0.94	1.06	2.43
			(−0.2)	(−0.4)	(−1.3)	(0.7)		(0.02)	
Italy	BMW 318	10	−0.13	−7.39	−1.49	−0.34	0.97	3.75	25.30
			(−1.6)[−2.7]	(−1.6)[−1.9]	(−2.0)[−1.9]	(−1.0)[−0.8]		(0.03)	
Mexico	VW Jetta	15	−0.06	−31.79	4.03	−2.39	0.90	0.84	2.99
			(−0.3)	(−2.6)	(1.9)	(−2.3)		(0.02)	
New Zealand	Toyota Corolla	12	−0.04	−29.79	3.44	−0.22	0.83	13.86	18.28
			(−0.4)[−0.4]	(−5.3)[−5.1]	(4.0)[3.5]	(−5.6)[−4.4]		(0.04)	
Norway	VW Golf	10	−0.19	−4.38	−0.97	−0.46	0.99	10.71	83.06
			(−6.8)[−7.3]	(−3.1)[−2.6]	(−5.3)[−3.9]	(−7.4)[−5.2]		(0.02)	

Austria	VW Golf	10	−0.18	−0.41	−2.17	−0.01	0.97	22.58	34.85
			(−3.2)[−4.0]	(−0.1)[−0.1]	(−4.7)[−2.9]	(−0.3)[−0.2]		(0.09)	
Poland	VW Golf	15	−0.20	−3.86	−1.03	0.01	0.98	2.73	7.92
			(−2.3)[−2.0]	(−1.2)[−0.9]	(−3.1)[−2.3]	(0.8)[0.6]		(0.03)	
Poland	Toyota Corolla	15	−0.15	−8.28	−0.53	−0.02	0.93	2.19	1.48
			(−1.7)	(−1.6)	(−0.7)	(−0.1)		(0.03)	
Poland	VW Passat	15	−0.09	−10.78	−0.44	−0.14	0.98	2.82	23.64
			(−1.2)[−1.4]	(−3.2)[−3.1]	(−1.1)[−1.0]	(−1.0)[−1.0]		(0.02)	
Sweden	VW Golf	10	−0.40	4.38	−2.73	0.33	0.98	9.66	88.42
			(−12.9)[−9.4]	(2.5)[1.5]	(−10.4)[−5.3]	(2.9)[1.3]		(0.02)	
Switzerland	VW Golf	10	−0.23	2.65	−2.52	0.11	0.97	20.69	21.02
			(−2.6)[−4.4]	(0.6)[0.7]	(−4.1)[−4.0]	(0.5)[0.4]		(0.12)	
UK	VW Golf 1.6/1.8	10	−0.26	−7.95	−2.29	0.16	0.98	28.27	40.33
			(−2.0)[−3.4]	(−1.7)[−2.1]	(−4.6)[−4.5]	(1.1)[0.9]		(0.14)	
UK	Toyota Corolla	10	−0.72	33.39	−6.86	1.78	0.96	10.45	11.63
			(−2.2)[−3.4]	(2.7)[3.6]	(−5.1)[−6.2]	(4.0)[4.4]		(0.12)	
UK	BMW 318i	10	−0.83	19.10	−4.52	0.73	0.97	19.92	9.03
			(−2.7)[−3.0]	(1.9)[1.9]	(−4.5)[−4.2]	(2.4)[2.1]		(0.13)	
USA	Cadillac Seville	10	−0.11	−9.69	−1.66	0.02	0.97	20.75	66.44
			(−1.3)[−1.5]	(−2.6)[−2.2]	(−3.7)[−2.7]	(0.1)[0.1]		(0.09)	
USA	Toyota Camry	10	−0.26	−23.90	−1.90	−0.05	0.98	11.42	61.11
			(−5.3)[−5.9]	(−0.9)[−0.9]	(−5.1)[−4.6]	(−0.3)[−0.3]		(0.03)	
USA	Honda Accord	10	−0.25	5.32	−3.64	0.75	0.96	32.40	35.88
			(−4.4)[−5.5]	(1.8)[1.9]	(−8.2)[−7.6]	(3.9)[3.4]		(0.06)	
USA	Honda Civic	10	−0.38	0.29	−2.96	0.57	0.96	28.14	27.32
			(−7.0)[−9.5]	(0.1)[0.1]	(−8.1)[−8.1]	(3.9)[3.5]		(0.06)	

[a] White's test without cross terms, the critical value of χ^2 (2) at the 5% level is 5.99; *t*-statistics in parenthesis, heteroscedasticity consistent *t*-statistics in brackets.

Table 6. OLS estimates of nonlinear depreciation for non-OECD countries – adjusted prices.

Country	Car model	Avg life	a_0	β_1*(10^2)	β_2*(10^2)	β_3*(10^3)	R^2	SSE (SSE/n)	White's test[a]
Egypt	Honda Civiv	20	0.66	−43.71	3.37	−1.04	0.94	0.26	2.21
			(1.5)[1.8]	(−3.3)[−3.9]	(2.6)[3.2]	(−2.6)[−3.4]		(0.01)	
Brazil	VW Gol	17	−0.13	−16.45	0.94	−0.52	0.97	2.87	29.21
			(−3.2)[−2.5]	(−8.6)[−7.3]	(4.0)[3.5]	(−6.6)[−5.7]		(0.01)	
Brazil	Ford Escort	17	0.27	−14.41	0.47	−0.38	0.96	1.44	16.82
			(2.0)[3.0]	(−2.3)[−3.5]	(0.6)[0.8]	(−1.3)[−1.7]		(0.01)	
India	Hindustan Ambassador	20	−0.08	−21.41	0.85	−0.21	0.93	24.79	29.78
			(−0.8)[−1.0]	(−7.0)[−7.2]	(4.1)[3.8]	(−5.3)[−4.7]		(0.15)	
India	Maruti 800	20	0.27	−22.41	1.56	−0.62	0.86	20.90	95.89
			(4.8)[5.5]	(−9.4)[−9.3]	(5.1)[4.5]	(−5.4)[−4.4]		(0.03)	
Indonesia	Toyota Corolla	20	0.16	−29.33	2.75	−1.23	0.91	1.37	7.59
			(3.0)[2.4]	(−10.6)[−8.8]	(6.1)[5.3]	(−5.6)[−5.1]		(0.01)	
Kenya	Nissan Sunny	20	0.08	−23.80	1.11	−0.35	0.76	8.01	14.78
			(0.3)[0.4]	(−2.8)[−3.6]	(1.2)[1.6]	(−1.2)[−1.5]		(0.05)	
Kenya	Peugeot 504	20	−0.49	−2.12	−0.79	0.16	0.78	7.36	5.20
			(−2.0)[−2.9]	(−0.3)[−0.4]	(−1.0)[−1.4]	(0.7)[1.0]		(0.06)	
Kenya	Toyota Hilux	20	−0.69	8.04	−1.44	0.32	0.82	2.52	3.12
			(−3.7)[−5.2]	(1.2)[1.4]	(−2.0)[−2.3]	(1.4)[1.6]		(0.03)	
Colombia	Mazda 323	17	0.88	−51.62	4.44	−1.57	0.93	0.54	2.12
			(0.9)[1.0]	(−1.6)[−1.9]	(1.5)[1.7]	(−1.7)[−2.0]		(0.02)	
Malaysia	Honda Accord	17	−0.05	−14.07	0.74	−0.70	0.96	2.80	12.97
			(−0.6)[−0.9]	(−3.9)[−4.8]	(1.6)[1.7]	(−4.3)[−4.2]		(0.02)	
Malaysia	Proton Saga/Wira	17	−0.13	−3.90	−0.74	0.08	0.99	0.65	6.44
			(−5.1)[−8.0]	(−2.8)[−3.6]	(−3.4)[−4.0]	(0.7)[0.8]		(0.0)	
Malawi	Toyota Corolla	20	−0.71	44.79	−7.74	3.22	0.86	0.38	7.06
			(−0.4)[−0.5]	(0.8)[1.0]	(−1.3)[−1.6]	(1.6)[1.8]		(0.01)	
Namibia	Toyota Hilux	20	0.19	−36.89	3.95	−1.51	0.70	3.14	6.77
			(1.1)[1.2]	(−4.2)[−4.3]	(3.3)[3.3]	(−3.2)[−3.2]		(0.06)	

Namibia	VW Golf	20	0.12	−23.93	1.22	−0.48	0.91	2.08	2.78
			(0.8)[1.2]	(−3.7)[−4.3]	(1.5)[1.8]	(−1.6)[−2.1]		(0.05)	
Philippines	Toyota Corolla	20	−0.36	−6.93	−0.30	−0.03	0.86	13.20	11.93
			(−3.9)[−2.6]	(−2.0)[−1.1]	(−0.8)[−0.4]	(−0.2)[−0.1]		(0.06)	
Philippines	Mitsubishi Lancer	20	−0.07	−19.31	0.97	−0.36	0.91	10.87	3.33
			(−1.0)[−1.2]	(−7.9)[−8.3]	(4.0)[4.0]	(−5.0)[−4.9]		(0.04)	
Philippines	Mitsubishi Galant	20	−0.21	−5.47	−0.72	0.09	0.97	4.72	46.73
			(−1.9)[−1.7]	(−1.5)[−1.2]	(−2.1)[−1.5]	(1.0)[0.7]		(0.03)	
Romania	VW Golf	15	−0.12	−3.84	−1.19	0.15	0.94	6.97	18.45
			(−1.9)[−3.0]	(−1.1)[−1.1]	(−2.6)[−2.4]	(0.9)[0.8]		(0.06)	
Romania	Opel Vectra	15	−0.10	−15.55	0.94	−0.88	0.92	1.59	7.41
			(−1.4)[−2.0]	(−3.0)[−3.7]	(0.9)[1.1]	(−1.5)[−1.7]		(0.02)	
Zimbabwe	Mazda 323	20	−0.36	−8.93	0.19	−0.18	0.87	8.78	11.49
			(−2.2)[−1.8]	(−1.4)[−1.1]	(0.3)[0.2]	(−0.9)[−0.7]		(0.05)	
South Africa	VW Golf	17	0.10	−14.03	−0.22	0.03	0.86	12.67	0.59
			(0.4)[0.4]	(−1.8)[−1.8]	(−0.3)[−0.3]	(0.2)[0.2]		(0.10)	
South Africa	Toyota Corolla	17	0.10	−25.52	1.44	−0.59	0.95	2.86	0.64
			(0.8)[0.9]	(−4.7)[−4.9]	(2.3)[2.3]	(−2.7)[−2.8]		(0.03)	
Swaziland	Nissan 1400	20	−0.14	−13.45	0.34	−0.13	0.86	1.94	16.54
			(−0.9)[−0.7]	(−2.0)[−1.2]	(0.4)[0.2]	(−0.5)[−0.3]		(0.03)	
Swaziland	Toyota Corolla	20	−1.47	41.43	−5.92	2.00	0.71	4.35	3.23
			(−3.5)[−4.4]	(2.6)[3.3]	(−3.2)[−4.2]	(3.1)[4.1]		(0.05)	
UAE[1]	Toyota Corolla	10	0.08	−25.74	1.75	−1.41	0.99	0.47	0.53
			(0.7)[0.9]	(−3.8)[−5.6]	(1.8)[2.4]	(−3.4)[−4.5]		(0.01)	
Uruguay	VW Gol	10	0.06	−31.03	3.14	−1.41	0.98	2.65	4.47
			(1.1)[1.7]	(−13.1) [−16.2]	(11.1)[12.4]	(−14.7) [−16.4]		(0.02)	

[a] White's test without cross terms, the critical value of χ^2 (2) at the 5% level is 5.99; *t*-statistics in parenthesis, heteroscedasticity consistent *t*-statistics in brackets.

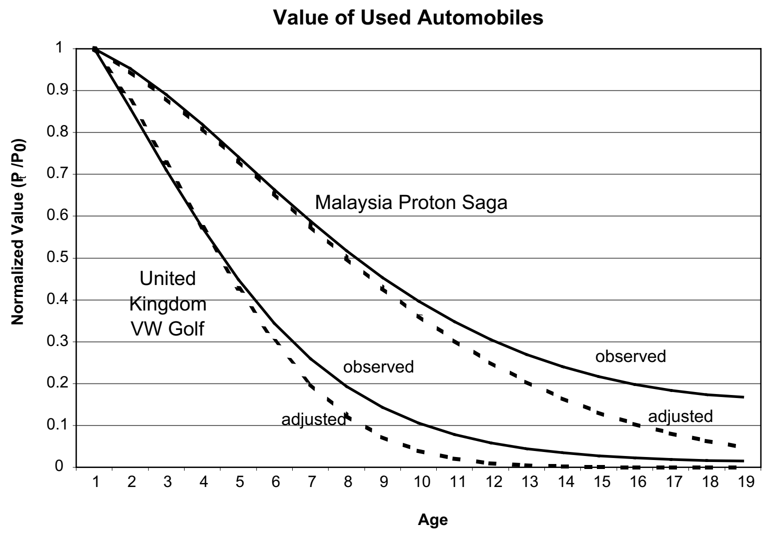

Figure 1. Value of used automobiles.

are higher in the United Kingdom than they are in Malaysia. A 10 year old car in the UK is worth only 10% of a new car's value; in Malaysia it still retains 40% of a new car's value.

Third, using adjusted prices substantially alters the depreciation curve. Because of the disproportionate devaluation of older cars the curve falls faster at its right tail. Given the assumed longer mean service life, this effect is more pronounced in developing countries.

Fourth, Figure 1 suggests that the depreciation curve in both OECD countries and non-OECD countries is convex or a straight line rather than concave. That is, depreciation follows a geometric or a straight-line pattern rather than a one-hoss shay path.

Fifth, despite relatively high goodness to fit values, the significance especially of the high-order age terms is comparatively low for most car models. Only very few car models exhibit consistently significant coefficients. The car models depicted in Figure 1, therefore, are exceptions. Hence, we estimated two restricted models allowing only for either straight-line depreciation or geometric depreciation.

Applying a linear depreciation pattern, i.e. using constant amounts of depreciation, the value of the asset (P) at time (t) is calculated as

$$P_t = (1 - \delta t)P_0, \tag{13}$$

where (δ) depicts the annual depreciation and (t) the age of the asset. P_0 is the price of a new automobile.

As for the geometric approach we chose the logarithmic type:

$$P_t = \mathrm{e}^{-\delta t} P_0. \tag{14}$$

Equations (12) and (14) were estimated separately for all 54 automobile types. Tables 7 and 8 show the estimates for the linear and the geometric pattern using observed automobile prices.

Both equation types show comparatively high determination coefficients with R^2 mostly being higher than 0.8. Thus, both methods of depreciation appear to be a good approximation to reality. Since the dependent variables of the linear and the geometric estimates are different a quasi R^2 was calculated to make both approaches comparable.[5] Except for four car models for which the straight-line method has a slight edge, the geometric pattern appears to be superior. This squares with the findings of prior studies in which the geometric depreciation pattern is referred to as the best approximation to real automobile depreciation (e.g. Wykoff 1970, 1973; Jorgenson 1973; Peles 1988).

Using observed price data, the linear model yields a constant depreciation rate lying between 1.5% and 8.8% of a new car's value per year. The respective values for the logarithmic model are between 5.5% and 24.9% per year. In both models the average rates are considerably higher for OECD countries than they are for non-OECD countries (see Table 11). For the linear approach the averages are 5.43% and 3.74%, respectively. For the geometric approach this is 16.86% and 10.33%. This confirms the hypothesis that the economic life of automobiles in poor countries is significantly longer than it is in wealthy countries. However, these depreciation rates are considerably lower than those calculated in prior studies. This is due to two reasons: technological change over time and the correction for the censored sample bias.

Peles (1988) used observed price data and found average depreciation rates of 24% for the US between 1975 and 1985. That is, cars are being depreciated longer now than 30 years ago. Among other reasons this is due to product enhancements. Decomposing depreciation into a "technical" and a "cyclical" (= economical) component (Greenspan & Cohen 1999), it is apparent that the first has led to decreasing depreciation within the last decades. For the U.S. it can be shown that the model years from 1970 forward are characterized by higher durability. This is true despite the decreasing average size of passenger cars, especially between 1980 and 1990. However, this trend appears to be reversed in more recent years (Davis 2001).

Figure 2 shows the strong influence of the "cyclical" component on the economic life of an automobile. Depicted are age-price combinations of two vehicles of comparable size in India (*Hindustan Ambassador*) and in the U.S. (*Honda Civic*). For the sake of comparability the prices are given in purchasing power parities (PPP). The graphic suggests that the Indian vehicle is significantly more expensive than the American car is and it has a far longer

Table 7. Depreciation of selected car models in OECD countries – observed prices.

Country	Car model	Linear depreciation			Geometric depreciation			
		a_0	δ	R^2	a_0	δ	R^2	quasi R^2
Australia	Toyota Camry	1.02	−0.063	0.80	0.18	−0.119	0.85	0.79
		[117.6]	[−39.9]		[9.9]	[−24.9]		
Australia	Honda Civic	1.04	−0.062	0.77	0.19	−0.109	0.76	0.76
		[16.3]	[−8.3]		[1.8]	[−7.6]		
Denmark	VW Golf	0.79	−0.052	0.80	−0.10	−0.126	0.90	0.91
		[44.4]	[−15.5]		[−8.5]	[−22.1]		
Germany	VW Golf 1.6/1.8	0.90	−0.072	0.87	0.21	−0.219	0.91	0.92
		[64.4]	[−31.4]		[8.2]	[−32.4]		
Germany	Opel Astra	0.76	−0.056	0.76	0.26	−0.249	0.81	0.93
		[23.8]	[−17.4]		[1.4]	[−22.6]		
Germany	Opel Omega	0.52	−0.034	0.63	−0.28	−0.206	0.78	0.95
		[13.3]	[−7.7]		[−1.7]	[−9.3]		
Germany	BMW 316i	0.89	−0.077	0.89	0.11	−0.212	0.91	0.93
		[90.6]	[−35.7]		[5.4]	[−29.0]		
Germany	BMW 520I	0.83	−0.069	0.88	0.07	−0.192	0.90	0.90
		[185.7]	[−92.4]		[7.3]	[−87.4]		
France	VW Golf	0.89	−0.067	0.77	0.00	−0.152	0.91	0.86
		[40.9]	[−13.3]		[0.0]	[−22.2]		
Ireland	VW Golf 1.6/1.8	0.99	−0.088	0.86	0.10	−0.154	0.89	0.88
		[36.8]	[−17.1]		[2.9]	[−19.9]		
Italy	BMW 318i	0.83	−0.070	0.89	0.07	−0.197	0.92	0.92
		[49.3]	[−23.0]		[2.2]	[26.4]		
Mexico	VW Jetta	0.65	−0.043	0.77	−0.34	−0.112	0.84	0.79
		[18.8]	[−10.5]		[−5.8]	[−15.7]		
New Zealand	Toyota Corolla	0.62	−0.039	0.64	−0.35	−0.110	0.64	0.68
		[51.6]	[−23.1]		[−11.1]	[−20.0]		

Norway	VW Golf	0.78	−0.044	0.87	0.02	−0.144	0.94	0.93
		[114.5]	[−37.5]		[1.3]	[−43.6]		
Austria	VW Golf	0.83	−0.058	0.89	0.09	−0.182	0.88	0.94
		[70.5]	[−30.5]		[2.9]	[−26.8]		
Poland	VW Golf 1.6/1.8	0.73	−0.039	0.80	−0.00	−0.134	0.95	0.93
		[27.6]	[−12.7]		[−0.1]	[−27.2]		
Poland	Toyota Corolla	0.80	−0.053	0.87	−0.08	−0.127	0.89	0.89
		[50.8]	[−25.8]		[−3.0]	[−38.4]		
Poland	VW Passat	0.71	−0.046	0.81	0.04	−0.163	0.95	0.95
		[25.3]	[−13.2]		[1.1]	[−32.9]		
Sweden	VW Golf	0.74	−0.051	0.85	−0.10	−0.145	0.91	0.88
		[108.4]	[−37.5]		[−7.6]	[−44.0]		
Switzerland	VW Golf 1.6/1.8	0.81	−0.052	0.88	0.10	−0.177	0.87	0.92
		[53.7]	[−29.5]		[2.4]	[−23.2]		
UK	VW Golf 1.6/1.8	0.50	−0.032	0.71	−0.05	−0.215	0.87	0.91
		[21.9]	[−14.9]		[−2.8]	[−26.0]		
UK	Toyota Corolla	0.84	−0.055	0.77	0.38	−0.199	0.80	0.79
		[21.4]	[−13.1]		[3.1]	[−12.7]		
UK	BMW 318i	0.55	−0.034	0.76	0.19	−0.216	0.85	0.87
		[22.8]	[−15.2]		[2.7]	[23.9]		
USA	Cadillac Seville	0.69	−0.049	0.77	−0.14	−0.163	0.83	0.93
		[40.9]	[−15.8]		[−3.2]	[−17.7]		
USA	Toyota Camry	0.73	−0.051	0.85	−0.01	−0.168	0.93	0.91
		[76.1]	[−37.7]		[−0.7]	[−53.2]		
USA	Honda Accord	0.82	−0.062	0.84	0.14	−0.191	0.89	0.89
		[88.7]	[−48.1]		[8.6]	[−57.8]		
USA	Honda Civic	0.65	−0.049	0.79	−0.15	−0.172	0.86	0.88
		[65.0]	[−31.1]		[−8.0]	[−46.0]		

Heteroscedasticity consistent *t*-statistics in brackets.

Table 8. Depreciation of selected car models in non-OECD countries– observed prices.

Country	Car model	Linear Depreciation			Geometric Depreciation			
		a_0	δ	R^2	a_0	δ	R^2	quasi R^2
Egypt	Honda Civic	0.49	−0.021	0.71	−0.52	−0.079	0.84	0.80
		[11.0]	[−5.6]		[−5.4]	[−9.8]		
Brazil	VW Gol	0.68	−0.036	0.76	−0.24	−0.104	0.93	0.83
		[51.1]	[−22.4]		[−14.1]	[−58.0]		
Brazil	Ford Escort	1.00	−0.056	0.85	0.25	−0.124	0.92	0.91
		[58.5]	[−18.6]		[10.1]	[−25.2]		
India	Hindustan Ambassador	0.50	−0.015	0.51	−0.69	−0.055	0.58	0.64
		[20.5]	[−11.6]		[−12.9]	[−13.4]		
India	Maruti 800	0.84	−0.043	0.76	−0.03	−0.095	0.80	0.82
		[86.2]	[−39.0]		[−2.1]	[−38.4]		
Indonesia	Toyota Corolla	0.73	−0.047	0.78	−0.20	−0.106	0.87	0.87
		[38.0]	[−16.3]		[−8.1]	[−25.6]		
Kenya	Nissan Sunny	0.56	−0.031	0.60	−0.38	−0.109	0.68	0.66
		[22.9]	[−13.7]		[−6.5]	[−19.9]		
Kenya	Peugeot 504	0.59	−0.029	0.70	−0.30	−0.099	0.67	0.74
		[28.0]	[−14.3]		[−6.0]	[−17.8]		
Kenya	Toyota Hilux	0.68	−0.028	0.61	−0.29	−0.068	0.69	0.59
		[30.9]	[−15.3]		[−7.1]	[−17.4]		
Colombia	Mazda 323	0.52	−0.023	0.81	−0.44	−0.083	0.82	0.84
		[19.4]	[−9.9]		[−5.8]	[−9.5]		
Malaysia	Honda Accord	0.78	−0.049	0.89	0.16	−0.158	0.90	0.92
		[40.7]	[−21.1]		[3.8]	[−24.8]		
Malaysia	Proton Saga/Wira	0.88	−0.052	0.97	0.03	−0.112	0.98	0.96
		[176.1]	[−85.4]		[3.1]	[−95.4]		
Malawi	Toyota Corolla	1.15	−0.059	0.71	0.37	−0.099	0.73	0.76
		[19.3]	[−10.8]		[4.5]	[−12.9]		

Namibia	Toyota Hilux	0.67	−0.030	0.41	−0.40	−0.065	0.50	0.47
		[12.7]	[−5.3]		[−5.1]	[−6.2]		
Namibia	VW Golf	0.77	−0.047	0.69	−0.16	−0.119	0.82	0.81
		[14.8]	[−8.2]		[−2.2]	[−14.9]		
Philippines	Toyota Corolla	0.62	−0.030	0.68	−0.28	−0.104	0.76	0.79
		[37.5]	[−14.6]		[−5.3]	[−11.3]		
Philippines	Mitsubishi Lancer	0.60	−0.029	0.71	−0.36	−0.093	0.83	0.80
		[38.1]	[−19.8]		[−12.7]	[−29.9]		
Philippines	Mitsubishi Galant	0.65	−0.032	0.80	−0.03	−0.129	0.93	0.93
		[41.5]	[−18.5]		[−0.8]	[−22.7]		
Romania	VW Golf	0.87	−0.055	0.85	0.00	−0.137	0.89	0.89
		[37.2]	[−19.4]		[0.1]	[−23.0]		
Romania	Opel Vectra	0.79	−0.058	0.88	−0.11	−0.130	0.90	0.89
		[76.0]	[−34.9]		[−5.5]	[−29.1]		
Zimbabwe	Mazda 323	0.58	−0.025	0.73	−0.37	−0.084	0.76	0.77
		[23.6]	[−13.9]		[−8.4]	[−20.0]		
South Africa	VW Golf	0.67	−0.034	0.58	−0.22	−0.106	0.66	0.69
		[20.2]	[−11.7]		[−2.7]	[−13.0]		
South Africa	Toyota Corolla	0.63	−0.036	0.81	−0.27	−0.119	0.89	0.91
		[28.5]	[−17.8]		[−6.7]	[−29.9]		
Swaziland	Nissan 1400	0.67	−0.032	0.74	−0.29	−0.085	0.76	0.81
		[38.3]	[−8.5]		[−6.4]	[−7.7]		
Swaziland	Toyota Corolla	0.68	−0.033	0.53	−0.20	−0.092	0.57	0.53
		[24.9]	[−10.5]		[−2.8]	[−9.9]		
UAE[a]	Toyota Corolla	0.73	−0.049	0.80	−0.17	−0.127	0.91	0.89
		[18.3]	[−9.8]		[−3.4]	[18.9]		
Uruguay	VW Gol	0.61	−0.030	0.76	−0.26	−0.107	0.85	0.85
		[38.7]	[−18.7]		[−7.3]	[−16.7]		

[a] United Arab Emirates. Heteroscedasticity consistent *t*-statistics in brackets.

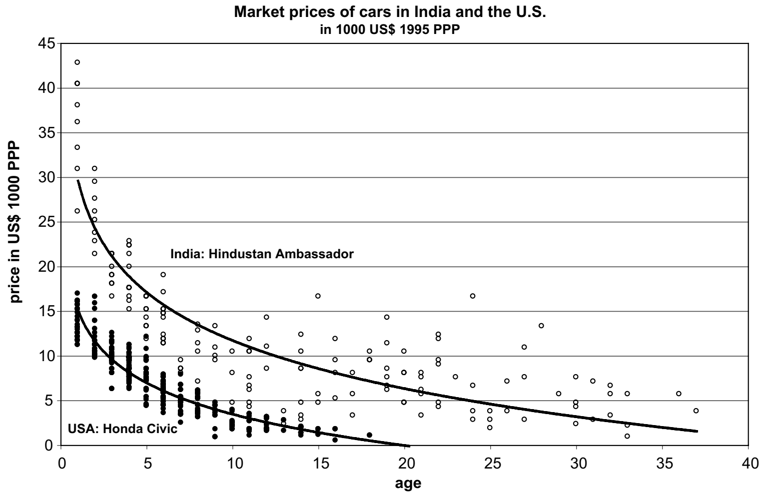

Figure 2. Market prices of cars in India and the U.S. in 1000 US$ 1995 PPP.

economic life: The *Honda* in the U.S. vanishes totally from the market after 19 years, whereas about 10% of all offered *Hindustans* are older than 30 years.

Other studies corrected the censored sample bias and found depreciation rates for the U.S. which are substantially over 30% (e.g., Jorgensen & Yun 1991; Jorgensen 1996;). These rates are close to the results for the adjusted price data given in Tables 9 and 10.

First, when adjusted prices are used, depreciation rates increase significantly for both OECD and non-OECD countries. Due to the shorter mean service life, price adjustments have a stronger impact on depreciation rates of OECD countries. Table 9 shows that the average geometric depreciation rate for OECD countries grows from 17% to about 31%, that one of non-OECD countries increases from 10% to 14.5%. Similar increases, however to a somewhat lesser extent, were computed for the straight-line pattern.

Second, when correcting for the censored sample bias the right tail of the depreciation curve bends further down entailing a straightening of the depreciation curve. Hence, the depreciation curve tends to become more similar to a straight-line pattern. Again, due to the assumptions regarding the mean service life, OECD countries are more affected than non-OECD countries. For OECD countries, the superiority of the logarithmic approach over the straight line pattern disappears. Both models become equally satisfactory estimates. In contrast, the superiority of geometric depreciation pattern in non-OECD remains almost unaffected by this procedure. Overall, the geometric approach appears to be the better approximation to real depreciation rates. Referring to observed price data the linear approach has an edge in goodness to fit in only

Table 9. Depreciation of selected car models in OECD countries – adjusted prices.

Country	Car model	Linear depreciation			Geometric depreciation			
		a_0	δ	R^2	a_0	δ	R^2	Quasi R^2
Australia	Toyota Camry	1.06	−0.076	0.86	0.42	−0.197	0.86	0.78
		[127.1]	[−53.6]		[12.8]	[−21.4]		
Australia	Honda Civic	1.12	−0.082	0.88	0.54	−0.191	0.89	0.77
		[16.4]	[−12.0]		[3.4]	[−11.1]		
Denmark	VW Golf	0.72	−0.055	0.83	0.10	−0.221	0.89	0.93
		[45.3]	[−17.2]		[2.0]	[−18.3]		
Germany	VW Golf 1.6/1.8	0.91	−0.079	0.89	0.57	−0.348	0.91	0.87
		[62.5]	[−30.7]		[12.3]	[−33.0]		
Germany	Opel Astra	0.67	−0.053	0.76	0.97	−0.443	0.92	0.86
		[22.2]	[−17.4]		[11.2]	[−47.5]		
Germany	Opel Omega	0.50	−0.035	0.62	1.39	−0.518	0.91	0.79
		[12.3]	[−7.6]		[6.9]	[−20.7]		
Germany	BMW 316i	0.90	−0.084	0.90	0.31	−0.308	0.88	0.92
		[86.8]	[−33.9]		[8.0]	[−22.1]		
Germany	BMW 520I	0.85	−0.079	0.88	0.38	−0.296	0.91	0.86
		[192.1]	[−104.4]		[24.2]	[−85.9]		
France	VW Golf	0.90	−0.074	0.82	0.18	−0.225	0.93	0.88
		[47.8]	[−15.2]		[5.3]	[−20.8]		
Ireland	VW Golf 1.6/1.8	1.02	−0.101	0.90	0.22	−0.204	0.92	0.89
		[40.4]	[−23.3]		[6.3]	[−27.0]		
Italy	BMW 318i	0.85	−0.080	0.91	0.38	−0.298	0.91	0.89
		[45.2]	[−21.8]		[5.0]	[−17.6]		
Mexico	VW Jetta	0.66	−0.047	0.81	−0.27	−0.132	0.87	0.82
		[19.6]	[−12.0]		(−4.7)	(−17.0)		
New Zealand	Toyota Corolla	0.65	−0.049	0.78	−0.07	−0.175	0.77	0.78
		[61.7]	[−35.3]		[−1.5]	[−21.5]		
Norway	VW Golf	0.78	−0.051	0.85	0.85	−0.376	0.87	0.80
		[88.4]	[−28.3]		[13.3]	[−26.6]		

Table 9. (Continued)

Country	Car model	Linear depreciation			Geometric depreciation			
		a_0	δ	R^2	a_0	δ	R^2	Quasi R^2
Austria	VW Golf	0.83	−0.066	0.90	0.55	−0.338	0.87	0.91
		[61.2]	[−27.0]		[7.1]	[−21.3]		
Poland	VW Golf 1.6/1.8	0.74	−0.043	0.83	0.48	−0.226	0.93	0.91
		[26.6]	[−12.6]		[6.6]	[−21.3]		
Poland	Toyota Corolla	0.81	−0.058	0.90	0.03	−0.159	0.92	0.89
		[54.5]	[−32.2]		[0.9]	[−32.2]		
Poland	VW Passat	0.72	−0.049	0.83	0.41	−0.233	0.93	0.94
		[25.2]	[−13.6]		[5.6]	[−21.5]		
Sweden	VW Golf	0.76	−0.062	0.89	0.30	−0.274	0.89	0.84
		[97.9]	[−35.6]		[8.3]	[−29.3]		
Switzerland	VW Golf 1.6/1.8	0.80	−0.058	0.88	0.73	−0.365	0.89	0.84
		[46.9]	[−26.0]		[7.9]	[−25.5]		
UK	VW Golf 1.6/1.8	0.48	−0.033	0.69	1.15	−0.477	0.94	0.70
		[19.8]	[−14.4]		[9.5]	[−34.3]		
UK	Toyota Corolla	0.82	−0.062	0.79	1.53	−0.421	0.92	0.62
		[19.6]	[−13.4]		[9.8]	[−24.7]		
UK	BMW 318i	0.52	−0.036	0.72	1.79	−0.491	0.93	0.81
		[18.5]	[−13.4]		[12.7]	[−31.8]		
USA	Cadillac Seville	0.70	−0.050	0.79	0.69	−0.378	0.92	0.88
		[38.4]	[−16.3]		[8.8]	[−24.9]		
USA	Toyota Camry	0.75	−0.060	0.88	0.57	−0.323	0.92	0.85
		[72.1]	[−36.6]		[13.8]	[−42.3]		
USA	Honda Accord	0.84	−0.071	0.87	0.68	−0.338	0.92	0.83
		[87.0]	[−49.5]		[21.8]	[−62.9]		
USA	Honda Civic	0.67	−0.056	0.84	0.43	−0.326	0.92	0.83
		[63.2]	[−32.4]		[11.5]	[−48.7]		

Heteroscedasticity consistent *t*-values in brackets.

Table 10. Depreciation of selected car models in non-OECD countries – adjusted prices.

Country	Car model	Linear Depreciation			Geometric Depreciation			
		a_0	δ	R^2	a_0	δ	R^2	quasi R^2
Egypt	Honda Civic	0.52	−0.025	0.80	−0.26	−0.114	0.91	0.85
		[12.7]	[−7.5]		[−2.5]	[−10.4]		
Brazil	VW Gol	0.70	−0.041	0.81	−0.05	−0.151	0.92	0.86
		[53.2]	[−25.6]		[−1.7]	[−25.9]		
Brazil	Ford Escort	1.02	−0.062	0.89	0.46	−0.171	0.93	0.90
		[65.5]	[−22.9]		[12.1]	[−22.4]		
India	Hindustan Ambassador	0.52	−0.020	0.68	−0.14	−0.141	0.89	0.89
		[22.0]	[−15.7]		[−2.9]	[−27.7]		
India	Maruti 800	0.86	−0.048	0.81	0.06	−0.114	0.86	0.86
		[93.9]	[−48.2]		[3.8]	[−44.9]		
Indonesia	Toyota Corolla	0.74	−0.049	0.80	−0.17	−0.113	0.88	0.88
		[39.9]	[−17.8]		[−7.2]	[−28.3]		
Kenya	Nissan Sunny	0.58	−0.034	0.66	−0.24	−0.130	0.76	0.70
		[24.5]	[−15.8]		[−4.4]	[−25.3]		
Kenya	Peugeot 504	0.61	−0.033	0.77	−0.10	−0.127	0.77	0.78
		[32.6]	[−18.8]		[−2.2]	[−25.2]		
Kenya	Toyota Hilux	0.70	−0.033	0.69	−0.15	−0.093	0.78	0.65
		[32.8]	[−20.6]		[−3.0]	[−18.0]		
Colombia	Mazda 323	0.57	−0.030	0.91	−0.06	−0.142	0.91	0.92
		[22.8]	[−15.2]		[0.7]	[−12.8]		
Malaysia	Honda Accord	0.79	−0.051	0.90	0.37	−0.197	0.88	0.90
		[41.5]	[−22.1]		[4.8]	[−17.1]		
Malaysia	Proton Saga/Wira	0.89	−0.057	0.98	0.12	−0.135	0.97	0.95
		[197.6]	[−111.1]		[7.9]	[−69.2]		
Malawi	Toyota Corolla	1.19	−0.066	0.77	0.50	−0.117	0.81	0.82
		[21.4]	[−12.9]		[6.7]	[−17.1]		
Namibia	Toyota Hilux	0.69	−0.034	0.50	−0.32	−0.083	0.63	0.56
		[13.5]	[−6.5]		[−4.3]	[−8.2]		

Table 10. (Continued)

Country	Car model	Linear Depreciation			Geometric Depreciation			
		a_0	δ	R^2	a_0	δ	R^2	quasi R^2
Namibia	VW Golf	0.79	−0.052	0.74	−0.00	−0.158	0.90	0.85
		[15.7]	[−9.4]		[0.0]	[−19.4]		
Philippines	Toyota Corolla	0.63	−0.033	0.73	−0.07	−0.144	0.83	0.81
		[40.4]	[−17.3]		[−1.2]	[−15.1]		
Philippines	Mitsubishi Lancer	0.62	−0.033	0.77	−0.16	−0.127	0.89	0.85
		[41.0]	[−24.0]		[−4.9]	[−32.4]		
Philippines	Mitsubishi Galant	0.66	−0.034	0.83	0.30	−0.183	0.95	0.91
		[43.1]	[−20.4]		[6.5]	[−29.2]		
Romania	VW Golf	0.88	−0.059	0.88	0.17	−0.186	0.90	0.89
		[38.2]	[−21.4]		[3.7]	[−23.2]		
Romania	Opel Vectra	0.80	−0.062	0.90	−0.07	−0.146	0.91	0.90
		[79.0]	[−39.5]		[−2.9]	[−26.6]		
Zimbabwe	Mazda 323	0.61	−0.030	0.82	−0.12	−0.122	0.86	0.84
		[26.1]	[−18.1]		[−2.8]	[−30.3]		
South Africa	VW Golf	0.71	−0.041	0.69	0.23	−0.174	0.86	0.77
		[22.6]	[−15.1]		[3.4]	[−26.1]		
South Africa	Toyota Corolla	0.65	−0.040	0.86	−0.02	−0.165	0.94	0.93
		[31.2]	[−21.6]		[−0.5]	[−37.8]		
Swaziland	Nissan 1400	0.69	−0.036	0.82	−0.18	−0.112	0.86	0.87
		[46.6]	[−12.1]		[−4.4]	[−10.8]		
Swaziland	Toyota Corolla	0.70	−0.037	0.61	−0.07	−0.113	0.67	0.58
		[28.4]	[−13.9]		[−1.0]	[−13.8]		
UAE[a]	Toyota Corolla	0.76	−0.063	0.87	0.33	−0.267	0.93	0.93
		[18.5]	[−10.9]		[2.8]	[−12.3]		
Uruguay	VW Gol	0.63	−0.036	0.84	0.14	−0.191	0.89	0.89
		[42.3]	[−24.0]		[2.4]	[−18.6]		

[a] United Arab Emirates. heteroscedasdicity consistent *t*-values in brackets.

four out of 54 cases. Regarding adjusted data this is the case for not more than 17 out of 54 vehicles.

4. Determinants of the depreciation rates

Although this paper is primarily focused on computing and comparing depreciation rates, this section will give a short evaluation of the main determinants of the depreciation rates found in the previous section. Given the results from section 3 we will focus on geometric depreciation rates based on censored bias corrected prices data only. In this case, the depreciation rate is identical with the rate of decay of the asset's service. Alternatively, the decay rate in period t can also be interpreted as the probability that the asset will fail in period *t* (Parks 1979). The literature on automobile mortality and scrappage and its determinants is vast in both theoretical and empirical respect (e.g. Parks 1977, 1979; Manski & Goldin 1982 (unpubl. ms.); Berkovec 1985).

The decay of an automobile's service stream depends on maintenance applied over the vehicle's lifetime as well as on the built-in durability characteristics embodied in the car (Parks 1979).[6] Parks (1977, 1979), Hamilton and Macauley (1996), Greenspan and Cohen (1999) and others find decay rates to be dependent on income, the vehicle usage (e.g. vehicles miles driven), and the relative price of new vehicles to repair cost. It is expected that income and usage variables are positively related to scrappage rates whereas the relative price ratio is expected to have a negative effect. The literature discusses the impact of fuel prices equivocally. One the one hand, it is argued that increasing gasoline prices proved an incentive to replace older, less efficient cars with efficient new cars (e.g. Eskeland & Feyzioğlu 1997). Hence, this results in a positive relation between gasoline prices and scrappage rates. On the other hand, Kahn (1986), as well as Greenspan and Cohen (1999), find a highly significant negative relationship between fuel prices and scrappage rates. Presumably, higher gasoline prices lead to less miles driven and less wear and tear.

Table 11. Depreciation rates for OECD and non-OECD countries.

	Observed prices	Adjusted prices
Straight-line model		
OECD countries	5.43	6.11
Non-OECD countries	3.74	4.22
Geometric model		
OECD countries	16.86	30.67
Non-OECD countries	10.33	14.50

Table 12. Determinants of geometric depreciation rates.

	All	OECD countries	Non-OECD countries
Income	0.055**	0.085**	0.084**
	(7.39)	(7.69)	(5.15)
New car price	−0.004**	−0.004	−0.002
	(−3.80)	(−0.70)	(−1.49)
Gasoline price	0.032	1.115**	0.025
	(0.53)	(5.38)	(0.46)
Dummy variable	−0.324**	–	−0.321**
(truck = 1, car = 0)	(−8.49)		(−4.18)
Constant	2.671**	1.443**	2.459**
	(19.86)	(3.82)	(13.49)
SSE	2.540	1.051	0.390
White's test	13.798[a]	4.843[b]	10.331[a]
R^2	0.790	0.692	0.765
adj. R^2	0.772	0.652	0.729

Own calculations. All parameters refer to a positive δ in %. *t*-Values in parenthesis.
*Significance >5%, ** Significance >1%; [a] the critical value of χ^2 (12) at the 5% level is 21.026; [b] the critical value of χ^2 (9) at the 5% level is 16.919.

In the following we will refer to the positive geometric depreciation rates given in Tables 9 and 10 and ascertain their main long-term determinants by applying a simple cross-sectional analysis.[7] However, not all of the relevant variables mentioned above are available for our sample. We, therefore, will focus on income, new car prices, and gasoline prices only. We included all three variables into the function and estimated the following cross-section equation for the 54 car types:

$$\delta_i = \exp(\alpha_0 + \alpha_1 Y_i + \alpha_2 \mathrm{CARP}_i + \alpha_3 \mathrm{GASP}_i + \alpha_4 \mathrm{DTR} + \varepsilon_i), \qquad (15)$$

where Y_i denotes per-capita private consumption in country i measured in \$1000. We took private consumption in lieu of income for two reasons: First, it has a closer link to private automobiles than the GDP does. Second, private consumption is often taken as proxy variable for lifetime income since it represents long-term expectations. Hence, it is less prone to singular events than income and, therefore, more appropriate to represent long-run adjustments. CARP denotes the list price of a new car in \$1000 and GASP the gasoline price in \$ per liter. All variables are converted into purchasing power parities (PPP). DTR denotes a dummy variable for pick-up trucks. It has a value of 1 if the vehicle is a pick-up truck and 0 otherwise.

Given the extremely limited data set, the results presented in Table 12 can only be regarded as suggestive; this applies in particular for the sub-samples of OECD and non-OECD countries which each consists of only 27 data points.

Income appears to be the dominant determinant of depreciation rates. It has a positive sign and is significant at the 1%-level for the entire sample as well as for the sub-samples. The marginal effect, $\alpha_1\delta_i$, increases with the size of the dependent variable and is, therefore, higher in industrialized countries than it is in developing countries. For the whole sample the effect of an income increase by \$1000 is an increase of the depreciation rate by about 1.3% (from 22.6% to 23.9%). Given an average depreciation rate of about 30% in OECD countries, an income increase by \$1000 PPP leads to an increase in the mean depreciation rate by about 2.5% (to 32.5%). In contrast, the same income increase in non-OECD countries leads to a higher depreciation of only 1.15%. However, since for the majority of the sample \$PPP > \$, the marginal effect of a consumption increase by \$1000 will be somewhat higher for the whole sample and in particular for developing countries.[8] Given the average purchasing power of \$1 = \$3.04 PPP in developing countries compared to \$1.06 PPP in OECD countries, the marginal effect becomes bigger in non-OECD countries (3.6%) than in OECD countries (2.7%) if dollar values are assumed.

Prices of new cars are similarly significant. The variable has a negative sign and is significant at the 1%-level for the entire sample. For the two sub-samples, however, the price variable is insignificant. The estimated parameter of -0.004 suggests a marginal effect of a change in new car prices by \$1000 PPP of 0.09%. When dollar values are assumed this will be 0.19%. Compared to the private consumption, the influence of changes in new car prices on the depreciation rate of cars is considerably lower. This is due to two different effects. On the one hand, increasing automobile prices will decrease the relative price of the vehicle in use compared to a new automobile. This will lead to decreasing depreciation rates and a longer economic life. On the other hand, increasing car prices will lead to substitution effects: Smaller and less expensive cars will substitute bigger cars. Since larger cars depreciate slower than smaller ones (e.g., RWI, 2002), this will lead to increasing depreciation rates, other things being equal. Overall, the first effect prevails, but – as expressed by the coefficient – it has a smaller impact than the income effect.

The estimation of Equation (15) shows no significant influence of gasoline prices for the whole sample. However, taking the estimates for OECD countries at face value, the high *t*-value suggests a positive relationship between fuel prices and depreciation rates. Since many European countries recently increased their gasoline taxes, which lead to higher fuel prices, this estimate might be misleading. Depreciation rates depend on long standing income and taxes rather than on immediate ups and downs. However, even fuel from prior years or an average do not show different results. Overall, due to the statistical insignificance we cannot verify any of the hypotheses mentioned above.

The sample contains three pick-up trucks, all of them in non-OECD countries. We included a dummy variable for trucks for two reasons. First, the technical traits of pick-up trucks are different from those of automobiles. Their higher robustness suggests a longer lifetime. Second, pick-up trucks are often used for a business-related purpose and breakdowns might be associated with higher opportunity cost. Both reasons will lead to a lower depreciation rate which is expressed by the sign and the significance of the dummy variable DTR. As the last variable, the intercept of the equation indicates an autonomous depreciation rate for the whole sample of about 14%.

5. Summary

Since older automobiles are less efficient and technologically obsolete, over-aged capital stocks are associated with higher environmental burden. Hence, influencing the age distribution of car stocks, especially in emerging nations, is one key to a successful environmental policy in the transportation sector. Given the rapid growth of over-aged car stocks in many poor countries, the knowledge of depreciation data, depreciation patterns, and their determinants in developing countries appears to become increasingly important. The purpose of this paper is to contribute to this knowledge.

This paper refers to used automobile prices and generates depreciation data for a sample of 54 cars from 30 countries. After outlining some theoretical aspects a third-order polynomial equation form was applied to estimate depreciation rates. This equation allows for a wide range of depreciation patterns, such as the one-hoss shay, straight-line, and geometric. The equation was estimated for observed data and for data which were corrected for the so-called censored data bias. Parameter estimates suggest a convex depreciation pattern, but were significant only for a few automobile models. Hence, in a second step, we restricted the equation form and estimated merely straight-line and geometric depreciation forms. We found the following results: (1) Overall, the geometric approach appears to be the better approximation to real depreciation rates. (2) Depreciation data are significantly lower in developing countries than in industrialized countries. (3) When using corrected price data, the depreciation rates increase substantially. This effect is particularly pronounced in developed countries. An average depreciation rate of about 31% for OECD countries squares with the results of prior studies using comparable techniques. In contrast, automobiles in non-OECD countries depreciate at an annual rate of below 15%.

Besides prices for new cars, the economic life of automobiles is particularly dependent on real income. In the long-run an income increase by $1000 PPP is likely to increase the annual depreciation rate by 1.3%. The marginal effect is

Table 13. Size of new registrations in selected European and African countries.

	Engine displacement (in cc)	Motor power (in CV)[a]
France (1995)	1635	5.6
Germany (1995)	1744	
Italy (1995)	1456	
United Kingdom (1995)	1678	
Burundi (1993)		8.3
Central African Republic (1991)		6.5
Kenya (1985)	1760	
Morocco (1997)		8.1

Source: European Conference of Ministers of Transport ECMT (1999b), République du Burundi (1994), République Centralafricaine (1992), Republic of Kenya (1986), Royaume du Maroc (1998).
[a]cheval à vapeur (fiscal horse power)

lower for developing countries and higher for developed countries. However, when referring to dollar values, that are not corrected for PPP, this increase will be 2.7% in OECD countries and 3.6% in non-OECD countries. This is due to the higher purchasing power of a dollar in non-OECD countries.

Increasing income is the crucial factor in decreasing a car stock's age structure and keeping the automobile fleet technologically updated. This is, however, only one determinant of the fleet's efficiency; the other is the size of the average automobile. In general, a larger car tends to be less fuel efficient than a smaller car, other things being equal. The German example shows that for decades technological advances have been offset by the increasing size of the average car. For example, from 1960 to 2000 the average motor power went up from 34 hp to 93 hp. At the same time, the fleet's average fuel economy declined from 29 mpg to 27.4 mpg (BMV 2000).[9] Since the tendency towards bigger cars is income induced, increasing income releases two directly opposed effects on a car fleet's efficiency: (1) it increases the efficiency by keeping the average age of the fleet down and (2) it decreases the efficiency by boosting the demand for bigger cars.

However, this rule is not applicable for many developing countries. Here increasing income will not only lower the average age of automobiles, but also their average size. This is caused by the high fraction of imported used cars and their technological traits. Due to the technological depreciation patterns in industrialized countries ("bigger cars depreciate slower than smaller cars"), developing countries import mainly larger used automobiles. Table 13 shows selected examples regarding the size of new registrations in European and African countries. Due to the adverse selection, the average engine size of a "newly registered car" is larger in African countries than it is in European countries. That is true with respect to the engine displacement as well as to the French fiscal horse power measurement CV (*cheval á vapeur*). Accordingly, low income not only causes the average automobile to be old, but also large, thus, doubling the negative effect on fuel efficiency.

A similar effect, albeit at a lower scale, is caused by car prices. Every price decrease by $1000 will increase the overall depreciation rate by about 0.2%, i.e. price decreases help to keep the automobile fleet efficient. Due to an array of trade barriers, cars are much more expensive in developing countries than they are in industrialized countries. Lifting those barriers can help to enhance the overall fuel economy. The best example is China: The opening of the market has decreased automobile prices substantially (e.g. Economist 2003) and will lead to a technological update of the current car stock.

However, it should not be overlooked that the efficiency of the capital stock is only one determinant of the total burden on the environment. The other determinants are the size of the capital stock (car stock) and its utilization (mileage per car). Empirical studies have shown that at least the car stock and the level of income are closely correlated. Particularly in developing and emerging countries the income elasticity may be well above one (e.g. Pindyck 1979; Dargay & Gately 1999).

Appendix A. Sources of used automobile prices

Australia	Carselect.Com, Online: http://www.carselect.com.au/
Austria	Oberösterreichische Nachrichten, Linz. Online: http://194.112.170. 105/kfz/anzclu_kfz.taf
Brazil	Estadao.com.br, Sao Paulo, online: http://www.estado.estadao.com.br/suplementos/autos.html
Columbia	El Tiempo, Bogotá. Online: http://clasificados.eltiempo.terra.com.co/vehiculos/
Denmark	Volkswagen AG, Denmark, online: http://www.volkswagen.dk/
Egypt	Cars.com.eg, Cairo, online: http://cars.com.eg/
France	Le Parisien, Paris, online: http://www.parisienpa.com
Germany	Reviermarkt, Bochum, online: http://www.reviermarkt.de/
India	Automartindia, Mumbai. online: http://www.automartindia.com/
Indonesia	Kompas, Jakarta, online: http://www.kompas.com
Ireland	The Irish Times, Dublin.
Italy	BMW Italia, online: http://www.bmw.it
Kenya	The Daily Nation, Nairobi.
Malaysia	New Straits Times, Kuala Lumpur. Online: http://www.nst.com.my/

Malawi	Daily News, Blantyre The Nation, Blantyre Malawi News, Blantyre
Mexico	Reforma, Mexico City, online: http://www.reforma.com/
Namibia	The Namibian, Windhuk, online: http://www.namibian.com.na/
New Zealand	AutoNet, online: http://www.autonet.co.nz/ Autopoint, online: http://www.autopoint.co.nz
Norway	Volkswagen AG, Norway, online: www.volkswagen.no
Philippines	Manila Bulletin, Manila. online: http://www.mb.com.ph/
Poland	Gazeta Wyborcza, Warsaw. online: http://www2.gazeta.pl/
Romania	Romania Libera, Bucharest. online: http://www.romanialibera.com/
South Africa	The Sowetan, Johannesburg. online: http://www.sowetan.co.za/
Sweden	Volkswagen AG, Sweden online: http://www.volkswagen.se/begagnat/
Switzerland	Fahrzeugpool, online: http://www.fahrzeugpool.ch/ Auto-net.ch, online: http://www.autonet.ch/ Autoclick.ch, online: http://www.autoclick.ch
Swaziland	Times of Swaziland, Mbabane. online: http://www.times.co.sz/
UAE	Gulf News, Dubai. online: http://www.gulf-news.com/Classifieds/
United Kingdom	Loot Motoring, Wembley. online: http://motoring.loot.com
Uruguay	El Païs, Montevideo. online: http://www3.diarioelpais.com/edicion/
USA	The Atlanta Journal-Constitution, Atlanta. online: http://www.ajcclassifieds.com/
Zimbabwe	The Chronicle, Harare.

Notes

1. After the mythical horse-drawn cart in "The Deacon's masterpiece or, The wonderful *one-hoss shay*: a logical story" a poem by Oliver Wendall Holmes (1895). The deacon built this cart so well that it ran perfectly for a hundred years without need for repair, thus providing a constant stream of transportation services until the day when it suffered catastrophic failure. During its service life neither input decay nor output decay reduced the quantity of services provided. "You see of course if you are not a dunce, how it went to pieces all at once – all at once and nothing first – just as bubbles do when they burst".
2. For the sake of simplicity we assumed that the rentals are received on the first day of each year, so that the first year's rental is not discounted.

3. The choice of a zero value is of course arbitrary. In their paper on the depreciation of farm tractors Perry and Glyer (1990) for example generated scrap values for retired tractors according to information provided by junkyards. This information is not readily available for each automobile model in industrialized countries, let alone in developing countries.
4. The L-0 curve allows a few assets to survive very old ages, i.e., the last unit will be retired after 410% of the mean service life (Winfrey 1935).
5. This involves the following steps: First, calculate fitted values of $\ln Y_i$. Then calculate $\hat{Y}_i = \exp(\widehat{\ln Y_i} + \hat{\sigma}^2/2)$. Finally, compute the square of the correlation between Y_i and $\hat{Y}_i$ to get the quasi R^2 (e.g., Ramanathan 2002).
6. Greenspan and Cohen (1999) call this "engineering scrappage" and "cyclical scrappage".
7. As pointed out by many authors (e.g. Griffin & Gregory 1976), cross sectional data show much less multicollinearity than do time series data. Furthermore, cross sectional data are characterized by wide intercountry differences of consumption patterns and prices, which tend to be the result of long-standing national tariff, tax and subsidy policies. That makes cross sectional analyses particularly appropriate to reflect long-term rather then short-term effects.
8. Within the sample, only in Austria, Denmark, France, Germany, Ireland, Norway, Sweden, Switzerland, and the UK the purchasing power of a U.S. Dollar is less than one. In India \$1000 equals about \$4700 PPP; in Zimbabwe and Indonesia this even exceeds \$5500 PPP
9. In the 1970s and the beginning 1980s the fuel economy was even lower than 22 mpg.

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