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PETRA - The COHORT Model

PETRA Working paper No. 5

September 1998

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Prepared: JJD, MOF
Checked: MOF
Approved: MOF

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1 Introduction

This paper describes the COHORT model for licence holdings which forms part of the PETRA model complex.

Licence holding at household level is described in the LICENCE model¹, based on cross-section data. However, cross-section analysis is not capable of accounting for all factors affecting future licence holding rates. In particular, long term effects arising from the difference in behaviour between generations cannot be seen on this basis. Therefore, the COHORT model is used to modify the forecasts from the LICENCE model in order to incorporate these effects.

A predominant feature of licence holding is the slow market penetration that has occurred in the past and which is still taking place. The generation born in 1930 has, at all ages, had a significantly lower propensity to acquire a licence than later generations.

For each age level, the propensity to acquire a licence, the entry rate, has been increasing with the coming of new generations. As the entry rates increase so do the licence holding rates.

Today, the population consists of generations having had lower entry rates during their life than new generations have now. Thus, the licence holding rate today is lower than it will be when later generations with higher entry rates replace the previous generations.

It takes a lifetime for such effects to penetrate fully. For men, penetration is close to completion with almost 90% of adult men having a licence and a saturation level of about 98%.² The small difference from 90% to 98% means that the prediction of future licence holding rates can be rather exact.

Women lag somewhat behind. Today, licence holding rates are high for younger women and low for old women, resulting in an average licence holding rate of approximately 61% for women.

¹ PETRA Working Paper No. 4, The Licence Holding Model. COWI, 1997.

² Institute of Transport Economics (TØI) 1992: The National Model System for Private Transport, TØI-rapport 150/1992.

Consequently, licence holding is going to increase in the future as the generations change, independently of other factors. This has implications for the prediction of future car ownership and transport demand.

2 Data

Two data sources were possible for the COHORT model.

- The TU data,
- The central police register of licence issues.

The TU is a national transport survey with around 1000 travel diaries being collected each month.

2.1.1 The police register

There is some uncertainty regarding the reliability of the statistics on licence holdings from the police register. It does not record the licence holding status of individuals but only holds total licence holdings by age and sex.

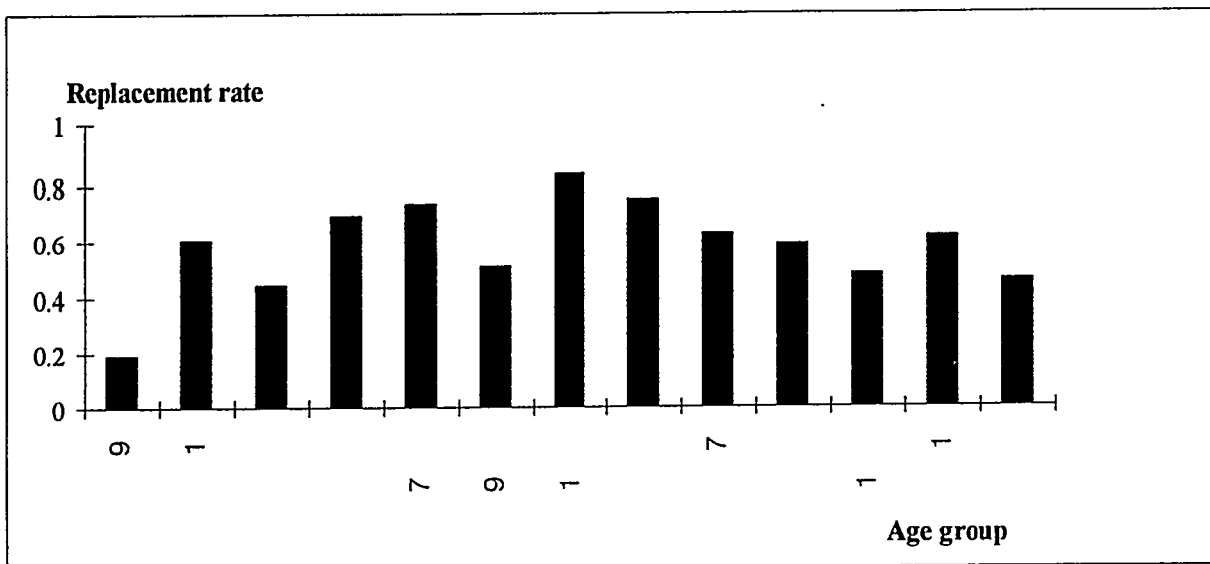
The main purpose of the register is to keep track of the actions of the authorities, issues of licences, rather than the licence holding status of individuals. Thus, a person who has obtained a licence more than once, e.g. for different categories of vehicle, can occur more than once in the register.

2.1.2 Renewals

In the period from 1990 to 1993, all licences in Denmark were required to be replaced by a new so-called EU licence. Since data on the numbers of renewals exist, this could give an indication of the total licence holding in Denmark.

Replacement or renewal was formally required as the old licence became invalid, but in practice it was possible to wait. A delay in the renewals could therefore be expected. Figure 2-1 shows licence holding rates calculated from the renewal rates.

Figure 2-1. Licence holding rates calculated from renewals, police register



The renewal rates imply unrealistically small licence holding rates, much lower than those calculated from the TU. This could be due to the renewal process not being completed yet and to issues of new licenses (for different categories of vehicles) not being registered as renewals.

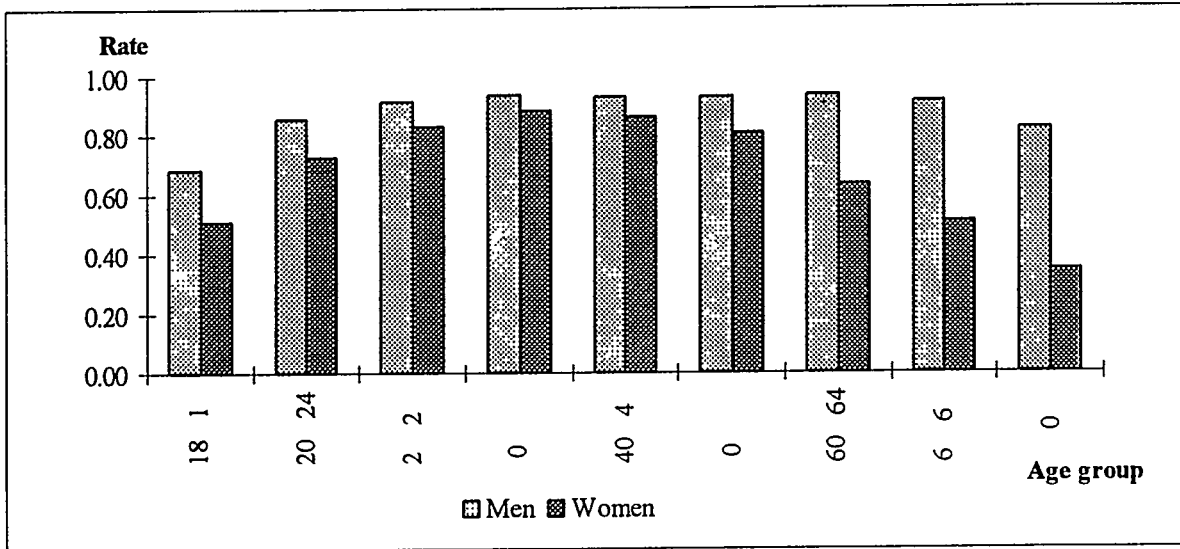
Because of the amount of uncertainty it has been decided not to use the police register on licence holdings.

2.1.3 TU data

Instead, the TU is chosen as the basis for the COHORT model, using observations from the period 1993-1995.

Using the TU it is possible to construct the data reaching many years back which is necessary for the analysis of cohort effects. Figure 2-2 shows licence holding rates calculated from the TU data.

Figure 2-2. Licence holding rates by sex and age



Entry rates

In the TU it is recorded whether the respondent has a licence and also the year when a licence was first acquired.

The year of acquisition is only recorded for respondents having a licence at the time of the interview. Some may have lost their licence on medical or other grounds, generating a selection bias. However, this potential bias is small in generations up till 50 - 60 years of age, since the exit rates in these generations are very small. Thus, direct observation of entry into licence holding is possible.

Over time the members of a specific cohort drop out because they die, resulting in small cohorts of high age. Using this approach to predict behaviour of earlier generations rests on the assumption that those who dropped out had the same average licence holdings as the ones still left in the cohort.

Exit rates

A licence is valid until the age of 70, no matter the age when the licence was issued. At 70 the licence must either be given up or renewed. Renewal requires a medical certificate, valid only for a period depending on age. Medical certificates are generally issued for the maximum period allowed, given below.

- 4 years for age groups 70 to 74,
- 2 years for age groups 75 to 79, and
- 1 year for age groups older than 80.

In the police register these renewals are registered. However, the police register only contains information about the total number of renewals in each year and nothing about how long these renewals are valid. The police statistics on renewals are not sufficiently detailed to allow for calculation of exit rates.

In the TU only people having a licence are asked when the licence was obtained. People having lost their licence are not asked when they acquired their licence

and when it was lost. Still, it could be possible to estimate the reduction in licence holding rates, exit rates, by comparing data from different years. But since the oldest person in the TU in normal years is 74, only some exit rates can be found in this way.

In connection with PETRA, information on people older than 74 have been included in the survey in the interviews conducted in 1995. Given some assumptions on the cohort effect it is possible to calculate exit rates for each age group.

3 The Cohort Model

Data of licence holdings and acquisitions can essentially be looked at in three ways.

- Cross-section
- Time series
- Cohort

Figure 3-1. Three ways to look at data

Age \ Year	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
18	cohort 1967						Cross section					
19			→					↓				
20												
21												
22												
23												
24	Time series			→								
25												
26												
27												
28												

The cross-section point of view looks at all generations at a single point of time while the time series approach follows the behaviour of each age group over time.

A cohort is here defined as people born in the same year and of the same sex. In Figure 3-1, the cohort born in 1967 is represented by the boxes following the diagonal.

In cohort analysis, a number of cohorts are followed through their life and comparisons of the different cohorts can be made. Letting cs denote a specific cohort where s is for sex, and c denotes year of birth, the licence holding rate for cohort cs in year t is expressed as

$$LH_t^{cs} = LH_{t-1}^{cs} + (S - LH_{t-1}^{cs}) \times En_t^{cs} - LH_{t-1}^{cs} \times Ex_t^{cs} \tag{1}$$

For a given cohort, the licence holding rate in year t is the licence holding rate of the previous year, plus the new entrants and minus the exits. S is an exogenous saturation rate and En_t^{cs} is the entry rate for cohort cs in year t for non-licence holders. Thus, the number of entries increases with the entry rate and the distance to the saturation rate in the previous year.

Similarly, the exit rate, Ex_t^{cs} , is the rate of people having a licence in year $t-1$ who lose it in year t . Multiplied by the holding rate of year $t-1$, the number of exits results.

4 Results

The forecast of licence holding rates for future cohorts is obtained through the analysis of time series of cohorts. These time series indicate whether entry and exit rates can be expected to be constant in the future.

Entry rates are estimated from the constructed cohort data material from the TU. Exit rates are more difficult, since it is unknown if people who have no licence at the moment have ever had one. Instead, it is chosen to use the change in licence holding rates calculated for the oldest age groups as a proxy for the exit rates.

4.1 Licence Holding Status

The following tables illustrate part of the data used. Table 4-1 shows observed shares of the total male population obtaining a licence for each year. In 1991, 48% of all 18-year-old males obtained a licence while only 5% of men aged 20 obtained one.

Table 4-1. Observed share of total population of men obtaining a licence

Year Age	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
18	0.56	0.50	0.45	0.53	0.48	0.45	0.49	0.48	0.46	0.44	0.49	0.55
19		0.16	0.23	0.28	0.19	0.23	0.32	0.22	0.28	0.27	0.28	0.31
20			0.06	0.07	0.09	0.11	0.08	0.05	0.07	0.07	0.09	0.04
21				0.04	0.05	0.05	0.06	0.03	0.05	0.05	0.03	0.06
22					0.05	0.02	0.02	0.01	0.03	0.03	0.01	0.02
23						0.02	0.01	0.01	0.02	0.01	0.01	0.03
24							0.03	0.01	0.01	0.01	0.01	0.01
25								-	0.01	-	0.01	0.01
26									-	0.01	0.01	-
27										-	0.02	-
28											0.01	0.01
29												0.01

The male cohort born in 1966 was 18 by the end of 1984. Looking at table 4-1 it is seen that 56% of these obtained a licence at the age of 18 and further 18% ob-

tained one at the age of 19. All in all 72% of this cohort had a licence by the end of 1985.

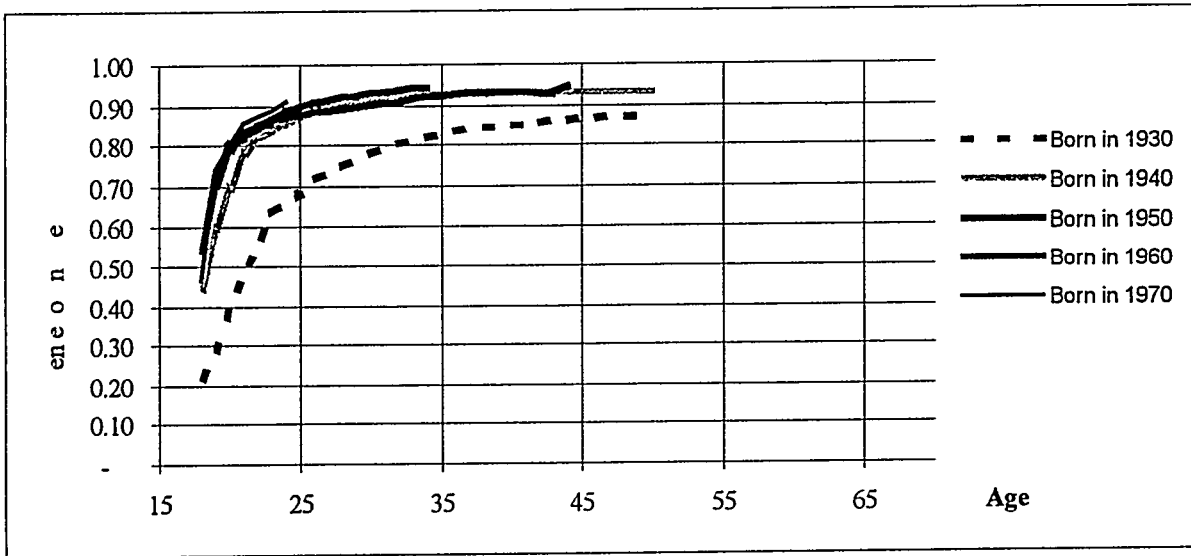
Summing these figures diagonally yields the aggregate licence holding rates for each cohort and year. This is shown in Table 4-2.

Table 4-2. Observed licence holding rates

Year Age	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
18	0.56	0.50	0.45	0.53	0.48	0.45	0.49	0.48	0.46	0.44	0.49	0.55
19		0.72	0.73	0.72	0.72	0.70	0.77	0.71	0.76	0.73	0.72	0.80
20			0.78	0.80	0.82	0.83	0.78	0.81	0.78	0.83	0.82	0.76
21				0.82	0.85	0.86	0.88	0.81	0.86	0.83	0.86	0.88
22					0.87	0.86	0.89	0.89	0.84	0.89	0.84	0.88
23						0.89	0.87	0.90	0.91	0.85	0.90	0.87
24							0.92	0.89	0.91	0.92	0.86	0.91
25								0.92	0.90	0.91	0.93	0.87
26									0.92	0.91	0.92	0.93
27										0.92	0.92	0.92
28											0.92	0.93
29												0.94

In all cohorts, the licence holding rate exceeds 0.75 at the age of 20. The data are also presented in Figure 4-1 below. The corresponding curves for women are shown in Figure 4-2.

Figure 4-1. Licence holding rates over time for different cohorts of men



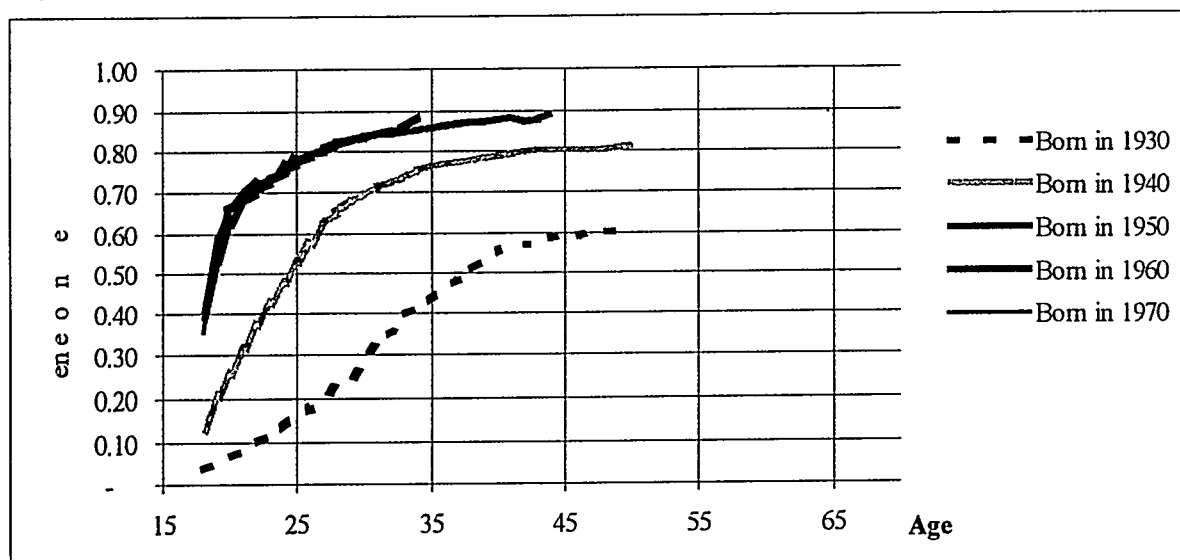
Note: The curves presented are found as the average of the 7 closest cohorts. Thus, the curve for the cohort born in 1930 is found as the average of curves for cohorts 1927 to 1933.

The figures show how licence holding rates have been increasing: Old cohorts have lower licence holding rates throughout their lives than younger cohorts. The vertical difference between curves shows how the licence holding rates have increased over time for each age group. The difference is generally highest for the youngest age groups, implying that men today acquire a licence earlier than they did before. For age groups over 50 there is only little difference in licence holding rates regardless of cohort.

The (vertical) difference in licence holding rates for different cohorts shown in Figure 4-1 is probably mainly due to a real cohort effect. However, the possibility also exists that it can be due to exits from licence holding, since in the TU non-holders were not asked whether they had held a licence previous to the interview, (refer to the section on exit rates).

The cohorts born in 1930 reached the age of 65 in 1995. Those who have lost their licence (on medical or other grounds) appear in the constructed data as if they never had a licence. It is assumed that this only concerns an insignificant number of persons.

Figure 4-2. Licence holding rates for different cohorts of women



From Figure 4-1 and Figure 4-2 it is observed that virtually all entry happens before the age of 40. In the estimations to follow it is assumed that no entry takes place after the age of 40, in order to simplify the calculations.

For women, the difference between cohorts is more pronounced. The female 1930 cohort shows much lower rates than the male 1930 cohort. For later cohorts, differences are much smaller: Women acquire a licence somewhat later but reach holding rates close to those of men.

From the figure it is apparent that the holding rates for old women have not (yet) been close to the saturation level. Therefore, most of the drop in holding rates for the oldest age groups is due to a cohort effect and not to exits from licence holding. This makes the estimation of exit rates for women based on the present data material very unreliable. Therefore the estimation of exit rates for both men and women will be based on exit rates for men.

4.2 Entry Rates

Assuming zero exit rates from ages 18 to 40, the entry rates for these age groups are calculated from (1) as:

$$En_t^{cs} = \frac{LH_t^{cs} - LH_{t-1}^{cs}}{S - LH_{t-1}^{cs}} \tag{2}$$

Figure 4-3 and Figure 4-4 show the calculated entry rates for 18, 19 and 20-year-olds for the past 50 years.

Figure 4-3. Entry rates for young men, 1935-1995

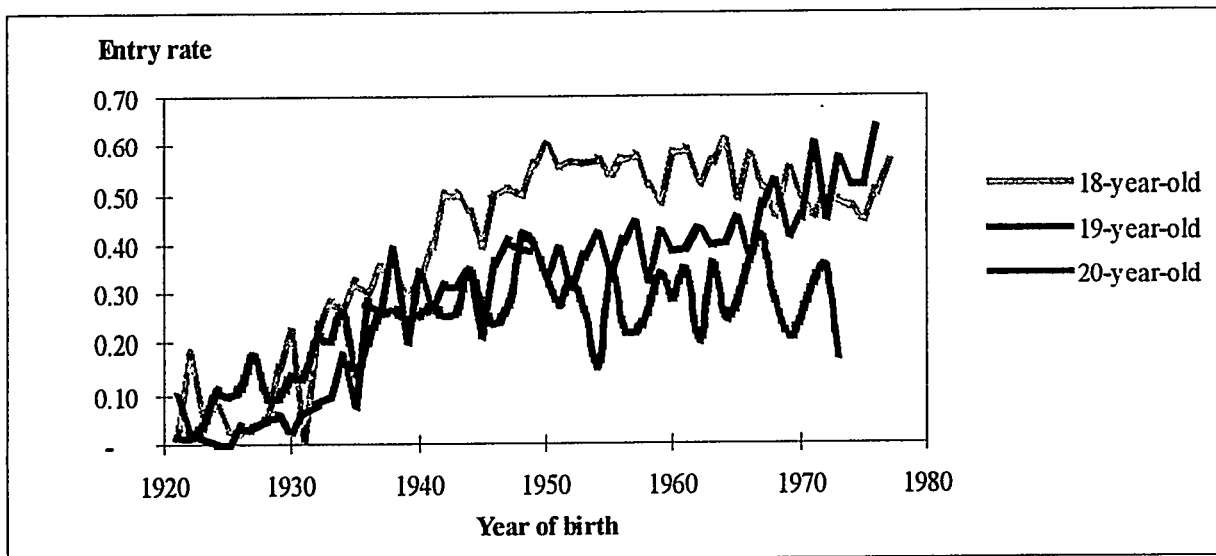
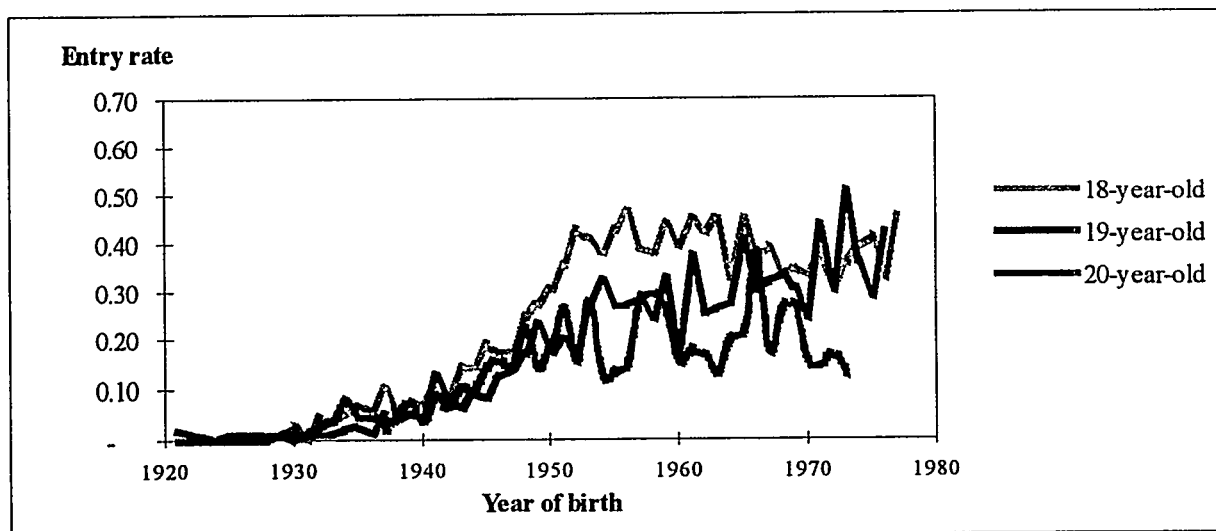


Figure 4-4. Entry rates for young women, 1935-1995



Both for men and women, entry rates started at a level close to zero and increased until the 1950 cohorts. For later cohorts the picture is more stable.

4.3 Exit Rates

No direct information on exit rates exists. Instead, the exit rates have been calculated on the basis of licence holding rates for people over 50.

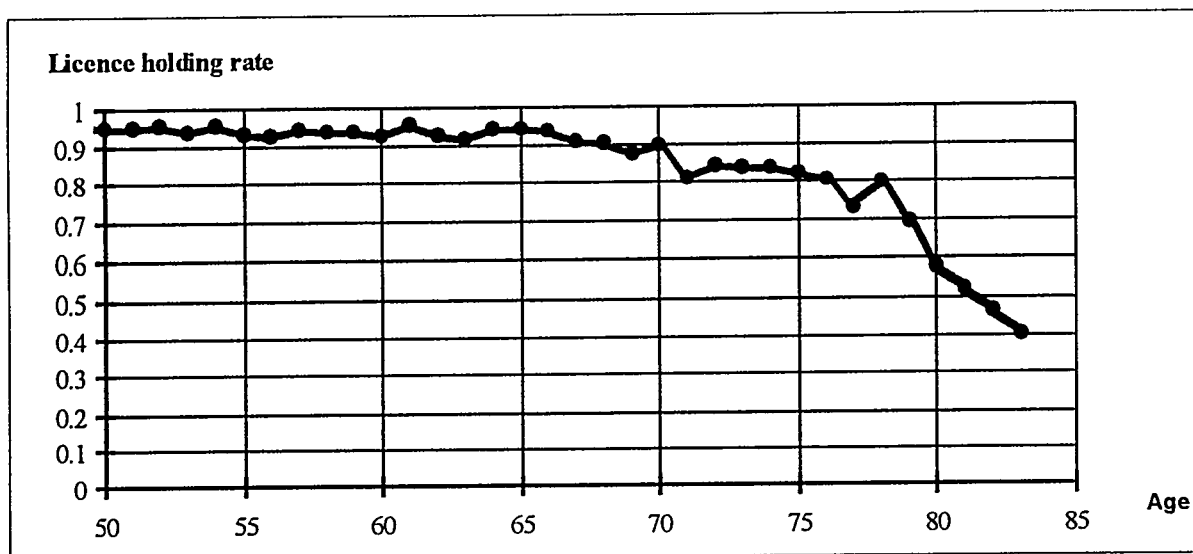
In the TU, observations exist for four years, indicating a possibility for analysing exit rates from the cohort point of view. However, the data only include persons younger than 75. Since the most important exit happens at the age of 75 to 85 years this data is not found suitable for the analysis of exit rates.

In connection with PETRA, the TU covering the period December 1994 to December 1995 has been expanded and include persons beyond the age of 75. Cal-

culations of exit rates are based on the TU data only from this period with extended coverage.

Figure 4-5 shows the observed licence holding rates of the oldest age groups in the data material. There is a tendency that licence holding rates are lower for age groups near 70 than for age groups near 50. Beyond the age of 70 the licence holding rate falls more quickly as age increases.

Figure 4-5. Observed licence holding rates for men over 50 years old



The decrease in licence holding rates with age cannot only be ascribed to exits from licence holding. Some of the decrease is due to the cohort effect, where earlier cohorts have lower licence holding rates. This is particularly the case for women, as is evident from Figure 4-2. Therefore, exit rates are calculated for men only and it is assumed that these also apply for women.

Restating the formula for licence holding of cohort c in year t with the subscript for sex dropped

$$LH_t^c = LH_{t-1}^c + (S - LH_{t-1}^c) \times En_t^c - LH_{t-1}^c \times Ex_t^c$$

it is seen that to calculate Ex_t^c , observations of LH_t^c and LH_{t-1}^c are necessary. However, only licence holding rates in 1995 are available.

Given the relation between holding rates for people of the same age but different cohorts, LH_{t-1}^c and LH_t^{c+1} , it would be possible to calculate the exit rate. This relation is called the cohort effect in what follows.

The cohort effect is measured as the difference between the licence holding of the same age group of two different cohorts.

$$d_t^c = \frac{LH_{t-1}^c - LH_t^{c+1}}{LH_t^{c+1}}$$

In the following, the cohort effect is assumed to be constant from the age of 50 so that

$$LH_{t-1}^c = LH_t^{c+1} + LH_t^{c+1} \times d = LH_t^{c+1} \times (1 + d)$$

where d denotes the cohort effect.

With the assumption that there is no entry past the age of 50 and that the cohort effect beyond this age is constant, the licence holding rates can be calculated according to:

$$\begin{aligned} LH_t^c &= LH_{t-1}^c - LH_{t-1}^c \times Ex_t^c = LH_{t-1}^c \times (1 - Ex_t^c) \\ &= LH_t^{c+1} \times (1 - Ex_t^c) \times (1 + d) \end{aligned}$$

Since exit rates are assumed to be constant over time the subscript t has been dropped on the cohort effect in the following.

Exit rates for different cohorts and cohort effect have been calculated by solving the following problem:

$$\underset{\{Ex^c, d\}_{c \in [1910;1945]}}{\text{Min}} \quad Z = \sum_{c=1910}^{1945} \left(\ln \left(\frac{LH_t^{c+1} \times (1 - Ex^c) \times (1 + d)}{LH_t^c} \right) \right)^2, \quad (3)$$

Where c = The birth year of the cohort
 d = The cohort effect (percent increasing licence holding rates)

This problem minimises the distance between the observed licence holding rate and the licence holding rate predicted by a model assuming constant cohort effect and varying exit rate.

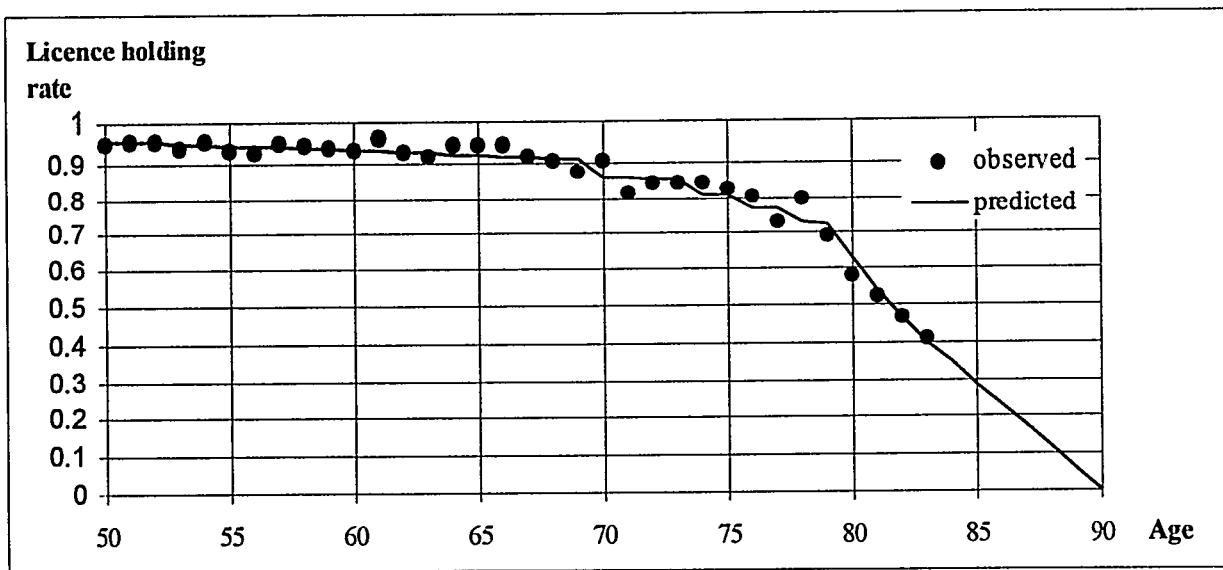
Some constraints are imposed on the estimation of exit rates to reflect the regulations for when a licence must be renewed. For age groups 60 to 69, equal exit rates for every year have been assumed. The exit rates for age groups 71, 72, 73 are set to zero since renewal takes place at 70 and typically has a duration of 4 years. From 74 to 79 the duration is 2 years. In these age groups equal exit rate are estimated for age groups 74, 76 and 78 while the rate is constrained to zero for age groups 75, 77 and 79. In age groups 80 to 85, equal exit rates for every year are assumed. From 85 to 90 the licence holding rate is assumed to fall linearly down to zero. Table 4-3 shows the estimated cohort effect and exit rates.

Table 4-3. Exit rates and cohort effect for men age 50 to 90 years old

Age	Cohort effect per year	Exit rates	Age	Cohort effect per year	Exit rates
50	.0022	0	70	.0022	.0522
51	.0022	0	71	.0022	.0000
52	.0022	0	72	.0022	.0000
53	.0022	0	73	.0022	.0000
54	.0022	0	74	.0022	.0480
55	.0022	0	75	.0022	.0000
56	.0022	0	76	.0022	.0480
57	.0022	0	77	.0022	.0000
58	.0022	0	78	.0022	.0480
59	.0022	0	79	.0022	.0000
60	.0022	.0009	80	.0022	.1360
61	.0022	.0009	81	.0022	.1360
62	.0022	.0009	82	.0022	.1360
63	.0022	.0009	83	.0022	.1360
64	.0022	.0009	84	.0022	.1360
65	.0022	.0009	85	.0022	.1645
66	.0022	.0009	86	.0022	.1978
67	.0022	.0009	87	.0022	.2478
68	.0022	.0009	88	.0022	.3311
69	.0022	.0009	89	.0022	.4978
			90	.0022	.9978

In Figure 4-6 the predicted licence holding rates resulting from these exit rates are shown graphically. It is observed that the predicted exit rates give a good match to the licence holding rates.

Figure 4-6. Observed and estimated licence holding rates



5 Forecast

The previous sections have analysed the past entry and exit rates. To forecast future licence holding rates, forecasts of future entry and exit rates are needed.

For both men and women, licence holding rates for young people are close to the saturation level. Licence holding rates also seem to have stabilised for the younger cohorts. Therefore the forecasts are based on the assumption that the future entry and exit rates will be constant at the present level.

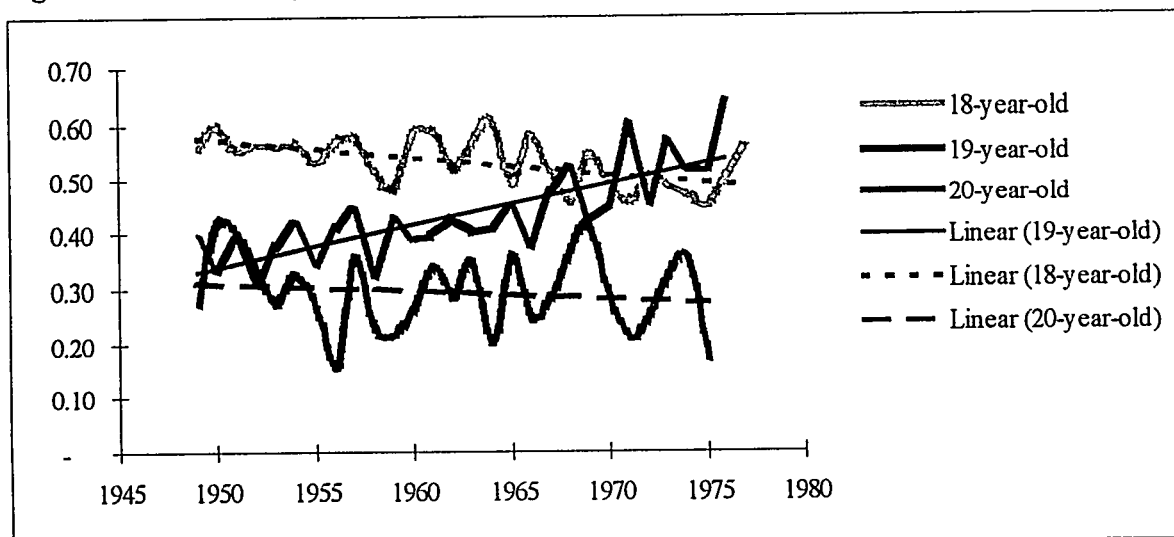
The past entry rates include some random variation. To calculate the rates used for forecast this noise must be filtered out.

5.1 Entry Rates

Figure 5-1 shows the observed entry rates for 18-20-year-old men for the past 30 years. Entry rates for older age groups are not shown since most of the entry takes place until the age of 20.

The rate for 18-year-olds has been falling while the rate for 19-year-olds has been increasing. For 20-year-olds, the rate has been almost constant.

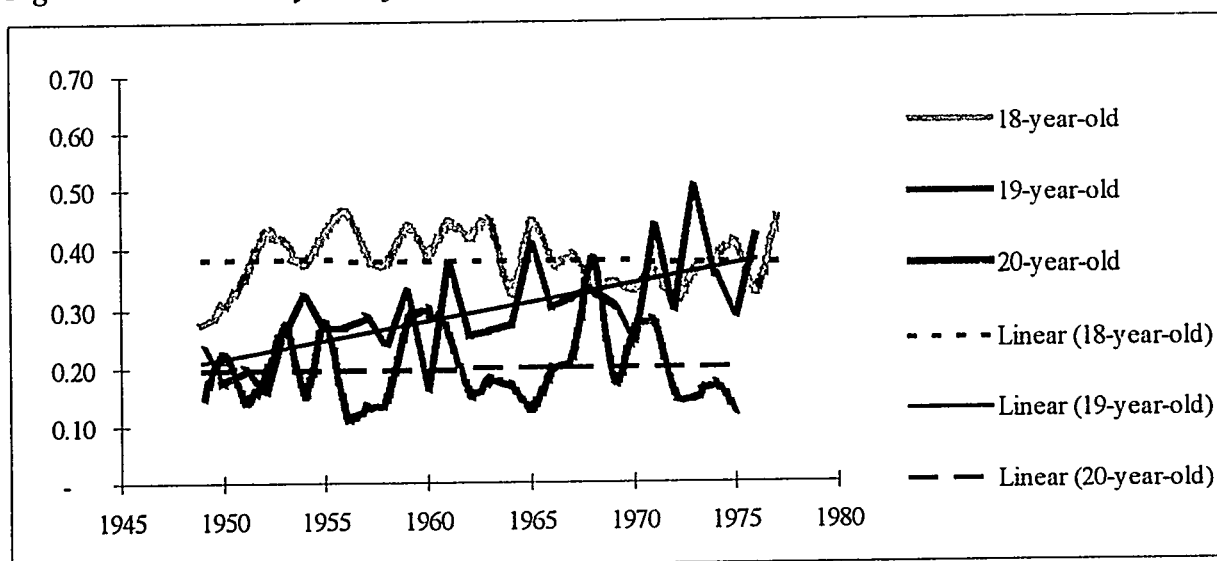
Figure 5-1. Recent entry rates for men



The corresponding Figure 5-2 for women shows the same trend towards higher entry rates for 19-year-olds. Unlike the case for men, this increase is not compensated by a decrease in the entry rate for 18-year-old women. Thus, the increase has resulted in a general increase in the licence holding rates for women.

Licence holding for women is now close to saturation and therefore the increase in the entry rate for 19-year-old women is expected to fade out in the near future.

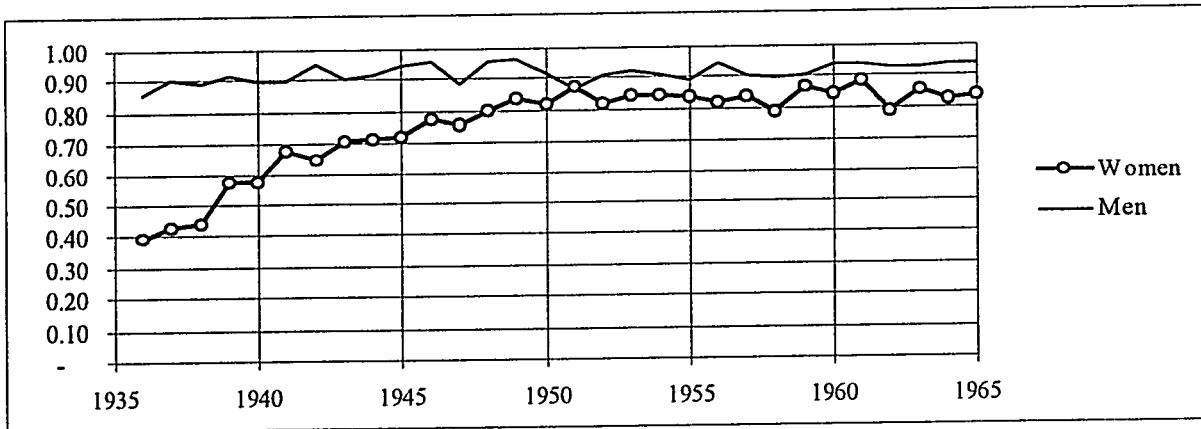
Figure 5-2. Recent entry rates for women



As the figures show, entry rates have evolved with some variation around a trend. The forecast assumes that future entry rates for both men and women will be constant at the level of the calculated trend line in 1995.

Looking at Figure 5-2 it does not seem as though the entry rates for women has stabilised. Alternatively it could be assumed that the entry rates for women approaches the entry rates for men after a period of time. However, there is no sign that the licence holding rates for women has approached the licence holding rates for men in the last years.

Figure 5-3. Licence holding for 30 years old men and women born 1935 to 1965



Rather, Figure 5-3 shows that the distance between male and female licence holding rates has been stable over the last fifteen years. This difference is retained for the forecasts.

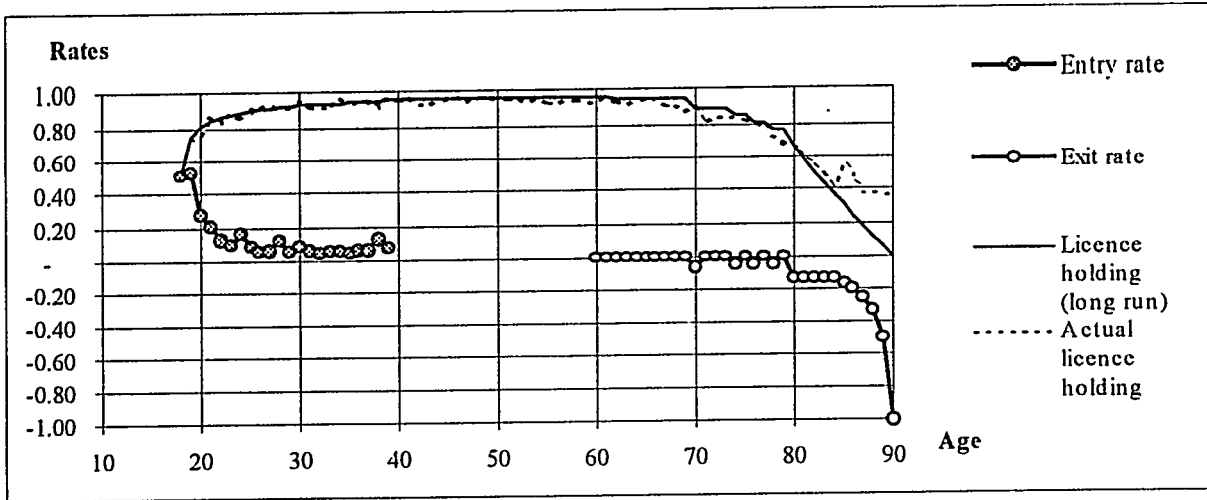
There is a tendency that high entry rates for 18 years old men lead to low entry rates for 19 years old persons the following year. The correlation between entry rates for 18 years old men and 19 years old men (the following year) is -0.66. The same is not the case for women, where the correlation is close to zero. Alternative calculations based on the cumulative licence holding rates (which is not correlated between the young age groups) shows that this correlation does not lead to bias in the forecast of entry rates.

5.2 Exit Rates

With the present data it is not possible to analyse the past development in exit rates. Further, there are too few women beyond the age of 70 with a licence to calculate reliable separate exit rates for women. Instead it has been assumed that exit rates for women are the same as for men.

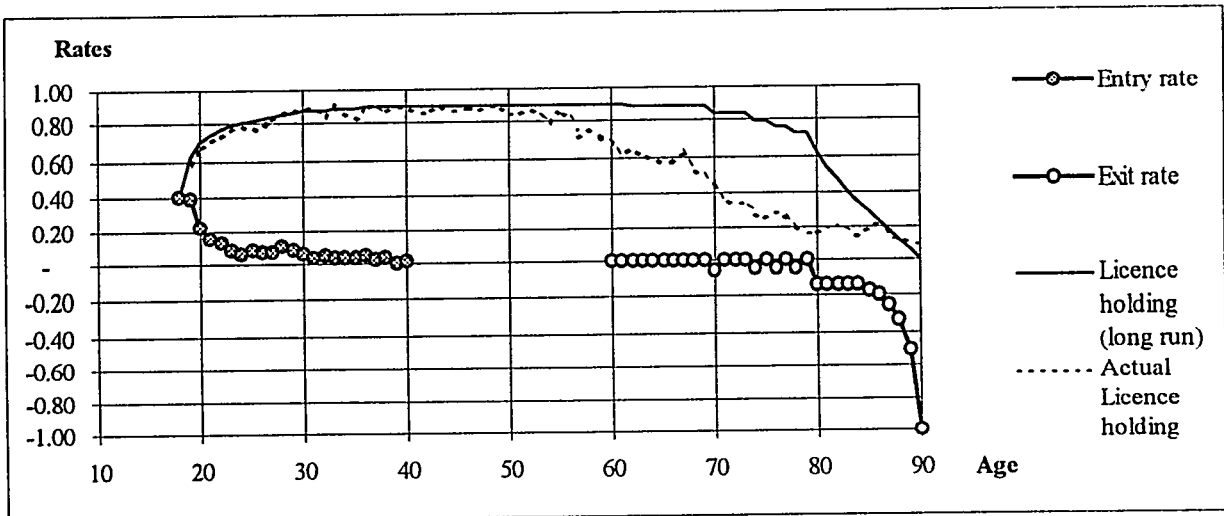
Figure 5-4 and Figure 5-5 show the calculated entry rates, exit rates and the resulting long run licence holding rates for men and women respectively.

Figure 5-4. Future entry rates, exit rates and licence holding for men



For comparison the actual licence holding rate for men is shown. As can be seen there is almost no difference between the actual and long run licence holdings, indicating that the market penetration for men is almost complete.

Figure 5-5 Future entry rates, exit rates and licence holding rates for women



The market penetration for women is less advanced compared to the market penetration for men. This is reflected in relatively few older women with a drivers licence today compared to the long run situation.

5.3 Licence Holding Rates

The starting point for the forecast of future licence holding rates is the observed licence holding rates in the TU data. For the following years it is assumed that licence holding rates are determined by the forecast entry and exit rates.

Table 5-1. Forecast of licence holding rates

Age	Men				Women			
	1995	2010	2020	2030	1995	2010	2020	2030
18 - 19	0.68	0.62	0.62	0.62	0.52	0.50	0.50	0.50
20 - 24	0.86	0.86	0.86	0.86	0.71	0.76	0.76	0.76
25 - 29	0.92	0.91	0.91	0.91	0.85	0.84	0.84	0.84
30 - 34	0.94	0.94	0.93	0.93	0.85	0.88	0.88	0.88
35 - 39	0.93	0.95	0.95	0.95	0.87	0.87	0.89	0.89
40 - 44	0.94	0.95	0.95	0.95	0.88	0.90	0.89	0.89
45 - 49	0.96	0.96	0.95	0.95	0.86	0.87	0.87	0.89
50 - 54	0.94	0.94	0.95	0.95	0.82	0.88	0.90	0.89
55 - 59	0.92	0.94	0.96	0.95	0.75	0.88	0.87	0.87
60 - 64	0.92	0.96	0.94	0.95	0.63	0.86	0.87	0.90
65 - 69	0.91	0.93	0.93	0.95	0.51	0.81	0.88	0.86
70 - 74	0.81	0.86	0.89	0.87	0.31	0.69	0.80	0.81
75 - 79	0.72	0.78	0.79	0.79	0.20	0.54	0.69	0.74
80 - 84	0.46	0.49	0.49	0.51	0.12	0.28	0.40	0.46
85 - 89	0.17	0.17	0.18	0.18	0.05	0.07	0.13	0.16
90 +	-	-	-	-	-	-	-	-
Total	0.88	0.89	0.89	0.89	0.61	0.72	0.74	0.74

For men the forecast only gives a little change relative to the present situation with an increase in the average licence holding rate from 88% to 89% of the adult male population. For women the model predicts an increase in licence holding rates for women over 50. This results in an increase of total licence holding among women from 61% to 74 % in the next 35 years. Most of this increase happens in the first 15 years.

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