Darmstadt Discussion Papers in ECONOMICS

TECHNISCHE UNIVERSITÄT DARMSTADT

Macroeconomic Development and the Life Cycle of the German Automobile Industry, 1886-1939

Jens J. Krüger
and
Kristina von Rhein

Nr. 224

Arbeitspapiere der
Volkswirtschaftlichen Fachgebiete der TU Darmstadt

ISSN: 1438-2733

Macroeconomic Development and the Life Cycle of the German Automobile Industry, 1886-1939

February 2015

by

Jens J. Krüger

Darmstadt University of Technology
Department of Law and Economics
Hochschulstraße 1, D-64289 Darmstadt, Germany
tel.: +49 6151 163 693, fax: +49 6151 163 897
e-mail: krueger@vwl.tu-darmstadt.de

and

Kristina von Rhein

Friedrich-Schiller-University Jena
Department of Economics
Carl-Zeiss-Straße 3, D-07743 Jena, Germany
tel.: +49 3641 943 004, fax: +49 3641 943 002
e-mail: vonrhein@uni-jena.de

Abstract

Empirical work studying the industry life cycle highlights the role of knowledge in various forms on the durations firms survive in the industry. This research leaves open the influence of historical events, which are reflected in macroeconomic factors like income, inflation, exports and interest rates on the industry life cycle. In this paper we investigate the relationship between the macroeconomic conditions and firm survival in the German automobile industry during the period 1886-1939. The results reveal that the macroeconomic conditions influence firm survival in addition to the knowledge variables traditionally considered and substantially contribute to explanatory power.

JEL classification: L16, L62, C41, N13, N14

Keywords: firm survival, macroeconomic factors, automobile industry

1 Introduction

The industrial organization concept of the life cycle of a product or an industry concerns the characteristic development of the number of firms in a narrowly defined industry from its birth until maturity. The number of firms increases slowly at first, experiences a so-called shakeout phase with a rapidly decreasing number of firms within a few years and then stabilizes so that the industry can best be described as an oligopoly. The model of Klepper (1996), which provides a very intriguing description of the forces leading to this characteristic development, focuses its explanation on forces related to the knowledge available within the firms in a wide sense.[1] Empirical studies based on this model rely on factors explaining the survival of firms and use variables to operationalize different forms of knowledge, i.e. pre-entry experience and post-entry experience.

The evolution of an industry unfolds in a specific historical time frame, characterized by specific events taking place and the development of the general macroeconomic conditions. Firm survival is of course influenced by positive or negative macroeconomic shocks which are beneficial for the survival of firms or may force firms to exit. Most empirical analyses of firm survival, however, neglect this influence of the macroeconomy and do not use indicators of the macroeconomic conditions of an economy for explaining firm survival. In general, the existing empirical literature on firm survival concerned with the application of methods of survival analysis divides into two main strands.

In the first strand are investigations of the determinants firm survival over shorter time spans and across broad cross-industry firm samples. Audretsch and Mahmood (1994, 1995), Agarwal and Audretsch (2001), Agarwal and Gort (2002), and more recently Buddelmeyer et al. (2010) are exemplary for this strand. Manjón-Antolín and Arauzo-Carod (2008) provide a survey. Within this strand, there are also papers with a specific focus on the influence of macroeconomic variables as determinants of firm survival in addition to variables suggested by industrial organization theory. Bhattacharjee et al. (2009) and Buddelmeyer et al. (2010) introduce macroeconomic variables such as output growth, the trend deviation of output per capita, inflation, exchange or interest rates in survival regressions. The results show frequently significant and overall plausible effects of the macro variables on the exit hazard rate. Other studies to mention in this area are Boeri and Bellmann (1995), Disney et al. (2003) and Ilmakunnas and Topi (1999). Caves (1998), in his survey article about firm mobility, summarizes related findings by the statement that "[a]nother apparently important influence on mobility and entry-exit turnover [...] is the stage of the business cycle" (p. 1975).

The second strand of literature comprises investigations following the development of a single industry from its birth to maturity which is at the heart of the industry life-cycle literature on which we focus here. This line of research has been initiated by Klepper (2002) by first estimating parametric survival regressions based on the Gompertz distribution and then extending the analysis using the Cox regression with its semiparametric flavor not requiring to specify the complete distribution of the survival times. This literature has a distinct theoretical basis with the model of Klepper (1996), predicting that firms which enter early in the life cycle face a lower exit hazard and that firms which are endowed with technological of business experience before entry also have a greater chance to survive. Klepper (2002) investigated four industries, including the US automobile industry. His results have been likewise found for the case of the German automobile industry by Cantner et al. (2006) and for the case of the British automobile industry by Boschma and Wenting (2007). The industry life-cycle literature mostly neglects the historical context and the resulting macroeconomic environment in which the evolution of the industry under consideration proceeds.[2] To our knowledge no studies exist in this literature investigating the role of macroeconomic variables for firm survival in single industries focused on narrowly defined product categories (such as an automobile) and an extended period spanning the relevant phases of the life cycle of this industry from its birth to maturity.

The question arises whether and to which extent the usual variables used in the life-cycle literature just pick up effects originating from the macroeconomic conditions which either promote firm survival or trigger exit. In this paper we report results from survival regressions for the German automobile industry spanning the period 1886-1939 from the birth of the industry until the outbreak of the Second World War. We introduce several macroeconomic variables capturing income per capita, inflation, export orientation, and an interest rate in the type of specification used in life-cycle survival analyses. The

[1] This model is based on previous work by Gort and Klepper (1982) and Klepper and Graddy (1990).

[2] See Geroski et al. (2010), Klepper and Simons (2000), Nelson (2003) and Thompson (2005), inter alia, for related studies on other industries.

macroeconomic variables considered are real GDP per capita, the CPI inflation rate, an exports to GDP index and an interest rate. In addition to the original Cox regression we also take account of unobserved heterogeneity by introducing frailty terms and apply a robust variant of the Cox regression to assess the outlier sensitivity of our results. Moreover, we also pay special attention to nonlinear effects of the macroeconomic variables by estimating regression splines in these variables.

Prior to the statistical analysis we expect a negative effect of real GDP per capita on the exit hazard because it mainly represents the ability to buy an automobile. The effect of the inflation rate is ambiguous a priori since high inflation is associated with greater uncertainty of the future business conditions on the one hand but may also stimulate demand for durable goods to rescue money from devaluation on the other hand. Likewise, a high value of the exports to GDP index may indicate opportunities for exports of automobiles but may alternatively indicate a greater openness in general and therefore more competition from abroad. Finally, a higher interest rate indicates worse financing conditions for the firms and is thus expected to increase the exit hazard. If a higher interest rate exerts a larger effect on the financing conditions of prospective new entrants to the industry, however, it may also promote survival of the incumbents and reduce their exit hazard.

Our results from various specifications show the expected negative effect of real GDP per capita on the exit hazard. Higher inflation and higher interest rates also appear to reduce the exit hazard, although not statistically significant in the case of the inflation rate. The effect of the exports to GDP index is positive and thus greater openness tends to raise the exit risk, although this is not always significant when the robust variant of the Cox regression is considered. The nonlinear specifications show that the effects can be rather different for different values of the respective explanatory variables. A clear indication of a nonlinear effect can only be established for real income per capita.

Accordingly, the plan of the paper is first to describe the data and variable definitions in section 2 together with descriptive statistics and an historical abstract. This is followed by a brief outline of the regression methods used for the survival analysis in section 3. The results obtained are presented and discussed in section 4 presenting coefficient estimates of different variants of the Cox regression including the robust estimator. Here, nonlinear effects by introducing regression splines in the Cox regression are discussed and we have a look at the survivor function for different macroeconomic conditions and firm types. Further conclusions are drawn in section 5.

2 Data and Variables

2.1 Firm Data and Variables

The firm data we utilize have been described previously in a series of investigations reported in Cantner et al. (2006, 2009, 2011), von Rhein (2008), Krüger and von Rhein (2009), Krüger (2015). Here, we provide a brief review while the full details can be found in the appendix of Cantner et al. (2006). The following analysis is based on a comprehensive data set of the firms operating in the German automobile industry starting from 1886, the year where Daimler and Benz designed the first motorcars[3], and continuing until the outbreak of the Second World War in 1939. The data are obtained from yearbooks, journals and books about veteran cars. The sample is restricted to automobile manufacturing firms, excluding suppliers or truck producers. Recorded are the year of entry into automobile production, the year of exit and a censoring indicator equal to unity when a firm was subject to a merger or an acquisition or survived beyond 1939. Furthermore, we use the following explanatory variables:

- To capture post-entry experience originating from knowledge accumulated during the operation in die automobile industry (e.g. by innovating or just through learning by doing) the firms are grouped into entry cohorts using Klepper's 15-15 rule.[4] This leads to four entry cohorts, the first ranging from 1886 to 1901 (indicated by the dummy variable E_1 equal to unity for the firms in this cohort), the second from 1902 to 1906 (indicated analogously by E_2), the third from 1907 to 1922 (indicated by E_3) and the fourth from 1923 to 1939 (indicated by E_4).

[3] Meaning a vehicle designed to be powered by an internal combustion engine as a predecessor of what we today understand as a car or an automobile.

[4] This means that "where feasible, entry cohorts are defined so that they have at least 15 survivors to age 15" (Klepper 2002, p. 47).

- Pre-entry experience is coded by the dummy variable P equal to unity if the founders of the firm were endowed with some form of technological or business experience at the time of entry. This form of experience could originate from already having managed a firm before entering into the automobile industry, having diversified into the automobile industry, or being a spinoff of an automobile firm. All other firms are treated as inexperienced with P equal to zero.

Complete data including the information about pre-entry experience are available for 333 firms. We exclude all censored observations since only firms which actually exit (and therefore are not censored) are used for our intended assessment of the macroeconomic conditions at the time of exit (or slightly before) on the hazard rate, thereby reaching a sample of $n = 284$ firms.

2.2 Macroeconomic Data and Variables

The macroeconomic data are obtained from the homepage of the Maddison Project, the book of Maddison (1991) and the NBER Macrohistory Database. We focus on four macroeconomic factors in the subsequent empirical analysis:

- The first macroeconomic factor considered is real GDP per capita (measured in 1990 Geary-Khamis dollars). This variable is intended to measure the general macroeconomic conditions and demand factors, i.e. the ability to pay for an automobile. The data are taken from the homepage of the first update of the Maddison Project[5] and are described in detail in Bolt and van Zanden (2013).
- Second, general price development also plays a role for the decision to buy an automobile and for the survival of automobile producing firms. This is represented by the CPI inflation rate which is computed as the (log) growth rate of the consumer price index provided by Maddison (1991) in appendix E. We mitigate the extraordinarily high price index of the year 1923 by replacing this observation by the average of the adjacent years 1922 and 1924, which themselves are both also quite high.
- Third, the openness of the economy and competition by foreign firms may also influence market structure and firm survival. The indicator used to capture this aspect is an exports to GDP index series. This series is constructed as the ratio of the volume of exports index and the GDP index (both with base year 1913 = 100) as provided by Maddison (1991) in appendices A and F, respectively. Therefore, it follows that this index is equal to unity in the year 1913.
- Fourth, new firm foundations as well as the survival opportunities of established firms also depend on external financing conditions. We use data for an interest rate as an indicator of the cost of credit supply. The particular indicator used is the private interest rate which can be obtained from chapter 13 of the NBER Macrohistory Database[6]. The series taken is abbreviated by m13018 (Germany private discount rate, prime banker's acceptance, open market, Berlin) which is in the database in monthly frequency and is aggregated to a yearly time series by averaging all months pertaining to the same year.[7]

Except for the inflation rate the macroeconomic variables enter the subsequent regressions in natural logarithms. These macroeconomic variables can safely be considered as exogenous since the automobile industry was rather small and unimportant compared to the entire German economy during the period under analysis. In addition to the variables defined above we introduce dummy variables pertaining to the First World War (ww1 = 1 if the firm exits during 1914-18), the German hyperinflation (hyper = 1 if the firm exits during 1922-23) and the world economic crisis[8] (wec = 1 if the firm exits during 1929-33). These dummies serve to take account for the special macroeconomic situations during these phases of German economic development of the first half of the 20th century.

[5] See http://www.ggdc.net/maddison/maddison-project/home.htm.

[6] See http://www.nber.org/databases/macrohistory/contents. More information on this database is given by Feenberg and Miron (1997).

[7] Among the interest rate series for Germany in the database only this series is consistently available during the required sample period.

[8] Termed "Weltwirtschaftskrise" in Germany and largely equivalent to the notion of the Great Depression familiar in the US.

2.3 Descriptive Statistics

Descriptive statistics focus here on the time series of the number of firms in each year, the number of entries and exits, and the four macroeconomic factors. Table 1 reports means and standard deviations of the whole period of investigation 1886-1939 and four subperiods comprising the years before the First World War (1886-1913), the years of the war and the German hyperinflation phase (1914-1923), the years of the shakeout and the world economic crisis (1924-1932) and finally the years until the outbreak of the Second World War (1933-1939).

Table 1: Descriptive Statistics

		1886-1939	1886-1913	1914-1923	1924-1932	1933-1939
means:	number of firms	27.704	22.679	46.100	38.889	7.143
	number of entries	5.259	4.214	9.300	6.889	1.571
	number of exits	5.259	3.000	4.600	14.889	2.857
	real GDP per capita	3226.987	2871.982	2936.831	3711.578	4438.473
	CPI inflation rate	0.010	0.009	0.433	-0.457	0.006
	exports to GDP index	0.616	0.710	0.475	0.657	0.388
	private interest rate	0.040	0.032	0.049	0.063	0.032
standard deviations:	number of firms	26.684	21.019	26.510	37.398	4.451
	number of entries	7.423	4.324	11.586	10.470	1.718
	number of exits	8.033	3.916	4.742	14.836	1.864
	real GDP per capita	684.025	400.580	203.294	318.716	648.460
	CPI inflation rate	0.674	0.022	0.798	1.350	0.016
	exports to GDP index	0.184	0.116	0.248	0.078	0.048
	private interest rate	0.018	0.009	0.023	0.015	0.004

Note: Shown are the means and standard deviations of the indicated variables for different subperiods.

It appears that the in-between subperiods 1914-1923 and 1924-1932 are particularly interesting. During these periods we find the largest number of firms in the market and also the largest numbers of entering and exiting firms. Entry and exit are both much lower in the subsequent period. Thus, the shakeout phase of the industry life cycle lies in these years. Note that all firms which survived beyond 1939 are censored and thus eliminated from the consideration here. The accompanying macroeconomic development can be characterized as follows. Real GDP per capita is relatively stagnant in 1914-1923 compared to the previous subperiod. The mean CPI inflation rate is largest in this subperiod despite the correction of the year 1923. The exports to GDP index is lowest during this subperiod, which can be attributed to the First World War and its aftermath, and recovers only slowly thereafter. Finally, the private interest rate is largest during 1924-1932. In the lower half of the table, the standard deviations are reported. Quite evidently the standard deviations support the claim of the much more volatile years 1914-1932 compared to the previous and the subsequent subperiods. Real GDP per capita is the exception, and here the lower volatility during the middle subperiods supports the stagnation assertion.

Table 2 shows the correlation matrix of the time series. Focusing on the correlation coefficients in the third column we see that the number of firms exiting is positively correlated with the number of firms in the market and also with the number of firms entering. The number of exits is furthermore positively correlated with the private interest rate and negatively correlated with the CPI inflation rate. Only weakly positive correlations are found with real GDP per capita and the exports to GDP index. There also is a quite close association of the number of firms with the numbers of entering and exiting firms. The macroeconomic variables are only rather weakly correlated with each other and only one of the correlation coefficients exceeds 0.2 in absolute value.

Table 2: Correlation Matrix of the Time Series

	number of firms	number of entries	number of exits	real GDP per capita	CPI inflation rate	exports to GDP index	private interest rate
number of firms	1.000	0.814	0.774	0.009	-0.239	0.253	0.638
number of entries	0.814	1.000	0.602	-0.072	-0.294	0.084	0.503
number of exits	0.774	0.602	1.000	0.171	-0.555	0.150	0.616
real GDP per capita	0.009	-0.072	0.171	1.000	-0.008	-0.156	0.184
CPI inflation rate	-0.239	-0.294	-0.555	-0.008	1.000	-0.041	-0.335
exports to GDP index	0.253	0.084	0.150	-0.156	-0.041	1.000	0.084
private interest rate	0.638	0.503	0.616	0.184	-0.335	0.084	1.000

Note: Shown are pairwise Pearson correlation coefficients of the respective time series.

These findings are further illustrated by the time series plots in figure 1 showing the time series of the firm data in the upper panel and those of the macro variables in the lower panel. In the figure the real GDP per capita series is normalized to unity in the first year and the interest rate series is multiplied by ten, both for scaling reasons. For the same reason the hyperinflation years 1922-24 with excessively high and low inflation rates are omitted for the CPI inflation rate. Compared to the development of the US automobile industry (cf. figure 2 on page 44 in Klepper (2002)), the number of firms in the German automobile industry appears to be much more affected by major macroeconomic crises. The development of the number of firms therefore looks less typical for the life cycle pattern than its US counterpart. In the following subsection we outline the macroeconomic development in Germany and its association with the development of the automobile industry simultaneously with the forces of technological change and market competition.

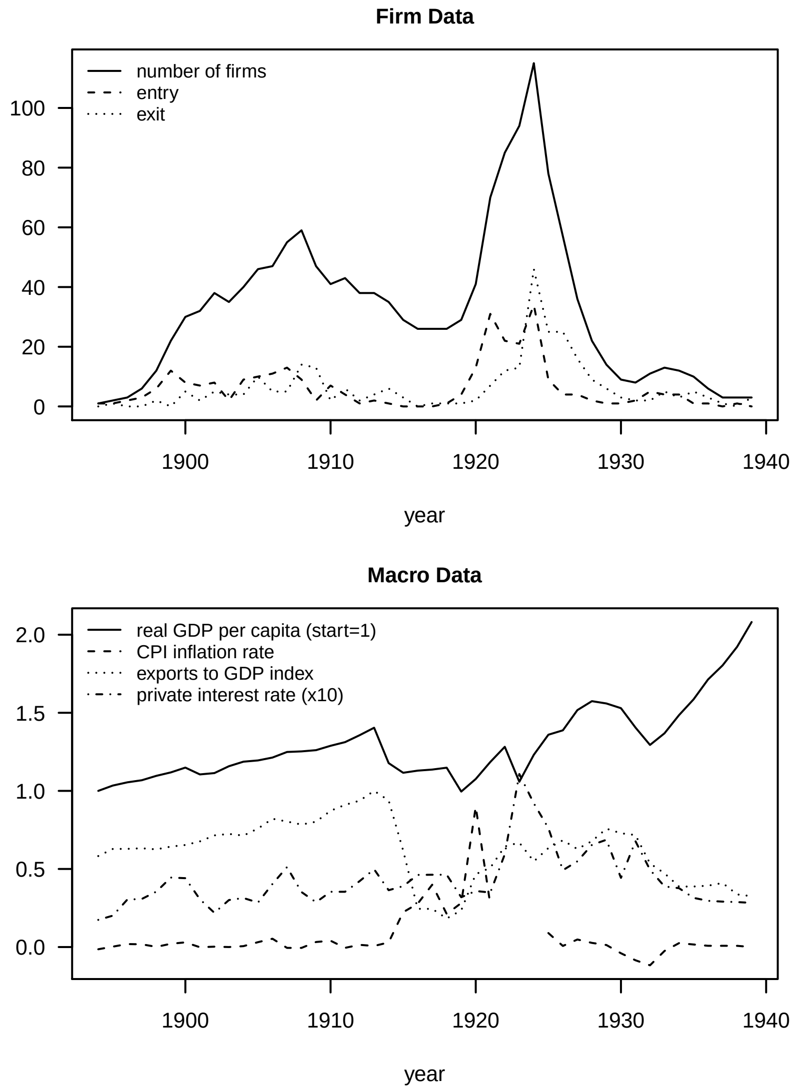
Particularly interesting also from an industrial organization point of view is the shakeout phase starting in 1925 and continuing until 1929 or 1930 when the number of firms stabilized. A shakeout is characterized by a massive decline of the number of firms in the market within a few years simultaneously occurring with many entries but even more exits (see Klepper and Simons (2005)). During this shakeout phase we observe a rather favorable macroeconomic environment with a rising GDP per capita, a recovering exports to GDP index after the First World War, a stabilized inflation rate after the hyperinflation and a declining interest rate. During the world economic crisis a deflationary period could be observed. At the industry level this phase is characterized by a widespread restructuring of the production processes towards methods of mass production (e.g. the assembly line introduced by Ford in the US before) and relaxing of import restrictions which also increased import competition. Thus, we argue that the shakeout is more likely caused by changes of technological and market conditions and less influenced by the general macroeconomic development.

2.4 Historical Abstract

For the description of the historical development we rely on the detailed studies of Flik (2001a,b) about the German automobile industry during the period covered by our sample. The industry really took off around 1900 with the entry of many firms which formerly produced bicycles or machinery (engines in particular) and diversified into automobile production. Private usage of automobiles was hampered by unfavorable liability and other legal arrangements (absolute liability (so-called 'Gefährdungshaftung'), the obligation to have a garage (so-called 'Garagenzwang'), high car-specific taxes, preferential treatment of the Reichsbahn), which, together with high gasoline prices, led to high operating costs. The production technology consisted of small-scale, less specialized manufacturing processes. The First World War came along with a suspension of civil car production and a strict orientation towards military needs. The inflationary phase after the war, culminating in the hyperinflation of 1922/23, favored automobiles in the course of the flight into real assets. The inflation phase resulted in a production boom and protected firms from foreign competition. Many new firms entered during this phase. These new firms, however, delayed the development towards large firms and they disappeared quickly after the currency reform (so-called 'Inflationsblüten'). Further promoting aspects were the relaxation of driving prohibitions, lowering of luxury taxes and easing of import protection measures.

After 1924 there was a further relaxation of import restrictions (but also infant industry duties, 1925-28) which promoted import competition and caused an adaption crisis with decreasing production and prices as well as an increasing stock of cars. This triggered pronounced exits of firms, the restructuring of

Figure 1: Time Series Plots



production processes oriented at American production methods (i.e. the assembly line) and important mergers. During 1925-29 about half of stock market value of automobile firms was lost. Market entry occurred by the orientation of motorcycle producers towards the production of smaller cars.

The world economic crisis starting in 1929 was associated with decreasing demand for automobiles, declining imports, but an increasing export surplus. The consequence was a shrinking car stock and this forced the exit of many additional firms. The whole period 1929-33 experienced a massive reduction of car sales (60 percent for passenger cars and 72 percent for trucks during 1928-32), a massive reduction of employment in the automobile industry, import reduction and protectionism. The surviving firms reacted by restructuring towards the production of smaller cars with less gasoline consumption.

Since 1933, after the end of the crisis, taxes and legal restraints were further lowered and the industry experienced a leap of car sales. The stock of cars growed strongly during the years 1932-38 by a factor of 2.5, production and exports both growed by a factor of seven. Nevertheless, the automobile industry remained too small for having a large impact on the business cycle. During these years, the national socialist regime also enforced an increasing orientation towards military needs and war production in general, which affected the automobile industry mainly by quota setting of raw materials, manpower shortage and finally the suspension of the production of civil cars.

3 Survival Regressions

There is a wide range of methods for analyzing duration data as we have here for the duration of firms operating in the German automobile industry. Therneau and Grambsch (2000) and van den Berg (2001) provide overviews of duration analysis and associated regression methods. Out of these methods, the Cox regression can be viewed as the 'workhorse' of survival analysis in economics. This proportional hazards model specifies the hazards rate of firm i as

$$\lambda(y_i \,|\, \boldsymbol{x}_i) = \lambda_0(y_i) \cdot \exp(\boldsymbol{\beta}'\boldsymbol{x}_i), \tag{1}$$

where the hazard rate $\lambda(y_i \,|\, \boldsymbol{x}_i)$ is split multiplicatively into the baseline hazard rate $\lambda_0(y_i)$ which depends only on the duration of survival y_i and the part $\exp(\boldsymbol{\beta}'\boldsymbol{x}_i)$ which depends only on the explanatory variables, collected in the vector $\boldsymbol{x}_i$ (excluding the intercept). The estimates of the parameters in the vector $\boldsymbol{\beta}$ can directly be interpreted as the rates of change of the hazard rate given that the corresponding explanatory variable changes by one unit.

The basic original Cox regression was introduced by Cox (1972, 1975) suggesting the maximization of a partial likelihood function to eliminate the baseline hazard rate. For the case of all durations being completed (no censoring) and in the absence of ties the log-likelihood function for the unique ordered duration times $y_1 < y_2 < ... < y_n$ after canceling out the baseline hazard rate is

$$\ln L(\boldsymbol{\beta}) = \sum_{i=1}^{n} \left[\boldsymbol{\beta}'\boldsymbol{x}_i - \ln \left(\sum_{j \in R(y_i)} \exp(\boldsymbol{\beta}'\boldsymbol{x}_j) \right) \right], \tag{2}$$

with $R(y_i)$ denoting the so-called risk set of observations which could have exited (and therefore are at risk) at survival time y_i. Censoring is handled by including the censored observations in the risk set but omitting them from the outer sum. Ties in the duration times are treated by the schemes of Breslow or Efron, where Efron's scheme (Efron 1977) is more efficient and is used as the default option in the R package 'survival'.[9]

The first-order conditions (score function) are given by

$$\frac{\partial \ln L(\boldsymbol{\beta})}{\partial \boldsymbol{\beta}} = \sum_{i=1}^{n} \left[\boldsymbol{x}_i - \frac{\sum_{j \in R(y_i)} \exp(\boldsymbol{\beta}'\boldsymbol{x}_j) \cdot \boldsymbol{x}_j}{\sum_{j \in R(y_i)} \exp(\boldsymbol{\beta}'\boldsymbol{x}_j)} \right] = \boldsymbol{0} \tag{3}$$

and can be solved numerically for the regression parameters $\boldsymbol{\beta}$, resulting in the Cox partial likelihood estimator $\hat{\boldsymbol{\beta}}$.

The neglection of unobserved heterogeneity potentially leads to biased parameter estimates. We take account of unobserved heterogeneity by using a variant based on a penalized likelihood approach as described in Therneau et al. (2003) with a Gaussian frailty term. In that case the model estimated can be stated as $\lambda(y_i \,|\, \boldsymbol{x}_i) = \lambda_0(y_i) \cdot \exp(\boldsymbol{\beta}'\boldsymbol{x}_i + b_i)$ with $b_i \sim N(0, \sigma_b^2)$ representing independently normally distributed random effects and σ_b^2 is a variance parameter to be estimated.

Since we are faced with a quite turbulent phase of the German history including the First World War, the German hyperinflation, the world economic crisis and the years before the outbreak of the Second World War it seems wise to pay special attention to the robustness of the results with respect to outliers in the data. Therefore, we apply robust estimation of the Cox regression as proposed in Bednarski (1993) and Minder and Bednarski (1996). This approach modifies the score function by introducing trimming using a kind of weights to reduce the influence of large values of $\exp(\boldsymbol{\beta}'\boldsymbol{x}_i)$. The weight function serves to smooth the estimator with respect to the data. Monte-Carlo results show that the downward biases (towards zero) of the parameter estimates and their standard errors caused by unobserved heterogeneity, omitted variables or measurement errors are smaller when the robust Cox estimator is applied (see Bednarski (1993) and Minder and Bednarski (1996) for the details).

[9]The general robustness of the Cox regression in the type of applications considered here with respect to various specification problems is demonstrated in Krüger (2015).

To explore nonlinear effects of the macroeconomic variables we use natural splines.[10] Those natural splines are represented by piecewise cubic splines with a B-spline basis and a fixed sequence of interior knots to be specified by the investigator. In addition, so-called natural boundary conditions are enforced which require the estimated function to be linear at the boundaries (with zero second derivatives there). These additional constraints let natural splines generally be more stable at the boundaries. In general, B-splines are a numerically stable choice of base functions which use polynomial pieces, joined together at a certain number of knots.

All computations are performed within the R programming environment (Chambers (2008)) employing the packages 'survival' for the original Cox regression and the Cox regression with frailty as well as the package 'coxrobust' for the robust Cox regression estimates. The package 'splines' contains the functions for an easily manageable implementation of the natural B-spline basis.

4 Results

The results discussed in this section are reported in table 3 for a "linear" regression specification of the macroeconomic factors as indicated in equation (1).[11] Discussed are estimates for the original Cox regression without and with frailty as well as for the robust variant of the Cox regression. For each of these three estimation methods we take the values of the macroeconomic variables pertaining to the year of exit of the respective firm (indicated by $[t = 0]$ in the table), the year before the year of exit (indicated by $[t = 1]$) and the average of both (indicated by $[\overline{t = 0, 1}]$). This is followed by the nonlinear estimates where the macroeconomic factors are augmented by a natural spline basis. Here, the regression results for the original and robust Cox regressions are relegated to the appendix table 4 and the results are discussed using plots of the splines for each macroeconomic variable in figures 2 and 3.

4.1 Cox Regressions

Turning first to the results of the linear Cox regression specifications in table 3 we find at first that the pattern of results for the entry cohort dummy variables and the dummy variable for pre-entry experience are close to those found consistently across several industries and countries in the empirical industry life cycle literature (see e.g. Cantner et al. (2006) and Klepper (2002)). This means that the coefficient estimates for the entry cohorts are significantly negative throughout (the last entry cohort E_4 is the omitted reference category) with large t-statistics (in parentheses). Furthermore, the coefficient magnitudes are declining in absolute value from E_1 to E_2 and E_3, indicating that entering earlier in the life cycle gives an advantage in terms of survival. The coefficient estimate for the pre-entry experience P is also significantly negative showing the additional risk-reducing effect of this form of knowledge. Skimming through the columns of the table we find these results to be robust with respect to the different estimation methods and most importantly also robust to the introduction of the macroeconomic variables.[12]

The dummy variables pertaining to the First World War, the German hyperinflation and the world economic crisis give quite different results. During the First World War the exit hazard was significantly lower regardless of the estimation method or the specification of the macro variables. This can be explained by the regulation during this period which forced automobile firms to war production and simply not allowed them to exit. The hyperinflation dummy is not significant if the macro variables are pertaining to the year of exit ($t = 0$) but gains significance if the macro variables are pertaining to the year before exit ($t = 1$) or the average of both years. From these cases we have a quite strong indication of higher exit hazards during this period. The dummy variable for the world economic crisis has a negative coefficient estimate but appears to be significant only in one occasion. Thus, we do not observe a special effect of the dummy variable for the world economic crisis so that this event appears to be explained well by the macroeconomic variables to which we turn next.

[10] See Hastie et al. (2009, ch. 5) for more on the use of splines in regression analysis and Therneau and Grambsch (2000, pp. 102ff.) for details in the context of Cox regressions.

[11] This is here to be understood as linear effects of the explanatory variables on the log of the hazard rate. If an explanatory variable enter in logs as well (such as real income per capita, the exports to GDP index and the private interest rate) the associated parameter estimate has the interpretation as an elasticity.

[12] Compared to the results without macroeconomic variables the coefficients of the cohort dummies are larger in absolute magnitude while the coefficient of pre-entry experience is lower in absolute magnitude (cf. the estimates for model 3 in table 2 on page 57 in Cantner et al. (2006)). The statistical significance and the qualitative pattern remains the same.

Table 3: Results for the Linear Specification and Different Estimation Methods

	original Cox regression			Cox regression with gaussian frailty			robust Cox regression		
	$[t=0]$	$[t=1]$	$[t=0,1]$	$[t=0]$	$[t=1]$	$[t=0,1]$	$[t=0]$	$[t=1]$	$[t=0,1]$
E_1	-4.146	-3.415	-4.278	-4.212	-4.131	-4.850	-4.376	-4.308	-5.140
	(12.258)	(11.024)	(12.270)	(12.232)	(11.310)	(12.429)	(4.872)	(3.915)	(4.439)
E_2	-3.181	-2.710	-3.334	-3.231	-3.239	-3.754	-3.371	-3.318	-3.903
	(13.064)	(11.118)	(12.881)	(11.201)	(10.272)	(11.383)	(7.186)	(5.061)	(6.649)
E_3	-1.992	-1.877	-2.091	-2.020	-2.163	-2.307	-2.044	-2.093	-2.244
	(12.709)	(11.899)	(13.590)	(11.146)	(10.403)	(11.176)	(7.316)	(6.514)	(8.059)
P	-0.475	-0.297	-0.349	-0.480	-0.318	-0.373	-0.461	-0.327	-0.372
	(3.948)	(2.421)	(2.909)	(3.462)	(1.985)	(2.452)	(3.284)	(2.056)	(2.816)
ww1	-1.953	-1.054	-1.695	-1.987	-1.148	-1.839	-2.225	-1.070	-1.745
	(6.007)	(2.747)	(4.376)	(5.344)	(2.837)	(4.604)	(5.060)	(2.375)	(4.820)
hyper	-0.054	1.279	0.739	-0.057	1.292	0.805	0.042	0.994	0.920
	(0.127)	(5.335)	(1.910)	(0.147)	(4.081)	(1.760)	(0.060)	(3.127)	(2.007)
wec	-0.716	-0.301	-0.551	-0.680	0.054	-0.252	-0.284	0.194	0.065
	(1.574)	(0.578)	(1.038)	(2.374)	(0.158)	(0.760)	(1.004)	(0.585)	(0.229)
log real GDP per capita []	-8.856	-6.609	-9.375	-8.994	-7.982	-10.443	-9.372	-8.154	-10.330
	(7.113)	(8.852)	(8.065)	(8.823)	(9.785)	(9.583)	(3.598)	(4.069)	(5.822)
CPI inflation rate []	0.018	-0.067	0.035	0.020	-0.071	0.008	0.018	-0.051	-0.130
	(0.261)	(1.555)	(0.236)	(0.276)	(0.990)	(0.045)	(0.171)	(0.603)	(0.730)
log exports to GDP index []	1.641	1.568	1.971	1.635	1.668	2.027	1.016	1.462	1.671
	(4.288)	(4.269)	(5.282)	(5.154)	(4.396)	(5.294)	(1.538)	(1.830)	(2.712)
log private interest rate []	-0.702	-1.111	-1.222	-0.724	-1.465	-1.526	-0.971	-1.585	-1.997
	(2.588)	(5.727)	(3.610)	(2.576)	(6.144)	(4.039)	(2.785)	(3.445)	(3.126)
gaussian frailty term				5.697	73.751	48.141			
				(0.391)	(0.016)	(0.089)			
n	284	284	284	284	284	284	284	284	284
ln L	-1188.528	-1200.069	-1182.008	-1183.010	-1143.777	-1142.381			
c-index	0.817	0.818	0.823	0.832	0.868	0.864	0.824	0.820	0.834

Note: Absolute values t-statistics based on robust standard errors are reported in parentheses below the coefficient estimates. In case of the frailty term the χ^2 test statistics and the p-value (in parentheses) are reported.

Concerning the macro variables which are in the focus of this paper we find that real GDP per capita (in logs) reduces the exit hazard significantly irrespective of the specification of the macro variables chosen and this remains robust to the introduction of the frailty term and the application of the robust Cox regression. Thus, the exit hazard is lower when real per capita income is larger which may be attributed to a demand effect. We also tried growth rates of real GDP per capita and the deviation from a Hodrick-Prescott filtered trend finding both variables also significantly negative. Reported are the results with the level of real GDP per capita since this variable is associated with a much larger goodness-of-fit measure than the other alternatives (the c-index as discussed below).

The CPI inflation rate has negative as well as positive coefficient estimates and is never significant statistically.[13] The effect of the years of the hyperinflation are captured separately by the hyper dummy variable. This outcome can most likely be attributed to a balancing of the positive and negative effects of inflation, where higher inflation destroys purchasing power and is harmful for the allocative function of markets on the one hand and intensifies the orientation of the economy towards real assets from which automobile producing firms may have benefited on the other hand. The shakeout with many exits took place after prices have stabilized which may explain the lack of significance.

The coefficient of the exports to GDP index (also in logs) is positive throughout. It is significant only for the ordinary Cox regression and when frailty is introduced, but is not significant when the robust Cox regression estimator is applied (and the coefficient estimates are lower in that case). The exception here is the case $[t = 0, 1]$ where the positive effect is also significant. Thus, overall the exit risk is positively influenced by exports. Given that this variable can be interpreted as a general measure of openness of the economy to foreign trade the positive effect indicates that German automobile firms suffer from competition from abroad which forced some firms to exit. This indeed happened during the shakeout phase.

Negative and strongly significant coefficient estimates are found for the private interest rate (again in logs). Thus, the exit hazard of the firms is lower when the interest rate is higher. This finding may be attributed to the entry-preventing effect of bad financing conditions when the interest rate is higher which benefits incumbent firms and supports their survival. This happened after the shakeout and sustained the stabilization of the number of firms.

The frailty term is significant when the macro variables are taken from the year before exit (abbreviated as $[t = 1]$) but not in the other two cases. Note that the number in parentheses below the χ^2 Wald test statistics reported for the frailty-terms are the p-values. The main results regarding coefficient estimates and their significance are not much affected by the consideration of frailty. This is similar to Manjón-Antolín and Arauzo-Carod (2008) and Strotmann (2007) who also find only modest effects of accounting for unobserved heterogeneity in regressions explaining firm survival.

Goodness of fit is measured by the concordance index or c-index for short. The c-index is defined as the "proportion of all pairs of subjects whose survival time can be ordered such that the subject with predicted higher survival is the one who survived longer" (Harrell (2001, p. 493)). It is the probability of concordance between predicted and observed survival with boundary values $c = 0.5$ for random predictions and $c = 1$ for a perfectly discriminating model. Here, we observe that all regressions have a c-index exceeding 0.8. This is quite large[14] and demonstrates a clear increase in goodness of fit compared to the regressions without macroeconomic variables where we get values of the c-index of about 0.71 without frailty and 0.79 with the consideration of frailty (results not shown). In the frailty case, the values of the c-index are also even larger than for the original and robust Cox regressions in table 3.

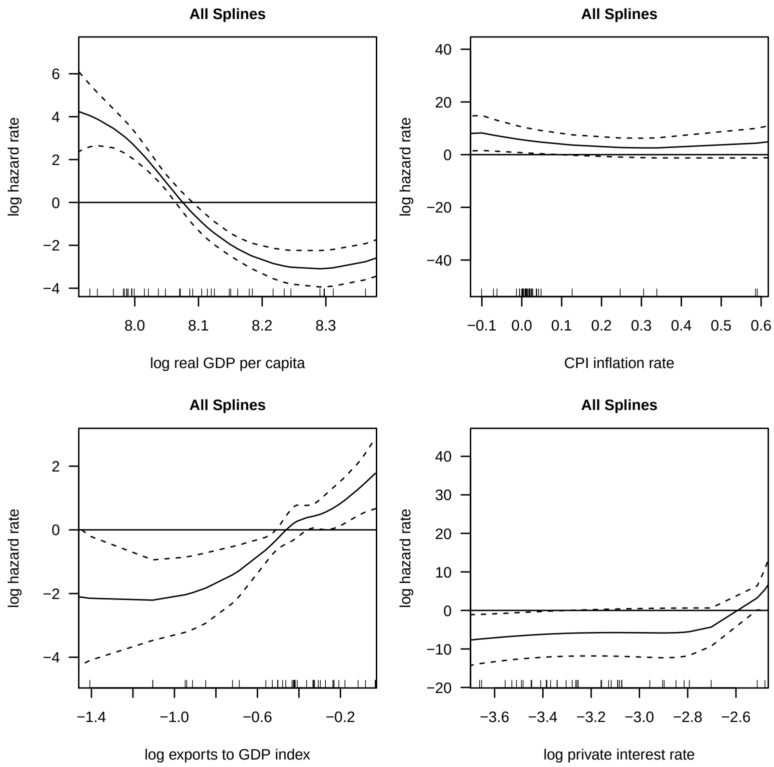
4.2 Regression Splines

Now we turn to a deeper investigation of possible nonlinear effects of the four macroeconomic variables using natural splines for the averages of $t = 0$ and $t = 1$ of the variables (case $[t = 0, 1]$). For the spline

[13] We rely here on the nominal interest rate, since the real interest rate would be totally dominated by the inflation rate (correlation coefficient ≈ -0.9997) which leads to a loss of many observations when the negative real rate is used in logs and causes numerical problems with the regression splines later on. In a linear specification without using logs only the results for the inflation rate would be affected while the other parameters and standard errors would be the same (since $\beta_\pi \pi + \beta_r r = (\beta_\pi + \beta_r)\pi + \beta_r(r - \pi)$ with π as the inflation rate, $r - \pi$ as the real interest rate and β_π, β_r as the corresponding regression coefficients).

[14] Therneau (on the help page for the function `survConcordance()` of his R-package 'survival') states that c-index values of 0.6 to 0.7 are common for survival data. There is also a relation to Somers' rank correlation between predicted probabilities and observed responses, $D_{xy} = 2 \cdot (c - 0.5)$.

Figure 2: Splines Estimated by the Original Cox Regression



specification we choose four degrees of freedom meaning in the case of a natural spline that the knots are positioned at the extremes as well as at the 0.25, 0.5 and 0.75 percentiles of the data. The results are robust to the choice of a larger number of degrees of freedom. The detailed estimation results for the original Cox regression and the robust Cox regression are shown in table 4 in the appendix.[15] We find that the c-index improves a bit but not by a large margin. Since the coefficient estimates for the spline terms are not particularly usefully interpretable for themselves we turn to analyzing the plots of the spline fits.

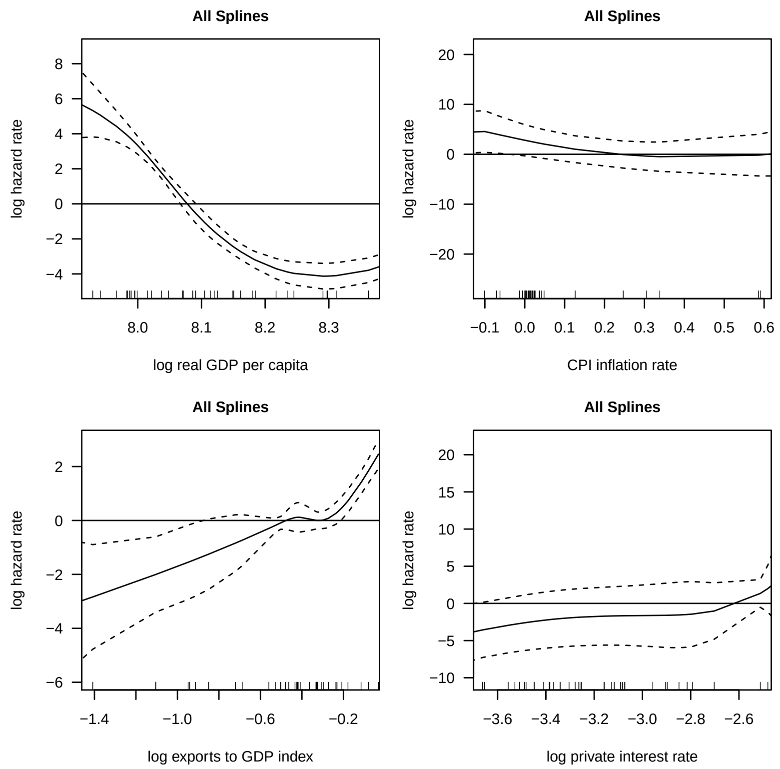
Looking first at the results for the original Cox regression, the four panels of figure 2 show the spline fits for the four macroeconomic variables. The tick marks at the abscissa (so-called rugs) indicate the positions of the data points of the respective macroeconomic variable. Note that the two largest and the two smallest values on the scale of the abscissa are trimmed away to obtain a clearer plot, but these values are of course used for the estimation. Shown are the spline fits as the solid lines and the 95 percent confidence intervals as dashed lines.

For real GDP per capita (upper left panel) we find the strong negative relation to the log hazard rate as above but also see that this relation is not linear but follows a kind of inverse S-shape. This is supported by rather narrow confidence bands. More specifically, we have at first a slowly declining hazard rate with increasing real income per capita, then a more rapid decline and finally a tapering off at medium to large levels of real income per capita. The lowest values are observed during the hyperinflation years, while the middle value of $e^{8.15} \approx 3500$ is close to that of the year 1912 just before the sequence of events leading to the First World War. The values around $e^{8.3} \approx 4000$ are observed in the years just before and after the world economic crisis. Finally, the largest value is that of 1939. It should be noted that the negative effect is concentrated in a rather narrow range of real GDP per capita values between $e^{8.1} \approx 3300$ and $e^{8.2} \approx 3600$.

In the case of the inflation rate (upper right panel) we see a rather flat curve corresponding to the insignificant effect already found above. In the range of inflation rates between zero and 0.05 (meaning 5 percent), where the majority of the observations is concentrated, the curve is weakly declining. The larger inflation rates are observed during the First World War and the following years, while the very

[15] Frailty here also has a negligible effect on the results so that we omit this regression.

Figure 3: Splines Estimated by the Robust Cox Regression



largest inflation rates are trimmed away from the scale of the figure as said above. The negative inflation rates occurred during the years of the world economic crisis, i.e. 1930-32.

The plot for the exports to GDP index (lower left panel) shows a somewhat nonlinear curve surrounded by wide confidence bands. Since the lower values are quite scant and occurred during the First World War and the subsequent years as well as during the years after the world economic crisis we can not rely much on the first flat part of the curve. In addition, the confidence bands are so wide that it is easily possible to fit a straight line with positive slope which would completely lie within the confidence bands. Thus, we take this as an indication that this effect is linear. Larger values of the exports to GDP index can be found in particular at the beginning of the 20th century until the First World War.

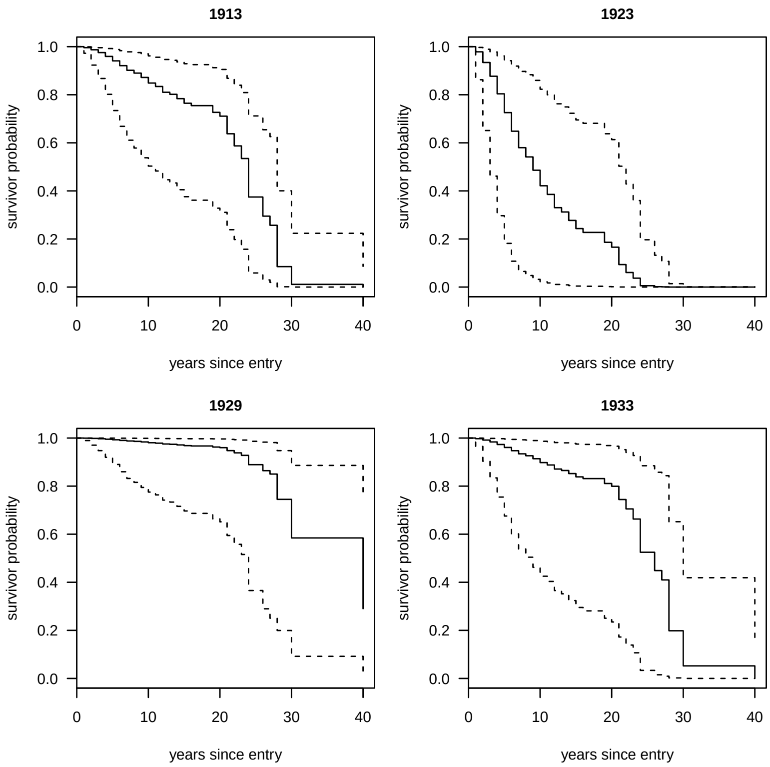
The curve for the private interest rate (lower right panel) is almost flat and only begins to rise for the largest values of the interest rate. But this positively sloping part appears to be exclusively driven by a few particularly large values which can be observed immediately after the hyperinflation years.

Turning to the findings of the robust Cox regression in figure 3 we observe some quantitative but no qualitative differences. Thus, the results obtained with the regression splines and the original Cox regression are largely confirmed by the robust version of the Cox regression. One recognizable difference is the curve for the exports to GDP index which now appears more clearly nonlinearly shaped and the nonlinearity is now better supported by the tighter confidence bands.

4.3 Expected Survival

In this section we have a look at the predicted survivor curves from the Cox regression at a variety of macroeconomic conditions and different firm characteristics. The basis is the robust Cox regression with coefficients estimated using the averages of the macroeconomic variables of the year of exit and the year before the exit. The objective is to provide an exploration of the influence of the macroeconomic conditions on the expected survivor probabilities at different ages of the firms (i.e. the probability of survival of a firm which survived up to a specific age). Thereby, we also investigate the hazard rate at different ages which is related to the negative slope of the survivor curve. Computational aspects are

Figure 4: Survival Curve in Selected Years (early-experienced firm)



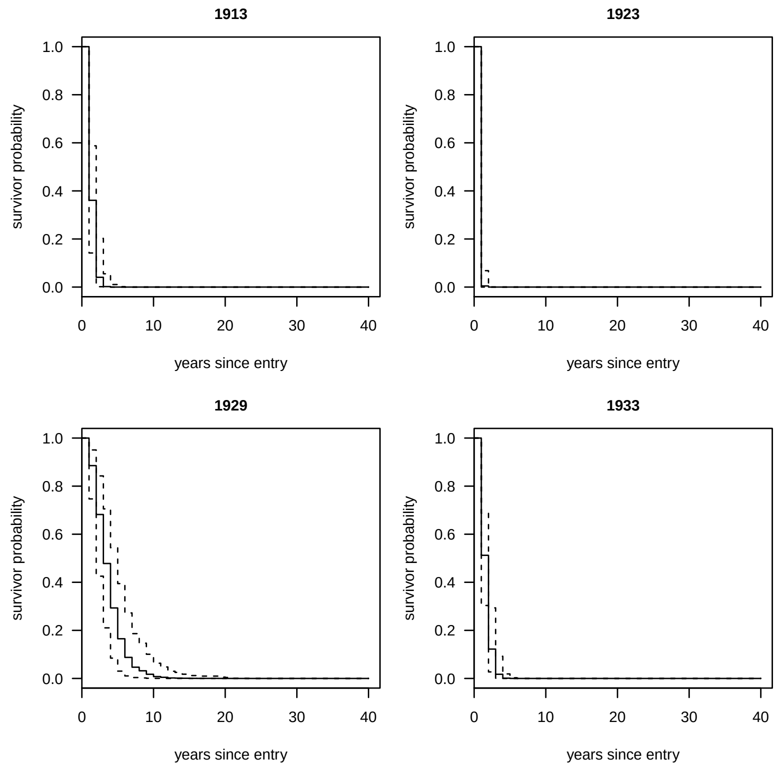
outlined in some detail in chapter 10 of Therneau and Grambsch (2000) jointly with direct relation to the R functions used.

The predicted survivor curves are computed for the values of the macroeconomic variables of the years 1913 (the year before the outbreak of the First World War), 1923 (the end of the hyperinflation), 1929 (the end of the shakeout phase and the start of the world economic crisis), 1933 (the end of the world economic crisis). The dummy variables ww1, hyper and wec are set to zero or unity according to the particular year under consideration. Two hypothetical types of firms are distinguished, namely the early-experienced firms of the first entry cohort which are endowed with pre-entry experience (with firm-specific variables set to $E_1 = 1$, $E_2 = 0$, $E_3 = 0$, $E_4 = 0$, $P = 1$) and the late-inexperienced firms of the fourth entry cohort without having pre-entry experience (with firm-specific variables set to $E_1 = 0$, $E_2 = 0$, $E_3 = 0$, $E_4 = 1$, $P = 0$).

Figure 4 shows the results for the early-experienced firms under the macroeconomic conditions prevailing the in years indicated above the respective plots. The dashed lines here also represent pointwise 95 percent confidence bands. We find the survivor curve to be slightly concave in 1913 which implies an increasing decline of the probability of survival for each additional year survived. After 20 years about half of the early-experienced firms were forced to exit (while the other half survived) when we fix the macroeconomic variables at the values of 1913. The survivor curve of the year 1923 is more convexly curved, implying a more rapidly increasing exit risk for young firms which is moderated at higher ages. In contrast, the survivor curve for 1929 after the end of the shakeout phase is again concave with high and almost constant survival probabilities which only later begin to decline somewhat. This may be taken as evidence for the stabilization of the firm number where mainly the early and experienced firms survived and these firms had a good change to survive even longer. Finally, the year 1933 is also characterized by a concave survivor curve but now with more rapidly declining survival probabilities.

The corresponding results for the late-inexperienced firms are shown in figure 5. For these firms we observe much more rapidly declining survivor probabilities with particularly pronounced declines at low ages. Under the macroeconomic conditions prevailing in the years 1913, 1923 and 1933 new late-inexperienced firms were almost immediately forced to exit. Survival chances were slightly better in 1929 but one has to take into account that only very few firms enter when the number of firm has been stabilized after the

Figure 5: Survival Curve in Selected Years (late-inexperienced firm)



shakeout.

5 Conclusions

We conclude with the main lessons which can be learned from the results of the preceding analysis of firm survival in the German automobile industry during 1886-1939. First, it appears that both the knowledge-related variables suggested by the microeconomic industrial organization context and the macroeconomic variables together shape the hazard rate and therefore the probability of firm exit. The findings for the microeconomic variables correspond to those of Cantner et al. (2006) and Klepper (2002). The macroeconomic variables clearly matter and lead to a considerable increase of explanatory power while the microeconomic variables robustly reflect the forces of pre- and post-entry experience addressed by industry life-cycle theory. Specifically, the exit hazard is reduced by increasing income (real GDP per capita), is largely unaffected by inflation, tends to rise with increasing export orientation of the economy and is lower when the interest rate is higher. For some macroeconomic variables (chiefly real income per capita) nonlinear effects can be detected. The survivor curves for selected years show the different effects of the macroeconomic conditions in selected years as well as the effects of the knowledge variables of two hypothetical firm types.

Second, taking into account the sequence of historical events it seems more likely that the shakeout phase with the rapid decline of the number of firms and the subsequent stabilization of the industry seems to be caused by the microeconomic factors (i.e. the technological switch to mass production methods and the increased competition) rather than by the prevailing macroeconomic conditions. This has also been argued by Klepper (2002) for the US automobile industry.

Third, from a more statistical perspective, we find that unobserved heterogeneity (or its neglection) exerts not much influence on the estimation results, as previously found in other empirical studies. Unobserved heterogeneity, however, seems to play a larger role in labor market studies (see e.g. the prominent treatment in van den Berg (2001)). The main conclusions also survive the re-estimation of the regressions by a robust variant of the Cox regression which is designed to be less influenced by outlying observations which may be caused by extreme macroeconomic conditions. The exception is the exports to GDP ratio with a drop in coefficient magnitude and loss in significance when the robust estimator is used. Cross-checking by robust regression methods is particularly important in analyses concerned with turbulent historical periods which may easily lead to badly recorded data and outlying influential observations.

Acknowledgment

We will ever remain grateful to Stephen Klepper, who passed away much too early, for his many thoughtful comments to our earlier papers and hope that he views this new paper with sympathy. We thank Benny Hampf for his careful proofreading and helpful suggestions.

Appendix

Table 4: Results for the Spline Estimation (for $[\overline{t=0,1}]$)

	original Cox regression	robust Cox regression
E_1	-5.695	-6.658
	(15.517)	(12.901)
E_2	-4.335	-4.894
	(15.652)	(8.537)
E_3	-2.636	-2.830
	(17.084)	(15.556)
P	-0.291	-0.398
	(2.031)	(3.160)
ww1	-2.601	-3.417
	(4.254)	(8.154)
hyper	-15.635	-6.463
	(2.203)	(1.427)
wec	-2.367	-1.098
	(2.751)	(2.455)
log real GDP per capita []1	-5.300	-6.981
	(3.692)	(4.448)
log real GDP per capita []2	-8.826	-11.678
	(6.505)	(9.793)
log real GDP per capita []3	-7.637	-11.023
	(2.784)	(4.688)
log real GDP per capita []4	-4.348	-6.103
	(4.960)	(9.661)
CPI inflation rate []1	35.394	17.112
	(2.294)	(1.732)
CPI inflation rate []2	-9.705	-8.516
	(4.058)	(5.918)
CPI inflation rate []3	103.281	44.669
	(2.243)	(1.457)
CPI inflation rate []4	14.549	4.872
	(1.988)	(1.083)
log exports to GDP index []1	2.389	3.521
	(1.713)	(2.529)
log exports to GDP index []2	2.671	2.123
	(3.154)	(3.076)
log exports to GDP index []3	2.613	6.313
	(0.825)	(1.932)
log exports to GDP index []4	4.140	4.688
	(4.665)	(5.834)
log private interest rate []1	3.778	4.149
	(2.195)	(2.937)
log private interest rate []2	2.390	3.439
	(1.127)	(1.403)
log private interest rate []3	27.952	14.146
	(2.161)	(1.914)
log private interest rate []4	29.217	10.220
	(1.992)	(1.081)
n	284	284
ln L	-1137.902	
c-index	0.866	0.874

Note: See table 3.

References

[1] Agarwal, R., Audretsch, D.B. (2001), Does Entry Size Matter? The Impact of the Life Cycle and Technology on Firm Survival, Journal of Industrial Economics 49, 21-43.

[2] Agarwal, R., Gort, M. (2002), Firm and Product Life Cycles and Firm Survival, American Economic Review, Papers and Proceedings 92, 184-190.

[3] Audretsch, D.B., Mahmood, T. (1994), Firm Selection and Industry Evolution: The Post-Entry Performance of New Firms, Journal of Evolutionary Economics 4, 243-260.

[4] Audretsch, D.B., Mahmood, T. (1995), New Firm Survival: New Results Using a Hazard Function, Review of Economics and Statistics 77, 97-103.

[5] Bhattacharjee, A., Higson, C., Holly, S., Kattuman, P. (2009), Macroeconomic Stability and Business Exit: Determinants of Failures and Acquisitions of UK Firms, Economica 76, 108-131.

[6] Bednarski, T. (1993), Robust Estimation in Cox's Regression Model, Scandinavian Journal of Statistics 20, 213-225.

[7] Boeri, T., Bellmann, L. (1995), Post-Entry Behaviour and the Cycle: Evidence from Germany, International Journal of Industrial Organization 13, 483-500.

[8] Bolt, J., van Zanden, J.L. (2013), The Maddison Project: The First Update of the Maddison Project Re-Estimating Growth Before 1820, Maddison-Project Working Paper WP-4.

[9] Boschma, R.A., Wenting, R. (2007), The Spatial Evolution of the British Automobile Industry: Does Location Matter?, Industrial and Corporate Change 16, 213-238.

[10] Buddelmeyer, H., Jensen, P.H., Webster, E. (2010), Innovation and the Determinants of Company Survival, Oxford Economic Papers 62, 261-285.

[11] Cantner, U., Dreßler, K., Krüger, J.J. (2006), Firm Survival in the German Automobile Industry, Empirica 33, 49-60.

[12] Cantner, U., Krüger, J.J., von Rhein, K. (2009), Knowledge and Creative Destruction over the Industry Life Cycle: The Case of the German Automobile Industry, Economica 76, 132-148.

[13] Cantner, U., Krüger, J.J., von Rhein, K. (2011), Knowledge Compensation in the German Automobile Industry, Applied Economics 43, 2941-2951.

[14] Caves, R.E. (1998), Industrial Organization and New Findings on the Turnover and Mobility of Firms, Journal of Economic Literature 36, 1947-1982.

[15] Chambers, J.M. (2008), Software for Data Analysis: Programming with R, New York: Springer.

[16] Cox, D.R. (1972), Regression Models and Life Tables, Journal of the Royal Statistical Society Series B 34, 187-220.

[17] Cox, D.R. (1975), Partial Likelihood, Biometrika 62, 269-276.

[18] Disney, R., Haskel, J., Heden, Y. (2003), Exit, Entry and Establishment Survival in UK Manufacturing, Journal of Industrial Economics 51, 93-115.

[19] Efron, B. (1977), Efficiency of Cox's Likelihood Function for Censored Data, Journal of the American Statistical Association 72, 557-565.

[20] Feenberg, D., Miron, J.A. (1997), Improving the Accessibility of the NBER's Historical Data, Journal of Business and Economic Statistics 15, 293-299.

[21] Flik, R. (2001a), Von Ford lernen?, Automobilbau und Motorisierung in Deutschland bis 1933, Cologne: Böhlau.

[22] Flik, R. (2001b), Automobilindustrie und Motorisierung in Deutschland bis 1939, in: Boch, R. (ed.), Geschichte und Zukunft der deutschen Automobilindustrie: Tagung im Rahmen der 'Chemnitzer Begegnungen' 2000, Stuttgart: Steiner, pp. 49-84.

[23] Geroski, P.A., Mata, J., Portugal, P. (2010), Founding Conditions and the Survival of New Firms, Strategic Management Journal 31, 510-529.

[24] Gort, M., Klepper, S. (1982), Time Paths in the Diffusion of Product Innovations, Economic Journal 92, 630-653.

[25] Harrell, F.E. (2001), Regression Modeling Strategies: With Applications to Linear Models, Logistics Regression, and Survival Analysis, New York: Springer.

[26] Hastie, T., Tibshirani, R., Friedman, J. (2009), Elements of Statistical Learning: Data Mining, Inference, and Prediction, 2nd ed., New York: Springer.

[27] Ilmakunnas, P., Topi, J. (1999), Microeconomic and Macroeconomic Influences on Entry and Exit of Firms, Review of Industrial Organization 15, 283-301.

[28] Klepper, S. (1996), Entry, Exit, Growth, and Innovation over the Product Life Cycle, American Economic Review 86, 562-583.

[29] Klepper, S. (2002), Firm Survival and the Evolution of Oligopoly, Rand Journal of Economics 33, 37-61.

[30] Klepper, S., Graddy, E. (1990), The Evolution of New Industries and the Determinants of Market Structure, Rand Journal of Economics 21, 27-44.

[31] Klepper, S., Simons, K.L. (2000), The Making of an Oligopoly: Firm Survival and Technological Change in the Evolution of the US Tire Industry', Journal of Political Economy 108, 728-760.

[32] Klepper, S., Simons, K.L. (2005), Industry Shakeouts and Technological Change, International Journal of Industrial Organization 23, 23-43.

[33] Krüger, J.J. (2015), Survival Analysis in Product Life Cycle Investigations: An Assessment of Robustness for the German Automobile Industry, Darmstadt Discussion Papers in Economics 223.

[34] Krüger, J.J., von Rhein, K. (2009), Knowledge, Profitability and Exit of German Car Manufacturing Firms, Economics of Innovation and New Technology 18, 107-122.

[35] Maddison, A. (1991), Dynamic Forces in Capitalist Development: A Long-Run Comparative View, Oxford: Oxford University Press.

[36] Manjón-Antolín, M.C., Arauzo-Carod, J.-M. (2008), Firm Survival: Methods and Evidence, Empirica 35, 1-24.

[37] Minder, C.E., Bednarski, T. (1996), A Robust Method for Proportional Hazards Regression, Statistics in Medicine 15, 1033-1047.

[38] Nelson, T. (2003), The Persistence of Founder Influence: Management, Ownership, and Performance Effects at Initial Public Offering, Strategic Management Journal 24, 707-724.

[39] Strotmann, H. (2007), Entrepreneurial Survival, Small Business Economics 28, 87-104.

[40] Therneau, T.M., Grambsch, P.M. (2000), Modeling Survival Data: Extending the Cox Model, New York: Springer.

[41] Therneau, T.M., Grambsch, P.M., Pankratz, V.S. (2003), Penalized Survival Models and Frailty, Journal of Computational and Graphical Statistics 12, 156-175.

[42] Thompson, P. (2005), Selection and Firm Survival: Evidence from the Shipbuilding Industry, 1825–1914, Review of Economics and Statistics 87, 26-36.

[43] van den Berg, G.J. (2001), Duration Models: Specification, Identification and Multiple Durations, in: J.J. Heckman, E. Leamer (eds.), Handbook of Econometrics, vol. 5, ch. 55, pp. 3381-3460.

[44] von Rhein, K. (2008), Heritage and Firm Survival: An Analysis of German Automobile Spinoffs 1886-1939, Economics Bulletin 12, 1-8.