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Evolution and Firm Survival in Vertically Related Populations: The Case of the German Piano Industry

Roland Stürz
Max Planck Institute for Innovation and Competition
Munich Center for Innovation and Entrepreneurship Research
roland.stuerz@ip.mpg.de

Abstract

Research on the evolution of industries has devoted little attention to the development of vertical structures of firms and the emergence of new, specialized supplier populations along the value chain of an industry as industries mature. The change of the vertical industry structure and the co-evolution of subpopulations of suppliers lead to the creation of an interdependent community of organizational populations. However, the impact of vertically related upstream suppliers on the survival of downstream end product manufacturers remains under-researched. This study addresses this research gap and explores the impact of upstream suppliers on downstream survival of all German piano manufacturers (1705-1929). Quantitative event history analyses show that the number of suppliers of the most important core components exhibits a positive effect on firm survival of piano manufacturers. However, the number of firms in other supplier subpopulations does not always affect the exit rates of quality and non-quality end product manufacturers in the same way, which is probably related to the different degree of vertical integration of these two types of firms. The study contributes to the understanding of the forces driving industry evolution and firm survival and makes it easier to predict long-term industrial developments.

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Keywords:

Organizational ecology, industrial evolution, firm survival, piano industry

1 Introduction

Research on the evolution of industries has led to a number of theoretical models dealing with the co-evolution of technology, innovation, legitimation and competition with industrial dynamics and the composition of organizational populations (Mueller/Tilton 1969; Utterback/Abernathy 1975; Carroll/Hannan 1989a, b, 2000; Nelson 1994; Klepper 1997, 2000; Núñez Nickel/Moyano Fuentes 2004). However, those models devote little attention to the development of vertical structures of firms and the emergence of new, specialized supplier populations along the value chain of an industry as industries mature (Klepper 1997). Only recently theoretical contributions and case studies enhanced our understanding of how industry evolution, vertical disintegration and market emergence for supply products might be related to each other (Christensen et al. 2002; Macher/Mowery 2004; Cacciatori/Jacobides 2005; Jacobides 2005; Arora/Bokhari 2007; Jacobides 2008; Malerba et al. 2008; Stuerz 2013). The beginning of an industry life cycle is often characterized by high uncertainty and the technology of the industry is not well understood (Mueller/Tilton 1969; Abernathy/Utterback 1988). Many diverse products with different features customized for specific consumer segments are developed (Abernathy/Utterback 1988; Christensen et al. 2002). Usually, markets for the exchange of specific supply products and specialized populations of suppliers do not exist (Cacciatori/Jacobides 2005; Jacobides 2005). Moreover, the complexity of the problems and the rather systemic or architectural innovations prevalent in the early phases of the evolution of an industry place integrated end product manufacturers at an advantage (Teece 1996; Christensen et al. 2002; Nickerson/Zenger 2004; Macher 2006; Wolter/Veloso 2008). As the industry matures the products usually get more and more standardized and a dominant design ultimately is established (Abernathy/Utterback 1988; Utterback/Suárez 1993). With the dominant design a sufficient degree of coordination simplification and information standardization necessary in order to allow for vertical disintegration within the industry might be accomplished and the development of specialized subpopulations of suppliers can start (Jacobides 2005; Argyres/Bigelow 2007; Stuerz 2013).

The change of the vertical industry structure leads to the creation of an interdependent community of organizational populations along the value chain of an industry. However, one major shortcoming of most of the existing empirical research on industry evolution and firm survival over long periods of time is that this change of the vertical industry structure and the emerging subpopulations of suppliers are often neglected as either only intra-population effects in end product manufacturer populations are investigated (see among others Suárez/Utterback 1995; Klepper 2002, 2007; Carroll/Hannan 2000; Núñez Nickel/Moyano Fuentes 2004) or inter-population effects of more or less overlapping horizontally related populations are explored (Rao 2005; de Figueiredo/Silverman 2012). Only de Figueiredo and Silverman (2012) started to investigate the influence of vertically related populations, analyzing the effect of the number of upstream laser engine producers on the survival of downstream laser printer manufacturers.

The following study aims to address this research gap and explores the impact of upstream suppliers on the survival of downstream manufacturers. In extension to de Figueiredo and Silverman (2012), the study not only investigates the effect of one core component supplier subpopulation but of different subpopulations of suppliers. This allows for theoretical predictions and empirical analyses of different effects relating to the importance of different supplier subpopulations for downstream producers.

It is argued that in general the number of suppliers reduces the risk of industry exit for downstream end product manufacturers but that, more specifically, supplier subpopulations of important core components in particular should be responsible for this life enhancing effect.

Quantitative event history analyses using data on industry exists of German piano manufacturers (1705-1929) partly support these predictions. On the one hand, the regression models show that uniformly counted suppliers, regardless of their supply product, have no impact on the survival of downstream piano manufacturers. However, on the other hand, the models reveal that especially the number of suppliers of the most important core components – claviatures and piano actions – has a positive effect on firm survival. Moreover, the number of firms in other supplier subpopulations does not always affect the exit rates of quality and non-quality end product manufacturers in the same way, which is probably related to the different degree of vertical integration of these two types of firms (Freygang 1949). In addition the estimated models support the notion of an intra-population density dependence (Carroll/Hannan 1989b). An intra-population density delay (Carroll/Hannan 1989a), however, cannot be found.

Research investigating the evolution of vertically related populations and the impact of the supplier subpopulations on the survival of downstream end product manufacturers is important for several reasons. First, in general, the survival and death of organizations are phenomena of great interest to business scholars as long-term survival is not only a basic goal for business ventures but also a fundamental requirement for success in other terms (Suárez/Utterback 1995). Second, the change of the vertical industry structure and competition along with the necessary competencies of firms has profound strategic implications for firms in the industry (Jacobides 2005). Third, a comprehensive understanding of the forces driving industry evolution and firm survival that goes beyond the mechanisms just within the end product manufacturer population is important for firms and policy makers to broaden the perspective on industry evolution and to facilitate predictions of long-term industrial developments (Jacobides/Winter 2005).

Using data on all known German piano manufacturers allows for a comprehensive test of the survival implications of supplier subpopulations on downstream manufacturers. The piano industry fosters comparisons with existing research on industry evolution and firm survival in other industries, especially as the industry seems to have followed the notion of the Abernathy-Utterback-Model (Utterback/Abernathy 1975; Abernathy/Utterback 1988) with the development of a dominant design as the industry matured (Lieberman 1996; Stuerz 2013).

The paper proceeds as follows: In the next section, theoretical predictions for intra- and inter-population dependencies are developed. The third section introduces the industry background and provides a short overview of the data collection process. In the fourth section, the statistical method and the variables are explained. Section five then displays the results. The paper concludes with a discussion of the results.

2 Theoretical Background and Hypotheses

Intra-population dependencies: The typical evolutionary pattern of industries is often characterized by a slow initial increase in firm numbers – the so-called population density (Carroll/Hannan 2000) – followed by a rapid rise to a peak. After the peak there is usually a sharp decline, followed by a stabilization of firm numbers (Mueller/Tilton 1969; Gort/Klepper 1982; Klepper 1997). Population ecologists believe that a very general and long-term intra-population model based on the two sociological forces ‘social legitimation’ and ‘diffuse competition’ can explain this observable evolutionary pattern (Hannan 1986; Carroll/Hannan 1989b, 2000; Hannan/Carroll 1992; Carroll 1997).

An organization of a new form typically lacks ‘social legitimation’ as it has not yet attained a taken for granted character (Meyer/Rowan 1977; Carroll 1997). At the beginning of the industry life cycle, when there are only few organizations of one kind, another new organization can highly increase legitimation. At later stages in the evolutionary process, however, when population density is already high, the addition of a new organization adds little or nothing to legitimation. Legitimation has a negative effect on the mortality rate in an organizational population as it makes it easier for organizations to maintain the necessary flow of resources (Hannan/Carroll 1992; Carroll 1997; Carroll/Hannan 2000).

The second evolutionary driving force is ‘diffuse competition’. In contrast to direct or head-to-head competition ‘diffuse competition’ arises when a set of organizations depends upon the same pool of limited resources (Carroll/Hannan 2000). As population density increases linearly, potential bilateral relationships and thus ‘diffuse competition’ increase geometrically. ‘Diffuse competition’ elevates mortality as competition makes it more difficult for organizations to maintain the necessary flow of resources (Carroll/Hannan 1989b, 2000; Hannan/Carroll 1992).

At very low levels of density, typically at the beginning of the industry life cycle, legitimation exceeds competition. At later stages in the evolutionary process – when density is high – competitive forces dominate. This in turn leads to the empirically testable implication of the density dependence model: the relationship between the mortality rate and contemporaneous intra-population density is believed to be U-shaped (Hannan/Carroll 1992):

$$h(t) = h_0(t)\ exp(\beta_1 N_{it} + \beta_2 N_{it}^2) \qquad (1).$$

The hazard rate h(t) is explained by the product of the time-variant baseline hazard rate $h_0(t)$ with a multiplier that depends on the contemporaneous population density of the focal population i N_{it} and its square N_{it}^2. The intra-population density dependence model predicts parameter estimates for $\beta_1 < 0$ and $\beta_2 > 0$ (Carroll/Hannan 1989b, 2000). A variety of studies created strong empirical support for the model in different organizational populations.[1]

Accordingly, an intra-population density dependence is also expected for the focal downstream end product manufacturer population.

H1: The contemporaneous population density of the focal downstream population exhibits a U-shaped relationship with the exit rate of organizations of that population.

While density dependence can account for the growth path of population density during the evolution of an industry, it cannot explain the usual sharp decline after the peak. Carroll and Hannan (1989a) extended the model suggesting a delayed effect of population density at the time of founding of a new organization. Following Stinchcombe’s (1965) imprinting hypothesis, “organizations differ from one another not because they adapt to changing environmental conditions, but instead because organizations are of necessity created out of the specific technological, economic, political, and cultural resources available in the founding context.” (Johnson 2007, p. 97 et seq.). Due to structural inertia, changes to the imprinted organization-

[1] See Singh and Lumsden (1990) as well as Núñez Nickel and Moyano Fuentes (2004) for a comprehensive review of empirical evidence.

al form are difficult and heighten the risk of organizational failure (Hannan/Freeman 1977). The prediction of a delayed effect of intra-population density at the time of founding is that organizations established under adverse environmental conditions, characterized by a high population density, are weak competitors with a persistently higher age-specific mortality rate (Carroll/Hannan 1989a). Times of high density are characterized by high competition and scarce resources. Thus, new ventures are primarily engaged in securing the necessary flow of resources and cannot devote much time on organization building. Moreover, when population density is high, niches in the resource space are tightly packed. Therefore, new organizations are often forced to use the margins of the resource space. Even if they succeed in developing routines and structures that secure a constant resource flow they are committed to inferior regions of the resource space (Carroll/Hannan 1989a). This extends the intra-population density dependence model:

$$h(t) = h_0(t) \exp(\beta_1 N_{it} + \beta_2 N_{it}^2 + \beta_3 N_{ifk}) \quad (2),$$

with N_{ifk} denoting the population density of the focal population i at the time of industry entry of organization k. The model predicts a parameter of $\beta_3 > 0$ (Carroll/Hannan 1989a).

Many studies also supported the density delay concept.[2] Accordingly, an intra-population density delay is expected for the focal downstream end product manufacturer population as well.

> **H2:** The density of the focal population of downstream manufacturers at the time of industry entry of a new organization has a positive effect on the hazard rate of this organization.

Research of intra-population density effects on the survival of firms has been conducted in a variety of organizational populations. This, however, is not the case for cross-density or inter-population density effects especially of vertically related populations.

Inter-population dependencies: As "most organizational populations do not exist in a vacuum, as their members interact with organizations in adjacent populations: they may buy from them, form political alliances, share interlocking directorates, and steal each other's members" (Staber 1992, p. 1191), one must assume that also inter-population dependencies are relevant for survival in the focal end product manufacturer population. The focus must therefore be extended especially to include the community of related populations along the value chain of an industry. The community ecology perspective (Astley 1985; Aldrich 1999) can be

[2] See Singh and Lumsden (1990) as well as Núñez Nickel and Moyano Fuentes (2004) for a comprehensive review of empirical evidence.

used to develop predictions of the impact of related populations on the focal population as it deals with “coevolving populations linked by ties of commensalism and symbiosis“ (Aldrich 1999, p. 298). As table 1 shows, two populations can either be symbiotically, dominantly or by a form of commensalism be related to each other.

Table 1: Possible relations between organizational populations (source: Aldrich 1999, p. 302)

Commensalism	Full competition: growth in each population detracts from growth in the other.
	Partial competition: relations are asymmetric, with only one having a negative effect on the other.
	Predatory competition: one population expands at the expense of the other.
	Neutrality: populations have no effect on each other.
	Partial mutualism: relations are asymmetric, with only one population benefiting from the presence of the other.
	Full mutualism: two populations in overlapping niches benefit from the presence of the other.
Symbiosis	Two populations are in different niches and benefit from the presence of the other.
Dominance	A dominant population controls the flow of resources to other populations. Effects depend on the outcome of commensalistic and symbiotic relations.

As detailed long-term data on linkages of individual organizations in a community of populations is generally unavailable, population density of different populations can be used in order to approximate the effects of one population on the other (Staber 1992).

Empirical research investigating inter-population density effects on mortality rates include among others the telephone industries in Iowa and Pennsylvania (Barnett/Carroll 1987; Barnett 1990, 1997), U.S. microbreweries, brewpubs and beer mass producers (Carroll/Swaminathan 1992), populations of cooperative sector organizations in Maritime Canada (Staber 1992), child day care centers in Metropolitan Toronto (Baum/Singh 1994), the U.S. trucking industry (Silverman et al. 1997), as well as financial organizations in Singapore (Dobrev et al. 2006).

„Generally, though, [most] these studies have focused on interactions among overlapping populations, or industry segments, competing for roughly similar resources and customers. In this sense, these papers examine horizontal interdependencies” (de Figueiredo/Silverman 2012, p. 1634). The effect of vertically related supplier subpopulations on the survival of downstream end product manufacturers, however, remains under-researched. Only de Figueiredo and Silverman (2012) started to explore such a relationship, investigating the impact of upstream laser engine producers on downstream laser printer manufacturers. They show a negative effect of the supplier population density on the hazard rate of especially nonintegrated downstream manufacturers. Moreover, this effect is weaker for forward-integrated suppliers.[3]

It can be argued that in a standardized system differentiated organizations can be complementary to each other and therefore exert mutualistic or symbiotic effects on each other (Barnett 1990). The number of suppliers increases upstream competition and in turn downstream manufacturers might profit from lower prices of supply products (Salinger 1988; de Figueiredo/Silverman 2012). A higher number of suppliers also simplifies the access to resources for end product manufacturers and reduces exchange hazards of specific transactions (Williamson 1985; de Figueiredo/Silverman 2012). More suppliers might also increase the variety of supply products thus enabling downstream manufacturers to differentiate their own products more easily. Moreover, a higher variety of upstream products may facilitate the access to new ideas and foster innovation of downstream products. This can lead to decreasing competitive pressures for downstream producers (de Figueiredo/Silverman 2012). Thus, in general, the number of suppliers is predicted to exhibit a negative effect on the exit rate of downstream end product manufacturers:

$$h(t) = h_0(t)\, exp(\beta_1 N_{it} + \beta_2 N_{it}^2 + \beta_3 N_{ifk} + \beta_4 N_{Zt}) \qquad (3),$$

with N_{Zt} denoting the contemporaneous density of the supplier population and an expected parameter of $\beta_4 < 0$.

H3a: The contemporaneous density of the supplier population has a negative effect on the industry exit rate of focal end product manufacturers.

De Figueiredo and Silverman (2012) analyze this hypothesis for one specific core component supplier subpopulation. However, if the impact of more than just one supplier subpopulation is investigated one can expect that not all supplier subpopulation densities exert the same effect on downstream producers. Whereas population densities of suppliers of general, generic and strategically less important goods may exercise a small or even no effect, it is expected that especially the densities of supplier subpopulations of core components have a strong positive effect on the survival of downstream manufacturers. This leads to an extension of the general hypothesis H3a, as it is predicted that the negative impact of the supplier population density on the exit rate of downstream manufacturers depends on the type of the supplier subpopulation. The effect should be the stronger the more central and important the supplier subpopulation is:

[3] Another study on the evolution of vertically related industries exists for the jet and turboprop aircraft and engine industries by Bonaccorsi and Giuri (2001), though, with a different focus on the transmission of the industrial dynamics via the structure of the network of vertical exchange relations.

$$h(t) = h_0(t) \exp(\beta_1 N_{it} + \beta_2 N_{it}^2 + \beta_3 N_{ifk} + \sum_1^j \beta_{4j} N_{Zjt}) \quad (4),$$

with N_{Zjt} denoting the contemporaneous density of the j-th supplier subpopulation. With decreasing importance of the supply products of the supplier subpopulation j = 1; 2; 3; … parameter estimates of $\beta_{41} < \beta_{42} < \beta_{43} < \ldots \leq 0$ are expected.

H3b: The more important the product of a supplier subpopulation is for end product manufacturers, the stronger is the negative effect of the density of this supplier subpopulation on the exit rate of focal end product manufacturers.

These hypotheses are tested using data on German piano producers and suppliers to the German piano industry. First, the industry and data backgrounds are explained.

3 Data and Industry Background

The term ‘piano’ is a short form of the term ‘pianoforte’ which refers to the musical feature of the piano that allows to play music ‘soft’ (‘piano’) as well as ‘strong’ (‘forte’) (Freygang 1949). The piano is a string keyboard instrument which generates sounds with swinging steel strings. By pressing a key on the keyboard the force of the player is transmitted by the keyboard to the piano action with its hammers. The hammer then strikes the strings and a tone is produced that is emitted by the soundboard (Henkel 1994). Today, two structural shapes of pianos continue to exist, the grand piano where strings and the frame are horizontally arranged in a longish form, and the upright piano (also known as ‘pianino’) where the frame and strings are vertically arranged (Cieplik 1923).

Data to compile the histories of German piano manufacturers were taken from Henkel (2000, n. d.). In his encyclopedia Henkel (2000) lists all German manufacturers of pianos that are traceable by conserved instruments or literary sources of information (Henkel 2000, p. 5). Henkel himself used more than 190 sources to prepare his encyclopedia (Henkel n. d.). The information in Henkel (2002, n. d.) was used to collect data on suppliers to the German piano industry. This encyclopedia lists all traceable suppliers.[4]

[4] Henkel (2000, 2002, n. d.) provide the industry tenure for each producer. Often industry tenure is determined by the first and/or last literary evidence in one of the sources. As the case may be this can lead to a deviation from real industry tenure of a producer that is, however, conservative as industry tenure in these cases is rather underestimated. In most cases, a producer could ultimately be detected in the last edition of the ‚Welt-Adressbuch der gesamten Musikinstrumenten-Industrie‘ from Paul de Wit in 1929 (Henkel 2000). In some cases craft producers or factories were transferred to new owners, which were themselves not traceable as independent producers before. Different entries for those firms in Henkel’s encyclopedias (2000, 2002) were consolidated and industry tenures combined. Known takeovers by already traceable piano manufacturers as well as firm dissolutions by owners that immediately started their separated own businesses were treated as

The first hammer piano action was developed by the harpsichord builder Bartolomeo Cristofori in 1698 in Florence at a time when growing string orchestras and new tonal finesses in Italy called for the development of a new keyboard instrument that provided a corresponding dynamic to stringed bowed instruments. Cristofori soon developed his action into the so-called escapement action (Hollfelder 1999; Restle 2000; Lechner 2006) and later this type of action was further developed especially in England and became known as the English action (Adlam 1983; Henkel 1994).

In Germany, the first piano makers entered the industry in the early 18th century (Henkel 2000). The profession of instrument builders at that time was closely orientated at other basic professions like carpenters or cabinet makers (Heyde 1986). This was mainly due to the local rules of the guilds, as for example only carpenters that were members of the respective guild were allowed to perform joineries (Speer 2000). The production was small as there were only few sales opportunities. Only from 1780 onwards piano manufacturers were able to make a living with the sole production of pianos (Henkel 1994).

Parallel to the development of the English action, German and later especially Austrian piano makers developed the so-called Viennese action. Both types of actions co-existed nearly up to the end of the 19th century (Henkel 1994; Lechner 2006). The early phase of the industry was characterized by a variety of different products and systemic or architectural innovations and thus is in line with the predictions of the Abernathy-Utterback-Model of the industry life cycle (Utterback/Abernathy 1975; Abernathy/Utterback 1988; Stuerz 2013).

Around 1800, about 200 German pianoforte producers but basically no specialized suppliers were traceable (Henkel 2000, 2002, n. d.). Figure 1 displays the evolution of the population of German piano manufacturers; figure 2 shows the evolution of the supplier population.

Despite growing firm numbers the German piano industry was unable to flourish in the first half of the 19th century. Unstable political conditions, changing tariff barriers of the German states in the German Confederation, the existing guild system as well as products that technologically lagged behind the pianos from England or Austria were reasons for this situation (Cieplik 1923; Heyde 1986; Henkel 2007).

censored cases. As a general rule, Henkel’s (2000, 2002, n. d.) direct indications were followed to code industry entry and exit dates. However, if more precise or deviating details in the remarks about a specific producer were available, adjustments have been undertaken. Non-producing labels have not been taken into account.

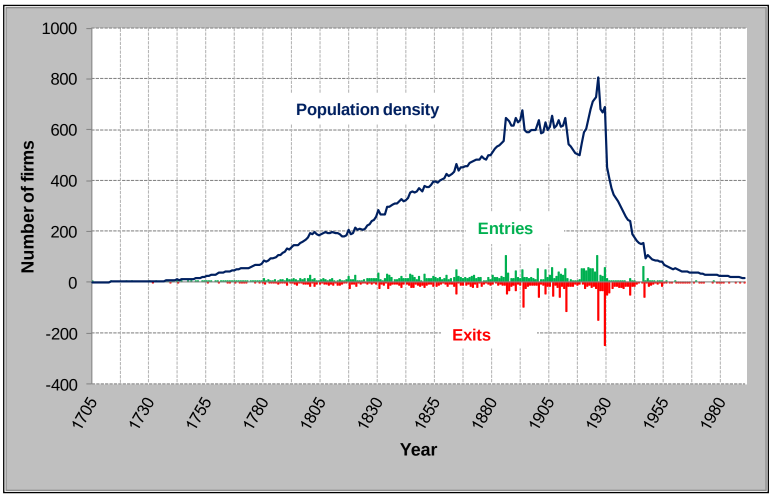

Figure 1: Population density and industry entries and exists of German piano manufacturers
(source: own illustration based on data collected from Henkel 2000, n. d.)[5]

In the first half of the 19th century a number of individual innovations from different piano makers in different countries including the so-called double escapement action (Adlam 1983; Good 2003), felt covered hammer heads (Hollfelder 1999; Restle 2000) and the full metal frame (Adlam 1983, Good 2003) paved the way for the modern piano. However, the most important step is attributed to Henry Steinway, who made some own improvements to the piano but first and foremost integrated all those individual innovations into the 'construction type Steinway' and thus implemented the dominant design in 1859. Today all modern pianos are built according to this construction type (Lieberman 1996).

Contrary to Austrian, English or French producers, the German piano industry was quick in the adoption of the dominant design and soon displaced the once famous industry in those countries (Cieplik 1923; Heyde 1994; Speer 2000). A gradual liberalization of guild and commercial regulations (Henning 1978), the fall of tariff barriers due to the establishment of the German Customs Union ('Zollverein') as well as the general industrialization contributed to the rise of the German piano industry (Cieplik 1923; Speer 2000).

[5] Industry tenures of firms that continued to exist after 1945 in Eastern Germany or Eastern Berlin have been treated as censored cases and are thus not part of the exit counts. Accumulations of industry entries and exits in the years 1886/87, 1893, 1900, 1903, 1906, 1909, 1912, 1926 and especially 1929 are due to the publication of the ‚Welt-Adressbuch der gesamten Musikinstrumenten-Industrie' from Paul de Wit in those years. In many cases this publication provides the first and the last evidence of a piano manufacturer (Henkel 2000).

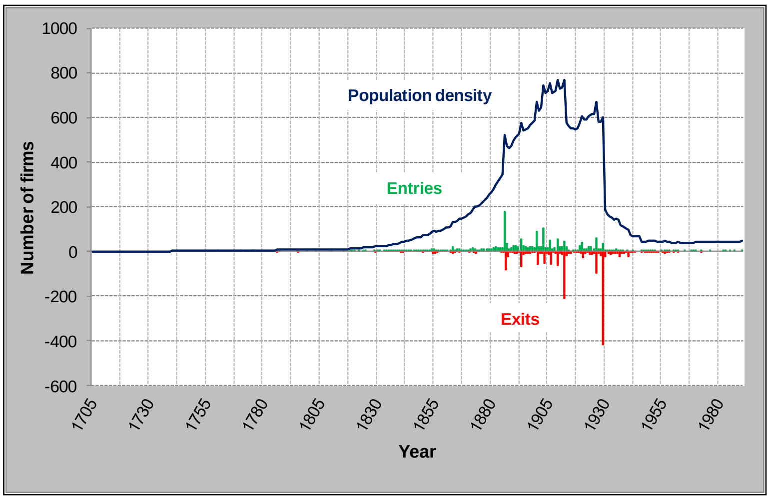

Figure 2: Population density and industry entries and exits of suppliers to the German piano industry (source: own illustration based on data collected from Henkel 2002, n. d.)[6]

The world exhibitions in London 1851 and Paris 1855 set the foundation for the export orientation of the German industry (Cieplik 1923; Speer 2000). Great Britain and its colonies, especially Australia, became vital sales territories for the German piano industry but also Russia with Finland and other European countries as well as countries in Central and South America imported mostly German pianos (Cieplik 1923). Smaller craft producers were now forced to exit the market as they were unable to compete with larger industrial factories (Speer 2000). At the same time, the first specialized claviature and piano action producers were founded (Henkel 2002). Presumably, the development of the dominant design led to the coordination simplification and information standardization necessary for the vertical disintegration of the industry and the development of specialized subpopulations of suppliers (Jacobides 2005; Stuerz 2013). By 1860, 425 piano manufacturers and 107 suppliers including 11 claviature and action producers could be traced (Henkel 2000, 2002, n. d.).

World War I was an incisive event for the German piano industry as especially at the beginning the industry was completely cut off from its important foreign sales territories. The military government closely administered the use and the export of goods containing metal and demanded that certain minimum sale prices were not undercut (Ibach-Preetorius 1922; Cieplik

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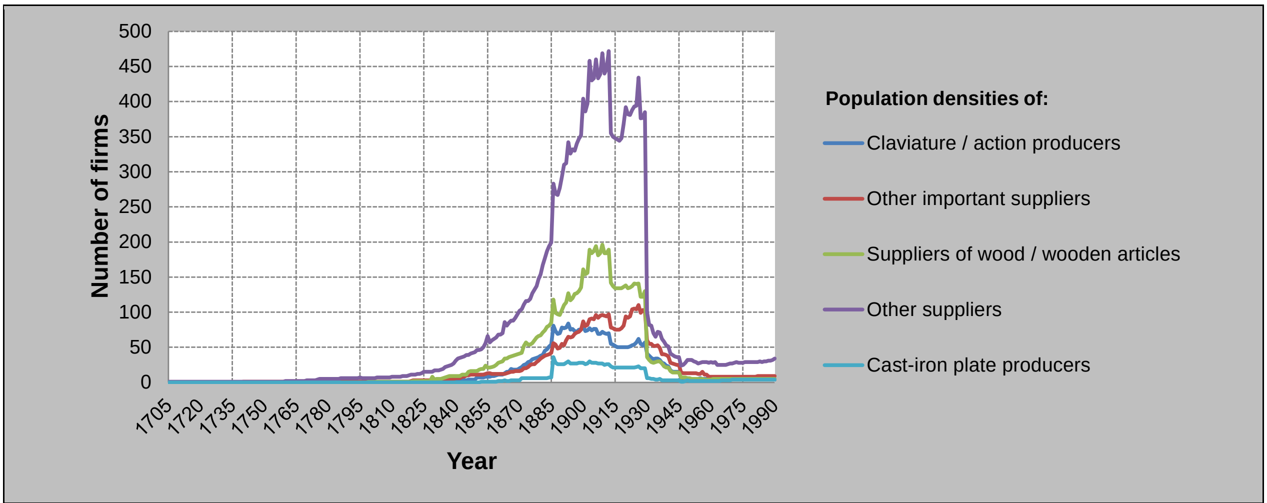
1923; Berghoff 2006). For this reason, a classification system of pianos was established sorting the products into three different categories: high-graded branded quality pianos, medium-graded and medium priced quality pianos and cheap low-graded non-quality commercial pianos (Freygang 1949).

After World War I sales conditions remained difficult. Nevertheless, especially small and medium sized firms entered the industry after the war in the hope of currency gains during a time of hyperinflation. However, most of these ventures were short-lived (Cieplik 1923; Henkel 1994). In 1926, a peak in population density of piano producers was reached and nearly 810 piano manufacturers as well as about 670 suppliers with more than 60 claviature and action producers could be traced (Henkel 2000, 2002, n. d.). Small and medium sized firms dominated the industry after the war, since the differentiated and specialized supplier subpopulations enabled also small firms to source intermediate goods and hence to stay in the industry (Euting 1931). The cost effective production of goods by suppliers and not by end product manufacturers as well as the expanding resource space due to growing export opportunities after the establishment of the dominant design might initially have prevented the predicted shakeout in firm numbers by the Abernathy-Utterback-Model (Abernathy/Utterback 1988; Bonaccorsi/Giuri 2000; Stuerz 2013).

The most important supply products were claviatures, piano actions and cast-iron plates. Claviature producers themselves sourced from ivory and other key covering firms as well as from semitone producers. Piano action manufacturers sourced from felt and leather producers, piano hammer and hammer head manufacturers. Other specialized firms supplied piano bridges, rests, soundboards, wood and wooden articles, strings and bass strings, metal goods, woven fabrics, glues, lacquers, mordant as well as other products (Euting 1931; Freygang 1949; Henkel 2002). Whereas basically all piano producers sourced claviatures, actions and cast-iron plates from specialized suppliers, high-grade quality manufacturers produced more input goods internally for quality reasons and did often not rely on other subpopulations of suppliers (Freygang 1949). Figure 3 separately displays the evolution of five aggregated subpopulations of suppliers according to their potential importance for the piano manufacturer population.



Supplier subpopulation:	Description:	Suppliers (supply product types) included:
Claviature / action producers	• Most important supplier subpopulation of core components for all piano manufacturers (Bethmann 1929; Freygang 1949)	• Claviatures • Piano actions
Other important suppliers	• Direct suppliers to claviature / action manufacturers and of other important intermediate goods • Less important than claviature / action manufacturers • Potentially close link to piano producers	• Ivory and other key coverings • Felt factories, piano leather, felt & leather stores • Semitone producers • Hammer head producers / repairers, piano hammer producers • Piano bridge producers • Rests, soundboards, piano conversions
Suppliers of wood / wooden articles	• Suppliers of the most important base material, if applicable partly prepared • Potentially close link, especially to manufacturers of cheap low-graded commercial pianos (Freygang 1949)	• Wood and veneer dyers, wood impregnating plants • Wood, veneer stores, sawmills, veneer cutteries (possibly including wood dyers) • Wood benders, wood embossing firms • Wooden article, wooden sculpture firms (possibly including wood dyers, wood bending firms) • Key blocks
Other suppliers	• Diverse supplier firms and stores • Potentially least important to piano manufacturers	• Architects, designers, drafts for cases, graphic art institutions, catalogue printers, clichés • Bass strings, string spinning mills • Lead wire and lead plug producers • Chenille and silk bristles • Glass coasters, glass company nameplates, glass fillings • Stores for component parts of all sorts • Inlays, company nameplates, medals • Piano blankets, woven fabrics • Piano cases • Piano chairs, chair seats • Piano chair spindles • Constructions, models, separations • Lacquer, mordant producers (possibly including stores), shellac stores • Glue producers for the piano industry • Metal goods, piano candlesticks, piano rolls • Back wall gauzes and fabrics • Strings (wire drawing firms) • Workshops for bronzing, painting and gilding of boards and frames • Tooling equipment • Other component companies
Cast-iron plate producers	• Specific supply product • Manufacturers of cast-iron plates normally produced a variety of products for other industries as well (Freygang 1949)	• Cast-iron plates

Figure 3: Population densities of five separated subpopulations of suppliers to the German piano industry (source: own illustration based on data collected from Henkel 2002, n. d.)[7]

[7] The mentioned single supplier types thus correspond to Henkel's (2002, p. 280) classification. In principle, suppliers can be included more than once (also within one of the five subpopulations) in the population density counts, depending on their produced supply goods. It has been taken into account if different supply products were traceable at different points of time. As a general rule, Henkel's (2002, p. 282 et seqq.) allocation of suppliers to categories has been followed. However, where more precise or deviating details in the remarks were available about a specific supplier or in cases where the delineation of products was difficult (company

Technical advances, such as the invention of the gramophone and radio, changed leisure time activities, the automobile, which displaced the piano as status symbol, together with the following Great Depression revoked the means of existence of the German piano industry in the late 1920s (Speer 2000). From 1929 to 1933, production declined by more than 90% (Freygang 1949) and most piano manufacturers and suppliers could ultimately be detected in the last edition of the 'Welt-Adressbuch der gesamten Musikinstrumenten-Industrie' from Paul de Wit in 1929 (Henkel 2000, 2002, n. d.).
In the following section the statistical method and generated variables to test the hypotheses are explained.

4 Method and Variables

Dependent variable: Firm survival as the most important success factor for organizations in the long run (Suárez/Utterback 1995) is the variable of interest in this study. Year mid-point approximation was used to determine the industry tenures of German piano producers where only the years of market entry and exit were known (Petersen 1991; Petersen/Koput 1992). If more detailed information on entry and exit timing was available, the respective (rounded down) quarter in the given year was coded as industry entry and the respective (rounded up) quarter in the given year was coded as industry exit of an organization. Due to data constraints from the fact that many organizations could ultimately be detected in the last edition of the world address book of the complete musical instruments industry from Paul de Wit in 1929 (Henkel 2000, 2002), the year 1929 was chosen as the end of the observation window. Accordingly, all observations of organizations that continued to survive afterwards or were ultimately detectable in the year 1929 were treated as censored cases in 1929.5.
Event history analysis is used to analyze these industry durations as traditional ordinary least squares (OLS) or binary dependent variable regression models would be inappropriate for this type of data, especially since they are unable to account for time-varying independent covariates (Cleves et al. 2002; Jenkins 2005).
As age dependence of organizational failure rates is a complicated and controversial theoretical issue (Freeman et al. 1983; Brüderl/Schüssler 1990; Ranger-Moore 1997; Henderson

nameplates, wood dyers, wood benders, piano chair spindle producers) amendments and adjustments in the classifications or no double counts have been undertaken. Due to unavailable appropriate weighting data, no weighted 'fuzzy' population counts were compiled (Hannan et al. 2007; see also de Figueiredo/Silverman 2012, p. 1640).

1999), there exists no clear ex-ante prediction for the parameterization of the baseline hazard rate for exit events of German piano manufacturers. In order to allow for maximum flexibility the semiparametric Cox hazard rate model (Cox 1972) is used as this model requires no specific functional form of the baseline hazard rate (Cleves et al. 2002). Table 2 lists the time under risk, the number of organizations as well as the quartiles of industry tenures for the focal population of German piano manufacturers.

Table 2: Summary of industry tenures of German piano manufacturers (1705-1929)

Time under risk (years)	Incidence rate	Number of organizations	Industry tenure (years)		
			25%	50%	75%
57484.50	0.039	2989	1	14	40.75

The estimations were conducted using maximum likelihood calculation as implemented in STATA 12.1.

Independent variables: Corresponding to hypothesis H1 about an intra-population density dependence (Carroll/Hannan 1989b), the variable population density piano producers / 100 denotes the time-varying number of piano manufacturers active in a given year divided by 100. The variable population density piano producers^2 / 10000 is the squared number of piano manufacturers active in a given year divided by 10000. The founding density piano producers / 100 denotes the time-invariant number of piano manufacturers active in the year of industry entry of a new organization divided by 100 and captures the classical intra-population density delay (H2) (Carroll/Hannan 1989a).

In order to control for population dynamics effects, the numbers of prior year industry entries into and exits from the end product manufacturer population are included as control variables (prior year entries piano producers; prior year exits piano producers) (Delacroix et al. 1989; Núñez Nickel/Moyano Fuentes 2004).

The dummy variables pianino factory (1/0), pianoforte factory (1/0), awarded products (1/0), royal warrant (1/0) and incorporated enterprise (1/0) allow for a rough approximate and due to data constraints only time-invariant control of certain firm-specific characteristics. On the one hand, the dummy variables pianino factory (1/0) and pianoforte factory (1/0) separate larger piano factories from the reference category of small craft enterprises. On the other hand, they account – however, only rough approximate (Henkel 2000, p. 8) – for a strategic aspect of the firms as the variable pianino factory (1/0) identifies factories that produced upright pianinos and the variable pianoforte factory (1/0) identifies factories that produced upright pianinos and grand pianos. According to the stylized fact that the survival of firms depends on their size (Dunne et al. 1988; Mata et al. 1995), a negative coefficient is expected for those two dummy variables. Also the variable incorporated enterprise (1/0) is expected to capture a size effect as it takes the value of unity for firms that were described as an incorporated business at any time up to the year 1929 (Henkel 2000, n. d.).

The dummy variable awarded products (1/0) takes the value of unity if the products of a firm are known to have received an award or a medal at any competition at an exhibition (Henkel 2000, n. d.). This variable indicates certain quality aspects of a producer but may also crudely approximate the degree of vertical integration of a piano manufacturer. As it is known, only producers of low-graded commercial pianos relied heavily on all types of suppliers, whereas high-graded quality producers often just sourced the three main components claviature, action and cast-iron frame from external suppliers (Freygang 1949).

The dummy variable royal warrant (1/0) indicates whether a firm owner was named as a royal warrant of appointment at any time during the existence of the firm (Henkel 2000, n. d.). As the practice to appoint royal warrants started early and as usually only high-quality producers had business relationships with the court (Heyde 1994), this variable may capture certain quality and size aspects but also aspects of legitimation.

In order to test the predicted inter-population dependency of H3a, the variable population density suppliers / 100 counts the number of suppliers active in a given year divided by 100. Here, each supplier is counted once, regardless of the produced supply products. The variables prior year entries suppliers and prior year exits suppliers are constructed as inter-population dynamics effects controls denoting the number of industry entries and exits of suppliers in the year prior to the focal year. The variable population density suppliers according to supply products / 100 extends the variable population density suppliers / 100 with multiple counts of suppliers that were active in more than just one supply product group. Thus, this population density count is an aggregation of the numbers presented in figure 3. Prior year entries suppliers according to supply products and prior year exits suppliers according to supply products capture entries and exits of suppliers into specific supply product segments and extend the variables prior year entries suppliers and prior year exits suppliers with multiple counts of suppliers that entered more than just one supply product group.

In order to test hypothesis H3b, the variable population density suppliers according to supply products is separated into five different subpopulations of suppliers according to their potential importance for downstream piano manufacturers. Population density claviature / action producers counts the number of claviature and action producers active in a given year, the population density other important suppliers counts the number of suppliers to claviature and action producers as well as of other important intermediate goods. Population density wood suppliers denotes the number of suppliers of the most important raw material for piano manufacturers and of processed wooden products in a given year. The population density other suppliers counts the number of all kinds of other, potentially less important suppliers active in a given year. Finally, the population density cast-iron plate producers denotes the number of cast-iron plate manufacturers in a given year and was separately compiled due to the distinctiveness of the product, as it was often produced as a side product by huge iron foundries (Freygang 1949). The five different population densities resemble the numbers displayed in figure 3. According to the reasoning of hypothesis H3a, a large negative effect is predicted of the population density claviature / action producers. The effect of the population density other important suppliers and wood suppliers should be smaller with the smallest negative effect expected of the population density other suppliers. No clear prediction seems to be possible for the effect of the population density cast-iron plate producers, as this variable may also reflect a variety of other social and economic aspects.

Table 3: Descriptive statistics, quarterly split dataset

Variable	N	Mean	S. D.	Median	Min	Max
Population density piano producers / 100	229938	4.679	1.780	5.010	0.010	8.080
Population density piano producers² / 10000	229938	25.061	15.081	25.100	0.000	65.286
Founding density piano producers / 100	229938	3.678	1.842	3.730	0.010	8.080
Prior year entries piano producers	229938	22.699	18.992	17.000	0.000	106.000
Prior year exits piano producers	229938	18.063	22.344	12.000	0.000	150.000
Pianino factory (1/0)	229938	0.384	-	0.000	0.000	1.000
Pianoforte factory (1/0)	229938	0.240	-	0.000	0.000	1.000
Awarded products (1/0)	229938	0.270	-	0.000	0.000	1.000
Royal warrant (1/0)	229938	0.180	-	0.000	0.000	1.000
Incorporated enterprise (1/0)	229938	0.110	-	0.000	0.000	1.000
Population density suppliers / 100	229938	3.278	2.680	2.630	0.010	7.690
Pop. density suppliers acc. to supply prod. / 100	229938	3.715	3.046	2.990	0.010	8.600
Prior year entries suppliers	229938	15.901	24.622	11.000	0.000	180.000
Prior year entries suppliers acc. to supply prod.	229938	18.030	26.705	12.000	0.000	189.000
Prior year exits suppliers	229938	10.487	26.526	1.000	0.000	211.000
Prior year exits suppliers acc. to supply prod.	229938	11.732	28.546	2.000	0.000	224.000
Population density claviature / action producers	229938	36.502	30.104	38.000	0.000	84.000
Population density other important suppliers	229938	43.416	37.423	34.000	0.000	110.000
Population density wood suppliers	229938	77.584	64.057	67.000	0.000	196.000
Population density other suppliers	229938	201.648	164.669	154.000	1.000	472.000
Population density cast-iron plate producers	229938	12.321	11.922	6.000	0.000	36.000
Real GDP per capita / 1000	133711	2.939	0.601	3.010	1.891	4.335
Dummy WW (1/0)	229938	0.044	-	0.000	0.000	1.000
Dummy 1887/88 (1/0)	229938	0.021	-	0.000	0.000	1.000
Dummy 1894 (1/0)	229938	0.010	-	0.000	0.000	1.000
Dummy 1901 (1/0)	229938	0.010	-	0.000	0.000	1.000
Dummy 1904 (1/0)	229938	0.010	-	0.000	0.000	1.000
Dummy 1907 (1/0)	229938	0.010	-	0.000	0.000	1.000
Dummy 1910 (1/0)	229938	0.010	-	0.000	0.000	1.000
Dummy 1913 (1/0)	229938	0.009	-	0.000	0.000	1.000
Dummy 1927 (1/0)	229938	0.011	-	0.000	0.000	1.000

To account for general economic conditions the real gross domestic product per capita (real GDP per capita / 1000) is included as a time-varying control variable originating from the "Historical Cross-Country Technology Adoption Dataset" (Comin/Hobijn 2004). As this dataset contains successive observation only from 1870 onwards, the variable real GDP per capita / 1000 can only be included in estimations with a left truncated population dataset. Analyses with a dataset starting from 1870 enables also a robustness check of estimates obtained with the full sample, as data on earlier entrants of the industry may be affected by a survival bias (Henkel 2000, 2002).

To control for the time period of World War I, a dummy variable for the war period [1914; 1918] was created (dummy WW (1/0)). Moreover, to control for peaks in the variables counting prior year entries and exits of downstream piano manufacturers and upstream suppliers in the years following the publication of the world address book of the complete musical instruments industry from Paul de Wit, dummy variables for the respective year(s) (1887/88; 1894; 1901; 1904; 1907; 1910; 1913; 1927) were generated.

All time-varying variables were updated annually and added to the population dataset which was split quarterly. Table 3 displays the descriptive statistics for the episode split data set. Descriptive statistics for a non-split version of the data at the time of entry of each organization as well as the correlation of those variables are available upon request.

5 Results

Tables 4 and 5 display the Cox hazard rate models of industry exits of German piano manufacturers. Model 1 represents an ecological baseline model estimating intra-population effects. The coefficients of the linear and squared population density piano producers are highly significant and provide support for hypothesis H1. The turning point of legitimation to competitive effects is at 194 piano manufacturers. The founding density piano producers / 100 is significant but in the opposite direction to the expectation of hypothesis H2. One possible explanation might be the growing export opportunities over a long period of time during the observation window that might have prevented the occurrence of a resource scarcity for most of the time necessary for the density delay (Carroll/Hannan 1989a, 2000). The negative effect of prior year entries piano producers supports the prediction of population dynamics (Delacroix et al. 1989). Prior year exits piano producers have a positive effect and thus seem to signal adverse environmental conditions. As the baseline model has precedents in prior ecological research (Núñez Nickel/Moyano Fuentes 2004), it provides confidence that the population or maybe the collected data are not special or deviating from stylized facts of industrial evolution.

Table 4: Cox hazard rate models of the exit rates of German piano manufacturers (1705-1929+)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Population density piano producers / 100	-0.211***	0.107	0.122	0.198***	-0.058	1.366***
	[0.067]	[0.072]	[0.077]	[0.076]	[0.088]	[0.114]
Population density piano producers² / 10000	0.054***	0.036***	0.035***	0.031***	0.083***	
	[0.006]	[0.006]	[0.007]	[0.007]	[0.010]	
Founding density piano producers / 100	-0.117**	-0.180***	-0.213***	-0.220***	-0.145***	-0.006
	[0.047]	[0.048]	[0.050]	[0.050]	[0.052]	[0.058]
Prior year entries piano producers	-0.013***	-0.013***	-0.017***	-0.017***	-0.009***	-0.006*
	[0.002]	[0.002]	[0.002]	[0.002]	[0.003]	[0.003]
Prior year exits piano producers	0.015***	0.013***	0.012***	0.008**	0.005	-0.002
	[0.003]	[0.003]	[0.004]	[0.004]	[0.004]	[0.006]
Pianino factory (1/0)		-0.628***	-0.636***	-0.625***	-0.582***	-0.136**
		[0.054]	[0.054]	[0.054]	[0.053]	[0.065]
Pianoforte factory (1/0)		-0.715***	-0.723***	-0.718***	-0.683***	-0.270***
		[0.082]	[0.082]	[0.082]	[0.082]	[0.095]
Awarded products (1/0)		-0.939***	-0.942***	-0.937***	-0.930***	-0.832***
		[0.086]	[0.086]	[0.086]	[0.086]	[0.094]
Royal warrant (1/0)		-0.854***	-0.857***	-0.855***	-0.869***	-0.983***
		[0.099]	[0.099]	[0.099]	[0.100]	[0.145]
Incorporated enterprise (1/0)		-0.419***	-0.408***	-0.417***	-0.399***	-0.463***
		[0.097]	[0.098]	[0.098]	[0.097]	[0.098]
Population density suppliers / 100			0.008			
			[0.024]			
Pop. density suppliers acc. to supply prod. / 100				-0.017		
				[0.021]		
Prior year entries suppliers			0.003			
			[0.003]			
Prior year entries suppliers acc. to supply prod.				-0.005*		
				[0.003]		
Prior year exits suppliers			0.013*			
			[0.007]			
Prior year exits suppliers acc. to supply prod.				0.032***		
				[0.006]		
Population density claviature / action producers					-0.042***	-0.033***
					[0.005]	[0.008]
Population density other important suppliers					-0.058***	-0.073***
					[0.006]	[0.009]
Population density wood suppliers					0.003	0.014***
					[0.003]	[0.004]
Population density other suppliers					0.014***	0.011***
					[0.002]	[0.003]
Population density cast-iron plate producers					0.025**	-0.005
					[0.011]	[0.013]
Real GDP per capita / 1000						0.308*
						[0.165]

Table 4 (continued)						
Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Dummy WW (1/0)	-0.183	-0.035	-0.115	-0.201	0.001	0.472***
	[0.151]	[0.151]	[0.153]	[0.151]	[0.161]	[0.180]
Dummy 1887/88 (1/0)	-0.049	0.044	-0.596***	-0.762***	0.183	0.197
	[0.153]	[0.155]	[0.227]	[0.220]	[0.156]	[0.168]
Dummy 1894 (1/0)	-0.884***	-0.598*	-1.319***	-1.879***	0.214	0.787
	[0.331]	[0.340]	[0.399]	[0.398]	[0.367]	[0.514]
Dummy 1901 (1/0)	-1.137***	-0.990**	-1.688***	-1.862***	-0.577	-0.330
	[0.382]	[0.386]	[0.417]	[0.416]	[0.394]	[0.437]
Dummy 1904 (1/0)	-0.448*	-0.318	-1.013***	-1.014***	-0.125	-0.012
	[0.265]	[0.269]	[0.313]	[0.313]	[0.281]	[0.316]
Dummy 1907 (1/0)	-0.972***	-0.802**	-1.363***	-1.997***	-0.768**	-0.691*
	[0.332]	[0.334]	[0.384]	[0.387]	[0.343]	[0.382]
Dummy 1910 (1/0)	-0.924***	-0.803***	-1.562***	-2.259***	-0.551*	-0.446
	[0.285]	[0.289]	[0.372]	[0.369]	[0.304]	[0.354]
Dummy 1913 (1/0)	-1.273***	-0.976**	-3.473***	-7.123***	-0.260	0.446
	[0.418]	[0.427]	[1.257]	[1.176]	[0.470]	[0.623]
Dummy 1927 (1/0)	-1.212***	-0.916**	-1.769***	-2.920***	0.359	0.791
	[0.431]	[0.447]	[0.554]	[0.574]	[0.496]	[0.708]
Number of split episodes	229938	229938	229938	229938	229938	133711
Number of organizations	2989	2989	2989	2989	2989	2110
Number of events	2246	2246	2246	2246	2246	1385
Log-pseudolikelihood	-15881	-15507	-15497	-15490	-15436	-8612
df	14	19	22	22	24	24
Wald-Chi²	260.6***	926.9***	947.2***	969.3***	1098***	763.3***

Robust and clustered standard errors in brackets;
Efron (1977) approximation for ties in industry tenures;
*** p≤0.01; ** 0.01<p≤0.05; * 0.05<p≤0.1 (two-sided test);
$^{+}$ Model 6: 1870-1929

In model 2 the firm-specific control variables are included. As expected, all have significant negative effects. An interesting additional result is that the effect of the linear population density piano producers is no longer significant once it is approximately controlled for direct legitimacy enhancing factors like the growth of firms into factories and the appointment of royal warrants. Also in the following models 3 and 5, a significant negative effect of the linear population density piano producers is estimated if these firm-specific characteristics are not included.[8] This at least provides some indication that the linear population density variable in fact serves as a proxy for legitimation (Zucker 1989; Baum/Oliver 1992; Baum/Powell 1995). Thus, hypothesis H1 can be regarded as being supported indirectly by these models as well.

The analysis of inter-population dependencies begins with model 3. However, the aggregated number of suppliers regardless of the supply product has no significant effect. Model 4 neither supports hypothesis H3a. The variable population density suppliers according to supply products again exhibits no significant effect.

[8] Results of these regressions are available upon request.

One reason for this becomes evident in model 5, which analyzes the five different subpopulation densities separately. Only the densities of the two most important supplier subpopulations exhibit the predicted negative effect on the exit rate of downstream manufacturers. An additional other important supplier reduces the hazard rate by about 5.6%, an additional claviature or action producer by about 4.1%. Thus, model 5 provides at least some support for hypothesis H3b, as the most important supplier subpopulations reduce the hazard rate even though the ordering of effect sizes is opposite to expectations. The population density wood suppliers has no significant effect and the population density other suppliers even elevates the failure rate of downstream manufacturers. One possible explanation for this positive effect might be that the variable also captures competitive effects with other population communities of music instrument producers. So the number of other suppliers that were not closely linked to the piano industry but that may have supplied producers of other instruments as well might reflect the competition between these different communities. Similarly, the positive effect of the population density cast-iron plate producers on the hazard rate might capture other social and economic effects due to the specialty of this subpopulation of suppliers.

Once a control for the general economic situation is included in model 6 for a left truncated dataset from 1870 to 1929, the effect of the population density cast-iron plate producers is no longer significant.[9] The real GDP per capita / 1000 has a positive effect on the exit rate of piano manufacturers, which is in line with anecdotal evidence from the history of the industry that due to the rise of the middle class and growing exports the industry was decoupled from the general economic situation for most of the time (Speer 2000). The population density wood suppliers now elevates the hazard rate of downstream manufacturers and again the two most important supplier subpopulations reduce it.

Finally, as the variable awarded products (1/0) not only captures quality aspects but may also approximate the degree of vertical integration of a piano manufacturer after the formation of a capable supplier population, models 7 and 8 in table 5 with interaction effects are estimated to dig deeper into inter-population dependencies. If the quantitative population data are consistent with anecdotal evidence from the industry, awarded quality producers should have been equally dependent on claviature, action and cast-iron plate suppliers than non-quality piano producers that have not received any awards. However, as quality producers didn't source other supply products extensively, the effects of other supplier subpopulation densities

[9] Note: As the legitimation phase of the industry is no longer part of the observation window in this model, only intra-population competitive effects are expected. Accordingly, the squared term of the population density piano producers is not included in the model (Baum/Powell 1995; Hannan/Carroll 1995; Carroll/Hannan 2000).

might not exhibit similar effects on awarded and non-awarded downstream manufacturers (Freygang 1949; Bethmann 1929).

Table 5: Cox hazard rate models of the exit rates of German piano manufacturers (1705-1929+)

Variable	(7)		(8)	
Population density piano producers / 100	-0.032	[0.088]	1.371***	[0.113]
Population density piano producers² / 10000	0.081***	[0.010]		
Founding density piano producers / 100	-0.150***	[0.052]	-0.024	[0.057]
Prior year entries piano producers	-0.009***	[0.003]	-0.006*	[0.003]
Prior year exits piano producers	0.005	[0.004]	-0.002	[0.006]
Pianino factory (1/0)	-0.570***	[0.053]	-0.136**	[0.065]
Pianoforte factory (1/0)	-0.670***	[0.082]	-0.270***	[0.095]
Awarded products (1/0)	-1.822***	[0.279]	-1.325**	[0.541]
Royal warrant (1/0)	-0.856***	[0.101]	-0.985***	[0.146]
Incorporated enterprise (1/0)	-0.407***	[0.098]	-0.460***	[0.098]
Population density claviature / action producers	-0.043***	[0.005]	-0.033***	[0.008]
Awarded prod. x Population density claviature / action producers	0.016	[0.015]	0.002	[0.019]
Population density other important suppliers	-0.063***	[0.006]	-0.079***	[0.010]
Awarded prod. x Population density other important suppliers	0.063***	[0.018]	0.059***	[0.019]
Population density wood suppliers	0.001	[0.004]	0.011**	[0.004]
Awarded prod. x Population density wood suppliers	0.030***	[0.009]	0.028***	[0.010]
Population density other suppliers	0.016***	[0.003]	0.014***	[0.003]
Awarded prod. x Population density other suppliers	-0.025***	[0.008]	-0.024***	[0.008]
Population density cast-iron plate producers	0.024**	[0.012]	-0.007	[0.014]
Awarded prod. x Population density cast-iron plate producers	-0.005	[0.036]	0.021	[0.038]
Real GDP per capita / 1000			0.318*	[0.165]
Dummy WW (1/0)	0.030	[0.161]	0.485***	[0.180]
Dummy 1887/88 (1/0)	0.195	[0.157]	0.212	[0.169]
Dummy 1894 (1/0)	0.234	[0.368]	0.818	[0.516]
Dummy 1901 (1/0)	-0.569	[0.394]	-0.310	[0.438]
Dummy 1904 (1/0)	-0.156	[0.279]	-0.021	[0.315]
Dummy 1907 (1/0)	-0.776**	[0.342]	-0.685*	[0.381]
Dummy 1910 (1/0)	-0.552*	[0.303]	-0.435	[0.354]
Dummy 1913 (1/0)	-0.229	[0.471]	0.473	[0.624]
Dummy 1927 (1/0)	0.373	[0.497]	0.823	[0.709]
Number of split episodes	229938		133711	
Number of organizations	2989		2110	
Number of events	2246		1385	
Log-pseudolikelihood	-15415		-8602	
df	29		29	
Wald-Chi²	1070***		772.4***	

Robust and clustered standard errors in brackets;
Efron (1977) approximation for ties in industry tenures;
*** p≤0.01; ** 0.01<p≤0.05; * 0.05<p≤0.1 (two-sided test);
+ Model 8: 1870-1929

In fact, model 7 shows that the interactions of the variable awarded products (1/0) with the five different supplier subpopulation densities are only insignificant for claviature and action producers as well as for cast-iron plate suppliers. The exit rate of awarded quality downstream piano producers is basically unaffected by the population density other important suppliers and the population density other suppliers. Again, one possible reason for the negative interaction effect of awarded producers and the density of other suppliers might be that competition with other communities of musical instrument producers was stronger for non-quality

producers than for quality producers. Model 8 in principle resembles the results of models 6 and 7 with the truncated dataset and a control for the general economic situation.
The final section provides a summary and discussion of the results.

6 Summary and Discussion

Research on the evolution of industries has for a long time neglected the development of vertical structures of firms and the emergence of new, specialized supplier populations along the value chain of an industry as industries mature (Klepper 1997; Jacobides 2005). Only recently theoretical contributions and case studies enhanced our understanding of how industry evolution, vertical disintegration and market emergence for supply products might be related to each other (Christensen et al. 2002; Macher/Mowery 2004; Cacciatori/Jacobides 2005; Jacobides 2005; Arora/Bokhari 2007; Jacobides 2008; Malerba et al. 2008; Stuerz 2013). The change of the vertical industry structure and the co-evolution of subpopulations of suppliers lead to the creation of an interdependent community of organizational populations along the value chain of an industry during the evolutionary process. This study is among the first to analyze those inter-population effects of different subpopulations of suppliers on vertically related downstream manufacturer survival.
It is argued that in general the number of upstream suppliers is expected to reduce the risk of industry exit of downstream end product manufacturers but that, more specifically, supplier subpopulations of important core components in particular should be responsible for this life enhancing effect. Quantitative event history analyses using data on industry exists of German piano manufacturers (1705-1929) support these predictions partly. On the one hand, the regression models show that uniformly counted suppliers have no impact on the survival of downstream manufacturers. However, on the other hand, the models reveal that especially the number of the suppliers of the most important core components – claviatures and piano actions – show a positive effect on firm survival of piano manufacturers. Moreover, the analyses show that the number of firms in other supplier subpopulations does not always affect the exit rates of quality and non-quality end product manufacturers in the same way, which might be related to the different degree of vertical integration of these two types of firms. In addition the estimated models support the notion of an intra-population density dependence (Carroll/Hannan 1989b, 2000; Hannan/Carroll 1992). An intra-population density delay (Car-

roll/Hannan 1989a, 2000), however, could not be found, probably due to the fact that the resource space was expanding for most of the time of the observation period.

The study contributes to the understanding of the forces driving industry evolution and firm survival, since it went beyond the mechanisms just within the end product manufacturer population. It broadens the perspective on industry evolution and makes it easier to predict long-term industrial developments (Jacobides/Winter 2005). The quantitative regressions show that important suppliers can increase life chances of downstream manufacturers. But as coordination simplification and information standardization are necessary conditions for vertical disintegration in an industry (Jacobides 2005), converging around a dominant design and developing community-wide standards seem to be important in young industries. This can help to elevate legitimation and may lead to the development of specialized suppliers (Hunt/Aldrich 1998; Stuerz 2013).

However, as the German piano industry is an old and special industry, the degree to which these results can be generalized is limited. Historical accident plays a major role in the evolution of industries and thus, other industries might develop in different directions (Jacobides 2005). As detailed quantitative data of historical events influencing the piano industry were unavailable, those events are potentially underplayed in the quantitative analyses. Furthermore, biases of estimated effects due to unobserved heterogeneity because of data constraints cannot be completely ruled out. Even though robustness checks with a left truncated dataset produced consistent results, a survival bias especially of early industry participants is possible as well. Another limitation of the study is the unidirectional estimation of exit rates of downstream manufacturers dependent on upstream supplier densities. On the one hand, the study in this vein follows previous research on inter-population cross-density effects (Núñez Nickel/Moyano Fuentes 2004; de Figueiredo/Silverman 2012). On the other hand, simultaneous influences on upstream supplier survival rates depending on downstream customers are likely as well.

As a consequence, a simultaneous analysis of upstream and downstream hazard rates is a next potential research step. Moreover, a multilevel analysis (Carroll/Hannan 2000) with an examination on different geographic levels seems promising.

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