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The Life Cycle of the U.S. Tire Industry

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We introduce a new theory of industry evolution. According to our model, the nonmonotonicity in firm numbers found in many young industries is a consequence of the gradual decline in unit costs. Early stages of the industry life cycle, when unit costs and profit margins are high, display positive net entry rates. In later stages, declining unit costs and increasing competition limit the market room for (fringe) firms accumulating in a shakeout. The model explains paths of output, price level, and firm numbers using a recursive system of equations. We apply the model to the U.S. tire industry.

1. Introduction

A recent literature has emerged focusing on industry evolution, or the dynamic patterns that industries and firms follow as they systematically evolve over time. This literature is important because of the insights provided about how industries change, why they change, and the consequences of industrial change. The year 1982 saw three fundamental contributions made to the research on the evolution of industry. Boyan Jovanovic published the first formal model of industry evolution, Richard Nelson and Sidney Winter presented their influential book on the causes and effects of this phenomenon, and Michael Gort and Steven Klepper published their careful analysis of the stages of the product life cycle. Knowledge concerning industry dynamics and industry evolution has expanded since then.[1] Despite this progress in the field of industry evolution, considerable gaps remain. For example, we lack an adequate empirical un-

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[1] Contributions in various fields include Geroski and Masson (1987) on simultaneous equation modeling in industrial economics, Dosi (1988) on causes and consequences of innovative activity, Chandler (1990) on the role of scale and scope economies in shaping the industrial landscape, and Mueller (1990) on persistence of profits. Recent contributions on various aspects of industry dynamics are Audretsch (1995) and Baldwin (1995). Ericson and Pakes (1995) and Klepper (1996) recently made important theoretical progress. An empirical test of the Jovanovic (1982) passive learning model versus the Ericson and Pakes (1995) active learning model is provided by Pakes and Ericson (1998). Fein's (1998) article is one of the few papers studying evolutionary processes in a nonmanufacturing industry (pharmaceutical wholesaling).

derstanding of the evolutionary process at the single-industry level from the early to the late stages of its life cycle. Shakeouts have been identified in the literature as an integral component of this evolutionary process. The sudden disappearance of large numbers of firms have been documented across a broad spectrum of industries, such as steel, airline carriers, financial intermediaries, automobiles, and tires. An important strand in the literature argues that the catalyst for these shakeouts is the introduction of a new dominant innovation. Confronted by a new technology introduced by a competitor, the inability of other firms to adopt this new dominant technology presumably forces them out of the market. Jovanovic and MacDonald (1994) made a pioneering and parsimonious contribution in this field of research by explaining patterns of number of firms, output, and prices of the U.S. tire industry. Despite the importance of their contribution, we argue that their model does not adequately describe the key historic developments that have taken place in this or many other industries that faced a shakeout of producers.[2]

The domain of relevance of the Jovanovic–MacDonald model is limited. It assumes that one innovation followed by just one refinement is responsible for the nonmonotonicity in firm numbers. This implies that the model is applicable only for those industries having experienced just two technologies in their entire history: an initial low-tech and a subsequent high-tech phase. Most industries, including the automobile tire industry that was the testing ground of Jovanovic and MacDonald, have an ongoing history of significant improvements in product quality and productivity. It seldom occurs that one innovation is dominant. This is certainly true for the tire industry. Nelson (1987), in his study on the U.S. tire industry, observed that "there was no single technical breakthrough that unlocked the industry's potential for high-speed production; nor was any individual or firm of overriding importance. The advent of mass production was a *cumulative process resulting from a vast number of successive small changes*" (pp. 331–2, italics added). Almost half a century ago, Reynolds (1938, p. 463) described a similar process: "The great improvement in tire quality during the past 30 years is undoubtedly due to constant repetition of [the] cycle of invention and imitation."

We take a different approach than Jovanovic and MacDonald and explain the nonmonitonicity in firm numbers as resulting from gradual unit cost reduction over time leading to declining profit margins. In the present paper, we relate this cumulative process to the concept of learning-by-doing. We will test the model using data of the American tire industry. We do this to facilitate the comparison between our model and that of Jovanovic and MacDonald and because this industry is one of the few for which data are available for a long time period. The process of learning-by-doing leading to decreasing marginal costs over time has an important impact on the number of firms in the industry. We show that because of this process, profit margins decrease over time, making entry less likely and exit more likely. Whereas in the early stages of the industry life cycle profit margins are high and entry exceeds exit, the reverse is the case in later stages. The model predicts a shakeout of firms in case the constant inflow of new market participants leads to increasing competition pushing the profit margins even further down to a level at which fringe firms cannot survive. After the shakeout, the learning-by-doing process still leads to lower margins, but this is then (partly) compensated by less competition, as the number of firms has decreased strongly.

[2] Recently, Malerba et al. (1999) stressed the importance of "history-friendly" models of industry evolution. Sutton (1994) makes a similar plea for detailed historical analysis. He claims that economists and business historians can fruitfully interact to increase our knowledge of evolutionary processes at the single industry level. The current study is in line with that approach, formulating a parsimonious model tailored to specific industrial characteristics.

This paper presents a new theoretical model of industry evolution for homogeneous goods industries, tests it on historic data of the U.S. tire industry, and finds reasonable estimates of the various parameters. The model is capable of explaining key common industry life cycle elements as for example discussed by Porter (1980, pp. 157–62). The remainder of our paper is organized as follows. In the next section, we describe the theoretical foundations of our model of industry evolution. The model is applied to the tire industry in section 3. The model explains the demand for automobile tires, the price of tires, and the net entry rate of firms producing tires. The shakeout in the number of producers is derived as a consequence of a continuous decrease in the profit margin per tire. Small producers can only survive in case this margin exceeds a certain critical value. We claim that the strong and persistent price competition in the U.S. tire industry in the 1920s followed by a strong decline in demand for tires during the Great Depression generated a rapid shakeout of the number of producers (Reynolds 1938). The model consists of three equations. The first equation relates the demand for automobile tires to the number of motor vehicles, the price index of tires, and a quality index. The second equation describes the decomposition of the price index of tires into a competition effect and a marginal cost effect. The third equation relates the net entry rate to the one-period lagged profit margin and growth of demand for automobile tires. Because of this lag, the model is a system of recursive equations. In section 4, we present the empirical results for the U.S. automobile tire industry over 1913–1973, and in section 5, we conclude.

2. A Model of Cournot Oligopoly

In this study, we use a simple recursive three-equation model of industry evolution. The first equation relates total demand to the price level of the good (P_t) and to exogenous variables. In this section, we introduce the assumptions behind our evolutionary model and derive the second and third equations. The industry is assumed to have a large fringe of small (potential) firms. Each entering and exiting firm is assumed to come from this group of market participants.

Price Level

We assume that the strategic interaction between firms in the tire industry can be modeled with a Cournot quantity competition game. Cournot rivalry is generally thought to be an adequate representation of strategic interaction in oligopolistic industries where capital investment is important, production capacity is relatively fixed, and a largely homogeneous good is produced (Tirole 1989, chap. 5). Kreps and Scheinkman (1983) show that the one-stage Cournot game is equivalent to a two-stage game in which firms simultaneously choose capacities and then, knowing each other's capacities, simultaneously choose prices. Hence, a valid interpretation of quantity competition is "a choice of scale that determines the firm's cost functions and thus determines the conditions of price competition" (Tirole 1989, p. 218). We assume that the industry has two groups of producers. The first group consists of a handful of large-scale producers that do not exit. This group may change over time, for example, because of mergers, or small-scale producers growing into large-scale producers or because of group members declining in size and becoming small-scale producers. However, we assume that new entrants and exiting firms are no part of this group. The second group is a fringe of (many) small-scale producers in which entry and exit does take place.[3] For simplicity, we assume, in contrast with the large-scale producers, that these firms have the same capacity (q^F) and identical cost functions. The profit of firm i in period t with a production capacity q_{it} equals:

$$\pi_{it} = P_t(Q_t)q_{it} - C_{it}(q_{it}) \qquad q_{it} \geq q^F \tag{1}$$

where C_{it} is the period t cost function of firm i and $Q_t = \Sigma_i\, q_{it}$ is total market output of the homogeneous good. Small-scale producers have a production capacity equal to q^F and total costs in period t of $C_t(q^F)$. The large-scale producers optimize their own output assuming that competitors do not change their production. That is, the market can be described as a (static) Cournot oligopoly.[4] Assuming a Cournot oligopoly, Cowling and Waterson (1976) derive the following relation between price (P_t), the weighted average of marginal costs (here, $c_t = \Sigma_i (q_{it}/Q_t)[dC_{it}(q_{it})/dq_{it}]$, the price elasticity of demand (e_t) and the Herfindahl index (H_t):

$$P_t = \left(1 + \frac{H_t}{e_t}\right)^{-1} c_t \qquad H_t < -e_t \;\; \wedge \;\; e_t < 0. \tag{2}$$

From Equation 2, it is apparent that the profit margin $P_t - c_t$ equals $[1 + (H_t/e_t)]^{-1}\,(H_t/|e_t|)c_t$ and hence decreases in case competition intensifies or marginal cost falls over time.

Net Entry

In order to derive the expected number of entrants, we must determine the size of the pool of potential entrants. There are at least two reasons to take the number of potential entrants proportional to the total number of incumbents in the previous period, that is, equal to $\eta_0 N_{t-1}$. A first reason is the demonstration effect as discussed by Gort and Konakayama (1982), who argue that perceptions of profit opportunities are positively related to the successful experience of others. A second reason is that entering entrepreneurs in most cases have obtained experience with the product and industry having had certain key positions at incumbent firms. All entrants and all exiting firms are assumed to produce the smallest possible output q^F. Both the probability of entry and of exit in period $t + 1$ is taken to be a logistic function of expected profit $E_t\pi^F_{t+1} = E_tP_{t+1}q^F - E_tC_{t+1}(q^F)$, where E_t is the expectancy operator. The probabilities are given in Equations 3 and 4, with corresponding Taylor expansions in $E_t\pi^F_{t+1} = 0$.

$$P[entry] = \frac{\eta_1 e^{E_t\pi^F_{t+1}}}{1 + \eta_1 e^{E_t\pi^F_{t+1}}} \approx \frac{\eta_1}{1+\eta_1} + \frac{\eta_1}{(1+\eta_1)^2} E_t\pi^F_{t+1} \tag{3}$$

$$P[exit] = \frac{\eta_2 e^{-E_t\pi^F_{t+1}}}{1 + \eta_2 e^{-E_t\pi^F_{t+1}}} \approx \frac{\eta_2}{1+\eta_2} - \frac{\eta_2}{(1+\eta_2)^2} E_t\pi^F_{t+1} \tag{4}$$

The net change in the number of firms is then approximated by $\Delta N_t = P[entry]\eta_0 N_{t-1} - P[exit]N_{t-1}$. We assume that the total costs for small-scale producers can be expressed as $C_t(q^F)$

[3] It is a stylized fact that entrants and exiting firms in manufacturing industries are on average much smaller than incumbent firms (MacDonald 1986; Dunne, Roberts, and Samuelson 1988; Geroski 1995). The large majority of firms in most industries is small, even if there are considerable scale economies. Audretsch (1999) explains this skewed firm-size distribution from a continuous process of entry of new (suboptimal) firms, of which some grow into large firms attaining the minimum efficient scale.

[4] We assume in our analysis that costs decrease because of industrywide learning-by-doing. That is, improved product quality or production processes are assumed to be publicly available (complete spillovers). This implies that firms are assumed not to be able to decrease marginal costs faster in future periods than competitors by increasing production in the current period.

$= (c_t + \theta)q^F + F$, with the parameter θ presumably positive, as large-scale producers have lower marginal costs than small-scale producers. Hence, the unit costs are equal to $C_t(q^F)/q^F = c_t + \theta + F/q^F = c_t + \kappa$. The net entry rate is a linear function of the profit margin:[5]

$$\frac{\Delta N_t}{N_{t-1}} = \left[\frac{\eta_0\eta_1}{1+\eta_1} - \frac{\eta_2}{1+\eta_2}\right] + \left[\frac{\eta_0\eta_1}{(1+\eta_1)^2} + \frac{\eta_2}{(1+\eta_2)^2}\right]q^F E_{t-1}(P_t - c_t - \kappa)$$
$$= \alpha + \beta E_{t-1}(P_t - c_t - \kappa). \quad (5)$$

For simplicity, we assume that net entry equals zero in case $E_t\pi^F_{t+1} = 0$ and that therefore $\alpha = 0$.

Equilibrium Degree of Market Concentration

In order to derive the systematic evolution of the equilibrium path of the Herfindahl index over time from Equations 2 and 5, we neglect any business-cycle effects for the moment and assume that the expected price–cost margin is proportional to the current one: $E_t(P_{t+1} - c_{t+1}) = \rho(P_t - c_t)$. By the equilibrium Herfindahl index, we mean that level of concentration at which no increase or decrease in the number of firms is predicted. In the empirical application, we assume that the expected difference between price and cost is determined by the current price-cost margin and by the current growth rate of demand (business cycle effect). In case the number of firms is at the equilibrium value, we have from Equation 5 that $P_t = c_t + \kappa/\rho = c_t + \gamma$. When we insert this into Equation 2, we find the following relation between the equilibrium Herfindahl index H^*_t and the marginal cost:

$$H^*_t = \frac{-\gamma e_t}{c_t + \gamma}. \quad (6)$$

In case the actual Herfindahl index is above the equilibrium level ($H_t > H^*_t$), then the low degree of competition implies that price–cost margins are high providing an incentive to enter.[6] In the reverse case ($H_t < H^*_t$), the Cournot model predicts low price–cost margins, leaving little room for fringe firms. The extent of competition among the large-scale producers, therefore, is the key determinant of net entry among the small-scale producers in our model. If the price elasticity of demand is constant over time, then the equilibrium value of the Herfindahl index rises with decreases in the marginal costs c_t because of, for example, technological developments.[7] In the early years of the industry evolution H^*_t and competition (here corresponding with a high H_t) are both low, leading to high rates of entry. However, the equilibrium Herfindahl index (H^*_t) rises over time, and the increase in the number of market participants is likely to lead to increased competition (a lower H_t). This will lead to lower rates of net entry and subsequently a period of "shakeout" of producers occurs in case H_t falls below the level of H^*_t. We note that the model does not have an equation predicting the level of concentration

[5] Whether the number of firms is increasing or decreasing depends on the difference between the price–cost margin and the ratio of F over q^F. Therefore, the assumption that F and q^F are constant over time can be easily relaxed to that the ratio of these variables (κ) is constant. The latter may be more realistic as constant costs and production of small-scale producers both are likely to increase over time.

[6] The "resource partitioning theory" has the related idea that specialist organizations will proliferate as the overall industry concentrates and becomes dominated by large generalist firms (Carroll and Hannan 1995; Swaminathan 1995). This theory provides a rationale how competition among large-scale mass producers (generalists) promotes the exploration of peripheral niches within the resource space by specialist organizations.

[7] See also Dasgupta and Stiglitz (1988) on the relation between decreases in costs due to (industrywide versus firm-specific) learning-by-doing, entry barriers, and industry concentration.

(H_t). This may be largely determined by, for example, mergers and acquisitions, outsourcing, and antitrust laws. The model does predict a level of concentration (competition) at which zero net entry is expected and that when the actual level of concentration falls below this level, there is a shakeout of firms.

3. The Evolution of Prices, Output, and Number of Firms

In this section, we discuss the model explaining the time paths of automobile tire prices, total output of tires, and number of firms producing tires over a period of several decades. The model consists of three equations and contains the following variables: Q_t = output in millions of tires in period t; P_t = real price index of tires (1967 = 1) in period t; M_t = output of millions of motor vehicles in period t; S_t = number of motor vehicles registered for one year or longer, in millions, in period t; R_t = real price index of natural rubber (1967 = 1) in period t; and N_t = number of firms producing tires in period t.

Output

The first equation relates the output of automobile tires, Q_t, to the output of motor vehicles, M_t, the number of motor vehicles registered for one year or longer, S_t, and the price index of tires, P_t. The demand for automobile tires can be decomposed into demand for original equipment and renewal purchases. The demand for original equipment depends on the output of motor vehicles. It is unlikely that this demand is influenced by the price of tires because this price is low compared with the total cost of the motor vehicle. The replacement demand depends on the number of motor vehicles already on the road for one year or more.[8] Because the replacement of tires can often be delayed, this demand will be negatively affected by the price of tires. The higher the price of tires, the longer drivers will wait to replace them. A simple estimate of the average number of tires drivers replace per year is $(Q_t - 5M_t)/S_t$. That is, we subtract the demand for original equipment from the total number of tires produced and then divide it by the number of registered motor vehicles. We assume here that every new motor vehicle needs five tires and that replacement does not occur within the year after the purchase of a motor vehicle. Five tires per new motor vehicle is somewhat low because trucks and buses are also incorporated in the number of motor vehicles and usually have more than five tires.

Jovanovic and MacDonald used a simple demand function: $Q_t = c_0 P_t^{-c_1}$. They find an estimate for c_1 of 0.763, implying that a 1% increase in price leads to a 0.8% decrease in the demand for tires. However, the demand function ignores not only the impact of the number of new and old motor vehicles on the demand for tires but also the improvement in the quality of both tires and roads. Therefore, c_1 should not be interpreted as a price elasticity of the demand for automobile tires. The plot of the rate of replacement variable $(Q_t - 5M_t)/S_t$ can be found in Figure 1. It shows a marked decline from about 5 in the period 1910–1917 until around 1.5 in the period 1930–1973 (1942–1946 excluded).[9] The downward movement of the replacement rate of tires is a consequence of large improvements in the quality of both roads and tires. The

[8] Replacement of tires for motor vehicles registered for less than one year is not taken into account. These vehicles are responsible for only a small portion of total replacement demand.

[9] We exclude the World War II period 1942–1946 here and in the rest of the paper because tire and car output were restricted in those years.

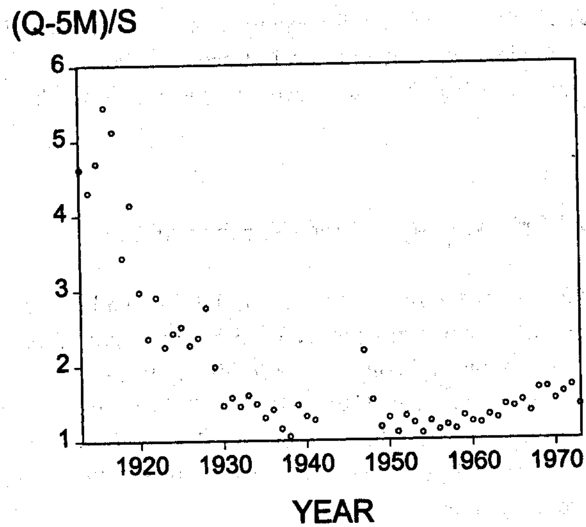

Figure 1. Estimated Rate of Replacement

average life of a tire increased from six months in 1910 to more than two years in the late 1930s (Reynolds 1938). The average tire life did not increase during the first decades after World War II.[10] In the 1917–1930 period, the price index also declined from about 5.7 to about 1.1. However, the main reason why total demand increases in this period is not because of lower prices but because of the strong increase in the number of motor vehicles. We propose an alternative specification for demand being a linear function of the number of motor vehicles produced and registered:

$$Q_t = a_0M_t + (a_1 + a_2QUAL_t + a_3\log(P_t))S_t + \epsilon_t^Q. \tag{7}$$

Clearly, the quality improvement of tires (and roads) starts in the beginning of this century when the industry life cycle was in its earliest phase. From Figures 1 and 2, it is clear that the rate of replacement diminished steadily up to 1930 even though the (relative) prices of tires were decreasing. After 1930, the replacement rate did not change very much. To correct for the increase in the average tire life, we introduce a quality index, $QUAL_t$, which equals "year minus 1930" for the period 1913–1930 and 0 afterward. The price effect on the rate of replacement is represented in Equation 7 by the logarithm of the price index. This implies a price elasticity of demand equal to a_3S_t/Q_t. We expect a_0 to be somewhat larger than five because each new motor vehicle needs at least five tires.[11] A positive value of a_1 in excess of the minimum of $a_2QUAL_t + a_3\log(P_t)$ is expected because replacement demand ought to be positive. The parameters a_2 and a_3 are expected to be negative, because both a higher quality and a higher price lead to a lower replacement rate of tires.

[10] A constant average tire life does not necessarily imply that the quality of roads and tires is constant as well. The quality increase may be compensated by an increase in the average mileage per motor vehicle per year. The introduction of the radial tire in the 1970s prolonged the average life of tires significantly. However, the period after the early 1970s is not under consideration in the present study.

[11] Note that the passenger cars sales as a percentage of total motor vehicle factory sales was between 74% and 91% from World War I up to 1973 (U.S. Department of Commerce 1975). As a consequence, the motor trucks and buses sales as a percentage of total sales have been between 9% and 26%.

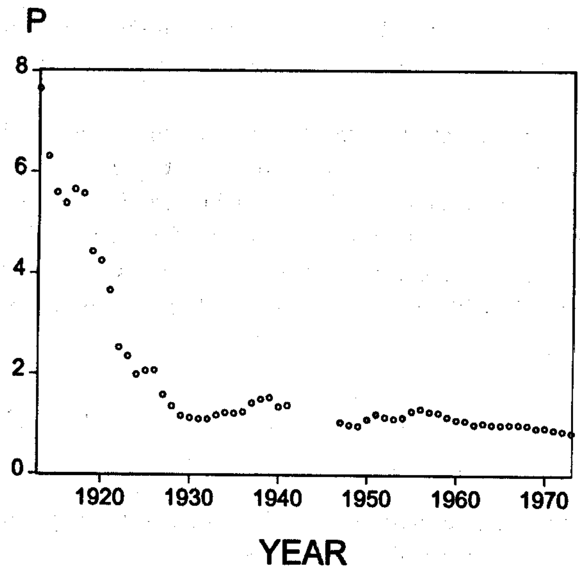

Figure 2. Price Index of Tires (1967 = 1)

Price Level

The price level of a good is determined by two factors: the level of production costs and the degree of competition prevailing in the market. Both elements are taken into account in our price equation, which is the empirical counterpart of Equation 2. The level of production costs of tires is assumed to consist of three parts. The first part refers to costs that are constant and unavoidable, such as transportation costs. The second part is the cost of rubber. The third part consists of costs that diminish as a result of learning-by-doing. We will first discuss this last part.

Learning-by-doing is essential for understanding technological development in most industries. As a result from experience with the production process, firms are able to save on production costs. Workers are found to increase their skills in specific tasks through repetition. The routing and handling of materials and the planning of required maintenance are steadily improved over time. In this process, the discrepancy between the supply of labor (employees) and the demand of labor (tasks) diminishes (Bahk and Gort 1993). These learning processes will be most forceful in the first years after the development of the production process, when many elements of the process are still to be optimized. That is, the learning rate declines with the age of the production process or the cumulative output produced. Jovanovic and MacDonald assume that technological know-how can be kept entirely proprietary. In their model, firms cannot imitate their more efficient rivals. They can only acquire know-how by chance. Their analysis indicates that total production costs of high-tech firms are only about 1% of that of low-tech firms at the same level of production. We doubt that any such cost differences have ever existed in the industry, and we doubt more generally that technological know-how was completely internalized within the firm (Ghemawat and Spence 1985; Irwin and Klenow 1994). We assume in our analysis that firms cannot keep their stock of experience proprietary. The learning process in the industry should not be thought of as restricted to increasing experience with one specific product or production process, but to also include a large number of small product and process innovations (gradual technological progress).[12] However, none of these innovations is considered to stand out as a dominant one, as in the Jovanovic–MacDonald model.

Let us now consider the extent of the learning economies in the U.S. automobile tire industry. This is important because the estimate of the learning rate will be used in our subsequent analysis. A common specification for estimating learning economies is the regression of the log of the price on the log of cumulative output (Irwin and Klenow 1994). Of course, this is only legitimate if the price is close to the marginal costs (Jarmin 1994). The regression results over the period 1913–1973 are as follows (standard error between brackets, DW is the Durbin-Watson statistic):

$$\log(P_t) = \underset{(0.115)}{2.928} - \underset{(0.017)}{0.371} \log\left(\sum_{s=1}^{t-1} Q_s\right) \qquad R^2 = 0.902 \qquad \text{DW} = 0.25. \tag{8}$$

The low Durbin–Watson statistic indicates that the residuals possibly have an autocorrelation coefficient of unity. This is confirmed by the adjusted Dickey–Fuller test statistic (with a constant) equal to −2.32. The hypothesis of a unit root in the residuals cannot be rejected (at a 5% significance level). We estimate the equation in first differences to find a somewhat lower learning rate (standard errors between brackets):

$$\Delta\log(P_t) = \underset{(0.080)}{-0.312}\Delta\log\left(\sum_{s=1}^{t-1} Q_s\right) \qquad R^2 = 0.090 \qquad \text{DW} = 1.64. \tag{9}$$

This equation implies that with each doubling of cumulative output, costs drop by about 19.4%. This rate is close to that found in the semiconductor industry (Irwin and Klenow 1994, table 1). It is noted that from 1914 to 1929, the automobile tire industry led all U.S. manufacturing in terms of growth in output per man-hour (French 1991, p. 52). An alternative measure of learning-by-doing is the age of the industry. The relation using this measure is also estimated in first differences using nonlinear least squares (standard errors between brackets):

$$\Delta\log(P_t) = \underset{(0.588)}{-1.134}\Delta\log(t - \underset{(4.78)}{1905.85}) \qquad R^2 = 0.127 \qquad \text{DW} = 1.57. \tag{10}$$

The first pneumatic car tire was produced by Michelin in France in 1895 and used during the 750-mile race from Paris to Bordeaux and back (Coates 1987, p. 87).[13] According to Equation 10, the learning-by-doing process in the industry, and hence the U.S. tire industry itself, is estimated to have started late in the year 1905. This corresponds remarkably well with the Thomas Register of American Manufacturers, which gives 1906 as the earliest date of positive output (Jovanovic and MacDonald 1994, p. 335). From here, we will assume that the index t is the year minus 1905. We use the age of the industry as a measure of learning-by-doing in the empirical analysis. However, the main conclusions are not affected when using cumulative output as a measure. The estimate of the learning rate parameter of −1.13 should be interpreted with caution. In general, price and cost decreases due to learning economies should be highly

[12] We are grateful to the referee who pointed this out. Jovanovic and MacDonald (1994) present a list of some of the more important innovations in the tire industry on page 345 of their article.

[13] It would take until 1899 before the first automobile, using Michelin tires, surpassed the then-magical 100 km/h barrier.

correlated, but of course they are not perfectly correlated. A better estimate may be found when explicitly formulating the marginal cost of producing tires and the degree of competition, to which we turn now.

Another important determinant of the cost of tires is the price of natural rubber. For example, the very strong decrease in the prices of tires in the early 1920s was triggered by the collapse of the natural rubber price in that period (French 1991, p. 40). In general, the price of natural rubber has declined strongly over the 1910–1932 period. To a certain extent, this decline explains the decline in the price of tires in the same period (Orton 1927; Reynolds 1938; French 1991). The rol̂e of natural rubber declined after World War II when synthetic rubber was introduced commercially. The simple correlation coefficient between the rubber price index and the tire price index is 0.90 for the period 1913–1973, whereas it is 0.89 for the period 1913–1941 and only 0.74 for the postwar period 1947–1973. Rubber prices fluctuated heavily during the 1920s and 1930s. The rubber price index almost tripled during the London rubber boom of 1925, and as a consequence, the tire price index rose for the first time since World War I. During the Great Depression, rubber prices collapsed, and a pound of rubber could be bought for as little as two cents in 1932 (Coates 1987, p. 255). In that same year, the tire price index reached its prewar minimum.

The weighted average of marginal costs for producers of tires is assumed to be a linear combination of constant unavoidable costs, b_1, of the cost of rubber, b_2R_t, and of costs subject to learning economies, $b_3t^{-b_4}$. In sum, our approximation for the average marginal production costs is $b_1 + b_2R_t + b_3t^{-b_4}$, where b_4 is fixed in some cases at the estimated value of 1.13 (see Eqn. 10) in the empirical analysis in order to avoid high correlation between the estimates of b_3 and b_4.

Tire prices are influenced not only by the cost of tires but also by the degree of competition. In times of severe competition, the prices of tires are closer to the cost of tires than in times when there is some degree of collusion in the industry. The price Equation 2 of the Cournot model presents a direct relation between a summary measure of the firm size distribution (number of firms and their market shares) and the degree of competition. This summary measure is the Herfindahl index, for which we require market shares for each of the periods. However, we have available market shares (for the largest tire producers) only for very few years and have had to resort to an approximation of the index. We approximate the Herfindahl index by $N_t^{-\upsilon}$, where $0 \leq \upsilon \leq 1$. The parameter υ can be seen as a measure of the degree of collusion. A value of υ close to zero corresponds to collusion comparable with that in a concentrated market with one firm having a market power (share) of nearly 100%. A value of υ close to unity corresponds to competition in a market with all firms having about equal market power (share). The choice of the above approximation implies that the degree of competition is a function of the number of firms in the industry. That is, tire prices are influenced negatively by the number of firms, but decreasingly so ($\partial P_t/\partial N_t < 0$, $\partial^2 P_t/\partial N_t^2 > 0$). The price equation with the estimated price elasticity derived from Equation 7 is as follows:

$$P_t = \left(1 + \frac{N_t^{-b_0}}{\hat{a}_3 S_t/Q_t}\right)^{-1} (b_1 + b_2R_t + b_3t^{-b_4}) + \epsilon_t^P. \tag{11}$$

A disadvantage of having the elasticity dependent on output is that we have introduced simultaneity between price, P_t, and output, Q_t. Therefore, we present (very similar) results with S_{t-1}/Q_{t-1} instead of S_t/Q_t, in order to have a recursive model. A recursive model has the advantage of the effects of misspecification in one equation not to carry over to the other equations in the system. It is also a simple method of predicting and simulating the industrial evolutionary patterns.

Net Entry

The last equation relates the net entry rate, $(N_t - N_{t-1})/N_{t-1}$, to expected profit opportunities. The expectation of profit opportunities is supposed to be influenced by two factors. The first factor is the profit margin of incumbents in the preceding period. A high average profit margin in the current period indicates a disequilibrium situation of a too low number of firms operating in the market. Potential entrepreneurs react to this disequilibrium situation by entering.[14] The second factor is the growth of demand for tires in the preceding period. It may be more costly for incumbents to adjust their capacity than it is for new firms to enter the industry (Hause and Du Rietz 1984). A growing demand may also increase the number of viable market niches.[15] Many new firms entered the tire industry during a period in which the growth of demand for tires was extremely high. The subsequent expansion of (replacement) demand during the 1920s was less than expected by these new entrants and helped to undermine several of the frailest firms (French 1991, chap. 5). The impact of the Great Depression hastened the shakeout of the tire industry (French 1991, chap. 6). Output of tires and number of firms in 1932 both were only half of those in 1928. By now it is a stylized fact that industries with higher growth rates generally have higher net entry rates.[16] We use the lagged change in the demand growth rate, $\Delta(\Delta Q_{t-1}/Q_{t-2})$, as an additional determinant of the net entry rate. This is in line with Liebowitz's (1982) argument that the change in the growth rate of demand is a better indicator of the change in profit rate from the previous to the current period than the growth rate of demand.[17] The empirical version of Equation 5 then becomes

$$\frac{\Delta N_t}{N_{t-1}} = c_0(P_{t-1} - c_1 - c_2 R_{t-1} - c_3(t-1)^{-c_4}) + c_5 \Delta \frac{\Delta Q_{t-1}}{Q_{t-2}} + \epsilon_t^N. \quad (12)$$

When we relate Equation 12 to the price Equation 11, we expect the constant c_1 to be larger than b_1 because of the presence of fixed costs (cf. Eqn. 5). The parameters c_2, c_3, and c_4 of the marginal cost approximation have the same interpretation as the parameters b_2, b_3, and b_4 in the price equation. Equations 11 and 12 are nonlinear in the parameters. Therefore, we will use nonlinear least-squares estimation.

Nearly all firms that enter and exit the market are small (MacDonald 1986). Small firms usually cannot survive the financial pressure of a low or even negative profit margin for a long time. Because they have lower sunk costs than large firms, they may also be less reluctant to

[14] See Carree and Thurik (1999) for a model of entering and exiting entrepreneurs adjusting for disequilibrium. This model is tested using a panel data set of retail industries.

[15] An important market niche in the tire industry has been the production of truck and bus tires (French 1991, p. 49). Specialist tire production may provide better margins than the average profit margin in the industry. Since the 1970s, small firms have increasingly concentrated on niches in specialist sectors, and some larger firms have abandoned specialist tire production (French 1991, p. 114–6). Acs and Audretsch (1989) and Rosenbaum (1993) find that net entry rates tend to be lower in industries in which there is already a considerable presence of small firms, and hence, most market niches will already have been filled.

[16] See Duetsch (1975), Hirschey (1981), Kessides (1986), Acs and Audretsch (1989), and Rosenbaum (1993) for U.S. manufacturing.

[17] We considered some alternatives to the lagged change in the demand growth rate. Among these were the lagged growth rate of demand, $\Delta Q_{t-1}/Q_{t-2}$, and the difference between the lagged growth rates of demand and number of firms, $\Delta Q_{t-1}/Q_{t-2} - \Delta N_{t-1}/N_{t-2}$. Both provided a worse fit, indirectly confirming Liebowitz's argument.

exit the industry. We argue that the rapid shakeout of firms in the 1920s and early 1930s was at least partly because of an unexpected low profit margin in the tire industry. Reynolds (1938, p. 464) reports that the average profit rate in tire manufacturing was only about half of that in the entire manufacturing sector in this period. In the period 1920–1935, there was only one year (1925) in which the percentage profit in tire manufacturing was higher than the average for the entire manufacturing sector.

Among the factors that caused the strong competition, and hence low profit margins, were the violent fluctuations of rubber prices, the rise of large retailers and the establishment of company stores, the shakeout in the number of car producers, decreasing growth rates of demand for automobile tires, and excess capacity (Reynolds 1938).[18] The strong decline of the rubber prices in the 1920–1921 recession gave new and small firms a temporary advantage because they could buy at the then-current low price levels while larger firms had to work off expensive inventories (French 1991, p. 40). The London rubber boom of 1925 had the reverse effect. Small firms faced high rubber costs while their larger rivals were still using cheap rubber (French 1991, pp. 52–3).

The Evolution of the Number of Firms

From Equation 6, it is apparent that a decrease in marginal costs over time leads to a higher equilibrium Herfindahl index. The equilibrium degree of concentration in the model is therefore bound to increase in an industry in which learning economies are important. Finally, only a few very large producers may survive while having competition fierce enough (in the sense of profit margins being that low that small firms cannot make up for fixed costs) not to have new entrants. This scenario has become reality in the tire industry, which is now dominated by only a handful of producers worldwide.[19] Of course, the actual degree of concentration may deviate from the equilibrium concentration rate. This deviation explains the typical pattern in many industries of the number of firms to increase and subsequently to decrease. The reason for this follows.

In the first years of the industry, the number of firms is low. Hence, the degree of concentration and price–cost margins are high. Many new firms enter, some of which grow into large-scale producers leading to a lower degree of concentration. Both the decreases in marginal costs and the intensification in competition lead to decreasing room for new entrants. This process continues until the actual level of concentration falls below the equilibrium level of concentration. This leads to increased competition and, possibly, a fierce shakeout. Small firms, many of which have entered only recently, exit because of low profit margins while leaving the degree of concentration largely unaffected. Only when very high numbers of small firms have exited or when large firms acquire their smaller counterparts or merge will the level of concen-

[18] The shakeout in the number of car producers occurred in the same period as the shakeout in the number of tire producers. Klepper and Simons (1993) report a decrease in the number of car producers from 175 in 1921 to 55 in 1925. Utterback and Suárez (1993) use a somewhat different data source and find a peak of 75 producers in 1923 followed by a rapid fall to only about 15 in the 1930s. The simultaneous decreases in the number of car and tire producers seems to be directly in line with Galbraith's 'Countervailing Power' argument (Schumacher 1991). It is certainly so that most small and new producers were not able to compete with the established contracts between large tire and car producers. However, the share of the replacement market of automobile tires in total tire sales was about 70% during the 1920s (Reynolds 1938, Table I). The development of the car industry into a highly concentrated industry is therefore likely to have affected prices of only about 30% of the tire sales.

[19] In 1996 Japanese Bridgestone, French Michelin, and U.S. Goodyear enjoyed a joint global market share of over 50%.

tration return to a level close to the equilibrium level. So the constant decreases in profit margins making fixed costs more and more a burden for small, fringe firms lead to the change from a phase of net entry to a phase of net exit.[20] The intensity of this change depends on the intensity of competition.[21] The time path for the number of firms has some similarities with the equilibrium time path of the number of firms in the Jovanovic–MacDonald model, although the underlying assumptions are clearly different. Jovanovic and MacDonald show that a model driven by a cost-reducing technological innovation can generate the pattern of firm numbers observable in many new industries. We show that a model driven by a gradual decline in unit cost can do the exact same. Both models can be used to explain why in the early and late stages of the industry the number of firms is low, whereas in between, there is a period in which the number of firms is at a higher level. The choice for either of the two models to apply to a certain industry life cycle should be based on which model assumptions are the most accurate descriptions of the available historic evidence.

4. Empirical Results

The data are available for the period 1913–1973 and include a United States price index of tires, the output of tires, and the number of firms producing tires.[22] The World War II period 1942–1946 is left out of the analysis because both tire and car output were restricted. In Figure 2, the price index of tires is displayed. The tire price index declined strongly from 7.7 in 1913 to 1.1 in the early 1930s and then rose slowly to 1.4 in the years before the war. After the war, the price index started from a low point of 1.0 and then rose slowly until 1.3 in the mid 1950s, followed by a steady decline to 0.9 in the early 1970s. The output of automobile tires can be found in Figure 3. The output rose strongly from 6 million tires in 1913 to 78 million tires in 1928. During the Great Depression, this number fell to 40 million tires but then rose gradually to 120 million tires in 1960. The rise in the output then accelerated in the 1960s and in 1968 more than 200 million automobile tires were produced. The nonmonotonicity in the firm numbers in the tires industry can be seen in Figure 4. The number of producers had only been 10 in 1906 but had already increased to 74 by 1913. The increase in the number continued until 1922, when there were 275 firms. The number of firms then dropped very fast, to about 120 before the Great Depression and to 62 in 1933.[23] This was followed by a monotone decline in the number of firms to around 30 in the 1970s.

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[20] Porter (1980, p. 161) discerns four stages in the industry life cycle and provides some characteristics of these stages. In the introductory stage, there are few competitors and prices and margins are high. In the growth stage, there are many competitors and prices have decreased. In the maturity stage, there is severe price competition, a shakeout of producers, and the lowest prices and margins throughout the life cycle. In the decline stage, there are fewer competitors and price and margins are low. These characteristics can be explained adequately by our model. As unit costs decline, prices and margins decline as well. Prices and margins may be especially low during the shakeout when competition is fierce because of the high number of firms having entered before.

[21] In case of entry "overshooting" the room available for fringe firms the shakeout will be especially fierce. See Klepper and Miller (1995) for a model of overshooting of an equilibrium number of market participants to account for shakeouts.

[22] Jovanovic and MacDonald assume a refinement date of 1913 (see their figures 3a and 4 and p. 341). Our period of investigation therefore only covers their "postrefinement period."

[23] See Fricke (1982) for a study on the remarkable struggle to survive of the McCreary Tire & Rubber Company during the 1930s. This company was the smallest of the tire manufacturers which survived the Great Depression. French (1993) discusses strategic problems and decisions from the 1920s onward of another small firm, the Seiberling Rubber Company.

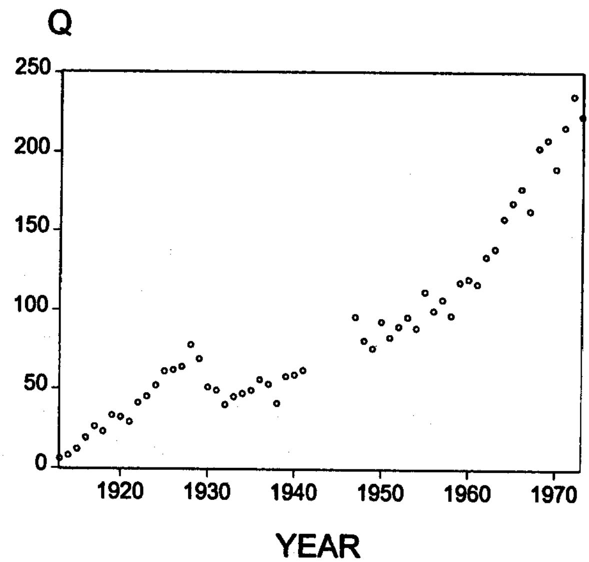

Figure 3. Output of Automobile Tires (in Millions)

We present summary statistics of the variables in Table 1. The sources of the data are table A1 of Jovanovic and MacDonald (1994) for the data on the price index of tires, the output of tires and the number of firms, the U.S. Department of Commerce (1975, 1989) for the data on the number of motor vehicles produced and registered, and Orton (1927), Coates (1987), and Citibase for the data on the natural rubber price. The high volatility of the rubber price (before World War II) is represented by the high standard deviation of the percentage yearly growth of the price index.

We first examine our claim that the shakeout has been caused by a strong price competition in the tire industry followed by a strong decline in automobile tire demand. In Table 2, we

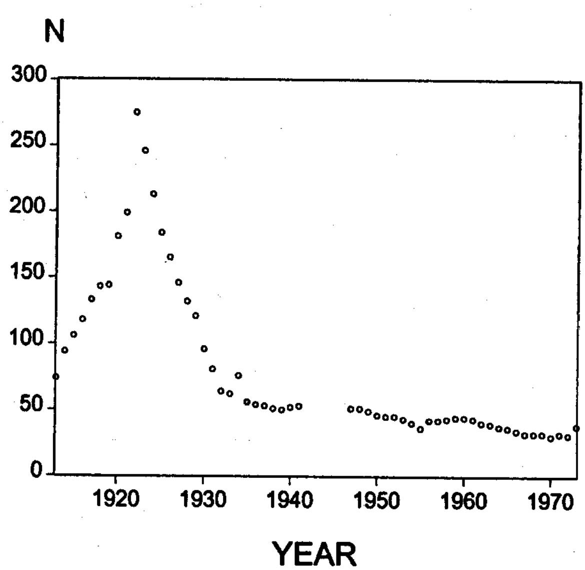

Figure 4. Number of Firms Producing Tires

Table 1. Summary Statistics

Description	Symbol	Mean	Standard Deviation	Growth Mean	Growth Standard Deviation
Output of tires	Q	90.07	58.96	8.4%	19.4%
Price index tires	P	1.82	1.45	−3.5%	9.1%
Output of motor vehicles	M	5.55	3.14	10.1%	28.8%
Motor vehicles registered	S	42.04	31.15	10.1%	13.5%
Price index rubber	R	2.05	1.88	2.2%	49.7%
Number of firms	N	80.45	60.57	−1.9%	11.8%

report the tire and rubber price index, the demand for tires, and the number of producers for five successive periods. In the 1915–1922 period, the demand for tires grew strongly, and the decline of tire prices was less than that of rubber prices. As a consequence, the number of firms increased at an average rate of 15% per year. The 1923–1929 period was characterized by fierce competition: tire prices declined more than in the previous time period while rubber prices rose. On average, the growth rate of demand was also nine percentage points lower. The net entry rate was −11% in that period. In the 1930–1933 period, price competition was still strong (French 1991, chap. 6). The cost of rubber did collapse, but it was only a fraction of tire production costs in this time period. More important, demand for tires declined 15% per year during the Great Depression. In this period, the tire industry suffered its most profound reorganization (French 1991, p. 60). The number of firms also decreased at a yearly rate of 15%.

The regression results of the three Equations 7, 11, and 12, estimated separately, are presented in Tables 3 through 5. In Table 6, restrictions on common parameters across these equations are imposed and results are presented. There is a problem with the price data in the World War I period. During World War I, the prices of tires were subject to regulation and did not decrease much despite the increase in output. The price index of tires shows an unexpected lack of decrease, especially in the last two years of World War I. Therefore, we also present estimation results, leaving out price data for the years 1917 and 1918.

Output

We have estimated the output Equation 7 using the entire sample, using the period before the war and the period after the war. The empirical results can be found in Table 3. The estimate of the effect of the output of motor vehicles on the number of tires is somewhat above 5. This is reasonable, as new trucks and buses usually have more than five wheels. The effect of motor vehicles already registered for one year or more is a constant of about 1.5 minus the quality effect and minus the price effect. Both the quality and price effects are highly significant. The

Table 2. Changes in Price Indexes, Demand, and Number of Firms

Period	$\%\Delta P_{t-1}$	$\%\Delta R_{t-1}$	$\%\Delta Q_{t-1}$	$\%\Delta N_t$
1915–22	−8.4	21.9	24.8	14.9
1923–29	−12.5	14.2	15.8	−11.0
1930–33	−4.9	−34.2	−15.0	−15.1
1934–41	2.8	46.2	6.3	−1.1
1948–73	−1.5	−2.2	6.3	−0.9

Table 3. Empirical Results of the Output Equation

Output equation: $Q_t = a_0M_t + (a_1 + a_2QUAL_t + a_3\log(P_t))\,S_t + \epsilon_t^Q$

	1913–73	1913–41	1947–73	1913–16 1919–73	1913–16 1919–41
a_0	5.642	5.880	5.000	5.610	5.780
	(0.993)	(1.044)	(1.490)	(1.018)	(1.094)
a_1	1.368	1.625	1.429)	1.371	1.648
	(0.118)	(0.188)	(0.175)	(0.121)	(0.196)
a_2	−0.325	−0.317		−0.325	−0.318
	(0.046)	(0.051)		(0.048)	(0.052)
a_3	−1.031	−1.365	−1.197	−1.029	−1.400
	(0.180)	(0.408)	(0.255)	(0.184)	(0.424)
R^2	0.980	0.940	0.958	0.980	0.937
DW	1.29	1.38	1.43	1.31	1.42

Standard errors are in parentheses. DW is the Durbin-Watson statistic.

higher the quality of the tires (and roads), the lower the replacement demand per registered motor vehicle. The higher the price of the tires, the more costly it is to replace tires, and hence the lower the rate of replacement. The ratio of registered motor vehicles to the output of tires (S_t/Q_t) rises from about 0.1 at the beginning of the sample period to 0.5 in the early 1930s and remains around that value until the end of the sample period. This implies that the price elasticity of demand became somewhat stronger over the first decades of the sample and stabilized afterward.[24] The estimated price elasticity of demand is much smaller (in absolute terms) than the one presented by Jovanovic and MacDonald. In the period starting in the early 1930s, a 1% increase in price led to a 0.5% decrease, on average, in the demand for tires. The effect of price on demand was even smaller in the years before that. The last two columns of Table 3 show that leaving out the years 1917–18 does not have a large impact on the results of the output equation.[25]

Price Level

The empirical results of the (log-linear) price equation can be found in Table 4. The estimate of the parameter a_3 from the output equation is used to create the variable $\hat{a}_3S_{t-1}/Q_{t-1}$, which is used as estimate of the price elasticity of demand. The Durbin–Watson statistics of the (log-linear) price equations are very low. This is confirmed by the adjusted Dickey–Fuller test statistics, which indicated the presence of unit roots in the residuals. Therefore, we also present results for the equation estimated in first differences. In that case, it is not possible to estimate b_1 through b_3.

The estimated value of υ has a theoretical maximum of unity, which is confirmed by the majority of the estimation results in Table 4. The estimated value of υ in the price equation

[24] Porter (1980, p. 161) mentions as one of the characteristics of the introductory stage of the industry life cycle that the price elasticity is less than in the maturity stage.

[25] The Durbin-Watson statistics in Table 3 suggest a positive autocorrelation in the residuals of the output equation. The autocorrelation parameter turned out insignificant (at the 5% significance level) in the pre-war (until 1941) and postwar period (from 1947 on), but it was significant (t value of 2.39) in the total period. Estimation results of the parameters of Equation 7 were, however, not much affected when we corrected for autocorrelation. We present results not corrected for autocorrelation as it becomes easier to deal with gaps in the time series (such as 1917–18).

Table 4. Empirical Results of the Log-Linear Price Equation

Log price equation: $\log(P_t) = -\log\left(1 + \dfrac{N_t^{-b_0}}{\hat{a}_3 S_{t-1}/Q_{t-1}}\right) + \log(b_1 + b_2 R_t + b_3 t^{-b_4}) + \epsilon_t^P$

	1913–73	1914–73	1913–16 1919–73	1914–16 1920–73	First Differences 1914–73	First Differences 1914–16 1920–73	First Differences 1914–16 1920–73
b_0	0.723	0.649	0.777	0.695	0.904	1.008	1.713
	(0.073)	(0.054)	(0.106)	(0.085)	(0.197)	(0.319)	(5.745)
b_1	0.267	0.271	0.291	0.312			
	(0.061)	(0.060)	(0.060)	(0.057)			
b_2	0.194	0.173	0.196	0.171			
	(0.058)	(0.054)	(0.057)	(0.053)			
b_3	34.473	32.600	34.389	31.861			
	(4.190)	(4.068)	(4.104)	(3.996)			
b_4	1.13	1.13	1.13	1.13	1.128	1.13	1.707
					(0.574)		(0.578)
R^2	0.916	0.909	0.909	0.892	0.285	0.327	0.341
DW	0.30	0.32	0.28	0.30	1.55	1.57	1.63

Standard errors are in parentheses. DW is the Durbin–Watson statistic. The last three columns are estimated in first differences. The adjusted Dickey–Fuller (ADF) test statistics of the residuals of the first two columns are −2.55 and −2.72, respectively. In both cases the null hypothesis of a unit root cannot be rejected at the 5% significance level.

case ranges from 0.649 to 1.008 (leaving aside the imprecise estimate of the last column). Values of υ close to 1 are higher than expected. This suggests fierce competition throughout the industry life cycle. The market shares of unit tires sales of the four leading companies (Goodyear, Firestone, U.S. Rubber, and Goodrich) were about 30%, 15%, 19%, and 8%, respectively, in 1933 (French 1991, p. 47). The market shares in original equipment sales of the leading U.S. companies in 1970 (Goodyear, Firestone, Uniroyal, and Goodrich) were 32%, 27%, 18%, and 16%, respectively, spanning almost the entire market (French 1991, p. 111).[26] However, despite the dominance of the big four tire manufacturers, the industry was very competitive before World War II (Reynolds 1938). This may be a reason for the estimate of the Herfindahl index to be biased downward. The constant in the marginal cost part of the equation (b_1) is estimated to lie around 0.3 in the first four columns of Table 4. This indicates that the costs of tires are predominantly composed of rubber costs and costs subject to learning-by-doing.

Both the effects of the natural rubber price (b_2) and costs that decrease through a learning-by-doing process (b_3) are positive and significant. The two estimates of the learning rate (b_4) are 1.128 and 1.707, respectively. These estimates are both significant (at a 5% significance level) but have high standard errors.

[26] The Herfindahl indices in 1933 and 1970 were therefore equal to about 0.17 and 0.24, respectively. These are both less than the estimated absolute price elasticity of about 0.5. The number of firms of 62 in 1933 would indicate υ to be around 0.43 [−ln(0.17)/ln(62)], whereas the number of firms of 30 in 1970 would indicate a very similar value, *viz.* 0.42 [−ln(0.24)/ln(30)]. These values are of course under the assumption of Cournot oligopoly as given in Equation 2. Higher values of υ may indicate the inadequacy of the approximation of the Herfindahl index by a function of the total number of firms or it may indicate that price competition among market participants exceeds that of Cournot oligopoly.

Table 5. Empirical Results of the Net Entry Rate Equation

Net entry equation: $$\frac{\Delta N_t}{N_{t-1}} = c_0(P_{t-1} - c_1 - c_2R_{t-1} - c_3(t-1)^{-c_4}) + c_5\Delta\frac{\Delta Q_{t-1}}{Q_{t-2}} + \epsilon_t^N$$

	1914–73	1914–73	1914–17 1920–73	1914–73	1914–73	1914–17 1920–73
c_0	0.131	0.138	0.199	0.116	0.124	0.194
	(0.030)	(0.030)	(0.032)	(0.036)	(0.035)	(0.038)
c_1	0.488	0.476	0.389	−3.712	−1.836	0.281
	(0.195)	(0.178)	(0.108)	(22.23)	(7.551)	(0.486)
c_2	0.066	0.060	0.101	0.174	0.156	0.115
	(0.100)	(0.092)	(0.058)	(0.135)	(0.126)	(0.081)
c_3	53.232	53.840	51.370	12.682	13.334	41.727
	(10.96)	(10.04)	(6.417)	(6.927)	(11.25)	(35.86)
c_4	1.13	1.13	1.13	0.254	0.397	1.043
				(1.079)	(0.884)	(0.360)
c_5		0.096	0.065		0.093	0.065
		(0.047)	(0.044)		(0.047)	(0.044)
R^2	0.388	0.434	0.546	0.414	0.458	0.547
DW	2.20	2.15	2.41	2.30	2.26	2.42

Standard errors are in parentheses. DW is the Durbin-Watson statistic.

Net Entry

The net entry Equation 12 was first estimated using the assumption $E_t(P_{t+1} - c_{t+1}) = \rho(P_t - c_t)$ in Equation 5, or $c_5 = 0$. The results can be found in the first column of Table 5. The results for the marginal cost approximation are similar to those found for the linear price equation reported when the data for the entire period are used. The main difference is the higher constant in the marginal cost approximation. This corresponds well to the hypothesis that c_1 should be larger than b_1 because of fixed costs. In the second column, we introduce the lagged change in the growth rate of demand into the model. The effect of this variable on the net entry rate is positive and significant (at 5% significance level), as can be seen in the second column of Table 5. Incumbents may expect the growth rate of demand to remain constant and adjust their capacity accordingly. As a consequence, a higher growth rate provides room for entrants, whereas a lower growth rate leads to excess capacity. The latter phenomenon occurred in the late 1920s when large plant construction occurred (Reynolds 1938, p. 465). The third column of the table shows the results when the years 1918 and 1919 are excluded. Including these years implies that price data of the last two years of World War I are used, which may bias results. The fit of the regression improves when leaving out the two war years, but estimates are not much affected.

The last three columns of Table 5 show results for the net entry rate equation when the learning rate is estimated simultaneously. The estimates of the learning rates are low and insignificant when the entire 1914–1973 period is used. However, the estimate of c_4 (1.043) becomes quite close to our earlier estimates when the years 1918 and 1919 are excluded.

System

We continue the empirical analysis by considering common parameters in the three equations. The output and price equations share the parameter a_3. The price and net entry equations

Table 6. Empirical Results when Imposing Parameter Constraints

$$Q_t = a_0 M_t + (a_1 + a_2 QUAL_t + a_3 \log(P_t))S_t + \epsilon_t^Q \qquad (7)$$

$$\Delta\log(P_t) = -\Delta\log\left(1 + \frac{N_t^{-b_0}}{a_3 S_{t-1}/Q_{t-1}}\right) + \Delta\log(b_1 + b_2 R_t + b_3 t^{-b_4}) + \epsilon_t^P \qquad (11)$$

$$\frac{\Delta N_t}{N_{t-1}} = c_0(P_{t-1} - c_1 - b_2 R_{t-1} - b_3(t-1)^{-b_4}) + c_5 \Delta\frac{\Delta Q_{t-1}}{Q_{t-2}} + \epsilon_t^N \qquad (12)$$

	1914–73	1914–16 1920–73	1914–73	1914–16 1920–73	1914–73	1914–16 1920–73	1914–73	1914–16 1920–73
a_0	5.570	5.607	5.576	5.604	5.653	5.663	5.658	5.665
	(0.951)	(0.986)	(0.952)	(0.986)	(0.949)	(0.983)	(0.948)	(0.983)
a_1	1.377	1.372	1.376	1.372	1.369	1.367	1.366	1.367
	(0.113)	(0.117)	(0.113)	(0.117)	(0.112)	(0.116)	(0.112)	(0.116)
a_2	−0.306	−0.297	−0.305	−0.297	−0.308	−0.295	−0.306	−0.296
	(0.044)	(0.048)	(0.044)	(0.048)	(0.044)	(0.048)	(0.044)	(0.048)
a_3	−0.987	−0.972	−0.985	−0.973	−1.000	−0.979	−1.000	−0.979
	(0.172)	(0.177)	(0.172)	(0.177)	(0.172)	(0.177)	(0.171)	(0.177)
b_0	1.252	1.346	1.272	1.300	0.916	1.027	0.870	(1.042)
	(0.128)	(0.212)	(0.165)	(0.188)	(0.171)	(0.304)	(0.143)	(0.330)
b_1	−0.387	−0.343	−0.471	−0.264	0	0	0	0
	(0.091)	(0.158)	(0.323)	(0.142)				
b_2	0.055	0.067	0.061	0.056	0.077	0.091	0.097	0.086
	(0.019)	(0.023)	(0.029)	(0.025)	(0.027)	(0.025)	(0.046)	(0.032)
b_3	53.367	54.005	44.053	74.549	51.197	51.830	31.594	58.092
	(5.821)	(4.020)	(32.50)	(37.31)	(5.722)	(3.867)	(18.86)	(27.75)
b_4	1.13	1.13	1.038	1.274	1.13	1.13	0.902	1.180
			(0.334)	(0.218)			(0.268)	(0.206)
c_0	0.129	0.189	0.129	0.198	0.134	0.197	0.133	0.200
	(0.027)	(0.030)	(0.028)	(0.035)	(0.028)	(0.030)	(0.027)	(0.034)
c_1	0.501	0.396	0.365	0.559	0.499	0.395	0.142	0.453
	(0.183)	(0.110)	(0.517)	(0.241)	(0.177)	(0.106)	(0.512)	(0.250)
c_5	0.099	0.069	0.099	0.067	0.096	0.066	0.095	0.066
	(0.045)	(0.042)	(0.044)	(0.042)	(0.045)	(0.042)	(0.044)	(0.042)
$R^2_{(7)}$	0.980	0.978	0.980	0.978	0.980	0.978	0.980	0.978
$R^2_{(11)}$	0.314	0.346	0.307	0.356	0.284	0.326	0.275	0.329
$R^2_{(12)}$	0.433	0.534	0.440	0.531	0.433	0.536	0.448	0.536
$DW_{(7)}$	1.29	1.30	1.29	1.30	1.28	1.29	1.28	1.29
$DW_{(11)}$	1.67	1.62	1.66	1.64	1.55	1.57	1.53	1.58
$DW_{(12)}$	2.14	2.39	2.17	2.37	2.15	2.41	2.21	2.40

SUR estimation with parameter restrictions across the equations is used. Standard errors are in parentheses.

share three parameters: b_2 through b_4 and c_2 through c_4. These three parameters should be equal when the marginal cost used in pricing considerations is the same as in entry and exit considerations. In Table 6, we display the results for the entire period and for the period without 1917–1919 by use of the method of seemingly unrelated regression (SUR) estimation for the three equations, restricting the parameters to be equal.

The first two columns of Table 6 show the results when the learning rate is fixed at 1.13. The results are roughly similar to those presented for the separate equations. Two important exceptions are b_0, which has a value larger than unity (although not significantly so at a 5% significance level), and b_1, which becomes negative. The third and fourth column of Table 6

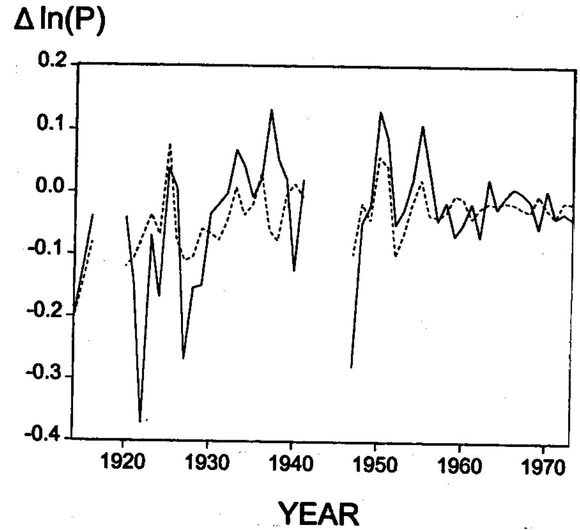

Figure 5. Actual and Estimated Change of Price Index (Solid Line is Actual; Dashed Line is Estimated)

present results when the learning rate is estimated as well. In case the entire sample period is used (third column), the learning rate is estimated to be 1.038. In case of the years 1917–1919 being left out of the sample, the learning rate is estimated somewhat higher, as 1.274. As a result of simultaneously estimating the learning rate, we find the estimate of parameter b_1 becoming insignificant (at a 5% significance level) and the standard error of b_3 increasing very strongly.

In the next four columns of Table 6, we restrict the parameter b_1 to be zero. It is estimated in the first two columns to be negative, which is not according to theory. The restriction on b_1 has as a consequence that the estimate of b_0 and the learning rate decrease. We still find evidence that competition has been fierce in the tire industry. However, one should bear in mind that the parameter b_0 is assumed to be constant over the entire period. Further research could focus on changes in the extent of competition from one period to another.

The results in Table 6 of the equations with the years 1917–1919 removed from the sample seem to provide a satisfactory description of the year-by-year determination of output, price, and net entry. We will further investigate the fit of the time series of changes in price level, the net entry rate, and the total number of firms by comparing the actual and fitted time series, which were found using the estimation results presented in the last column of Table 6.

The solid line in Figure 5 is the logarithmic change of the price index, whereas the dashed line is the predicted logarithmic change. In Figure 6, the solid line is the series of actual net entry rates, whereas the dashed line is the series of predicted rates. Finally, Figure 7 contains the actual number of firms (solid line) and the predicted number given the number of firms equal to 74 in 1913 and 144 in 1919. Note that the two war periods 1917–1919 and 1942–1947 have been left out in each of the three figures.

The variance of both the actual changes in the price index and in the net entry rate is much larger than that of the predicted change in the price index and net entry rate. The model does a poor job in predicting the price wars of the early and late 1920s. It indicates that competition was especially fierce in those periods given the number of firms in the market and the changes in marginal costs. Both the actual and predicted net entry rates change from positive

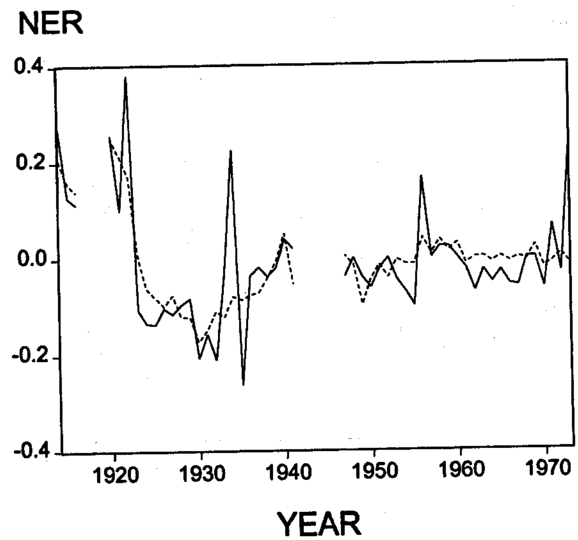

Figure 6. Actual and Estimated Net Entry Rate (Solid Line is Actual; Dashed Line is Estimated)

to negative in 1923. Therefore, the regression results correctly predict the peak of the number of firms in 1922. The sharply higher net entry rate in 1922 was not predicted by the model. One may wonder whether the bulk of entrants in the early 1920s made well-considered decisions. Many of these entrepreneurs had only very brief careers in tire manufacturing (French 1991, p. 47).

Equilibrium Degree of Market Concentration

The empirical analysis is concluded by considering the predicted equilibrium value of the Herfindahl index. This equilibrium value can be found in Equation 6 and equals $-\gamma e_t/(c_t + \gamma)$.

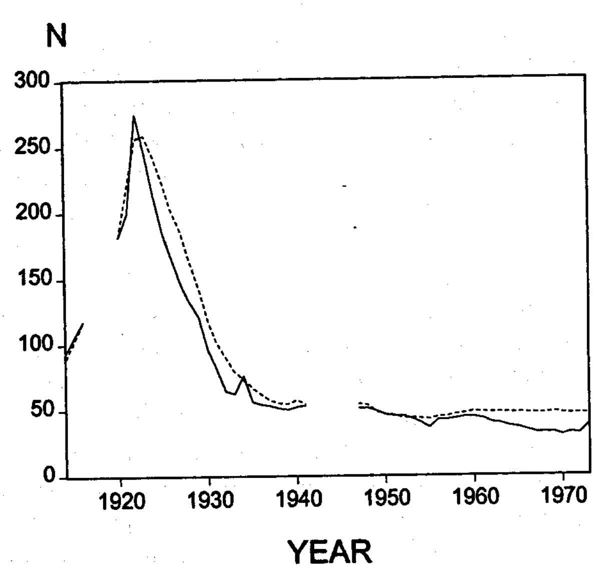

Figure 7. Actual and Estimated Number of Firms (Solid Line is Actual; Dashed Line is Estimated)

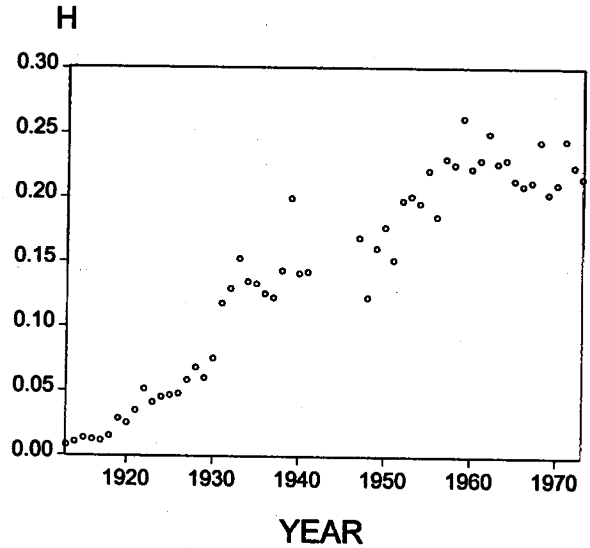

Figure 8. Estimated Equilibrium Herfindahl Index

Using the results presented in the last column of Table 6, we have as estimates $\hat{\gamma} = 0.453$, $\hat{e}_t = -0.979 S_{t-1}/Q_{t-1}$ and $\hat{c}_t = 0.086 R_t + 58.092 t^{-1.180}$. When we insert these estimates into the expression for the equilibrium Herfindahl index, we find a time series of predicted concentration rates. This series is presented in Figure 8. The equilbrium index increases quickly in the 1920s, 1930s, and the 1950s. At the end of the sample period, the equilibrium Herfindahl index lay between 0.20 and 0.25, quite close to the actual Herfindahl index in 1970, which was approximately 0.24 (see discussion on the empirical results of the price equation).

5. Conclusion

We present a new model of industry evolution and apply it to the U.S. tire industry over the period 1913–1973. The model we introduce suggests that the rapid shakeout of the number of firms in the U.S. tire industry has not been the result of any dominant innovation. Instead, the shakeout was triggered by a strong and persistent price competition in the tire industry (partly due to overshooting in the number of firms), followed by a strong decline in demand for tires during the Great Depression. Our model consists of three equations. The first explains the output of tires using the number of motor vehicles, the quality of tires (and roads), and the price index of tires. The second equation relates the price index of tires to the competition in the market, to the natural rubber price index, and to costs that decrease due to nonproprietary learning-by-doing. The last equation explains the net entry rate using the prevailing profit margin in the preceding period and the growth rate of demand for tires. The model predicts that the equilibrium degree of concentration increases as marginal costs decline such as in the case of important learning economies.

Jovanovic and MacDonald (1994) present an explanation of the nonmonotonicity in firm numbers found in many young industries. Their model shows that innovations could account for the nonmonotonic pattern of firm numbers. They claim that the number of firms initially rises because of innovation opportunities but that subsequent failure to innovate then leads to a gradual or catastrophic shakeout. We suggest a very different reason for shakeouts and provide an alternative model of the life cycle of a competitive industry. This model is applicable in particular to industries where a single innovation is not as dominant as the Jovanovic–MacDonald model assumes. We think that this is the case in most industries. Furthermore, we deal with some shortcomings of their analysis of the automobile tire industry.

The rise and fall of individual firms and even entire industries has a profound impact on employment, productivity, and welfare. Evolutionary models may provide important insight into what the role is that public policy can play, if any, in shaping the evolution. The model we present suggests some implications for public (antitrust) policy. In the early stages of the industry life cycle, high market concentration does not appear harmful for economic welfare. In case the incumbents (ab)use their market power and have high profit margins, new firms will enter to erode those margins. In later stages of the industry life cycle, market concentration can become harmful. Even if rivalry among the incumbents is low, potential competitors may not have the means to achieve a scale large enough to compete successfully. That is, the role of potential competition changes radically over the industry life cycle.

The focus of the current paper has been to develop a model for explaining patterns of output, prices, and number of firms over time in the tire industry. An important obstacle has been the lack of firm-level data. This required us to make some approximations and simplifying assumptions. The lack of firm data also makes it hard to determine whether these approximations and assumptions are valid. This should make us cautious when interpreting the estimation results. Nevertheless, we think that the model framework may be useful to explain patterns of industry evolution in industries with a relatively homogeneous product. Our model does require some more industry-specific information with regard to the demand function and marginal costs than the (parsimonious) Jovanovic–MacDonald model. We claim that this additional information is important for predicting the way in which output, prices, and the number of firms evolve over time in an industry. Industry-specific information plays an essential role in answering the question why some industries have no shakeouts and why some have slow and others rapid shakeouts (Gort and Klepper 1982; Klepper and Graddy 1990; Klepper and Simons 1993). Whether or not the model of industry evolution we identify for an American industry holds in the different institutional context of other countries needs to be confirmed by future research. Applying this model to other countries would provide important insight into whether the process by which industries and firms evolve over time is shaped by characteristics particular to that industry or can be fundamentally altered by institutions and policy specific to the country. Only the requisite research will shed light on the role that policies play in shaping the evolution of industries.

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