Competition and Innovation:

A Dynamic Analysis of the US Automobile Industry*†

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and

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Abstract

We study the relationship between competition and innovation in the US automobile industry using a dynamic stochastic industry model. We model R&D investment as a strategic decision and estimate the parameters of the model using recently developed techniques in estimation of dynamic stochastic games.

Key words: Competition and Innovation; Automobile Industry; Dynamic Games

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1 Introduction

The US automobile industry has undergone quite significant changes over the last few decades. Perhaps the most significant of these changes has been an increase in the intensity of competition in the industry. Since 1980s when the Japanese car makers started setting up assembly plants in the US, the competitive environment in the US automobile industry has changed quite remarkably with far reaching consequences. Increased competition has reduced overall profit margins and the market shares of the big-three US car manufacturers (GM, Ford and Chrysler) have also decreased. In the meantime, the market shares of Toyota and Honda have steadily increased.

In this paper we investigate how this significant change in competition has affected the innovative activity in the industry. Apparently, since most of the firms in the industry have been increasing their R&D expenditures during the 80s and most of the 90s, one might be tempted to conclude that there is a simple positive relationship between competition and innovation in the industry. However, this would be a simplistic conclusion. For example, both GM and Ford were increasing their R&D rapidly until the mid-1990s. Since then, GM has been spending less and Ford’s spending on R&D has roughly been flat. However, Honda and Toyota have persistently been increasing their R&D investment. Why is the innovative activity in these two sets of firms responding differently to increasing competition and if the relationship between competition and innovation is not monotonic, how exactly are the two related? Overall, the innovative activity in the industry was increasing rapidly until the mid-1990s and since then the increase has been slowing down. What are the factors responsible for this change?

These questions are interesting in their own right but they also have welfare implications. Since competition in the market can be affected by a policy action and welfare of the consumers is tied to the quality of the products they consume which in turn depends on the innovative
activity, a better understanding of the relationship between competition and innovation will enable us to assess the welfare implications of competition policy.

We try to understand the varied response of firms in terms of their innovative activity to the changes in competition in the industry with the help of a dynamic model in which firms produce differentiated products that differ in quality. The firms invest in R&D to improve the quality of their products. The market share of a firm depends on the relative quality and price of its product. The outcome of R&D is uncertain and successful R&D leads to increased technical knowledge of the firm. Increased knowledge translates stochastically into a better quality product. The investment in R&D is modeled as a strategic decision: a firm takes the relative position of its rivals and their possible future actions into account before making its R&D decision. The structural parameters of the model will be estimated using the data from the US automobile industry. Our objective is to try to match the moments of key competition and innovation related variables as observed in the data. Once this is accomplished, one can use the model to do counter factual experiments. For example, one such experiment could be to see what would be the optimal investment in R&D if the industry were operated by a social planner. This experiment could shed light on the question of over-investment in R&D. Another interesting experiment could be to explore how a monopolist would have done in the face of a potential threat of entry.

We see this paper as a part of the broad literature on the relationship between competition and innovation. The earlier literature on the subject has been inconclusive as some studies find a positive relationship between competition and innovation, some find a negative relationship and some do not find any significant relationship at all.\(^1\) There could be many reasons for

these mixed results but an important one is the huge differences among industries with respect to this relationship (see section 4, Cohen and Levin [1989]). To avoid this problem, we focus on one industry and try to uncover the channels through which competition affects innovation and vice versa. The choice of the automobile industry for our analysis is motivated by at least three reasons. First, although the interaction between competition and innovation has been the subject of active research since Schumpeter [1950], to our knowledge this question has not been explicitly studied for the automobile industry. Second, the competition in the industry has increased tremendously over the last three decades. This dramatic change in competition will be helpful in identifying its effect on innovation. Third, the firms in the industry spend large amounts of money on R&D and innovation plays a key role in determining the relative success of a firm in this industry. For example, in the year 2000 the Michigan state, which accounted for 85% of the nationwide vehicle related R&D, spent $13.5 billion dollars on vehicle related R&D and employed 65,000 people for the purpose (Hill [2002]). The Michigan state spent around $180,000 per capita on industrial R&D in 1999 and ranked first among all the states. More than three quarters of this amount was spent by the automotive industry.

On the methodological front, we employ recently developed techniques in estimation of dynamic games. Our study is one of the first to put these recent techniques to a practical test, demonstrate their usefulness and highlight some practical difficulties associated with their application.

We start off by showing some trends in competitive environment and innovative activity in the industry. Each of the following figures (Figures 1-5) is a scatter plot. An observation in a scatter-plot is marked with a two-letter abbreviation of the company name followed by two digits representing the year. For example, GM66 is the observation on General Motors for the

\textsuperscript{2}Source: State Science and Technology Institute (2002), Westerville, OH.
year 1966. The data is an unbalanced panel of the following six firms: Daimler-Chrysler (DC), Ford (FD), Fiat (FT), General Motors (GM), Honda (HM) and Toyota (TM). The data are from Standard and Poor’s online database Compustat and cover the time period 1950-2004. The variables in the graphs are defined in the data appendix.

Figure 1 plots profit margins of six big automobile firms over time. The figure shows a general downward trend in the profit margins. Since profit margins are a commonly used measure of competition in the literature (for example see Nickell [1996] and Aghion et al. [2005]), we interpret this decline in profit margins as an indication of increase in competition. In addition to overall negative trend in profit margins, at least two other features of the figure are notable. First, the profit margins are sensitive to business cycles. Especially note the big decline in GM and Ford profits during the recession of 1980-82. Also note low profit margins during and after 1990-91 recession and again after the 2001 recession. Second, profit margins also reflect idiosyncratic firm conditions. For example, during the 90s, Ford made above average profits while Daimler-Chrysler (which was Chrysler until 1998) and Fiat made below average profits.

In Figure 2 we plot market shares overtime. Until 1980 the market is dominated by GM and Ford. During 1980s, GM and Ford lose their market shares mainly to Toyota but also to Honda. During the 1990s the competition gets very intense and by the turn of the century GM, Ford, Daimler-Chrysler and Toyota have roughly equal market shares followed by Honda and Fiat. The most striking feature of figure 2 is the convergence of the market shares of GM, Ford, Daimler-Chrysler and Toyota.

Figure 3 plots the real R&D figures. We see a sharp increase in R&D during the 1980s

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3The grey areas in the figure mark the years in which at least one quarter was part of the NBER’s official recessions.
led mainly by GM and Ford. This trend continues until the mid 90s. Since then, the R&D investment by GM and Ford has been on decline and by Honda and Toyota on a steep rise.

Figures 2 and 3 relate in an interesting way. To see this, we plot market shares against R&D in Figure 4. The resulting figure shows a clear inverted-U shape: for the big firms, market shares and R&D are negatively related and for the small firms they are positively related. The R&D is the highest for the firms with 20 to 30% of the market share. This inverted-U relationship is statistically significant and robust to the inclusion of fixed time and firm effects (see Table 1, last column).

Figures 1 and 3 are also related in a similar way. To see this we plot profit margins against R&D in Figure 5. The inverted-U pattern is there and statistically significant (see Table 1, column 2) but it is not as clear as in Figure 4. Perhaps this is because of sensitivity of profit margins to business cycle conditions and also to big idiosyncratic variations in the profit margins.

The main message of these figures is that there is a clear inverted-U relationship between market share and R&D. There is also an inverted-U relationship between profit margins and R&D, though it is not as clear as the one between market share and R&D. Our main task in the following pages will be to explain these patterns theoretically.

This observation of inverted-U relationship between competition and innovation is not new. Aghion et al. [2005] find a similar relationship for 17 manufacturing industries in the UK. They also offer a theoretical model to explain this relationship. However, our work is different from theirs in at least three respects. First, the focus in Aghion et al. [2005] is more general. They argue that at the economy level the relationship between competition and innovation is

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4Hashmi [2005] finds a similar inverted-U for 2-digit and 3-digit US manufacturing industries. However, in Hashmi [2005] the inverted-U is not robust to the inclusion of industry fixed effects.
inverted-U. To derive this relationship they combine the traditional Schumpeterian effect (i.e. more competition hampers innovation) with a new escape-competition effect (i.e. firms innovate more when faced with more competition because if they do not and their rivals do, they would be worse off). They then combine these two effects in a general equilibrium setting and derive an inverted-U relationship between competition and innovation. Our focus instead is on a single industry and we apply their idea of the interaction between the Schumpeterian effect and the escape-competition effect to a more detailed model of the industry. Second, unlike a static duopoly market structure which is essential to keep the model tractable in Aghion et al. [2005], we allow for a dynamic market structure with entry and exit and an arbitrarily large number of firms. This feature enables us to incorporate the dynamics of competition into our model. Third, in Aghion et al. [2005] competition is exogenous and innovative activity does not have any effect on it. This is not satisfactory because it is possible that a successful innovator may increase her profits and/or share of the market and hence reduce the level of competition in the industry. In fact, theorists in this area have long recognized the need for modeling competition and innovation in such a way that both are simultaneously determined in equilibrium (see, for example, Dasgupta and Stiglitz [1980]). In our model, competition and innovation are simultaneously determined in equilibrium. Nonetheless, our work is motivated by Aghion et al. [2005] and should be considered an application of their idea to a more detailed model of the industry.

The rest of the paper is organized as follows. Section 2 presents the model, section 3 discusses the estimation techniques and Section 4 presents the estimation results. Section 5 presents the simulation results of the counterfactual experiments and section 6 concludes.
2 The Model

The US automobile industry is a mature oligopoly (Klepper [2002a] and Klepper [2002b]) and one of the most innovation intensive industries. A natural environment to model this industry is a dynamic oligopoly model along the lines of Ericson and Pakes [1995].

2.1 The Demand Side

Following Berry et al. [1995] and several others studying the automobile industry, we use a discrete choice model of individual consumer behavior to model the demand side.\(^5\) There are \(n\) firms in the industry producing differentiated products. Products differ in quality \((g(\omega))\) that is positively related to firm’s technological knowledge \((\omega)\) i.e. \(\partial g(\omega)/\partial \omega \geq 0\). There are \(m\) consumers in the market. The utility consumer \(j\) gets from consuming good \(i\) is

\[
    u_{ij} = \theta_1 g(\omega_i) + \theta_2 \log(Y - p_i) + \nu_{ij}, \quad i = 1, \ldots, n, \quad j = 1, \ldots, m. \tag{1}
\]

\(g(\omega_i)\) is the quality of the good produced by firm \(i\), \(Y\) is consumer’s income, \(p_i\) is the price of the good and \(\nu_{ij}\) is the idiosyncratic utility that consumer \(j\) gets from good \(i\). \(\theta_1\) and \(\theta_2\) are preference parameters. \(\theta_1\) shows how quality conscious the consumers are and \(\theta_2\) is a measure of their price sensitivity. We assume \(\nu\) are i.i.d. Gumbel distributed with pdf given by \(f(x) = \exp(-x - \exp(-x))\) and cdf given by \(F(x) = \exp(-\exp(-x))\).\(^6\) Consumers maximixe utility and buy only one product each period. There is an outside good that gives zero utility. Let \(\tilde{u}(g(\omega_i), p_i) = \exp(\theta_1 g(\omega_i) + \theta_2 \log(Y - p_i))\). The expected market share of each firm is

\[
    \sigma(\omega_i, s, p) = \frac{\tilde{u}(g(\omega_i), p_i)}{1 + \sum_i \tilde{u}(g(\omega_i), p_i)}. \tag{2}
\]

\(^5\)Anderson et al. [1992] is a good reference on discrete choice models. They derive a multinomial logit model very similar to the one described below (see Anderson et al. [1992] pp.39-40).

\(^6\)The assumption of i.i.d. Gumbel (or double exponential) distribution ensures that the choice probabilities are given by the multinomial logit model (see Anderson et al. [1992] Theorem 2.3 p.40).
where $s$ is the vector of technological knowledge of all the firms in the industry and $p$ is the price vector. We assume that marginal cost ($mc$) is the same for all firms and firms choose prices to maximize their profits. The first order condition is

$$Y - p_i + \theta_2(p_i - mc)(\sigma(\omega_i, s, p) - 1) = 0. \quad (3)$$

The unique Nash equilibrium is a price vector $p^*$ and expected profits are given by $7$

$$\pi(\omega_i, s) = m\sigma(\omega_i, s, p^*)(p_i^* - mc). \quad (4)$$

### 2.2 The Supply Side

Time is discrete. At any time there are $n \in \mathbb{N}$ firms in the industry. Firms differ in their level of technological knowledge denoted by $\omega \in \mathbb{R}^+$. The knowledge ($\omega$) is an observable composite variable that contains all the information about payoff relevant characteristics of a firm. Firms compete in a spot market and their profits are given by (4). A firm can improve its knowledge by investing in R&D. We denote R&D investment by $x \in \mathbb{R}^+$. The knowledge of the firm evolves according to the following equation:

$$\omega_{it+1} = f(\omega_{it}, x_{it}) + \epsilon_{it}. \quad (5)$$

Each period, a firm receives a private offer to sell off its assets for $\phi_{it}$. $\phi_{it}$ is i.i.d. across firms and over time and follows a well defined probability distribution. $8$ If the expected discounted value of profits conditional upon staying is less than $\phi_{it}$, the firm will exit the market.

$7$Although inventories play an important role in determining automobile prices (Copeland et al. [2005] and Zettelmeyer et al. [2006]), we abstract from inventory considerations in our model because we are interested in how average annual profit margins and R&D expenditures are related. Since most inventory-related fluctuations occur within the year, their inclusion will complicate the model without yielding any positive benefit.

$8$The requirement that $\phi$ be drawn randomly from a probability distribution is important for existence of equilibrium. See Doraszelski and Satterthwaite [2005] for details.
receiving a one-time payment of $\phi$. The value function of the firm is given by the following Bellman equation:

$$
V(\omega, s) = \max_{\chi \in \{0, 1\}} \left\{ \chi \max_{x \in \mathbb{R}^+} \{ \pi(\omega, s) - cx + \beta EV(\omega', s') \} + (1 - \chi)\phi \right\}, 
$$

(6)

where $\chi$ is the exit policy of the firm. If the firm chooses to stay then $\chi$ is one, it is zero otherwise. $\pi(\omega, s)$ is one period profit function that depends on firm’s own knowledge $\omega$ and the distribution of firms by knowledge $s$. Amount of R&D is $x$, $c$ is the unit cost of R&D, $\beta$ is the discount factor and $\phi$ is the sell-off value. The dynamics of $\omega$ are determined by (5). There is an implicit entry function $\eta(s, \omega_e, c_e)$ that is taken into account by the firm while forming expectations about $s'$. We describe this entry function in some detail below.

New firms can enter the industry after paying a fixed cost equal to $c_e$. Entrants are identical in terms of their knowledge. We denote the common knowledge of entrants by $\omega_e \in \mathbb{R}^+$. Entrants do not produce or invest in R&D in the period of their entry and from the next period they act like any other incumbent with knowledge $\omega_e$. There is no restriction on number of entrants ($\eta$) but as more firms enter simultaneously, the net expected value of entry declines. To see this, let us first define the net present value of entry as:

$$
V_e(\omega_e, c_e, \eta) = \beta EV(\omega_e, s'(\eta)) - c_e. 
$$

(7)

If there are more entrants, the expected $s'$ will involve a greater number of firms, reduce expected market share and profits of the entrants and hence result in a lower value of $EV(\omega_e, s'(\eta))$. Hence $(\partial EV(\cdot)/\partial \eta) \leq 0$. We require $V_e$ to be equal to zero in equilibrium (zero profit condition) and hence given $c_e$, $\omega_e$ and $s$, we can determine $\eta$ endogenously such that one of the following conditions is satisfied.

$$
\eta(\omega_e, c_e, s) > 0 \quad \text{and} \quad V_e(\omega_e, c_e, \eta) < 0 \quad \text{or} \quad \eta(\cdot)V_e(\cdot) = 0.
$$

(8)
In each period the sequence of events is the following.

1. Firms observe individual and industry states.

2. Production, investment, entry and exit decisions are made.

3. Profits and investment outcomes are realized and firms enter and exit.

4. Individual and industry states are updated.

2.3 The Markov Perfect Equilibrium

The Markov Perfect Equilibrium consists of $V(\omega, s), \pi(\omega, s), x(\omega, s), \chi(\omega, s), Q(s', s)$ and $\eta(s, \omega_e, c_e)$ such that:

1. $V(\omega, s)$ satisfies (6) and $x(\omega, s)$ and $\chi(\omega, s)$ are optimal policies;

2. $\pi(\omega, s)$ maximizes profits in the spot market;

3. $\eta(s, \omega_e, c_e)$ satisfies (8);

4. $Q(s', s)$ is the transition matrix that gives the probability of state $s'$ given that the current state is $s$.

3 Estimation of the Model

There are at least two ways to proceed from here. The first is to estimate the parameters of the model from the data and then compute the Markov Perfect Equilibrium (MPE) as defined above. Benkard [2004] takes this route in his study of the market for wide-bodied commercial aircraft. The main disadvantage of this approach is that it is computationally very intensive. For example, the model in Benkard [2004] “requires over 100 CPU-days to solve on a Sun Ultra
Despite some recent innovations by Pakes and McGuire [2001], Doraszelski and Judd [2004] and Weintraub et al. [2005], the computation remains the biggest hurdle in the use these models.

The second is a two-step approach proposed by Bajari et al. [2006]. Their main assumption is that the data we observe represents an MPE. Under this assumption, in the first step, one can use the available data to estimate the state transition probabilities, equilibrium policy functions and the value functions. In the second step, the estimates from the first step are combined with the equilibrium conditions of the model to estimate the structural parameters of the model. We now explain these steps in some detail.

We need data on the state variable and the policy actions for each firm in the sample. In our study, the policy action is directly observable: it is the R&D investment of the firm. However, the state variable, which is some measure of technological knowledge of the firm, is not directly observable. We can construct a proxy for the firm’s knowledge from the available data. One way to do so is to use the patent data and construct a measure of patent stock. Suppose a firm has a total of $N_t$ patents upto time period $t$, where $t$ is the first period in our sample. For this firm we can set $\omega_t = N_t$. Next period, suppose the firm gets $\Delta N_{t+1} (= N_{t+1} - N_t)$ new patents and its existing stock of patents depreciates by a fraction $\delta$. Then $\omega_{t+1} = (1 - \delta)\omega_t + \Delta N_{t+1}$.

Similarly $\omega_{t+2} = (1 - \delta)\omega_{t+1} + \Delta N_{t+2}$ and $\omega_{t+T} = (1 - \delta)\omega_{t+T-1} + \Delta N_{t+T}$, where $t + T$ is the last period in our sample. This way we can construct a time series of patent stocks for each firm and use this new variable as a proxy for technological knowledge of the firm.

Once we have data on the state variable and the policy actions we can apply the two-step procedure suggested by Bajari et al. [2006] to estimate the model. In the first stage, we shall...
estimate the transition probabilities and policy functions and use them to obtain simulated value functions. In the second stage, we shall use the results from the first stage together with the equilibrium conditions to recover structural parameters of the model. We note that the demand side in our model is static and hence we do not need the full model to estimate its parameters. This can be done using standard techniques for such static models as in Berry et al. [1995].

Since our state variable is continuous, we estimate a state transition function of the form:

$$\omega_{t+1} = \alpha_0 + \alpha_1 \omega_t + \alpha_2 x_t + \epsilon_t.$$  \hspace{1cm} (9)

The fixed time- and firm-effects can be added to the above function. To estimate investment and exit policies we follow Bajari et al. [2006] and use local linear regressions with a normal kernel.

The next step is to use forward simulations and get a numerical estimate of the value function given the structural parameter vector \(\theta\). To do so, we start from an initial state \(s_0\). Given \(s_0\), using our demand parameter estimates we find profit and denote it by \(\pi_0(s_0)\). Given the estimated policy functions we determine the investment and exit policies and denote them by \(x_0(s_0)\) and \(\chi_0(s_0)\). Next we use our state-transition function to find the state next period \(s_1\). Using the new state, we can repeat the above steps until either the firm exits or \(\beta^t\) becomes very small. In other words, we evaluate the following equation:

$$V(s_0|\theta) = \mathbb{E} \left[ \sum_{t=0}^{T^e} \chi_t(s_t) \beta^t [(\pi_t(s_t) - x_t(s_t)) + (1 - \chi_t(s_t))\beta^T \phi_T] \right],$$  \hspace{1cm} (10)

where the expectation is over future states and \(T^e\) is the time period when the firm exits. If the firm never exits we can stop the forward simulations when \(t\) is sufficiently large such that \(\beta^t\) has become very small. We run these forward simulations a large number of times and take their average as a numerical estimate of \(V(s_0|\theta)\).
In stage two, we use the value function estimates and recover the vector of the structural parameters of the model $\theta$. The following steps assume that the model is identified and there is a unique true parameter vector $\theta_0$. Bajari et al. [2006] propose a minimum distance estimator for this true parameter vector. Let $x^*|s$ be the equilibrium policy profile. For this to be an MPE policy profile, it must be true that for all firms, all states and all alternative policy profiles $x|s$

$$V_i(s, x^*|s, \theta) \geq V_i(s, x|s, \theta), \quad (11)$$

where $x \neq x^*$, provided that we use true value of the parameter vector $\theta_0$. The minimum distance estimator for $\theta_0$ is constructed as follows. For each firm $i$ and initial state $s$ we use forward simulation method to estimate $V_i(s, x^*|s, \theta)$ and then do the same using alternative policy profile $x|s$ and compute the difference $V_i(s, x^*|s, \theta) - V_i(s, x|s, \theta)$. Let us denote this difference by $d((i, s, x|s)|\theta)$. We can then find $d$ for all $i$, $s$ and $x|s$ for a given value of $\theta$ and compute the sum of $(\min\{d(i, s, (x|s)|\theta), 0\})^2$. The $\theta$ with the smallest sum is our estimate of $\theta_0$. 

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References


A. Copeland, W. Dunn, and G. Hall. Prices, Production and Inventories over the Automotive Model Year. Working paper, Yale University, 2005.


A The Data Appendix

This appendix defines the variables used in Figures 1-5. The profit margin is defined as:

\[
\text{Profit Margin} = \frac{\text{Income after depreciation} + \text{R&D Expenditure} - 0.085 \times \text{Capital}}{\text{Sales}}.
\]

The subscript \(i\) refers to the firm and \(t\) to the year. The data on Income after depreciation, R&D expenditure, capital and sales are from Standard & Poor’s Compustat database (from here on, Compustat) annual series numbers DN0178, DN0046, DN0008 and DN0012, respectively. The market share (MS) is defined as:

\[
MS_{it} = \frac{Sales_{it}}{\sum_{j=1}^{n} Sales_{jt}}.
\]

If the information on a firm’s sales is not available for a given year, sales for that firm-year are set equal to zero in the sum. The R&D is simply the R&D expenditures as defined above.
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Figure 1: Profit margins over time
Figure 2: Market shares over time
Figure 3: R&D over time
Figure 4: Market share and R&D
Figure 5: Profit margins and R&D