FORD'S MODEL-T: PRICING OVER THE PRODUCT'S LIFE CYCLE*

RAMON CASADESÚS-MASANELL

ABSTRACT

The pricing decisions monopolistic firms make over time are determined to a large extent by the complex interplay of two distinct sets of elements: demand- and supply-based considerations. Demand factors include the possibilities of (a) exercising dynamic price discrimination, and (b) enhancing information diffusion about the product's characteristics. The main cost (i.e., supply) element influencing pricing over the Product Life Cycle is the possibility to exploit learning economies. Although these two sets of factors — demand and supply — are inter-linked in complex ways, I will propose a methodology to separate them. I will apply this procedure to the case of Ford's Model-T. We will be able to disentangle by how much demand issues (as opposed to cost based factors) affected the level and slope of the observed price sequence. I will also point out some issues regarding experience curve estimation and will outline a technique that allows for endogenous generation of sales and unit cost predictions.

Keywords: Product Life Cycle, Experience/Learning Economies, Pricing

JEL Classification: D90

RESUMEN

Las decisiones sobre precios tomadas por compañías monopolísticas en entornos dinámicos vienen en gran medida determinadas por la interacción compleja de dos distintos grupos de consideraciones económicas: elementos de demanda y elementos de oferta. Los principales factores de demanda incluyen las posibilidades de (a) ejercitar discriminación dinámica de precios, y (b) apalancar el proceso de difusión de aquella información que los consumidores consideran relevante sobre las características del producto. El principal elemento de oferta que influye sobre las decisiones de precio a lo largo del Ciclo de Vida del Producto, es la posibilidad de tomar ventaja de las

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economías de aprendizaje existentes en la tecnología de producción y distribución. Es bien sabido que en la práctica empresarial real, tales condiciones de demanda y de oferta aparecen interrelacionadas en formas complejas y no triviales. Este artículo propone una metodología que permite separar y distinguir la influencia relativa de cada uno de los mencionados grupos de factores en las decisiones sobre precios tomadas por empresas monopolísticas para productos durables en entornos dinámicos. El procedimiento es aplicado al caso específico del automóvil Modelo-T de Ford. En concreto y para este modelo, se distinguirá el efecto relativo de los factores de demanda y oferta sobre los niveles y pendiente de la secuencia de precios observada. Algunos aspectos importantes sobre estimación de la curva de experiencia serán a su vez analizados. Finalmente, se apunta una técnica que permite generar predicciones endógenas de ventas y de coste.

The economics and marketing disciplines have been interested in how strategic decisions are made by firms over the Product Life Cycle. Although there is profuse literature, both theoretical and empirical, on how such decisions are made in static environments (Tirole (1988), Scherer (1970)), not much work has been done on dynamic settings (notable exceptions are Spence (1981) and Bass (1980)). It is well accepted that the main short-term strategic variable is price (Tirole (1988)). Historically, this has also been the variable that has received the most attention by theorists. Furthermore, data on pricing decisions abound (compared to that on R+D spending and/or capacity choices).

The studies in the economics tradition (Spence (1981)) have tended to stress the influence of cost based factors on the optimal determination of price over time — with little regard to demand-based elements. The main result of this line of work is that price should be set equal to a markup times the dynamic marginal cost. The existence of experience economies implies a downward sloping price path. On the other hand, the work in the marketing arena has focused on demand-related aspects, such as:

3 Other strategic variables include: capacity investment, product diversification, advertising and R+D investment. Note that all of these are to be considered as medium to long term strategic variables; using any one of them to gain competitive advantage makes sense only if a medium to long term planning horizon is in mind.
4 It has mainly been of the interest of Industrial Organization economists.
5 Dynamic Marginal Cost = Static Marginal Cost - Present value of future cost reductions resulting from producing one extra unit today.
6 Or learning economies.
as information transmission among present and potential consumers, or the possibility of “skimming” (dynamic price discrimination). Marketing theorists have developed models in which: (a) it takes time for the potential buyers to become aware of the existence of the product; (b) there is imitation in purchasing; and (c) firms can take advantage of dynamic price discrimination (given the reasonable assumption that the first consumers to be aware of the product’s existence are those who value the product the most). In these models, whenever the profits that can be realized by dynamic price discriminating outweigh those that arise from low pricing in the first periods of production in order to leverage the imitation effect, a downward sloping price path results.

In this paper I will investigate the relative influence of supply and demand factors on the pricing decisions made over time by a monopolist. In particular, I will propose a method to separate demand- from supply- related elements affecting the pricing decisions made by a monopolist for a durable good over the Product Life Cycle. The model will be applied to analyze the actual price sequence of Ford’s Model-T back in the 1910s.

Section I presents the model and methodology that allows for the separation between demand and cost based factors influencing the pricing decisions over the Product Life Cycle. Section II introduces the data used to perform the analysis. Section III proceeds to estimate the model. Interpretation of the results is given in Section IV. Section V concludes. The appendix discusses those issues on experience curve estimation and prediction which can be learnt from the econometric exercise performed herein.

I. THE MODEL

The theoretical model taken as the basis for estimation is a simplification of Jeuland and Dolan’s (1982). Their model incorporates as price determinants over the Product Life Cycle: a cost function which exhibits experience economies, and a demand function that captures the idea of imitation and the possibility of dynamic price discrimination. The elements of the model are:

\[ x(t) = \text{cumulative number of buyers at time } t. \]

\[ m = \text{market potential} \]
\[ \alpha = \text{parameter of innovative trial} \]
\[ \beta = \text{parameter of imitative trial} \]
\[ p(t) = \text{price at time } t. \]
\[ \eta = \text{demand elasticity} \]
\[ c(x(t)) = \text{marginal cost of production at time } t \text{ (given accumulated production volume } x(t)). \]

It is assumed that \[ \frac{dc(x(t))}{dt} < 0 \] to capture the presence of experience economies.
\[ \lambda = \text{discount rate}. \]

Demand is assumed to have the following form:

\[ \frac{dx(t)}{dt} = \dot{x} = (m - x(t)) \left( \alpha - \beta x(t) \right) p(t)^{-\eta}. \tag{1} \]

The interpretation of this formula is as follows: at any time \( t \), \( m - x(t) \) is the number of potential consumers who have not bought yet \( \left( \alpha - \beta x(t) \right) p(t)^{-\eta} \) represents the proportion of \( m - x(t) \) who will actually purchase at time \( t \). This proportion is a function of (i) the importance of innovative trial \( \alpha \); (ii) how much imitation there is \( \beta \) and how many people are out there to imitate from \( x(t) \); (iii) current price \( p(t) \) and demand elasticity \( \eta \). Hence, demand at period \( t \) is just a percentage of the total number of consumers who are still in the pipeline by that time; this percentage is a function of the basic demand parameters of the model: the extent of innovative trial, imitation and price elasticity. The optimization problem to be solved by the monopolist over the planning interval \([0,T]\) is:

\[ \max_{p(t)} \int_0^T \left[ p(t) - c(x(t)) \right] \frac{dx(t)}{dt} e^{-\lambda t} dt \tag{2} \]

The solution to the previous maximization problem yields the following pricing function (hereinafter the supply):

\[ p(t) = \frac{\eta}{\eta - 1} \left[ c(t) + \gamma^{(\eta-1)} \int_t^T e^{-\lambda(u-t)} \frac{dc(u)}{du} \left( c(u) g(u)^{-\gamma(u-1)} \right) du \right] \tag{3} \]
where \( g(t) = (m - x(t))(\alpha - \beta x(t)) \).  

Whether the price sequence will be monotonically decreasing or will have an initial increasing segment is ambiguous. It depends on whether the benefits of low introductory prices arising from more imitation in the first production periods (faster diffusion) are larger or smaller than those that would be obtained by charging high prices to the first individuals to buy (to get the benefits of dynamic price discrimination).

To leave aside dynamic demand factors is equivalent to assume that the buying potential, \( g(t) \), is constant over time. In this case, the optimal price sequence for the monopolist (in the presence of learning, economies), adopts the following form:

\[
p(t) = \frac{\eta}{\eta - 1} \left[ c(t) + \int_t^T e^{-\lambda(u-t)} \frac{d}{du}(c(u))du \right]
\]

This expression tells us that if dynamic demand factors are not taken account for, the optimal price at any moment in time equals a markup, \( \eta/(\eta - 1) \), times the dynamic marginal cost at that time \( t \),

\[
\left[ c(t) + \int_t^T e^{-\lambda(u-t)} \frac{d}{du}(c(u))du \right]
\]

Note that this is precisely the result obtained by Spence in his seminal 1981 paper.

We follow the Boston Consulting Group (1970) in designating a cost function subject to learning economies. According to this institution a natural specification for such a cost relationship is:

\[
c(t) = c_0 \left( \frac{x(t)}{x_0} \right)^{-q}
\]

where,

- \( c_0 \) = cost of the first unit produced
- \( x_0 \) = units produced in the first period.
- \( q \) = learning parameter (slope of the log-log learning curve).

\( g(t) \) will be referred to as the buying potential at time \( t \).

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7 See Jeuland and Dolan (1982).
Note that the larger is \( q \), the larger will be the reduction in unit cost induced by higher levels of accumulated production. A value of \( q = 0 \) means that there is no learning; that is, unit cost remains constant at the level of the first unit of production.

In order to successfully apply this model in real business situations, it is important to realize and understand the underlying theoretical assumptions upon which it is built. The main assumptions are: (1) the product is a \textit{durable} ¹⁰ (no repetitive purchase), (2) the demand function has a very specific functional form (with constant short term elasticity, \( \eta \)) which only admits a uniform price per time unit; (3) the firm behaves as a profit maximizing monopolist who is not price discriminating \textit{within} any given period, and (4) the cost function does not explicitly assume the existence of static economies of scale.¹¹

⁹ As in any other economic model, we can adopt two alternative points of view in interpreting it. First, we can take a positive perspective, and consider the model as \textit{what firms do}. In this case, given data on sales and costs, we can estimate the parameters of the model and perform experiments such as the one proposed herein, namely, infer by how much did dynamic demand considerations influence the pricing decisions made by a monopolist over the Product Life Cycle. On the other hand, we can also adopt a normative perspective and consider the model’s outcome as a recommendation of \textit{what firms should do}. In this case, the firm could determine what is the value of its vector of parameters \( \{x, \beta, \eta, \lambda, q, m\} \), and use the model as a recommendation on how the pricing decisions should be made over time (in order for them to be optimal). (Market research informs on the values of \( \{x, \beta, \eta, m\} \), introspection and the state of financial markets determine \( \{x\} \), and engineering analysis leads to a value for \( q \)). The approach taken in most of this paper is positive; that is, I assume that the model presented depicts how monopolistic firms make pricing decisions for durable goods over the Product Life Cycle, and then I compare those to the decisions that would had taken place had the firm used a (simpler) model which happens to be nested to the one assumed to be the true representation of firm behavior. In Section V, I will adopt a normative perspective and introduce a technique to generate sales and cost predictions for durables offered by monopolists in dynamic settings.

¹⁰ This assumption is relaxed in the more general framework introduced by Jeuland and Dolan (1982). In their model, the demand function adopts the following form:

\[
\hat{x}_t = \hat{x}_t + \beta \hat{x}_t (t)^{-\eta}
\]

where

\[
\hat{x}_t = (m - x(t))(\alpha - \beta x(t))x(t)^{-\eta}.
\]

\( \beta \) represents the extent of repeat purchase activity. The case treated in the present paper is \( b=0 \), which stands for the good being a durable.

¹¹ When such economies are present, they will generally be translated into an overestimated learning parameter.
We will assume that the correct pricing model for Ford’s Model-T is
the one described by the equation referred to above as supply. This
assumption will rationalize its estimation and the consideration of its
parameters as reasonable approximations to the true values describing Ford’s
behavior. After estimating the parameters characterizing this equation, we
will be able to construct the price sequence that would have taken place
had cost (that is, supply) been the only determinant of price dynamics, and
compare it to the actual series.

II. DATA

The chosen product to perform the analysis to is Ford’s Model-T.\textsuperscript{12} This
was America’s first mass-produced automobile. Mr. Ford’s goal was to
produce Model-T at a low enough cost so that the average American family
would be able to afford an automobile. In this sense, we can talk of Ford
being a monopolist for this specific model, given that even though at that
time there existed other car manufacturers in the United States, they didn’t
target the average American family as the potential customer for their cars.\textsuperscript{13}

I have borrowed the data from Abernathy and Wayne (1974) and Yalle
(1980) which were originally gathered from: Ford Archives; Federal
Session (1940), House Document 468. The unit cost figures were estimated
using cost accounting data (labor hours per vehicle, labor rate, fixed assets
per dollar of sales and operating profits). Selling price was obtained from
Ford’s pricing list.

The figure used in the study are shown in Table 1. The Model-T was
introduced in 1908 but the 1908-1909 period can be considered as the trial
term that had to lead to the mastering of mass-production by 1910.

The market potential, $m$, has been chosen\textsuperscript{14} to be 15,200,000.
Accumulated sales in 1926 amounted to 14,312,000 units. Model-A, which
came to substitute Model-T, was introduced in 1928. Model-T’s sales in

\begin{footnotesize}
\begin{itemize}
\item \textsuperscript{12} Two important previous studies on Ford’s strategy and the Model-T are those of Abernathy
and Wayne (1974) and Yelle (1980).
\item \textsuperscript{13} According to Yelle (1980), in 1926 Ford’s market share of total U.S. new car sales was
approximately 80%.
\item \textsuperscript{14} There is an underlying \textit{rational expectations} assumption in this choice
\end{itemize}
\end{footnotesize}
TABLE 1
DATA

<table>
<thead>
<tr>
<th>Year</th>
<th>Sales</th>
<th>Acum.Sales</th>
<th>Price</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1910</td>
<td>32</td>
<td>50</td>
<td>3,050</td>
<td>2,578</td>
</tr>
<tr>
<td>1911</td>
<td>70</td>
<td>120</td>
<td>2,550</td>
<td>2,243</td>
</tr>
<tr>
<td>1912</td>
<td>170</td>
<td>290</td>
<td>2,000</td>
<td>1,765</td>
</tr>
<tr>
<td>1913</td>
<td>203</td>
<td>493</td>
<td>1,800</td>
<td>1,431</td>
</tr>
<tr>
<td>1914</td>
<td>308</td>
<td>801</td>
<td>1,750</td>
<td>1,458</td>
</tr>
<tr>
<td>1915</td>
<td>501</td>
<td>1,302</td>
<td>1,750</td>
<td>1,602</td>
</tr>
<tr>
<td>1916</td>
<td>735</td>
<td>2,037</td>
<td>1,500</td>
<td>1,258</td>
</tr>
<tr>
<td>1917</td>
<td>664</td>
<td>2,701</td>
<td>1,350</td>
<td>1,273</td>
</tr>
<tr>
<td>1918</td>
<td>498</td>
<td>3,199</td>
<td>1,250</td>
<td>1,059</td>
</tr>
<tr>
<td>1919</td>
<td>941</td>
<td>4,140</td>
<td>1,090</td>
<td>941</td>
</tr>
<tr>
<td>1920</td>
<td>463</td>
<td>4,603</td>
<td>1,000</td>
<td>862</td>
</tr>
<tr>
<td>1921</td>
<td>971</td>
<td>5,574</td>
<td>960</td>
<td>831</td>
</tr>
<tr>
<td>1922</td>
<td>1,307</td>
<td>6,881</td>
<td>950</td>
<td>769</td>
</tr>
<tr>
<td>1923</td>
<td>2,019</td>
<td>8,900</td>
<td>900</td>
<td>804</td>
</tr>
<tr>
<td>1924</td>
<td>1,929</td>
<td>10,829</td>
<td>820</td>
<td>709</td>
</tr>
<tr>
<td>1925</td>
<td>1,920</td>
<td>12,749</td>
<td>775</td>
<td>661</td>
</tr>
<tr>
<td>1926</td>
<td>1,563</td>
<td>14,312</td>
<td>725</td>
<td>641</td>
</tr>
</tbody>
</table>

Quantities in thousands of units. Prices and costs in constant 1958 dollars.

1927 and 1928 totaled approximately 850,000 units. In the case of a product like the Model-T we are fortunate to have such a precise figure for \( m \) - we know exactly when Ford took the product out of the market and almost the exact number of units sold. In actual business situations when a new product is introduced into the market, the determination of \( m \) is a much more complex issue.\(^{15}\)

\(^{15}\) In such circumstances, some considerations that will lead to an educated guess of \( m \) include:
(a) If the product has been already introduced in other countries, perform international comparisons.
(b) If the product is a complement (or a substitute) to some other existing product, gather information on the market for the existing complement (or substitute).
One issue worth analyzing is the validity of the assumption that the product under study is durable enough so that the same buyer will not purchase it twice in the period considered. In this respect, it seems reasonable to assume that cars lasted longer in the same hands back in the 10’s and 20’s than they do nowadays - since: (a) technical change was not as accelerated then as it is now, (b) fashion was not so important, (c) the [car price]:[income] ratio was higher then than it is now, (d) marketing campaigns were not so aggressive, and (e) a structured used car market had not developed. Therefore, I will assume throughout that there are no repeat purchases in the time period considered for the analysis.

A potential problem with the data is that the time series is not a very long one. Nevertheless, since the model to be estimated is highly structural, even a few data points will give precise estimates.

### III. ESTIMATION

The key parameters to be estimated are the price elasticity of demand, $\eta_1$, the firm’s specific discount rate, $\lambda$, and the learning coefficient, $q$. With these estimates in hand we will be able to discern what would have been the optimal price path had dynamic demand factors been left aside as determinants of the price sequence, and compare it to the actual price path observed - which is assumed to be the outcome of the optimization program introduced in Section 2.

The model to be estimated is composed of three non-linear equations:

1. the demand relation (equation (1));
2. supply (equation (3));
3. the cost function (relating unit costs to cumulative production; equation (6));

The supply equation embodies two of the parameters of interest ($\eta_1$ and $q$).

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16 Two historical facts which may have somehow affected the cleanness of the data, are worth mentioning. First, in 1917-1918, the United States joined the Allied force in World War One and second, in 1920-1921 the United States were immersed in the post-war recession. The natural way to treat these facts is by introducing dummy variables to account for such plausible variation in the data. However, in the context of the present model this is problematic since there is no obvious way in which such dummies should enter the structural equations that define it. On the other hand, introducing new variables causes a reduction in the degree of freedom of the model, which are already very low given the limited database with which the methodology is illustrated.
\(\lambda\)). However, simultaneity issues arise as this equation relates price with total accumulated volume sales, \(x(t)\), and cost, \(c(x(t))\). Therefore supply cannot be estimated consistently without taking into consideration the fact that these two variables are indeed endogenous. Even when endogeneity issues are taken into account, this is a quite complex equation and direct estimation of its parameters is not an easy task.

The demand equation will certainly help us estimate \(\lambda\), given that we can first estimate \(\alpha\), \(\beta\) and \(\eta\) in this equation and then plug these values in the supply relation and go on from there to estimate \(\lambda\). The estimation of \(q\) will be relatively straightforward.

The demand equation implies the following non-linear econometric specification:

\[x_t - x_{t-1} = (m - x_t)\left(\alpha - \beta x_t\right)p_t^{-\eta}\]  

(7)

Rewriting this equation as

\[x_t - x_{t-1} = (m - x_t)(1 - \gamma x_t)p_t^{-\eta\alpha}\]  

(8)

where \(\gamma = \beta / \alpha\), and taking logs, we have

\[\log(x_t - x_{t-1}) = \log(m - x_t) + \log(1 - \gamma x_t) - \eta \log p_t + \log \alpha\]  

(9)

This suggests the following specification

\[\log(x_t - x_{t-1}) - \log(m - x_t) - \log(1 - \gamma x_t) = \log \alpha - \eta \log p_t\]  

(10)

and estimation procedure: for every given value of \(\gamma\) this is a linear equation in \(\log p_t\) and can be estimated by IV (Instrumental Variables) using lagged price values as the instrument for current price. Our task is now to find the value of \(\gamma\) such that the sum of the squared residuals of the IV estimation is minimized. Once this has been done, it is immediate to retrieve the estimates of \(\alpha\), \(\beta\) and \(\eta\). To find such a value for \(\gamma\) I have set a grid search that has led to the following estimates:
TABLE 2
GRID SEARCH FOR $\gamma$

<table>
<thead>
<tr>
<th>$\gamma$</th>
<th>SSR</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\eta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00E-08</td>
<td>4.799785</td>
<td>5.71E+11</td>
<td>571.09710</td>
<td>3.8517</td>
</tr>
<tr>
<td>1.00E-07</td>
<td>3.975368</td>
<td>5.13E+09</td>
<td>51.30531</td>
<td>3.2337</td>
</tr>
<tr>
<td>3.00E-07</td>
<td>3.681135</td>
<td>2990885.33</td>
<td>0.89727</td>
<td>2.5685</td>
</tr>
<tr>
<td>4.40E-07</td>
<td>3.658522</td>
<td>362427.60</td>
<td>0.15947</td>
<td>2.2994</td>
</tr>
<tr>
<td>4.50E-07</td>
<td>3.658452</td>
<td>319422.51</td>
<td>0.14374</td>
<td>2.2833</td>
</tr>
<tr>
<td><strong>4.51E-07</strong></td>
<td><strong>3.658413</strong></td>
<td><strong>315457.74</strong></td>
<td><strong>0.14227</strong></td>
<td><strong>2.2818</strong></td>
</tr>
<tr>
<td>4.52E-07</td>
<td>3.658434</td>
<td>311548.41</td>
<td>0.14082</td>
<td>2.2802</td>
</tr>
<tr>
<td>4.60E-07</td>
<td>3.658470</td>
<td>282241.96</td>
<td>0.12983</td>
<td>2.2677</td>
</tr>
<tr>
<td>5.00E-07</td>
<td>3.659811</td>
<td>176259.04</td>
<td>0.08813</td>
<td>2.2081</td>
</tr>
<tr>
<td>1.00E-06</td>
<td>3.736409</td>
<td>3533.96</td>
<td>0.00353</td>
<td>1.7196</td>
</tr>
<tr>
<td>1.00E-05</td>
<td>4.592515</td>
<td>0.17</td>
<td>0.00000</td>
<td>0.5899</td>
</tr>
</tbody>
</table>

As can be seen in the table above\(^{17}\), there exists one single value of $\gamma$ that minimizes the sum of the squares of the residuals (SSR). The corresponding values of $\gamma$, $\log \alpha$ and $\eta$ are 4.51e-07, 12.6618 and 2.2818, respectively.

TABLE 3
REGRESSION OUTPUT

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta$</td>
<td>2.281759</td>
<td>0.3519798</td>
<td>-6.487</td>
</tr>
<tr>
<td>$\log \alpha$</td>
<td>12.66178</td>
<td>2.508976</td>
<td>5.047</td>
</tr>
</tbody>
</table>

Observations | F(1,14) | R-Squared | SSR  |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>42.0</td>
<td>0.7515</td>
<td>3.658413</td>
</tr>
</tbody>
</table>

The following graphs compare fitted and observed values.

\(^{17}\) The attached table is enclosed for illustrative purposes. It contains only some of the values of the grid used in search of the optimal $\gamma$. 
With these estimates in hand, we can now undertake the task of estimating the supply relationship

\[ p(t) = \frac{\eta}{\eta - 1} \left[ c(t) + g(t)^{(\eta-1)} \int_t^\infty e^{-\lambda(u-t)} \frac{d}{du} \left( c(u) g(u)^{-1/(\eta-1)} \right) du \right] \]  

(11)

where \( g(t) = (m - x(t))(\alpha - \beta x(t)) \). Following Jeuland and Dolan (1982), the optimality condition on price, \( p \), can be rewritten as

\[ \frac{d}{dt} \left( \frac{\eta-1}{\eta} p - e \right) g^{-1/(\eta-1)} e^{-\lambda t} = -e^{\lambda t} \frac{d}{dt} \left( cg^{-1/(\eta-1)} \right) \]  

(12)

With these estimates in hand, we can now undertake the task of of estimating the supply relationship
Denoting the functions $g^{-1}(\eta^{-1})$ by $b$ and $e^{-\lambda t}$ by $k$, the equation above becomes

$$\frac{\eta-1}{\eta}(pbk)' = (cbk)' - k(cb)'$$

that is

$$\frac{\eta-1}{\eta}(p'b + p(b' - \lambda b)) = -\lambda cb$$

An econometric model arising from this equation may be written as

$$\frac{\eta-1}{\eta}\left((p_t - p_{t-1})b_t + p_t\left((1-\lambda)b_t - b_{t-1}\right)\right) = -\lambda cb$$
The only unknown parameter in this equation, $\lambda$, can be estimated by NL2SLS, that is, searching for the value of $\lambda$ such that the following equation is minimized.

For every initial value of $\lambda$ for which the Gauss-Newton algorithm converges, the convergence point is $\lambda = 0.3174$, with standard deviation of 0.0539. The following graph compares observed and fitted values.

---

or

$$p_t = \left[ \frac{b_t}{(2-\lambda)b_t-b_{t-1}} \right] \left( p_{t-1} - \frac{\lambda \eta}{\eta - 1} c_t \right) + \xi_t$$

Let

$$f_t(x_t, e_t; x_{t-1}, p_{t-1}) = \left[ \frac{b_t}{(2-\lambda)b_t-b_{t-1}} \right] \left( p_{t-1} - \frac{\lambda \eta}{\eta - 1} c_t \right)$$

The only unknown parameter in this equation, $\lambda$, can be estimated by NL2SLS, that is, searching for the value of $\lambda$ such that the following equation

$$(p - f)' D (D' D)^{-1} D'(p - f)$$

is minimized. The matrix of instruments used in the analysis is

$$D = \begin{bmatrix} x_{t-1}^2 \\ p_{t-1}^2 \end{bmatrix}.$$
The third and last equation to be estimated is the cost function (6). Taking logs, we get the following linear equation

\[
\log c_t = \log c_0 - q \log \left( \frac{x_t}{x_0} \right)
\]

which is estimated by IV using \( p_{t-1} \) as the instrument for \( x_i \) and setting \( x_0 = 18,000 \) - the accumulated number of vehicles produced by 1909. The estimation yields a value for \( \log c_0 \) of 8.3160 with standard deviation of 0.099, this corresponds to \( c_0 = 4,088.8 \). The estimated learning coefficient is \( q = 0.2705 \), with standard deviation of 0.019.
The following graph compares observed and fitted values for the cost function.

### TABLE 4
**REGRESSION OUTPUT**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q$</td>
<td>0.2704534</td>
<td>0.0194062</td>
<td>-13.936</td>
</tr>
<tr>
<td>$\log c_0$</td>
<td>8.315994</td>
<td>0.0998878</td>
<td>83.253</td>
</tr>
</tbody>
</table>

Observations  | F(1,14)  | R-Squared  | SSR  |
---------------|----------|------------|------|
16             | 194.22   | 0.9299     | 0.152725 |

**FIGURE 4**
**COST**
IV. INTERPRETATION OF RESULTS

A value for $\lambda$ of 0.3174 seems surprisingly high. Its interpretation is that Ford weighted current profits heavily. This fact certainly prevented Ford from exploiting to the maximum extent possible the existing experience economies and information diffusion. Price elasticity of demand is $\eta = 2.28$, not an enormous figure but high enough to make possible substantial increases in revenues by means of price cuts. Finally, we get a reasonably large learning parameter, $q = 0.2705$, i.e. there existed learning economies to take advantage from.

Comparing Ford’s actual decisions to those that would had been optimal had dynamic demand considerations not been taken into account\(^{20}\) we observe:

\[ p_t = \frac{\eta}{\eta - 1} \left[ c_0 + \sum_{u=t+1}^{T} \lambda^{u-t}(c_u - c_{u-1}) \right] \]

$T$ has been chosen to be 5 years, which is a reasonable medium term planning horizon. We will refer to the outcome of this equation as cost-based pricing.
A- Levels. As can be seen in the graph above, under cost-based pricing it would have been optimal to set prices at a higher level in every period (an average 30.34% higher in every one of the years considered in the analysis). This is the consequence of two distinct phenomena:

(1) In the former periods of production, prices are lower than those implied by cost-based pricing because of the existence of imitation in demand. The lower the price in the first periods of the Product Life Cycle, the more buyers will purchase at that time, and this will allow Ford to take advantage of a faster information spread (mouth to mouth communication about the utility derived from the use of the Model-T) and a quicker reach of the market potential. Note also that had the internal discount rate, \( \lambda \), been lower, cost-based prices would have also been lower early in the Product Life Cycle, soon increasing demand and production. This would have allowed Ford to take advantage of the existing learning economies, which do have their maximum effect in the first periods of production, when accumulated production is doubled with greater frequency.

(2) If demand considerations are taken into account, in the last periods of the Product Life Cycle it is also optimal to price lower than what cost-based pricing would recommend. This is so because at this stage of the Cycle, all high value consumers have already bought and the only potential individuals left to buy are those who value the product the least. As Jeuland and Dolan (1982) point out,

\[ \text{...as favorable demand conditions erode over time due to market saturation, it is optimal to lower price.} \]

Note also that late in the Product Life Cycle there is little advantage to be gained from learning economies since doubling accumulated production is not feasible anymore.

In summary, demand conditions have pushed prices down an average 23.04% in every period\(^{22}\) as compared to what would had been optimal under cost-based pricing.

\(^{21}\) In general, there is a tense trade-off between the benefits of lower prices (which, as mentioned, favor information spreading) and those of dynamic price discrimination (skimming strategy: charging higher prices to high value consumers, those who buy early in the Product Life Cycle). In the case of Ford’s Model-T, this trade-off has been resolved (we assume optimally) by favoring a faster information spread.

\(^{22}\) This corresponds to prices being 30.34% higher on average in every period.
B- Slopes. It is interesting to note that the average percentage price reduction under cost-based pricing is 8.06% which is less than one percentage point below the average price reduction under overall optimal pricing (9.04%). Thus, we conclude that dynamic demand considerations have not been important determinants of the slope of the price sequence for the case of Ford's Model-T.

IV CONCLUSION

The strategic planning process involves the determination and assessment of how choices on a firm's decision variables affect the expected outcomes to be realized in the market arena. We have centered our attention on the case of a monopolistic firm whose decision variable is price. By choosing prices over time, the sequence of sales and cost savings is determined. Hence, through a systematic analysis of the dynamics of market demand and of the learning curve, a firm should effectively anticipate the effect of such decisions on sales and on costs and, ultimately, envision their profit consequences. In the case of the Model-T, we have based our analysis on the hypothesis that Ford effectively foresaw the existence of a learning curve in production and the existence of imitation effects in demand. Given this, Ford priced so as to take advantage of dynamic price discrimination, information spreading and learning.

Under this assumption we have proposed and implemented a method to separate the effect of cost based considerations from demand based issues affecting the pricing decisions made for the Model-T over time. Under the fundamental assumption that the estimated model is a fair approximation to the observed pricing behavior, we concluded that demand factors (dynamic third degree price discrimination and information diffusion) played an important role in determining the observed price levels (pushing them down compared to what would have been optimal, had dynamic demand considerations been set aside). We resolved also that the observed slope of the price sequence is mainly determined by the learning process experienced in production, with little effect of demand based factors.

Centering our attention on the monopoly case has the advantage of

23 The estimated theoretical model assumes away the effect of potential entrants on the pricing decisions made by the existing monopolist.
wiping away the effect of the existing competitors’ expected reactions to the firm’s pricing decisions of the firm. This makes it easier to isolate the relative influence of demand and supply factors on pricing choices. From a managerial perspective, the work presented in this paper is to be read as a first step towards the development of a game theoretical model which allows for firms to compete over the Product Life Cycle. In an oligopolistic setting, the knowledge of what the relative effects of demand and supply factors are on the pricing decisions made by competitors over time, turns out to be a very powerful strategic weapon, since such knowledge allows for the informed delineation of strategies in response to the anticipated moves by rivals.

Even when the conclusions outlined above apply to a specific product, in a specific industry, for a specific period of time, the methodology presented is certainly exportable to other products in other industries and to other time frames, with the only requirement that these sufficiently satisfy the theoretical assumptions upon which the estimated model is based.
APPENDIX
ISSUES ON EXPERIENCE CURVE ESTIMATION AND FORECASTING

From the econometric exercise in Section III, we learn the following issues with regard to experience curve estimation and sales and cost forecasting.

A. Estimation

Two points should be made with regard to the estimation of the cost relationship

\[ c(t) = c_0 \left( \frac{x(t)}{x_0} \right)^q \]  \hspace{1cm} (A.1)

First of all, the manner in which this equation has been traditionally estimated is by taking logs and applying OLS to

\[ \log c_t = \log c_0 - q \log \left( \frac{x_t}{x_0} \right) + \zeta_t \]  \hspace{1cm} (A.2)

It is clear that under our more general model, such procedure will lead to inconsistent estimates of the parameters. To see this, note that \( x_t \) is endogenous and thus correlated with the error term \( \zeta_t \). That is, shocks in \( \zeta_t \) affect directly \( c_t \), this perturbs \( p_t \) through the supply relationship, and by the demand equation, \( x_t \) is also affected. Therefore, such a cost equation must be estimated by IV in order to get consistent estimates. On the other hand, one significant problem in experience curve estimation is the lack of availability of cost data. Because of this, in order to estimate \( c_0 \) and \( q \), what generally has been done in the literature is to equate the slope of \( \log p_t \) to the slope of the log–log experience curve -- sometimes corrected by an estimated discount rate, \( \lambda \). Again, under the more general framework presented above, such an approach will only be correct by chance since, as we have seen, dynamic demand issues directly affect the pricing decisions.
B. Forecasting

How can we proceed to estimate $c_0$ and $q$ when cost data is unavailable? In such a case, the model suggests to incorporate the cost function into the supply equation as follows

$$p(t) = \frac{\eta}{\eta - 1} \left[ c_0 \left( \frac{x(t)}{x_0} \right)^{-q} + g(t)^T \int e^{-\lambda(u-t)} \frac{d}{du} \left( c_0 \left( \frac{x(u)}{x_0} \right)^{-q} g(u)^T \right) du \right]$$

(A.3)

which, for estimation purposes, may be rewritten as

$$p_t = \left[ \frac{b_t}{(2-\lambda)b_t - b_{t-1}} \right] \left[ p_{t-1} - \frac{\lambda \eta}{\eta - 1} \left[ c_0 \left( \frac{x_t}{x_0} \right)^{-q} \right] + \xi_t \right]$$

(A.4)

and estimate it as we have done previously but now with two extra parameters, $c_0$ and $q$. Note that this approach only requires time series data on price and cumulative production. Furthermore, the model presented in this way allows to do prediction (say, for business strategy): once the parameters $(\alpha, \beta, \eta, \lambda, q, c_0)$ have been estimated, the system of equations which represent supply and demand can be solved numerically for $x_t$ and $p_t$. This will allow for the endogenous generation of cost predictions which could be used for strategic planning. That is, given a level of accumulated output $x_t$, we can solve the following system where

$$b_{t+1} = \left( (m-x_{t+1})/\alpha - \beta x_{t+1} \right)^{-1/\eta}$$

to get a prediction for $x_{t+1}$. We can then substitute this value in the cost function and obtain the unit cost prediction for period $t+1$.

This system is:

$$\begin{align*}
p_t &= \left[ \frac{b_t}{(2-\lambda)b_t - b_{t-1}} \right] \left[ p_{t-1} - \frac{\lambda \eta}{\eta - 1} \left[ c_0 \left( \frac{x_t}{x_0} \right)^{-q} \right] \right] + \xi_t \\
n_t &= \left( p_t^3 + \alpha - \eta \beta \right) + \sqrt{\left( p_t^3 + \alpha - \eta \beta \right)^2 + 4 \beta \left( n\eta t + x_{t-1} p_t^3 \right)}
\end{align*}$$

Where the first equation represents supply and the second demand.
REFERENCES