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# Evolutionary trends of industry variables

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**Abstract**

The paper offers empirical evidence on the evolutionary trends of industry variables. It investigates the time path of patents, product price and quantity, and number of firms from the first introduction of a product to maturity of the market. The paper extends earlier work by Gort and Klepper by expanding the data on products through 1991, and augmenting it with new products and new data sources. The reexamination of the aging patterns reveal the Gort and Klepper results to be robust. The time trends follow the expected patterns with remarkable consistency and are strongly significant for most products. New evidence on patenting activity reveal an eventual decline in technological activity over the later years of the product market life-cycle. © 1998 Elsevier Science B.V.

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## 1. Introduction

Gort and Klepper (1982) investigated the life-cycle of product markets that are born as a result of a major innovation and drew attention to the empirical regularities observed in key industry variables. Their study distinguished between five stages in the evolution of the product markets, and compared the number of firms, prices, quantity and patents across the five stages. In tracing the history of the diffusion of product innovations, Gort and Klepper introduced the time path of events as being critical determinants of the ultimate structure of the product

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markets. According to the Gort–Klepper model, when a market is first introduced, substantial information external to the existing firms renders entry into the market attractive, firms enter rapidly to exploit their information, prices decline and output increases. When a product market is more established, the incumbent knowledge (type 1 information) exceeds the external information (type 2 information), hence net entry declines and becomes negative as inefficient firms are forced to exit. As a product market evolves, the number of firms first increase and then decrease, product price declines and quantity increases. This evolutionary approach has spawned significant research in the area. Nelson and Winter (1982); Jovanovic (1982); Jovanovic and Lach (1989); Hopenhayn (1994) and Jovanovic and MacDonald (Jovanovic and MacDonald, 1994a,b) have developed theoretical models explaining the observed evolutionary phenomena, while Acs and Audretsch (1991); Audretsch (1991) review case studies and present anecdotal evidence.

Given the importance of the Gort–Klepper findings to the subsequent literature, this paper extends the data on the products through 1991, and augments it with some new products and new data sources to reexamine the aging patterns of a number of product markets. Rather than using stages of the product life-cycle to discern between average levels, the paper uses trend analysis to capture the relationship between market age and the key industry variables. The Gort–Klepper patterns are seen to be remarkably robust, and patent statistics provide additional evidence on the increase and subsequent decline in the number of innovations relevant to the product market.

Section 2 provides a description of the data. Section 3 discusses the results of the empirical analysis and Section 4 briefly discusses the economic forces that are likely to generate the time trends, based on the theoretical models developed to explain the phenomena. Finally, Section 5 deals with the limitations of the present study and avenues of future exploration.

## 2. Data

Data on the number of firms are gathered from the Thomas Register of American Manufacturers. Thirty-one of the 33 product markets analyzed in this study are drawn from the pool of products analyzed in the Gort–Klepper study.[1]

[1] While the study draws from the same pool of products as the Gort–Klepper study, the data are developed independently. Fifteen of the 46 products in the Gort–Klepper study could not be used for new data development for various reasons. Some products, like nylon, telemeter, computers and solar batteries had breaks in consistency either because the listing was missing in the Thomas Register of American Manufacturers, or due to substantial changes in definition of product over the years. Products like DDT and cryogenic tanks were omitted since they were discontinued over the years for which the analysis was extended (from 1973 to 1991). Other categories like streptomycin and penicillin were discarded in favor of a broader product group antibiotics. Finally, a few products were not included in the analysis due to time limitations on the development of data.

To incorporate later day innovations, and to maintain a representative sample of commercial and industrial products, two product markets—contact lenses and video cassette recorders—that gained prominence in the last few decades are added. Technical products (high tech) are distinguished from non-technical products (low tech) based on Hadlock, Hecker and Gannon's (Hadlock et al., 1991) classification of high technology 3-digit Standard Industrial Classification (SIC) industries. Appendix A gives a list of the products in the study, the year they were first introduced, and the technological index.

Patent statistics, first used by Schmookler (1966), are widely used as an indicator of innovative activity and a proxy for innovations. Their use, however, has been criticized for four major reasons. First, patent classification by the U.S. Patent Office (Classification Definitions U.S. Patent Office) is based on technological–functional rather than industry-of-use principle, which leads to a problem in reclassification of patents corresponding to industries based on SIC codes. Second, patent counts fail to capture the importance and varying impact of innovations on the technological environment. Third, industries vary in their propensity to patent, due in part to the existing trade-off between obtaining exclusive rights granted by a patent and the loss of secrecy thereof. Finally, as Griliches (1989) points out, patent data may not be a constant yardstick measure due to constraints on the number of patent officers and budgetary allocations of the patent office.

In spite of all the associated problems, patent data provide at least a crude proxy for innovative activity. Hall, Griliches and Hausman (Hall et al., 1986) show that patents are strongly and positively correlated with Research and Development (R&D) activity. In addition, the first and third problems above are avoided in this analysis. Since a time series analysis of patents within the separate products is considered, the problem of industry differences in the propensity to patent is avoided. Further, the analysis is based on a narrow product level definition of the market rather than on the broad four or five digit SIC industry level. The reclassification of patent class/subclass into a category corresponding to the product is hence greatly simplified and conducted by referring to the Index of U.S. Patent Classification System; Manual of Classification. The annual patent data for the products are compiled from the corresponding class/subclass definitions of the US Patent Office for 31 of the 33 products in the study.[2]

Data on product price and quantity are relatively difficult to obtain at the product level, and are successfully compiled on only 17 of the 33 products. The price and quantity data used in the Gort–Klepper study is augmented by

[2] The class/subclass definition for each product is available on request. Paints and contact lenses are the two exceptions. For some products, initial redefining of the product category was necessary. For example, antibiotics had to be broken down into the different drug classes which compose the group. Expert advice and consultation of technical dictionaries were undertaken where necessary. Also, the patents granted for photograph records could not be distinguished from patents granted for compact discs—a product clearly a superior substitute for phonograph records introduced within the last couple of decades. For this reason, the patent series is only considered for the first 62 years of the life-cycle of phonograph records.

information on six additional products. Information from trade journals, the Census of Manufactures (Bureau of the Census) and the Producer Price Index (Bureau of Labor Statistics) are used to construct as complete a historical data set as possible. Appendix B gives the list of products for which price and quantity data were obtained, the years for which data are available and the sources used. Producer price indices (PPI) are used where available, and implicit prices calculated by dividing the value of shipments (sales) by the production (quantity sold) are used elsewhere. The price series for each product is then deflated by the PPI for all goods and services to correct for inflation and general productivity changes (economy wide rather than product specific).

## 3. Empirical analysis

The present study abstracts away from the breakdown of the product life-cycle in stages used in the Gort–Klepper analysis. Using annual data rather than differences across stages, the study summarizes the time trends of the industry variables by regressing the key industry variables on product market age. To capture the increase and subsequent decline in the number of firms and patenting activity within a product market, these two industry variables are regressed on a quadratic function of product age. The patterns of growth in quantity and price and the rate of change of growth are summarized by regressing the log of quantity and the log of price on a quadratic function of age. Eqs. (1)–(4) give the quadratic regressions on product market age for each of the four industry variables.[3]

$$\text{Patent} = \alpha_1 + \alpha_2\ \text{Age} - \alpha_3\ \text{Age}^2 + u \quad (1)$$

$$\text{Numfirm} = \delta_1 + \delta_2\ \text{Age} - \delta_3\ \text{Age}^2 + v \quad (2)$$

$$\log(\text{Price}) = \beta_1 - \beta_2\ \text{Age} + \beta_3\ \text{Age}^2 + w \quad (3)$$

$$\log(\text{Quantity}) = \chi_1 + \chi_2\ \text{Age} - \chi_3\ \text{Age}^2 + z \quad (4)$$

where Age represents the age of the product market, and the signs of the

[3] Gross entry and exit underlying the trend in the number of firms have recently been studied in the context of stages in the evolutionary cycle by Agarwal and Gort (1996), who extend the Gort–Klepper analysis. They show that the patterns of gross entry and exit are consistent with the time trends hypothesized for the number of firms, with gross entry peaking early in stage 2 and gross exit peaking in stage 4.

Table 1
Quadratic regression of patents on product age

| Product | Adjusted $R^2$ | Constant | ($p$-value) | Age | ($p$-value) | Age$^2$ | ($p$-value) | Peak[a] |
|---|---|---|---|---|---|---|---|---|
| Technical products | | | | | | | | |
| Antibiotics | 0.78 | 3.414 | (0.0001) | 0.14 | (0.0001) | −0.002 | (0.0001) | 29 |
| Betaray gauges | 0.15 | 0.311 | (0.5058) | 0.11 | (0.01) | −0.003 | (0.009) | 16 |
| Cathode ray tubes | 0.41 | 3.523 | (0.0001) | 0.03 | (0.02) | −0.0001 | (0.47) | 38 |
| Electrocardiographs | 0.43 | 0.131 | (0.8745) | −0.009 | (0.66) | 0.0007 | (0.05) | no peak |
| Gas turbines | 0.51 | 2.185 | (0.0001) | 0.12 | (0.0001) | −0.002 | (0.0001) | 17 |
| Guided missiles | 0.45 | 0.368 | (0.2098) | 0.14 | (0.0001) | −0.003 | (0.0003) | 16 |
| Gyroscopes | 0.64 | 1.983 | (0.0001) | 0.10 | (0.0001) | −0.001 | (0.0001) | 52 |
| Jet engines | 0.49 | 3.586 | (0.0001) | 0.13 | (0.0001) | −0.002 | (0.0001) | 15 |
| Microfilm readers | 0.43 | 2.551 | (0.0001) | 0.06 | (0.001) | −0.0005 | (0.04) | 34 |
| Nuclear reactors | 0.52 | 2.820 | (0.0001) | 0.13 | (0.0001) | −0.003 | (0.0002) | 33 |
| Outboard motors | 0.52 | 1.828 | (0.0001) | −0.004 | (0.74) | 0.0004 | (0.01) | no peak |
| Phonograph records | 0.40 | 3.024 | (0.0001) | 0.04 | (0.08) | −0.001 | (0.003) | 29 |
| Photocopying machines | 0.92 | 1.732 | (0.0001) | 0.09 | (0.0001) | −0.0003 | (0.28) | no peak |
| Piezoelectric crystals | 0.33 | 2.385 | (0.0001) | −0.06 | (0.67) | 0.0005 | (0.09) | 48 |
| Radar antenna assemblies | 0.01 | 4.090 | (0.0001) | −0.01 | (0.37) | 0.0005 | (0.33) | no peak |
| Radiation meters | 0.79 | 1.892 | (0.0001) | 0.09 | (0.0001) | −0.0007 | (0.07) | no peak |
| Recording tapes | 0.33 | 0.025 | (0.9602) | 0.15 | (0.01) | −0.002 | (0.06) | 35 |
| Rocket engines | 0.51 | 5.441 | (0.0001) | −0.06 | (0.05) | 0.0004 | (0.57) | 9 |
| Styrene | 0.42 | 2.043 | (0.0001) | 0.11 | (0.0001) | −0.002 | (0.0001) | 35 |
| Video cassette recorders | 0.76 | 2.908 | (0.0001) | 0.16 | (0.01) | −0.003 | (0.30) | 15 |
| Non-technical products | | | | | | | | |
| Artificial christmas trees | 0.15 | 0.788 | (0.0067) | 0.04 | (0.11) | −0.0003 | (0.42) | 37 |
| Ball-point pens | 0.01 | 2.570 | (0.0001) | −0.01 | (0.61) | 0.0003 | (0.52) | 14 |
| Combination locks | 0.48 | 4.402 | (0.0001) | −0.08 | (0.0001) | 0.0009 | (0.0001) | 11 |
| Electric blankets | 0.38 | 0.131 | (0.6651) | 0.05 | (0.0004) | −0.0003 | (0.03) | 35 |
| Electric shavers | 0.01 | 0.7194 | (0.0270) | 0.026 | (0.22) | −0.004 | (0.26) | 14 |
| Freezers | 0.17 | 1.711 | (0.0001) | 0.08 | (0.004) | −0.002 | (0.002) | 17 |
| Freon compressors | 0.06 | 5.217 | (0.0001) | −0.01 | (0.24) | 0.0003 | (0.11) | 32 |
| Heat pumps | 0.01 | 3.880 | (0.0001) | 0.01 | (0.48) | −0.0002 | (0.55) | 31 |
| Oxygen tents | 0.13 | 0.167 | (0.4243) | −0.01 | (0.10) | 0.0002 | (0.03) | no peak |
| Polariscopes | 0.58 | 0.164 | (0.7270) | 0.03 | (0.06) | −0.001 | (0.05) | 43 |
| Radiant heating baseboards | 0.09 | 0.584 | (0.0190) | −0.0037 | (0.85) | −0.0001 | (0.67) | no peak |

Source: Data compiled from the US Patent Office. Technical and non-technical products based on Hadlock, Hecker and Gannon (Hadlock et al., 1991) classification of 3-digit SIC industries as technological by ratio of R&D personnel to sales. [a] Product age at which the number of patents are at the maximum.

coefficients of each of the time terms ensure the shape of the trends[4] (see Perry (1954); Chiang (1974)).

Table 1 gives the time trend regression analysis of patents for 31 of the 33 products. The quadratic specification of product age for patents is designed to capture the increasing and then declining trend in patents. As seen in Table 1, fifteen of the twenty technical products have the expected signs for the coefficients of product age. The coefficients are significant at the 0.01 level for eight products, while four more are significant at the 0.1 level. The relation between patents and product age is a little weaker for non-technical products. Six of the eleven products have the expected signs, of which three are significant at the 0.1 level. A reason for the weaker relation could be the much smaller annual rate of patenting when compared to the technical products.[5] As the results show, while only 55 percent of non-technical products show the quadratic trends, 75 percent of the technical products exhibit a quadratic relation of patenting activity with time. Table 1 also shows the age of the product at which the patent data reaches its peak; in all but five products the peak is reached well before the end of the sample period. For some of non-technical products, the annual count of patents is no more than three or four, and no clear mode is present. The observed decline in the patent trend is a departure from the results in the Gort–Klepper analysis. The earlier study showed the patenting rate to increase over the stages and could not capture the peak and subsequent decline in patenting activity. Since the peak in patents occurs in most products in the later stages, the decline in patenting activity could not be discerned by the earlier study which focused on differences over stages of mean levels of patenting rather than the annual trend of patents.

Table 2 presents the results of a quadratic regression of the number of firms on product age. The results indicate that 25 of the 33 products have the hypothesized signs, showing an initial increase in the number of firms followed by a decline. The last column in Table 2 gives the product age at which the number of firms peak, and reveals that 26 products show a distinct peak in the number of firms. The number of firms in electric shavers peaks very early in its product cycle, which is the reason that the trend fails to capture the phenomenon.

A comparison of the peaks observed in the trends for number of firms and patents is also of interest. Among the twenty technical products, eleven products show that the peak in patent data occurs in the period of contraction of the number of firms, while three products experience the peak in patenting and number of

[4] For patents and number of firms, a positive coefficient of age and negative coefficient of $Age^2$ will yield the increasing and then declining trend. The functional forms for quantity and price allow the growth rate and its rate of change to have the same or different signs. The mean growth rate can be positive or negative, and increase or decrease with age.

[5] The average annual number of patents in the technical products category is 57, as opposed to 23 in the non-technical category.

Table 2
Time trend of number of firms: quadratic regression of number of firms on product age

| Product | Adjusted $R^2$ | Constant | ($p$-value) | Age | ($p$-value) | $Age^2$ | ($p$-value) | Peak[a] |
|---|---|---|---|---|---|---|---|---|
| Antibiotics | 0.55 | 5.352 | (0.0168) | 1.373 | (0.0001) | −0.024 | (0.0001) | 20 |
| Artificial christmas trees | 0.56 | 1.977 | (0.1720) | 0.908 | (0.0001) | −0.014 | (0.0001) | 29 |
| Ball-point pens | 0.96 | 10.668 | (0.0104) | −1.952 | (0.0001) | 0.113 | (0.0001) | no peak |
| Betaray gauges | 0.79 | −1.132 | (0.1055) | 0.975 | (0.0001) | −0.024 | (0.0001) | 16 |
| Cathode ray tubes | 0.87 | −3.943 | (0.0327) | 1.828 | (0.0001) | −0.021 | (0.0001) | 26 |
| Combination locks | 0.92 | 7.118 | (0.0001) | 0.002 | (0.0001) | 0.004 | (0.0001) | no peak |
| Contact lenses | 0.87 | 9.531 | (0.0001) | −1.220 | (0.0001) | 0.033 | (0.0001) | no peak |
| Electric blankets | 0.57 | 1.131 | (0.1814) | 0.508 | (0.0001) | −0.006 | (0.0001) | 48 |
| Electric shavers | 0.49 | 20.199 | (0.0001) | −0.367 | (0.0001) | 0.002 | (0.0001) | 5 |
| Electrocardiographs | 0.54 | 0.013 | (0.9923) | 0.927 | (0.0001) | −0.019 | (0.0001) | 24 |
| Freezers | 0.51 | 38.007 | (0.0001) | 1.290 | (0.007) | −0.041 | (0.0001) | 10 |
| Freon compressors | 0.76 | 3.325 | (0.0084) | 0.796 | (0.0001) | −0.009 | (0.0001) | 52 |
| Gas turbines | 0.89 | 5.889 | (0.0320) | 0.711 | (0.0068) | 0.010 | (0.0479) | no peak |
| Guided missiles | 0.60 | −24.376 | (0.3521) | 21.526 | (0.0001) | −0.513 | (0.0001) | 14 |
| Gyroscopes | 0.66 | −10.178 | (0.0047) | 1.017 | (0.0001) | −0.005 | (0.0512) | 53 |
| Heat pumps | 0.92 | 3.486 | (0.1810) | 0.714 | (0.0238) | 0.020 | (0.0118) | no peak |
| Jet engines | 0.73 | 3.935 | (0.0245) | 1.593 | (0.0001) | −0.028 | (0.0001) | 18 |
| Microfilm readers | 0.94 | −1.576 | (0.2306) | 0.487 | (0.0001) | 0.005 | (0.0106) | no peak |
| Nuclear reactors | 0.54 | 12.256 | (0.0073) | 2.767 | (0.0001) | −0.081 | (0.0001) | 11 |
| Outboard motors | 0.42 | 9.708 | (0.0001) | 0.420 | (0.0001) | −0.004 | (0.0005) | 53 |
| Oxygen tents | 0.72 | −2.749 | (0.1037) | 1.505 | (0.0001) | −0.025 | (0.0001) | 32 |
| Paints | 0.84 | −32.677 | (0.0001) | 7.272 | (0.0001) | −0.101 | (0.0001) | 34 |
| Phonograph records | 0.59 | 9.844 | (0.0036) | 0.754 | (0.0001) | −0.003 | (0.1138) | 17 |
| Photocopying machines | 0.40 | 1.835 | (0.5491) | 1.562 | (0.0001) | −0.027 | (0.0001) | 26 |
| Piezoelectric crystals | 0.68 | 8.314 | (0.0001) | 1.368 | (0.0001) | −0.020 | (0.0001) | 24 |
| Polariscopes | 0.72 | 1.784 | (0.0302) | 0.610 | (0.0001) | −0.007 | (0.0001) | 31 |
| Radar antenna assemblies | 0.56 | 4.614 | (0.2087) | 2.820 | (0.0001) | −0.060 | (0.0001) | 14 |
| Radiant heating baseboards | 0.90 | −3.095 | (0.0072) | 2.157 | (0.0001) | −0.043 | (0.0001) | 23 |
| Radiation meters | 0.63 | 2.724 | (0.0493) | 1.172 | (0.0001) | −0.023 | (0.0001) | 18 |
| Recording tapes | 0.96 | −1.573 | (0.4277) | 3.137 | (0.0001) | −0.040 | (0.0001) | 35 |
| Rocket engines | 0.52 | 6.994 | (0.0001) | 0.644 | (0.0001) | −0.013 | (0.0001) | 27 |
| Styrene | 0.93 | −3.533 | (0.0122) | 0.982 | (0.0001) | −0.004 | (0.0531) | 44 |
| Video cassette recorders | 0.97 | 3.181 | (0.0206) | 0.058 | (0.8479) | 0.076 | (0.0002) | no peak |

Source: Based on data compiled from the Thomas Register of American Manufacturers. [a] Product age at which the number of patents are at the maximum.

Table 3
Time trend for price: quadratic regression of log(price) on product age

| Product | Adjusted $R^2$ | Constant | ($p$-value) | Age | ($p$-value) | Age$^2$ | ($p$-value) |
|---|---|---|---|---|---|---|---|
| Antibiotics[a] | 0.93 | −3.586 | (0.0001) | −0.269 | (0.0001) | 0.0033 | (0.0001) |
| Ball-point pens | 0.91 | 2.060 | (0.0001) | −0.108 | (0.0001) | 0.0014 | (0.0001) |
| Cathode ray tubes | 0.87[b] | 1.579 | (0.0659) | −0.146 | (0.0974) | 0.0024 | (0.2649) |
| | 0.95[c] | 6.419 | (0.0001) | −0.254 | (0.0001) | 0.0024 | (0.0001) |
| Electric blankets | 0.97 | 4.841 | (0.0001) | −0.171 | (0.0001) | 0.0013 | (0.0001) |
| Electric shavers | 0.90 | 0.168 | (0.0061) | −0.036 | (0.0001) | 0.0002 | (0.1161) |
| Electrocardiographs | 0.60 | 2.642 | (0.2629) | −0.010 | (0.0939) | 0.0011 | (0.5864) |
| Freezers | 0.92 | 2.771 | (0.0001) | −0.048 | (0.0001) | 0.0004 | (0.0062) |
| Freon compressors[a] | 0.98 | 1.622 | (0.0001) | −0.065 | (0.0001) | 0.0006 | (0.0039) |
| Heat pumps[a] | 0.98 | 3.236 | (0.0001) | −0.048 | (0.0001) | 0.0002 | (0.0551) |
| Jet engines[a] | 0.69 | 8.597 | (0.0001) | −0.073 | (0.0046) | 0.0027 | (0.0001) |
| Outboard motors | 0.86 | 2.650 | (0.0001) | −0.041 | (0.0001) | 0.0007 | (0.0001) |
| Phonograph records | 0.84 | −3.472 | (0.0001) | −.0183 | (0.0002) | −0.00006 | (0.3103) |
| Piezoelectric crystals | 0.77 | 1.823 | (0.3067) | −0.117 | (0.0232) | 0.0005 | (0.6799) |
| Radiant heating baseboards[a] | 0.87 | 0.626 | (0.0954) | −0.083 | (0.0027) | 0.0007 | (0.0920) |
| Recording tapes | 0.84[d] | −3.461 | (0.0025) | −.120 | (0.0295) | −0.0001 | (0.9749) |
| | 0.94[e] | 1.944 | (0.0314) | 0.423 | (0.0005) | −0.0066 | (0.0236) |
| Styrene | 0.78 | −3.566 | (.0001) | −0.089 | (0.0001) | 0.0014 | (0.0001) |
| Video cassette recorders[a] | 0.97 | 3.826 | (0.0001) | −0.275 | (0.0001) | 0.0065 | (0.0017) |

Refer to Appendix B for source of data on particular products.

[a] Price and quantity data on these products were not used in the Gort–Klepper study.

[bc] The time trend of prices of cathode ray tubes is affected by a sudden increase in prices at the time corresponding to the introduction of color television. In order to correct for this factor, separate regression analysis is conducted for period [b] black and white CRT, and [c] predominantly color CRT.

[de]The time trend of recording tapes is discontinuous at Age 27 due to a change in the units of measurement of the product (from mil. sq. ft. to mil. units). Hence separate regression analysis is considered for each of the periods [d] before and [e] after Age 27.

Table 4
Time trend for log(quantity): quadratic regression of log(quantity) on product age

| Product | Adjusted $R^2$ | Constant | ($p$-value) | Age | ($p$-value) | $\text{Age}^2$ | ($p$-value) |
|---|---|---|---|---|---|---|---|
| Antibiotics[a] | 0.99 | 6.635 | (0.0001) | 0.159 | (0.0001) | −0.0015 | (0.0001) |
| Ball-point pens | 0.98 | 9.403 | (0.0001) | 0.429 | (.0001) | −0.0097 | (0.0001) |
| Cathode ray tubes | 0.45 | 0.534 | (0.1563) | 0.089 | (0.0004) | −0.001 | (0.0031) |
| Electric blankets | 0.90 | −13.094 | (0.0001) | 0.508 | (0.0001) | −0.0044 | (0.0001) |
| Electric shavers | 0.94 | −0.344 | (0.0019) | 0.114 | (0.0001) | −0.0011 | (0.0001) |
| Electrocardiographs | 0.26 | −1.716 | (0.2646) | 0.252 | (0.0105) | −0.0035 | (0.0132) |
| Freezers | 0.56 | −0.659 | (0.0001) | 0.0743 | (0.0001) | −0.0012 | (0.0001) |
| Freon compressors[a] | 0.96 | −5.912 | (0.0004) | 0.387 | (0.0001) | −0.0041 | (0.0020) |
| Heat pumps[a] | 0.89 | 3.072 | (0.0001) | 0.093 | (0.0329) | 0.0005 | (0.5831) |
| Jet engines[a] | 0.69 | 8.571 | (0.0001) | 0.116 | (0.0001) | −0.0030 | (0.0001) |
| Outboard motors | 0.84 | 0.717 | (0.0146) | 0.120 | (0.0001) | −0.0018 | (0.0001) |
| Phonograph records | 0.88 | 2.842 | (0.0001) | 0.085 | (0.0001) | −0.0004 | (0.0002) |
| Piezoelectric crystals | 0.53 | −1.926 | (0.4822) | 0.491 | (0.0030) | −0.0057 | (0.0078) |
| Radiant heating baseboards[a] | 0.74 | 5.086 | (0.0001) | 0.199 | (0.0001) | −0.0034 | (0.0001) |
| Recording tapes | 0.80[b] | −9.559 | (0.0106) | 0.438 | (0.0396) | −0.0076 | (0.0205) |
| | 0.91[c] | 1.727 | (0.6079) | 0.139 | (0.0494) | −0.0003 | (0.9149) |
| Styrene | 0.95 | 0.977 | (0.0002) | 0.363 | (0.0001) | −0.0042 | (0.0001) |
| Video cassette recorders[a] | 0.96 | 1.727 | (0.0039) | 0.964 | (0.0001) | −0.0303 | (0.0001) |

Refer to Appendix B for source of data on particular products.
[a] Price and quantity data on these products were not used in the Gort–Klepper study.
[bc]The time trend of recording tapes is discontinuous at Age 27 due to a change in the units of measurement of the product (from mil. sq. ft. to mil. units). Hence separate regression analysis is considered for each of the periods [b] before and [c] after Age 27.

firms at approximately the same time. For non-technical products the peak in patenting occurs just as often before and after the peak in the number of firms. The maximum patenting activity occurs, particularly for technical products, predominantly in the period of contraction in the number of firms in the industry. This can be interpreted in two ways. First, it may be a reflection of the increase in competitive intensity experienced by firms in later stages of the product market. Alternatively, it may simply indicate that as major technological avenues are exhausted, there are many more minor enhancements that are patented. Further analysis clearly requires better data than are currently available.

Table 3 gives the results of the quadratic regression of log(price) on product market age. The hypothesis that price decreases ($\beta_2 + 2\beta_3 < 0$) at a decreasing rate ($\beta_3 > 0$) over the product life-cycle is strongly supported by the trend analysis. The high adjusted $R^2$ show the low variance of price from the trend element. Price is seen to decline significantly with product age for all products,[6] and for thirteen of the seventeen products, the decline in price occurs at a significantly decreasing rate. The initial rate of decline in price ranges from about one percent annually for electrocardiographs to a 26 percent decline seen in products like antibiotics and video cassette recorders. The mean annual decline rate in the first year of the products in the sample is almost 10 percent. After 30 years, the mean decline rate of the sample is less than one percent, showing stability in prices as the product market matures.[7]

Table 4 displays the results of the quadratic trend in log(quantity). The hypothesis that quantity increases ($\chi_2 + 2\chi_3 > 0$) at a decreasing rate ($\chi_3 < 0$) over the product life-cycle is also strongly supported by the trend analysis, with high adjusted $R^2$ for most products in the analysis. The growth rate of quantity is significantly positive for all the products, and the decline in growth is significant for all but one product. The initial annual growth in quantity ranges from a modest seven percent increase for freezers to a 90 percent increase for video cassette recorders. The mean growth rate in quantity in the first year for the products in the sample is almost 28 percent, but 30 years later, the growth rate slows down to less than five percent.[8]

## 4. Economic forces underlying the observed trends

The aging patterns in key industry variables revealed by the above trend analysis are remarkably consistent over a wide variety of products. In the

[6] The latter period of recording tapes is the only exception.

[7] The coefficients of Age in electrocardiographs, jet engines and outboard motors reveal prices rising at Age 30. Price increases in electrocardiographs could be attributable to rising health care costs and significant changes in the technology of the product.

[8] Products like ball point pens, jet engines and radiant heating baseboards show a modest decline in quantity after 30 years.

Gort–Klepper analysis, these patterns are attributed to a change in information source in the industry from external forces to incumbents as the product market ages. A similar explanation is given in the concepts of technological regimes, developed by Winter (1984) and later elaborated by Audretsch (1991). They distinguish between a 'routinized' regime and an 'entrepreneurial regime'. A routinized regime, like the Gort and Klepper type 1 information, aids incumbents and is more likely to be observed in the mature period of the product market, while an entrepreneurial regime, more likely to be observed in an infant product market, encourages entry.

The theoretical model developed by Jovanovic and MacDonald (1994b) focuses on the life-cycle of a competitive industry and distinguishes between firms that employ different levels of technology in production. The analysis is simplified by assuming two major innovations in the market. The first innovation results in the introduction of the market, and the subsequent innovation is a refinement of the technology. Low-tech firms (firms that use the first type of technology) have a higher cost of production than high-tech firms (firms that adopt the refinement). As the industry evolves, the proportion of high-tech firms in the market increases. As a result, industry output increases, and price declines. The model shows an exit of low-tech firms (catastrophic or gradual) following the introduction of the refinement in the shake-out period.

Stylized facts developed in the evolutionary literature by the above researchers and Jovanovic and Lach (1989), Dosi, Marsilli, Orsenigo and Salvatore, and Hopenhayn (1994) suggest that technological change is the chief economic force generating the observed patterns. Firms enter a new product market introduced due to a major product innovation, and competition is initially technology oriented. As the product market grows, there is an increase in innovative activity, number of firms, and product quantity. Product price declines due to increases in both competitiveness and productivity. A shake-out of firms occurs when a dominant technology emerges, and inefficient firms are forced to exit the market. In the later stages of the market evolution, technological avenues are exhausted and product design is standardized, resulting in relatively constant price and quantity levels.

## 5. Conclusion, limitations and avenues of future research

The present study extends the Gort–Klepper analysis to reexamine the aging patterns of a product market. The period of study is extended to 1991, an almost twenty year update. The time period extension represents not only a longer time series on all products, but more importantly, seventeen of the products currently under analysis had not reached their final stage in the Gort–Klepper study. There is new information on two recent product markets, and price and quantity data are constructed successfully for six more products (See Appendix B). Finally, the analysis of the patent data updates the earlier work, and by stratifying the products according to technological activity, the paper examines whether the hypothesized pattern holds more strongly for high-tech products than low-tech products.

The Gort–Klepper results are seen to be remarkably robust. The new evidence supports their findings over a longer period of time, other product markets, and for products introduced in a later span of time. The longer period of analysis (from 1974–1991) reveals no change in the main results from the Gort–Klepper analysis. For the seventeen products that did not reach the final stages in the earlier study and the two products that gained prominence in the last two decades, the current study replicates the Gort–Klepper findings with remarkable consistency.

While patent data cannot capture changes in the importance of innovations over the product life-cycle, counts of innovative activity still show an eventual decline in technological activity for most of the products in the analyses, lending support to the stylized fact that the rate of technological change slows down in the latter stages of the life-cycle. The pattern is more strongly observed in product markets which are generally more technical in nature. While only 55 percent of non-technical products exhibited the hypothesized pattern, 75 percent of the technical products in the sample showed an initial increase in patenting followed by a decline in later years. Similarly, the number of firms in the product market follows the hypothesized pattern, with 75 percent of the products in the study showing an increase, followed by a decline in the number of firms. A comparison of the peaks of the patent and the number of firms trends reveal that, particularly for technical products, the peak in patenting activity occurs after the peak in the number of firms. Product price declines at a declining rate over the life-cycle, and product quantity grows at a declining rate over time. The price and quantity trends are remarkably consistent for almost all the products in the study, with highly significant coefficients for the trend terms and low amounts of unexplained variation.

While the data yield consistent time trends simultaneously for a broad range of products, they suffer from certain limitations. The study uses only a count of the number of patents and number of firms. As stated before, patents fail to capture the degree of importance of the innovation, hence they cannot be used to distinguish major and minor innovations. If the patent information could have been weighted by information on the possible impact of the particular innovation, one could also have proceeded to test the hypothesis that innovations decline in importance over time. However, to the extent that the price trend shows a decreasing slope, one can infer that productivity increases decline over time.

The price and quantity series used are clearly limited insofar as they do not capture the effect of quality changes. As the quality of the product increases over the product life-cycle (an additional innovation has at least a non-decreasing effect on quality), the specifications of the product change even though the inherent product definition is still maintained (current video cassette recorders are far superior to the first introduction, however the product still serves the same basic use). The present series understate the decrease in prices and increase in quantity per unit quality. This implies that the bias caused by quality, if removed, would yield stronger results than those obtained in the study.

The count of the number of firms implicitly assumes that the firms are homogenous and have the same attributes over time. It would be interesting to explore how the firm attributes, such as size, product diversity, initial endowments and learning by doing change over the evolutionary cycle of the product.

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## Appendix A

### Products in study, year of introduction, corresponding SIC code and technological index

| Product name | Year of commercial introduction[a] | SIC code[b] | Technological index[c] |
|---|---|---|---|
| Antibiotics | 1948 | 28 331 | 1 |
| Artificial christmas trees | 1938 | 3 999 813 | 0 |
| Ball-point pens | 1948 | 39 511 | 0 |
| Betaray gauges | 1956 | n.a. | 1 |
| Cathode ray tubes | 1935 | 36 712 | 1 |
| Combination locks | 1912 | n.a. | 0 |
| Contact lenses | 1936 | 38 516 | 0 |
| Electric blankets | 1916 | 3 634 583 | 0 |
| Electric shavers | 1937 | 36 342 | 0 |
| Electrocardiographs | 1942 | 3 845 101 | 1 |
| Freezers | 1946 | 36 322 | 0 |
| Freon compressors | 1935 | 35 854 | 0 |
| Gas turbines | 1944 | 35 112 | 1 |
| Guided missiles | 1951 | 37 611 | 1 |
| Gyroscopes | 1915 | 381 112 | 1 |
| Heat pumps | 1954 | 35 851 | 0 |
| Jet engines | 1948 | 372 402 | 1 |
| Microfilm readers | 1940 | 38 614 | 1 |
| Nuclear reactors | 1955 | 34 436 | 1 |
| Outboard motors | 1913 | 35 195 | 1 |
| Oxygen tents | 1932 | 3 841 176 | 0 |
| Paints | 1934 | 28 513 | 1 |
| Phonograph records | 1908 | 36 520 | 1 |
| Photocopying machines | 1940 | 38 612 | 1 |

| | | | |
|---|---|---|---|
| Piezoelectric crystals | 1940 | 36 797 | 1 |
| Polariscopes | 1928 | n.a. | 0 |
| Radar antenna assemblies | 1952 | 3 662 021 | 1 |
| Radiant heating baseboards | 1947 | 3 634 820 | 0 |
| Radiation meters | 1949 | 3 829 240 | 1 |
| Recording tapes | 1952 | 36 522 | 1 |
| Rocket engines | 1958 | 3 724 220 | 1 |
| Styrene | 1938 | 2 821 361 | 1 |
| Video cassette recorders | 1974 | 36 516 | 1 |

n.a.: not available.

[a] Based on the Thomas Register of American Manufacturers.

[b] SIC codes obtained from the Alphabetical list of SIC codes, Census of Manufactures 1987 Manual (Bureau of the Census) and from Predicasts Basebook.

[c] Technological index based on Hadlock, Hecker and Gannon (Hadlock et al., 1991) classification of 3-digit SIC industries as technological by ratio of R&D personnel to sales.

## Appendix B

### Sources and period for data on price and quantity by product

| Product | Period | Source(s) |
|---|---|---|
| Antibiotics[a] | 1950–91 | ITC |
| Ball-point pens | 1951–91 | WIMA, BLS |
| Cathode ray tubes | 1948–91 | EMDB, Predicasts, BLS |
| Electric blankets | 1946–81 | DM |
| Electric shavers | 1937–82 | DM |
| Electrocardiographs | 1963–86 | Predicasts |
| Freezers | 1947–91 | DM, BLS |
| Freon compressors[a] | 1960–77 | Predicasts |
| Heat pumps[a] | 1960–91 | Predicasts |
| Jet engines[a] | 1948–91 | AIAA |
| Outboard motors | 1925–91 | BC, Predicasts, BLS |
| Phonograph records | 1909–91 | BC, BLS |
| Piezoelectric crystals | 1963–91 | Predicasts |
| Radiant heating baseboards[a] | 1963–91 | Predicasts |
| Recording tapes | 1961–91 | Predicasts |
| Styrene | 1942–91 | ITC |
| Video cassette recorders[a] | 1977–91 | DM |

[a] Price and quantity data on these products were not used in the Gort–Klepper study.

AIAA: Aerospace Industries Association of America, Aerospace Facts and Figures.

BC: Bureau of the Census, Census of Manufactures and Annual Survey of Manufactures.

BLS: Bureau of Labor Statistics, Producer Price Index. (Previous name: Wholesale Price Index).

DM: Dealerscope Merchandising (Previous Names: Merchandising, Merchandising Week).
ITC: U.S. International Trade Commission, Synthetic Organic Chemicals: Production and Sales.
Predicasts: Predicasts Basebook
WIMA: Writing Instruments Manufactures Association, Mechanical Handwriting Instruments Industry

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