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An Analysis of Innovation in Materials and Energy

A dissertation submitted to the

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by

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Abstract: This dissertation presents an analysis of innovation in engineering materials and energy sources. More than fifty engineering materials and fourteen energy sources were selected for an evaluation of the relationship between the yearly production activity and yearly patent counts, which may be considered as a measure of innovation, for each. Through the employment of correlation theory, best-fit and origin shift analyses, it has been determined here that engineering materials and energy sources display similar life cycle and innovative activity behaviors. Correlation theory revealed a relationship between the yearly production and yearly patent counts indicating the extent that production and innovation affect each other. Best-fit analysis determined that four-stage life cycles exist for both engineering materials (metals and non-metals) and energy sources. Correlation and best-fit indicators of an estimated Stage III are confirmed by the presence of an origin shift of the patent data when compared to the production data which indicates that patents, or innovation, are driving, or being driven by, production. This driving force could represent the constructive or destructive side of the innovative process, with such sides being delineated by a possible universal constant above which there is destructive innovative behavior and below which exists constructive innovation. The driving force may also illustrate the manner in which an engineering material or energy source transitions into an innovatively less active state, enter Stage IV and possibly become a commodity. A possible Stage V, indicating "Final Death", is introduced in which production is on a steep decline with no signs of recovery. Additionally, innovatively active energy sources are often found to utilize or be supported by innovatively active engineering materials. A model is presented that can be used for the evaluation of innovation and production that can be applied to both engineering materials and energy sources that may be used to predict the innovative behavior of these resources in order that they can be more effectively allocated and utilized.

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Introduction

This dissertation continues a valuable and timely study concerned with the relationship between the production and innovation of materials. Invention is the realization and development of new and original ideas and products, while innovation is the successful utilization of such ideas and products, as well as means to conduct business, to market, and to finance, with the ultimate goal of making a profit. Innovations are often much more than inventions. Invention is the creative act or flash of genius while innovation is the exploitation of, and change caused by, the invention itself. Most inventions are technical, but innovations do not have to be technical at all, since, for example, technology is not necessary for the development of market or business model innovations [1,2]. This work examines the linkage between patent and production life cycles for various engineering materials (metals and non-metals) and explores whether such relationships also apply to energy sources and how such relationships can be employed as a possible predictive tool for the more efficient use and development of these materials and sources for, ultimately, a greater profit.

Invention is necessary for innovation to occur, but invention by itself is not enough for innovation to take place. Innovation can be described as being multi-dimensional, in that innovation requires vision concerning the invention, market need, timing, technology convergence and an implementation strategy [2]. Inventions are relatively low-risk with technology and intellectual property issues dominating. Innovations have large risks attached to them and are dominated by marketplace effectiveness, cost and profit concerns [2]. Anyone with a good idea and imagination can invent, but it takes someone with foresight, knowledge and courage to innovate effectively.

This dissertation expands the previously published work [1-3] on life cycle best-fit analysis to over fifty engineering materials, as well as fourteen energy sources. The selected engineering materials are listed in Table 1 and were not only chosen for the availability of complete sets of production and patent data between the years of 1900-2007, but also as representatives of a wide variety of materials and their applications. Likewise, Table 2 presents fourteen energy sources that were chosen for their representative value as well as the availability of complete production and data sets for the years 1900-2008.

Table 1. Engineering Materials chosen for this study.

Aluminum	Chromium	Iodine	Nickel	Silver
Antimony	Cobalt	Iron	Niobium	Sulfur
Arsenic	Copper	Kyanite	Nitrogen	Talc
Asbestos	Feldspar	Lead	Phosphate	Tantalum
Barite	Fluorspar	Lithium	Platinum	Tin
Bauxite/Alumina	Gold	Magnesite	Potash	Titanium
Beryllium	Graphite	Magnesium	Rare Earths	Tungsten
Bismuth	Gypsum	Manganese	Salt	Vanadium
Boron	Helium	Mercury	Selenium	Zinc
Cadmium	Hydraulic Cement	Molybdenum	Silicon	Zirconium

Table 2. Energy sources chosen for this study.

U.S. Biofuel Energy	U.S. Hydroelectric Energy	U.S. Solar Energy
U.S. Biomass Energy	U.S. Natural Gas Energy	U.S. Total Energy
U.S. Coal Energy	U.S. Nuclear Energy	U.S. Wind Energy
U.S. Fossil Fuel Energy	U.S. Oil Energy	U.S. Wood Energy
U.S. Geothermal Energy	U.S. Renewable Energy	

A major goal of this work is to discover relationships between patents (technological inventions) and how such relationships affect, or are affected by, material production. During the 21st Century, which is a period of knowledge driven economies, it has been demonstrated that intellectual property could be a dominant force providing the capital that will continue to drive future worldwide economic growth [1,4-54]. However, there is no clear quantitative connection that has been established between patents and production excepted for limited work [1-3]. In order to perform such investigations, innovation needs to be defined and then a measurable proxy for it must be found. Sekhar et. al. [2,3] have clearly demarcated the difference between invention and innovation based on the overall long-term life cycle. Here, further correlations are made between the production innovation activity, i.e., Stage III and patent activity in a similar Stage III or beyond for the overall life cycle for both measures. Several other methods have been employed to measure and define innovation starting with the work of Joseph Schumpeter [55-57].

Correlation theory was originally applied to the above listed engineering materials to determine if a relationship exists between the production data and the patent data. Best-fit analysis was then applied to the production data sets to generate the life cycles of each material, and then to the patent data sets to discover if any origin shifts in the equation result. Such an origin shift would indicate a driving force being present for the innovative activity that could be ascribed to the patent activity [1-3]. Here is sought a dividing line, possibly numerical, between the creative and destructive modes of the innovative process, which define the driving and driven behavior of innovation. Best-fit analysis will also be applied to determine if a method can be developed to positively identify Stage III materials by seeking common trends in patent and production data and resulting origin shifts in the life cycles of the data.

The procedures applied to engineering materials will then be applied to energy sources to determine if such resources have similar four-stage life cycles, driving force behavior and origin shifts produced by best-fit analysis, and in general follow similar patterns as do engineering materials. Similar behavior will permit already proven engineering material analyses to be applied to energy sources and may reveal relationships between energy sources and related materials that will allow predictions concerning future innovative growth and can lead to a more efficient and profitable allocation of ever more scarce natural and monetary resources.

Section 1: Measuring Innovation

Innovation. An important figure in modern attitudes toward innovation and its measurement is the economist Joseph Alois Schumpeter (1883-1950) [55]. Schumpeterian theory perceives the importance of innovation, and suggests that it is a central part of capitalist economies. This theory postulates that innovation propels the economy, which is in a state of constant change [55]. Capitalism is defined by an ebb and flow with cycles existing in it, which need to be evaluated using the historical record [55]. Innovation destroys and causes havoc as it builds anew. Old conditions and ways of thinking and acting are destroyed when innovations introduce new ideas, making the innovative act a double-edged sword. Entrepreneurs, called "New Men" drive innovation by making creative responses to change, in the form of innovative acts [55].

Schumpeter's writings define his concept of innovation or "new combinations" as carried out by the entrepreneur or "new man" in the following manner:

> This concept covers the following five cases: (1) The introduction of a new good – that is one which consumers are not yet familiar – or of a new quality of good. (2) The introduction of a new method of production, that is one not yet tested by experience in the branch of manufacture concerned, which need by no means be founded upon a discovery scientifically new, and can also exist in a new way of handling a commodity commercially. (3) The opening of a new market, that is a market into which the particular branch of manufacture of the country in question has not previously entered, whether or not this market has existed before. (4) The conquest of a new source of supply of raw materials or half-manufactured goods, again irrespective of whether this source already exists or whether it has first to be created. (5) The carrying out of the new organization of any industry, like the creation of a monopoly position (for example through trustification) or the breaking up of a monopoly position [56].

Or put more simply, an innovation is an invention that becomes economically successful and earns profit, where the invention is the creation and establishment of something new [57].

The prime motivation for the innovator in implementing the above is entrepreneurial profit. "When other participants in the same industry see the new level of high profit, they quickly try to imitate the innovation. The entrepreneur tries to preserve his high profit for as long as possible, through patents, further innovation, secret processes and advertising – each move an act of 'aggression directed against actual and would-be competitors [55].'" The process of incessant revolution of the economic structure from within by destruction of the old system and creation of a new one is titled "Creative Destruction [56]." Innovation is used to make profits, and in doing so great change occurs where new ways are created and old are cast aside. Schumpeterian theory stresses the centrality and importance of innovation in the economy, but methods are needed to quantify innovation to make it a useful indicator of present and future economic growth.

Measurement of Innovation. There is truly a multi-disciplinary interest in innovation and its quantification, with multiple books and articles being written on the subject in many diverse areas of research [58-77]. Measurement of innovation has proven to be a difficult task with much argument and difference of opinion, especially when patents are used as an indicator of innovation. Innovation measurement using patent data, and alternatively, innovation measurement excluding patent data, will be discussed below.

Measurements Excluding Patents. The belief has been put forward that patents may not be a reliable or representative measurement of innovation and that patents may even hamper innovation itself [58-72]. Some suggest that patents of dubious quality end up at the heart of legal disputes making everyone pay more for innovation and making it less likely to occur [58]. Fewer products in the marketplace are the result, since companies decide not to innovate with new products [58]. Other reports suggest that patents inhibit the innovative process by restricting other people's creativity or that the costs of patenting could be used better elsewhere by businesses and that these costs are burdens on emerging businesses [59]. Patent infringement suits are considered by some as evidence of a patent system gone wild leading to the stifling of innovation [60]. Some studies have also indicated that stronger, or broader patents do not increase innovation [61,62].

Even those who support the use of patent data have pointed out several direct problems with the use of patents as indicators of innovation. The reliability of patent measurement of innovation has been questioned since not all patented inventions prove to be innovations, many innovations are never patented and patents differ greatly in their economic impact [63]. On account of the differences in national patent offices, the interest in patenting by inventors differs between countries, and firms more often patent domestically rather than in foreign patent offices [64]. Patents do not always represent commercially exploited innovation and seem to be better used as representative of an input into the innovation rather than an output evidence of it [65].

There are no shortages in the literature of alternative innovation measurement techniques. One suggested method of innovation measurement, which was applied to French biotechnology firms, was by linking innovation with firm performance through the efficiency and efficacy of innovation performance [66]. The efficiency of an innovation reflects the degree of success of the innovation while efficacy indicates the effort carried out to achieve that degree of success [66]. Efficacy and efficiency, considered as complimentary dimensions that shape innovation performance, are measured through twelve items, including market share, new markets, cost per innovation, average number of innovation projects, working hours and product range extension [66].

Literature-based Innovation Output (LBIO) data has also become increasingly popular as a means of measuring innovation. LBIO data is compiled by screening specialist trade journals for new-product announcements instead of drawing on R&D figures that are seen as being not comprehensive [67]. Such methods have been applied to public service innovations as well as product innovations [68]. LBIO data methods correctly compiled have no biases, are cost effective and can be an alternative to other innovation data, though they do tend to over-estimate domestic innovation and are limited where there are relatively few trade journals in a specific industry [67].

Research and Development data has been put forth as an innovation measurement. R&D measurement is seen by some as a poor measure since many small companies are innovative but spend little on R&D [69]. This data is also an input data, showing what was spent to get to a possible innovation and not indicative as an output of implemented innovations. Other measurement methods include valuation by royalties [70], radicalness and relative advantage [71], and radical versus incremental innovation [72].

Measurement with Patents. Though many options are presented concerning measurement of innovation without the use of patent data, the majority of the literature presents methods of measurement that are based upon some form of patent data. As indicators of technological change or innovation, patents have several advantages. Some of their advantages are:

- They are a direct outcome of the inventive process, and more specifically of those inventions, which are expected to have commercial impact. They are a particularly appropriate indicator for capturing the proprietary and competitive dimension of technological change.
- Because obtaining patent protection is time-consuming and costly, it is likely that applications are filed for those inventions, which, on average, are expected to provide benefits that outweigh these costs.
- Patents are broken down by technical fields and thus provide information not only on the rate of inventive activity, but also on its direction.
- Patent statistics are available in large numbers and for a very long time series.
- Patents are public documents. All information, including patentees' names, is not covered by statistical confidentiality. [64]

Patent data is easily accessible and cost-free through many national and international patent offices such as the United States Patent and Trademark Office (USPTO) and the

European Patent Office (EPO). The ease and simplicity of acquiring patent data make the use of it an obvious choice for analyzing of invention and innovation.

Patents are often cited as indicators of innovative growth, however a rigorous study has never previously been carried out to determine if they are leading or lagging indicators. A study on urban and regional innovation in metropolitan statistical areas (MSA) has found that in the absence of a better set of indicators that patents can serve as a rough measure of innovation. Further, because inventors frequently seek patent protection for new knowledge or processes, patents can serve as a proxy for innovation [73]. A metropolitan area's innovative strengths and growth rates can be indicated through patent data by technical classification of the patents [73]. Patent analysis can provide assistance in strategic planning efforts to firms involved in the ITS (Intelligent Transportation Systems) sector. ITS covers the application of computer, communication, positioning, sensing, control and other systems used to improve aspects of surface transportation. Patent information from the USPTO, EPO and JPO (Japanese Patent Office) concerning ITS and other related worldwide patent developments has been used to assess and provide an overall picture of ITS innovations and future markets [74].

Examples of innovation measurement techniques that are not technology or business specific but in some way depend on patent data information are available from various sources [76-77]. The patent success ratio (PSR) is defined as the ratio of successful patent applications to total patent applications. Supporters of this method claim that the PSR is an accurate measure of how innovative activity has changed over time. Correlations between the PSR and economic growth, or gross domestic product (GDP) are often claimed as being better than the correlation between successful patents and GDP, thus making PSR a better proxy for innovation [75]. The citations made in any patent document have been suggested as indicators of innovation, knowledge flows and spillovers, and thus of technological impact.

The suggestion is often made that the importance and impact of patents are greater when they are cited in succeeding patents [77,78]. The preceding discussion illustrates the divergence in opinion concerning the measurement of innovation. Much time and effort has been spent in seeking the discovery of an accurate measuring technique of something that itself is difficult to perfectly define. On balance the available literature appears to favor the use of some form of patent data as an indicator for innovation and innovative activity.

This dissertation uses patent data as an indicator of innovation and introduces a new long life cycle approach to qualify patents when they become important as innovation drivers. Short-term product cycles have been well studied [3-33]. Long-term life cycles, however, are relatively unstudied [2]. Long-term life cycles are possibly more suited to explain the impact of patents on production activity.

Section 2: Data Collection

Engineering Material Production Activity Data Collection. Production activity data was collected from the United States Geologic Survey (USGS) web site [78]. In all fifty cases, world production, by year, of the material in question was used for the activity data. This information was found in the historical statistics compilations of the minerals section of the USGS web site [79]. All activity is reported in metric tons. World production was chosen as the basis for activity due to its relevance to activity in global materials production, the completeness of the data sets available and the generally comparable definitions of world production between the individual materials. World production, for the most part, is based upon primary mine production with specific production definitions for each material being available in Appendix 3. The inclusion of recycled materials, beyond those generally included in primary production, was decided against due to the unavailability of consistent worldwide recycling data covering the years researched. Also, where recycling production data was available it was apparent that the amount of world production attributed to recycling was at times already included in the primary production numbers or not significant to the world production totals.

Patent Data Collection. Data for patents published per year was collected from the European Patent Office (EPO) using its patent search engine [80]. The EPO web site was chosen because it offered the widest database for collection of global patents from 1900 to the present, while the United States Patent and Trademark Office (USPTO) on-line patent data only goes back to the 1970's. The EPO site provides worldwide searches, encompassing the patent offices of over 80 countries and regional intellectual property organizations including the United States, Germany, Great Britain, Japan, Korea, India, China, the EPO and the World Intellectual Property Organization (WIPO) [80]. The use of the EPO worldwide search, which includes countries who are signatories of the Patent Cooperation Treaty (PCT), is thus more thorough in coverage and scope than searches used to evaluate patent counts and innovation as presented, for example, by reference [74] above in section 1 which uses patent counts to investigate future markets and innovation.

The patent search was conducted through the EPO, using keywords to be found in the title or the abstract of the patent by the year of publication of the patent. As examples, for aluminum, the keywords employed were aluminum, Al and aluminium and for zinc, the keywords chosen were zinc and Zn. All other materials were done in a similar manner.[1] Multiple patent counts of the same patent, caused by multiple filings of patents in different patent offices, were not an issue as the search produced only one listing per patent. This listing would have the various patent offices through which the patent application was published, but would only list it once in the yearly patent count.

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[1] A complete list of patent search keywords is included in Appendix 6.

Title and abstract fields were chosen, as it was clear that they provided the most likely option for finding the most complete set of patents. Also, this choice was made because the EPO search engine does not provide a claims field, which would have been preferred. Choosing the titles field gives any patent with the selected keywords in the title of the patent document. The abstract field will indicate any patent with the keywords in the abstract and gives any patents that do not include the keywords in the title, which is often the case.

The date of publication field was opted for as well. This selection provided the most complete set of data concerning patents containing the keywords and also was made due to the fact that there was no field for the date of patent issuance. The patents listed in this search field were not necessarily granted patents, but in some cases may be applications that are still pending. The date of publication, is not necessarily the date of issuance, but exhibits an accurate model of the relative innovation occurring during a specific year, since the existence of innovations is proven by publication rather than by an issuance of a patent for them.

Section 3: Patent and Production Activity Data Correlation

This section describes the method of comparison between the data gathered, representing the production activity per year of an engineering material, and the number of patents published per year for the same material. In correlation theory, two data sets, x and y, are tested to determine the existence of correlation between them. In this case, x is the production activity of a specific material in metric tons per year and y represents the number of patents published involving the same material for the same year. Through correlation theory, a number called the correlation coefficient is generated that expresses the amount of correlation that exists between two groups of data [81-83]. When the coefficient is squared and then multiplied by 100 a percentage is given, which expresses the percentage that changes in group y can be attributed to changes in group x [81,82]. In this manner, a percentage of the changes in the patent numbers of a material were attributed to changes in the production of the material [83]. A more detailed description of the calculation of the correlation coefficient with an example can be found in Appendix 1. Examples of strong and weak correlations are discussed below in Figs. 1 and 2. A graphical representation of the correlation between the rare earth elements activity and patents is presented in Fig. 1, which indicates that the curves for activity and patents have a strong correlation to each other. A weak correlation is shown in Fig. 2, for beryllium.

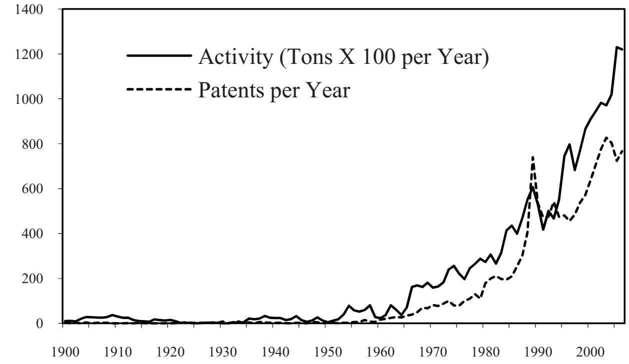

Figure 1. Rare Earths: Activity and Patents. A strong correlation is illustrated by this figure. The curves track each other fairly well and much of the change in the patents can be attributed to changes in the production according to correlation theory. The calculated correlation coefficient was 0.9659. Data scaled to fit on same figure.

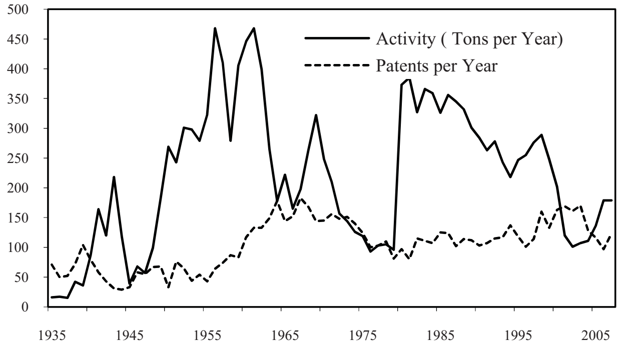

Figure 2. Beryllium: Activity and Patents. Weak correlation is exhibited in this figure with the two curves showing scant resemblance. Even visually it is noted that a change in the patents cannot be attributed to change in the production and vice-versa. The calculated correlation coefficient was 0.1132. Data scaled to fit on same figure.

The evaluation presented here indicates weak to strong relationships existing between the material activity and patent data sets depending on the material under study. As is shown below in Table 3, most materials investigated showed some degree of correlation between their activity and their patents. Table 3 gives comparative results arrived at after application of the correlation equations to the remaining forty-eight materials in the same manner as the previous examples for the rare earths and beryllium.

Table 3. Overall Correlation Coefficients (*r*) and *$100r^2$*. These r values represent the percent of variations in one data set, that affect variations in the other set for all materials studied. The best correlation is when r is one (i.e. 100%). An *$(100)r^2$* of 90% means that 90% of the differences between points in one set of data can be attributed to corresponding differences in the other set of data [81-83].

Material	Overall Correlation Coefficient (r)	(100) r^2	Material	Overall Correlation Coefficient (r)	(100) r^2
Aluminum	0.9652	93.16%	Magnesite	0.8108	65.74%
Antimony	0.8518	72.56%	Magnesium	0.9078	82.41%
Arsenic	0.3375	11.39%	Manganese	0.6835	46.72%
Asbestos	0.7288	53.11%	Mercury	-0.1117	1.25%
Barite	0.7486	56.04%	Molybdenum	0.9290	86.30%
Bauxite/Alumina	0.9310	86.68%	Nickel	0.9563	91.45%
Beryllium	0.1132	1.28%	Niobium	0.7543	56.93%
Bismuth	0.7651	58.54%	Nitrogen	0.9164	83.98%
Boron	0.8691	75.53%	Phosphate	0.8708	75.83%
Cadmium	0.7401	54.77%	Platinum	0.9569	91.57%
Chromium	0.9495	90.16%	Potash	-0.1414	2.00%
Cobalt	0.9269	85.91%	Rare Earths	0.9700	94.09%
Copper	0.9507	90.38%	Salt	0.8996	80.93%
Feldspar	0.9490	90.06%	Selenium	0.6871	47.21%
Fluorspar	0.7399	54.75%	Silicon	0.8893	79.09%
Gold	0.9385	88.08%	Silver	0.8735	76.30%
Graphite	0.9287	86.25%	Sulfur	0.9156	83.83%
Gypsum	0.9211	84.84%	Talc	0.9383	88.04%
Helium	0.7460	55.65%	Tantalum	0.7181	51.57%
Hydraulic Cement	0.9299	86.47%	Tin	0.6576	43.24%
Iodine	0.9105	82.90%	Titanium	0.9151	83.74%
Iron	0.8741	76.41%	Tungsten	0.7420	55.06%
Kyanite	0.9242	85.41%	Vanadium	0.7840	61.47%
Lead	0.7013	49.18%	Zinc	0.9387	88.12%
Lithium	0.9272	85.70%	Zirconium	0.9239	85.36%

The summary presented by Table 3 indicates that forty-eight of fifty materials investigated, according to the correlation methods referred to, establish a possible relationship between the material's activity and patent data. Most of the materials tested showed some degree of correlation, although correlation for arsenic and beryllium was weak and mercury and potash had negative correlation, which indicates a lack of a relationship. Correlation theory has thus shown that the data sets of production activity and patents for the materials evaluated here are not randomly connected, but are in fact related to each other. This relationship implies that a change in patent trends is due to a corresponding change in the production activity allowing for the confident use of these data sets in further evaluations employing best-fit models of selected metals and non-metals.

From the discussion above it can be concluded that there is a correlation between the data gathered concerning material activity and the numbers of patents published, which represent innovations utilizing such materials, making further comparisons and evaluations of the data sets more valid. This has been proven employing standard statistical procedures for forty-eight of fifty materials studied in this paper. The variations in the patent data during the dominant part of the life-cycle, namely Stage 3, illustrated in Figure 3 below, [2,3] do not appear to occur on their own, but can be correlated to the variations in the material production activity.

Where correlation exists, as here in reference to engineering material production and patenting data, the disclosed relationship could possibly be used for predicting the future behavior of one set of data based upon knowledge of future behavior of the other data set. For example, if a material has strong correlation between production and patenting, or innovation, and the government announces that it will provide billions of dollars for innovative development of the material, it might be a good option to provide resources for future production of the material since correlation theory predicts a rise in production will mirror the announced increase in innovative activity measured by patents.

Section 4: Best-Fit

Now that the correlation between activity and patents has been established, these sets of data can be used in conjunction with the common pattern equation for production of metals initially proposed by Yerramilli and Sekhar [2] and modified by Connelly and Sekhar [1]. A further modification is proposed below in this section. The equation predicts and illustrates a four-stage life cycle for metals. These four stages are the Initial Stage (I), the Lift Off and Decay Stage (II), the Revival and Rapid Growth Stage (III) and the Survival Stage (IV) [2]. The patterns found are common to the materials tested and are similar to common patterns and cycles found in overall life behaviors as illustrated by long wave theory [2]. A similar hypothesis for shorter life products, which postulates that that most successful products pass through recognizable stages during their life cycles was first proposed by Levitt and has been applied by others in evaluations of industry and business activities for various products and product groups [84-89].

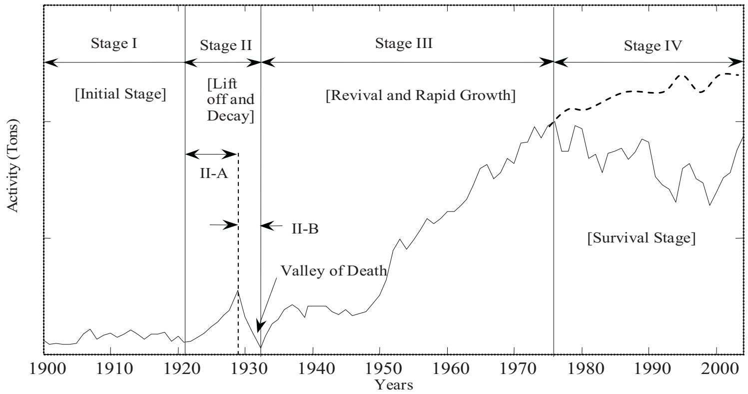

Figure 3. Illustration of a Typical Long-term Life Cycle for a Metal from References 1-3. The plot indicates the division of the life cycle into four stages that is common to metals. All metals may not have all four stages depending on the length of time that the metal has been in use. Such life cycles are also applicable to non-metals.

Figure 3 illustrates an example of a life cycle of a material, comprised of the four previously mentioned stages. Stage I (*Initial Stage*) is the developmental stage that begins with the discovery and the invention of a process and ends when the development of the technology is enough to start low-scale industrial production of the material. Stage II (*Lift Off and Decay Stage*) begins with the rise in the activity of the material and ends at the low point of the activity in the so-called "valley of death." Stage III (*Revival and Rapid Growth*) begins at the "valley of death" and continues through the material's full growth potential with the take-off in activity typically being at a high rate. Stage III ends at the onset of Stage IV (*Survival or Low Growth Stage*) where the material has reached maturity and the activity has leveled off or has begun to die [2,3]. Invention driven activity occurs during Stages I and II while innovation is dominant in Stages III and stage IV. Stages I and II are the periods, in the life of a material, where the invention itself is developed into a market innovation with technological R&D, possibly being very important. Stages I and II may be technically driven whereas Stages III and IV include market, teaming and financial factors. The type of leadership required may evolve as the stages are transitioned [1-3]. Dramatic changes in Patents and Production activity occur in Stages III and IV compared to the early stages, i.e. when innovation becomes the major focus. In these latter stages any early invention is fully developed, mature and possibly patented. R&D is complete for the most part and marketplace interest in the product begins to develop. Stages III and IV are the times in the life cycle of the product for commercial exploitation. Market place effectiveness as well as cost and profit issues predominate. If the invention has not previously been patented, it may be patented now as a means to protect the invention as well as any follow-on innovation that arises from it [1].

Platform equation with Chromium as an example. As shown in Section 3, chromium displays good positive correlation between its activity and patent data. Chromium has been widely used for over several decades. This wide use has provided strong and consistent numbers for production activity as well as patents per year.

The best-fit method requires the determination, by trial and error, of multiple parameters to be entered into an equation and a MatLab computer program, examples of which are found in Appendix 3. The common pattern equation for this method is

$$y = x^n\ [\alpha^n x^2 + \beta^n\ x\ sin(\omega x)] + (exp[(x - \mu)\ /\ v]\ exp[-exp[(x - \mu)\ /\ v]]\ \delta / v), \qquad (1)$$

with the variables, α, β, ω, n, μ, v and δ defined in Table 4 to be determined for each material tested. The original equation in reference [2] is modified by substitution of α and β with α^n and β^n to eliminate the possibility of multiple values of α and n giving equally acceptable R^2. Only one set of α and n give an obvious best R^2, which is the value consistently chosen, with the α^n and β^n equation while the α and β equation might give a less obvious choice concerning the generated R^2 value.

Table 4. **Common Pattern Evaluation Variables.** Variables to be determined in connection with the common pattern equation (1). Normalized years are the span of years under consideration and are represented by x. Production is y. The remaining variables are found through trial and error.

α	Called the "Take-off constant". Facilitates the rate of take-off after the end of Stage II. The rate of growth of activity is very sensitive to α. Dimension is dependent on *n*.
β	Increases the amplitude (visibility) of the cyclicity. Magnitude of cyclicity increase as β decreases. The dimensions of β are dependent on *n*. Dimension is dependent on *n*.
ω	Called the "wavelength constant". Increases in ω increase cyclicity. Value of ω expressed in "per year" and equals $(2*\pi)$/wavelength.
μ	Called the "Stage II location constant". Position of the Stage II hump is shifted to the right as value of μ increases and is expressed in "years".
v	Called the "Stage II scaling constant". As value of v increases, the Stage II hump is stretched out and is also expressed in "years".
δ	As the value of δ increases, the peak (amplitude) of the Stage II hump increases. δ is given in tons.
n	Along with α has a strong influence on the shape of the curve. It is a positive number between 0 and 2. *n* is dimensionless. Dimensionlessness is assured through normalizing by dividing by n_0, which is one.
x	Time in normalized years. Actual year of data (x_r) minus year of origin (x_0).
y	Metric tons per year (In some cases scaled to kilotons, megatons or kilograms). Entered by thousands.

These seven parameters, as well as the date of origin, x_0, of the data are entered into a MatLab computer program which generates an actual curve of the data, a fitted curve and an

R^2 value, which is an established measure of best-fit, and which needs to be as near one as possible to obtain the best fitted curve [1]. The origin, x_0 is determined from the earliest available production data and is usually 1900. Some materials have an x_0 later than 1900 due to lack of data back to 1900 because of missing data or a material whose production, or use, did not begin until after 1900.

Equation 1, from reference [1], is a modified form of the first published form of equation 1, in references [2,3]. It is further noted that n is non-dimensional while α and β have the same units as y. For $x=(x_r-x_0)$, x_r is the actual year of the data and x_0 is the first year of the data set. Also, $n=n/n_0$ where n_0 always takes the value of 1 (below it is noted that n_0 appears to be a universal constant which is determined from Figures 12(a-c)).

The optimal parameters and resulting R^2 value for chromium activity are listed below in Fig. 4. It has been determined that α and n cause the most drastic change in R^2 and are used during the fitting to get the R^2 value closest to one. The origin, x_0, is simply the first year of the data. For chromium, an R^2 of .9731 was found for its production data, which produces a best-fit curve that tracks, the actual data curve that displays Stage III features and indicates a Stage III best-fit for chromium production.

In general, as with chromium, the production is entered in the best-fit production equation as thousands of tons. For many materials this leads to a high R^2 value and also to an eventual shift in origin. In other cases the production must be scaled differently to achieve a high R^2 value and an origin shift. Scaling is sought to achieve the least differential between the scale of the production and patent data. A material with production numbers much larger than its patent numbers may need to be scaled up and entered as thousands of kilotons or megatons. When patent data counts are much greater than production, the production is entered as thousands of kilograms. This procedure allows for a more accurate evaluation of the best-fit of both production and patent data by resulting in R^2 values generally closer to one and resulting origin shifts, but also is representative of the same amount of production only in a different scale. It is possible that the relative changes from year to year in the production data create the features in the plots that determine the stage of the material rather than the scale of the data. A material would be in the same stage whether its data is in tens, hundreds or thousands because the relative changes between data points would be the same from year to year resulting in identical plots with different y-axis scales.[2]

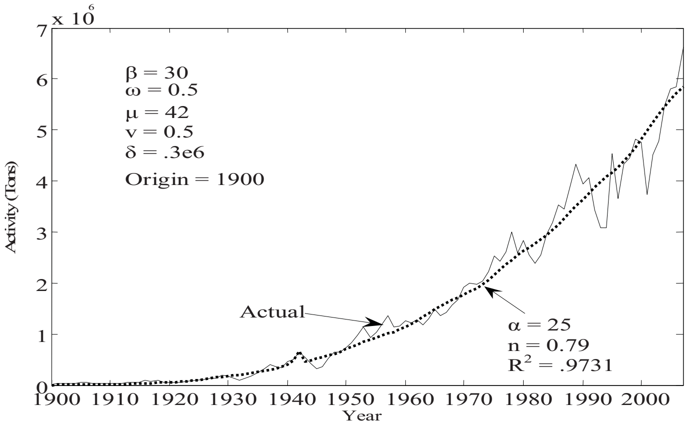

Figure 4. USGS World Chromium Production. Fitted chromium production activity curve with best-fit parameters and R^2 value and origin. The data is from the US Geologic Survey world chromium production by year [78]. Shown in the figure are both the actual data curve and a best-fit curve.

An identical best-fit equation was employed for the patent data using the same parameters as were found for the production activity to generate a modified patent fit curve as apposed to an independent patent best-fit curve which has parameters independent of the production common pattern equation. Minimal changes were made in the program code to allow for differences of the scaling for the plots, i.e. between the production activity and the patent data. The only changes in the parameters were the use of the number of patents data rather than metric tons of production for y, and the choice of origin, x_0. Identical δ were used for modified best fits, but were scaled down on the figures, such as Fig. 5, by a factor of one

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[2] A discussion of scaling is found in Appendix 7.

thousand to better reflect the scale of the Stage II hump in reference to the patent data. The patent data was not entered as thousands as was the production data, but was instead accounted for by scaling the *δ* on the modified best-fit figures. The origin for the patent best-fit was moved a number of years backwards or forwards relative to the origin of the activity best-fit equation, i.e. 1900 for chromium. An R^2 as close to one as possible was sought. In the case of chromium, as displayed on Fig. 5, a shift of origin to 1897, with all other parameters the same, gives an R^2 of .9320 which results in a fitted curve that tracks the actual patent data curve, having stage III attributes, and signifies a possible Stage III fit for chromium patent data.

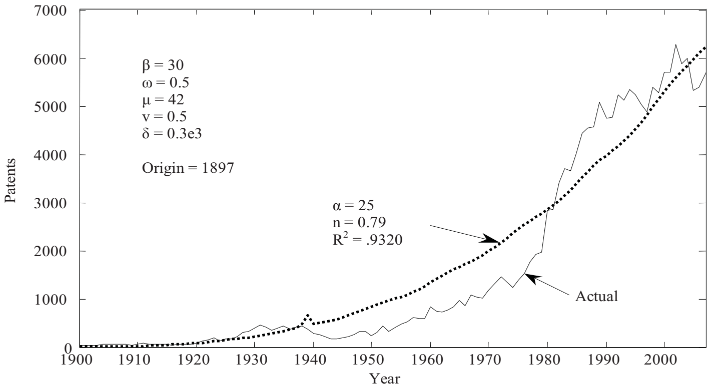


Figure 5. EPO Worldwide Patent Search: Chromium, Cr or Chrome in Title or Abstract by Date of Publication. Chromium modified patent fit curve with best-fit parameters and R^2 value and origin. The data is from the European Patent Office worldwide patents containing chromium or Cr in the title or abstract of the patent by date of publication. ***δ*** scaled down from .3e6 to .3e3 (See Appendix 7).

The origin of 1897 for the chromium patent best-fit curve signifies a 3-year lag for the activity data when compared to patenting. The 3-year lag of production activity can be observed by examining the Stage II hump of the activity curve and that of the patents. Fig. 4 shows the hump at roughly 1942 for the patent best-fit while Fig. 5 shows the hump for activity best-fit at about 1939. Three years after the patent data met this point in its life cycle, the activity data crossed the same normalized position in its own life cycle.

Table 5. **Engineering Material Production, Independent Patent and Modified Patent R^2 Values, Correlation Coefficients (*r*), Origins, Origin Shifts and Stage.** Materials are listed in order of descending Production R^2 values. An origin shift indicates the presence of a material in Stage III of its life cycle. Strong correlation and R^2 values near one are indicators of possible overall Stage III, but are not definitive evidence. Negative Production R^2 values, no correlation and lack of origin shift are indicative of Stage IV materials. (*Estimations were made to fill in gaps in the USGS production data for lead following patterns suggested by existing data. $^+$ Indicates materials using Equation (2) presented below). Possible Stage V materials are indicated.

Material	Production R^2	Independent Patent R^2	Modified Patent R^2	Correlation *r*	Production Origin	Patent Origin	Origin Shift	Stage
Nickel	0.9823	0.9502	0.7331	0.9563	1900	1831	(-)69 years	III
Aluminum	0.9818	0.9554	0.9658	0.9652	1900	1915	(+)15 years	III
Hydraulic Cement	0.9743	0.9328	0.9280	0.9299	1926	1925	(-)1 year	III
Chromium	0.9731	0.9368	0.9320	0.9495	1900	1897	(-)3 years	III
Copper	0.9576	0.9416	0.9320	0.9507	1900	1911	(+)11 years	III
Molybdenum	0.9538	0.9388	0.4214	0.929	1900	1712	(-)188 years	III
Platinum	0.9539	0.9121	0.6065	0.9569	1900	1810	(-)90 years	III
Bauxite/Alumina	0.9521	0.9074	0.4465	0.931	1900	1721	(-)179 years	III
Sulfur	0.9322	0.9678	0.2273	0.9156	1900	1650	(-)250 years	III
Talc	0.9226	0.9108	0.2900	0.9383	1904	1571	(-)333 years	III
Phosphate	0.8815	0.9668	0.5014	0.8708	1900	1741	(-)159 years	III
Zinc	0.8805	0.9617	0.9669	0.9387	1900	1918	(+)18 years	III
Cobalt	0.8796	0.9652	0.3584	0.9269	1901	1645	(-)256 years	III
Gypsum	0.8740	0.9543	0.7123	0.9211	1924	1865	(-)59 years	III
Lithium	0.867	0.9284	0.5000	0.9272	1925	1819	(-)106 years	III
Titanium	0.86	0.9620	0.9630	0.9151	1925	1926	(+)1 year	III
Iron	0.8599	0.9329	0.6888	0.8741	1904	1815	(-)89 years	III
Salt	0.8438	0.9782	0.3468	0.8996	1913	1663	(-)250 years	III
Kyanite	0.8387	0.9040	0.8825	0.9242	1928	1948	(+)20 years	III
Rare Earths	0.8256	0.8152	0.4483	0.97	1900	1799	(-)101 years	III
Niobium	0.8235	0.5007	0.5237	0.7545	1964	1827	(-)137 years	III
Magnesite	0.8231	0.7719	0.5681	0.8108	1913	1743	(-)170 years	III
Graphite	0.8122	0.9617	0.9045	0.9287	1900	1876	(-)24 years	III
Vanadium	0.8038	0.5164	0.7590	0.784	1960	1870	(-)90 years	III
Feldspar	0.7833	0.7775	0.4073	0.949	1908	1800	(-)108 years	III
Barite	0.7803	0.8540	0.3185	0.7486	1919	1760	(-)159 years	III
Magnesium	0.7502	0.9733	0.7010	0.9078	1937	1854	(-)83 years	III
Nitrogen	0.7316	0.8936	0.4491	0.9164	1946	1770	(-)176 years	III
Antimony	0.7192	0.9664	0.7644	0.8518	1900	1825	(-)75 years	III
Iodine$^+$	0.7185	0.3816	0.6347	0.9105	1960	1827	(-)133 years	III
Zirconium	0.6913	0.8964	0.9536	0.9239	1944	1923	(-)21 years	III

Potash	0.6511	0.0208	-	-0.1414	1951	-	No Shift	IV
Tungsten	0.6449	0.8969	0.3494	0.742	1905	1673	(-)232 years	III
Helium	0.6286	0.8457	0.4755	0.746	1935	1779	(-)156 years	III
Silicon^{+}	0.6029	0.6195	0.8980	0.8893	1964	1934	(-)30 years	III
Manganese	0.5728	0.9132	0.9666	0.6835	1900	1923	(+)23 years	III
Fluorspar	0.5703	0.8372	0.4717	0.7399	1913	1800	(-)113 years	III
Tantalum	0.5484	0.3886	-	0.7181	1969	-	No Shift	IV
Lead^{*+}	0.5368	0.9172	0.7303	0.7013	1900	1859	(-)41 years	III
Silver	0.5027	0.7582	0.3484	0.8735	1900	1921	(+)21 years	III
Boron	0.4209	0.4225	-	0.8691	1964	-	No Shift	IV
Asbestos	0.3850	0.0131	-	0.7288	1900	-	No Shift	IV-V
Gold	Negative	Negative	-	0.9385	1900	-	No Shift	IV
Arsenic	Negative	0.8399	-	0.3375	1910	-	No Shift	IV
Beryllium	Negative	0.0455	-	0.1132	1935	-	No Shift	IV-V
Bismuth	Negative	0.9463	-	0.7651	1937	-	No Shift	IV
Cadmium	Negative	0.8552	-	0.7401	1900	-	No Shift	IV
Mercury	Negative	0.8454	-	-0.1117	1900	-	No Shift	IV-V
Selenium	Negative	0.7969	-	0.6871	1938	-	No Shift	IV
Tin	Negative	0.9400	-	0.6576	1905	-	No Shift	IV

The remaining materials were also evaluated using the same best-fit procedure. However, in the cases of iodine, lead and silicon, where the first year of the production data is much greater then zero, a further modification was made to Equation 1 in order to obtain a more reasonable R^2 value. A constant, $C1$, was added to both the production and modified patent equation giving

$$y = C1 + x^n [\alpha^n x^2 + \beta^n x \sin(\omega x)] + (\exp[(x - \mu) / v] \exp[-\exp[(x - \mu) / v]] \delta / v). \qquad (2)$$

$C1$ was equal to the first year of production for the specific material and allowed the fitted curve to match up better with the actual production producing an R^2 closer to one. In effect, the addition of $C1$ is a form of scaling similar to that discussed above, and in Appendix 7, causing the actual production data to be closer to the generated fitted data.

Table 5 shows that seven materials had lags in their patent life cycles, indicating positive shifts forward in years in their fitted patent life cycles compared to their production activity life cycles. Positive shifts forward in origin mean that activity occurs before the patents and that patent output may be driven by the activity. Thirty-one materials have lags in their activity life cycles, rather than a lag in the patent life cycles, which illustrate negative shifts backwards in these materials' fitted patent life cycles. Negative origin shifts indicate that the patent production precedes the activity of the material and that the patents may drive the activity. Fig. 6 and Fig. 7 display these shifts graphically for chromium and zinc and show a negative and positive lag respectively.

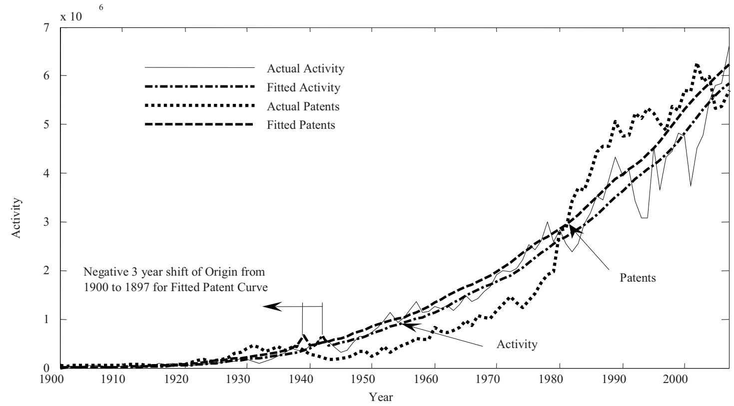


Figure 6. **Chromium Best-Fit Activity and Patents.** Plot showing the origin shift of patent and activity best-fit curves for chromium. The shift is negative, indicating patent activity occurring before production activity and thus possibly driving the production.

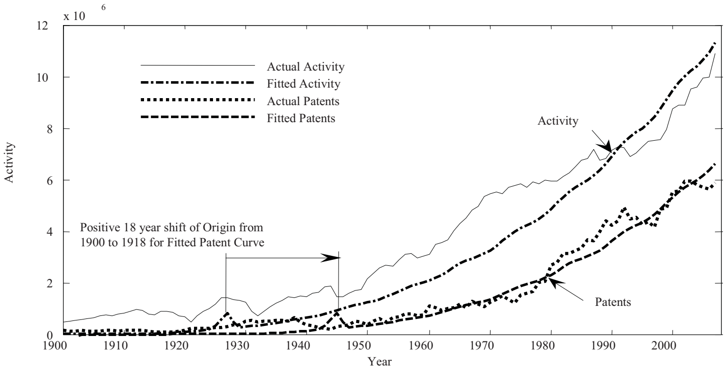


Figure 7. Zinc Best-Fit Activity and Patents. Plot depicting the origin shift of patent and activity best-fit curves for zinc. The shift is positive, indicating patent activity occurring after production activity and thus possibly being driven by the production.

The shifts in the fitted patent life cycles appear to be dependent on the material itself and outside factors affecting production and patenting. A negative shift, or lag in the activity life cycle illustrates where patenting precedes the production of the material and suggests that patenting may drive production. In such cases the patent represents the innovation that drives the economy and causes production of the material. The positive shift, or lag, of the patent life cycle may be attributed to the case where production of a material precedes the patenting of ideas related to that material. Invention and innovation follow and are possibly driven by production of the material. A lack of a shift occurred in all cases where Stage IV behavior might be evident and may indicate a lack of innovation [1,83]. The case where patents drive activity could be analogous to innovation driving the economy in a creative manner. Patents give an incentive to innovate by offering property rights and cause increased production activity as a result. In the same way, the destructive activity of innovations, where they destroy to build the economy anew, may be analogous to activity leading patents, where patents are employed to prevent innovators from effectively competing [1,83].

Correlation theory and best-fit analysis provide tools for the examination of the life cycle of a material. Through study and manipulation of the production and patent data of materials, curves can be generated that can be used as indicators in determining the stage where a specific material resides in its life cycle by looking for the classic features common to the four identified material stages identified in Fig. 3.

Stage Indication

The estimated stage of the material is based upon a combination of indicators that point towards the stage in its life cycle that the material is in. Strong correlation is the first indicator of possible Stage III (Table 3), which is illustrated by a graphical plot of the production and patent data. At times the plots relating to correlation reveal curves with Stage

III features. This first indicator signals possible Stage III when the correlation coefficient is strong, or approaching one. Best-fit R^2 values approaching one for either or both the production activity and patent data of a material are also indicators of a possible Stage III material. Such R^2 values are produced for curves that have Stage III life cycle attributes as shown in Fig. 3. and are generated from Eq. 1 using linear alphas, which are found to generate Stage III best-fit curves [2].

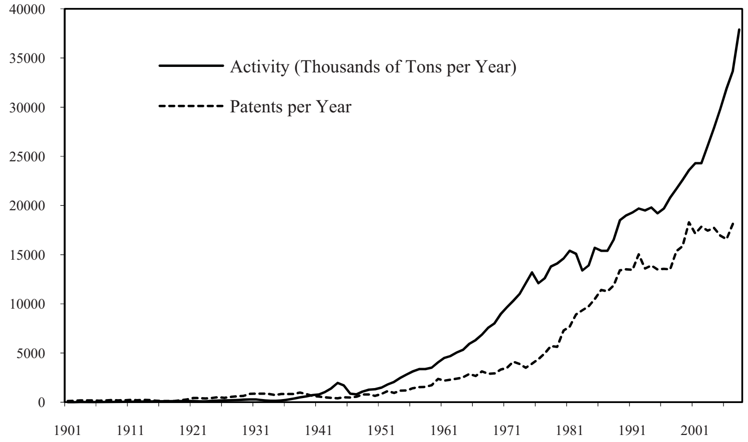


Figure 8. Aluminum: Activity and Patents. Aluminum Production curve displaying typical Stage III features. “Valley of Death” crossed in 1946 with high rate of growth since and into 2007 with patents tracking the growth, indicating continuing innovation.

Aluminum is shown to be an estimated Stage III material in Fig. 8, where in 2007 it is still exhibiting rapid innovative stage (stage III) growth and has strong correlation and R^2 values approaching one. Stage IV behavior is displayed by arsenic in Fig. 9. Arsenic shows no rapid growth, but instead a general leveling off with local oscillations depicted, indicating less innovative activity and has weak correlation and a negative production R^2. In examples such as aluminum and arsenic the stage of the material is suggested by examining the plots of the activity and patents as well. In cases where there is no clear delineation between stage III and IV, as in manganese in Fig. 10, the correlation coefficient, r, and the best-fit R^2 and origin shifts can be employed as indicators in the determination of the possible stage of the material.

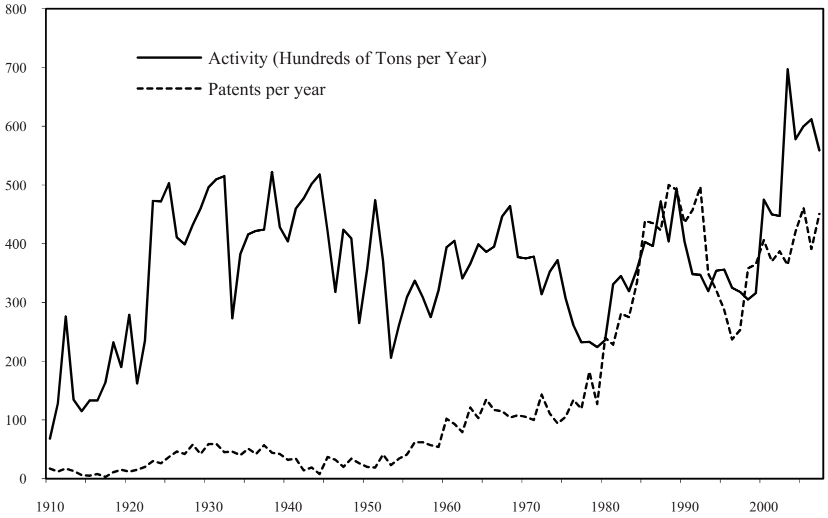


Figure 9. Arsenic: Activity and Patents. Arsenic production curve displaying typical Stage IV features. This material appears to have reached maturity with no more sustained rapid growth and activity generally leveling off. Oscillations for growth and shrinkage are common in Stage IV materials. Production is stagnant in a time averaged since, but patents grow in number.

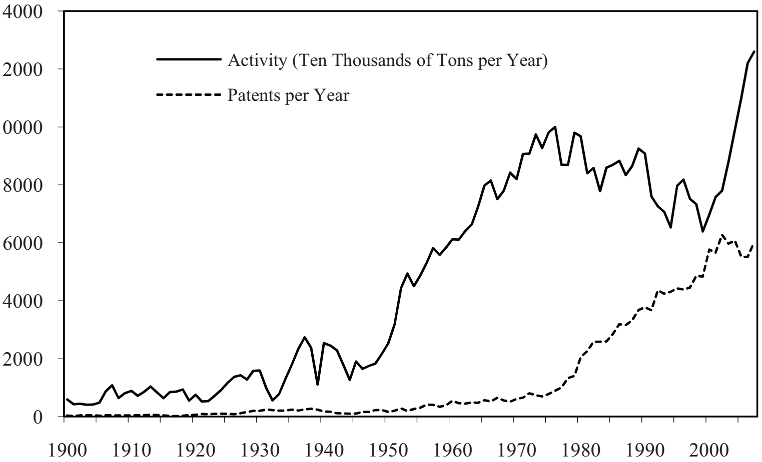


Figure 10. **Manganese: Activity and Patents.** Manganese production curve possibly illustrating a material fluctuating between Stage III and IV. As indicated by Best-fit analysis below Manganese is in Stage III in 2007. However, in 2005 when the data was studied,, Mn appeared to be a Stage IV material. This suggests that materials can be in a place in their life cycle where they fluctuate between stages depending on the production numbers for those years.

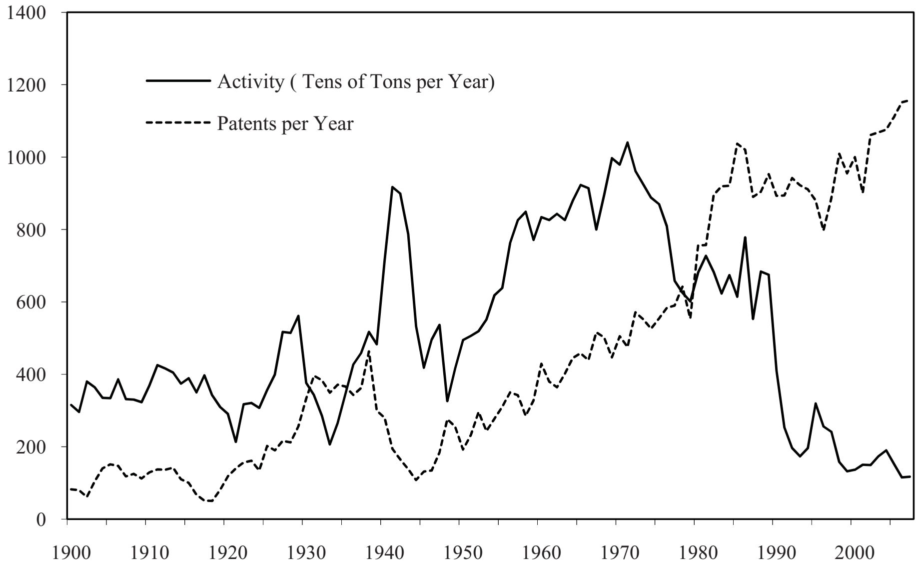


Figure 11. Mercury: Activity and Patents. Mercury production curve displaying a possible Stage V. Production is well beyond the survival stage and has greatly dropped in a sustained manner. Correlation theory indicates little relationship between production and activity and Best-fit analysis produces a negative R^2. There is very little production for any patents to drive.

Mercury, in Fig. 11, presents an interesting case. It has a negative R^2, its correlation coefficient is negative, which indicates no relationship between production and patents, and there is no shift in its origin. Fig. 11 presents a curve that reveals no growth, and not even a leveling off, but instead a sustained downturn in production having no signs of stopping. Mercury appears to be in its death throes of production, due to its toxicity and environmental concerns regarding it [90]. Production of this material is being replaced by recycling of presently available material. Any innovation associated with mercury is generally innovation away from it or in replacement of it, which would explain increasing patenting activity seen in Fig. 11 [90]. Such a material could be in a Stage V or "Final Death Stage." Other toxic materials such as asbestos and beryllium exhibit such behaviors and could be called Stage V materials as well.

Sometimes the stage of a material is suggested by the appearance of its curves. In other cases the stage is not obvious, but the combination of these indicators allows an intelligent inference of the stage of a metal or non-metal. From this, assumptions can be made concerning the innovative activity, past and present, of a material allowing for more educated and informed decisions concerning the future behavior of a material and more efficient development and use of them. A more definitive method is needed that will strongly identify a material as being in Stage III rather than just indicating the possibility of it existing. Such a novel method is presented below utilizing the origin shift of the patent best-fit data that is present in all materials that exhibit the above mentioned Stage III indicators.

Section 5: Best-Fit, Origin Shift and Innovation

The best-fit approach can be applied to comparisons of activity and patent data with patent and origin shifts, allowing inferences to be made concerning the relationship of innovations to production. For this application, the best-fit equation and program were applied to all of the studied materials' activity and patent data independently. This analysis was performed successfully on the materials listed below in Table 6. These materials were estimated to be in Stage III since, in general, they had strong correlation, High R^2 values and production plots that revealed common Stage III attributes. Origin shift analysis was not successful in the remaining materials where an origin shift could not be found and where such materials were considered to be in Stage IV due to their weak correlation, low R^2 values and production curves that exhibited Stage IV features. The presence or absence of an origin shift verified these stage assumptions in all cases.

Table 6. α and n Parameters, α^n Ratio and Origin Shifts, Origin Ratios and Modified R^2. Alpha and *n* are from the pattern equation. Ratio of α^n indicates strength of the driving force of the material. The farther the ratio is from one, in either direction, the greater the driving force. A positive origin shift could indicate patents being driven by production. A negative origin shift suggests production being driven by patents. A positive origin shift results in an origin ratio greater than one, while a negative origin shift leads to an origin ratio less than one. Note that (n_a/n_p) is less than one when the origin shift is negative and one or greater when the shift is positive. Modified R^2 generally becomes smaller then one as the origin ratio moves farther from one. The materials are listed by descending order of origin shift and origin ratio.

	α_a	n_a	α_a^n	α_p	n_p	α_p^n	**Drive Ratio**	n_a/n_p	**Origin Shift**	**Origin Ratio**	**Modified R^2**
Manganese	23	0.9	16.81	22	0.8	11.86	1.418	1.13	+23	1.012	0.5728
Silver	5	1.2	6.90	3	1.1	3.35	2.060	1.09	+21	1.011	0.3484
Kyanite	22	0.6	6.39	16	0.5	4	1.597	1.2	+20	1.010	0.8825
Zinc	20	0.9	14.82	24	0.8	12.71	1.17	1.13	+18	1.009	0.9669
Aluminum	13	1.1	16.80	15	1.0	15	1.12	1.1	+15	1.008	0.9658
Copper	13	1.0	13	9	1.0	9	1.44	1	+11	1.006	0.9320
Titanium	19	1	19	18	1	18	1.06	1	+1	1.001	0.9630
Hyd. Cement	15	0.5	3.87	15	0.51	3.98	0.973	0.980	-1	0.999	0.9280
Chromium	25	0.79	12.72	26	0.8	13.55	0.939	0.99	-3	0.998	0.9320
Zirconium	16	0.85	10.56	15	1	15	0.704	0.85	-21	0.989	0.9536
Graphite	18	0.6	5.66	16	0.7	6.94	0.813	0.86	-24	0.987	0.9045
Silicon	16	1.2	27.85	16	1.5	64	0.435	0.8	-30	0.985	0.8980
Lead	12	0.8	7.30	23	0.9	16.81	.434	0.89	-41	0.978	0.7303
Gypsum	28	0.4	3.79	34	0.6	8.30	0.457	0.67	-59	0.969	0.8740
Nickel	43	0.58	8.86	14	0.9	10.75	0.824	0.64	-69	0.964	0.7331
Antimony	42	0.3	3.07	35	0.5	5.92	0.519	0.6	-75	0.961	0.7644
Magnesium	15	0.7	6.66	25	1	25	0.266	0.7	-83	0.957	0.7010
Iron	13	0.7	6.02	27	0.9	19.41	0.31	0.78	-89	0.955	0.6888
Vanadium	75	0.4	5.62	21	0.9	15.49	0.363	0.44	-90	0.954	0.7590
Platinum	14	0.5	3.74	31	0.7	11.07	0.338	0.71	-90	0.953	0.6065
Rare Earths	22	0.26	2.23	33	0.5	5.74	0.389	0.52	-101	0.947	0.4483
Lithium	23	0.5	4.80	16	0.9	12.12	0.396	0.56	-106	0.945	0.5000
Feldspar	11	0.01	1.02	11	0.3	2.05	0.499	0.033	-108	0.943	0.4073
Fluorspar	1	0.003	1	15	0.3	2.25	0.444	0.01	-113	0.941	0.4717
Iodine	10	0.4	2.51	9	1	9	0.279	0.4	-133	0.932	0.6347
Niobium	16	0.5	4	13	1.16	19.6	0.204	0.43	-137	0.930	0.5237
Helium	20	0.23	1.99	15	0.7	6.66	0.299	0.33	-156	0.919	0.4755
Phosphate	30	0.35	3.29	27	0.7	10.05	0.327	0.5	-159	0.916	0.5014
Barite	14	0.017	1.05	18	0.4	3.18	0.329	0.04	-159	0.917	0.3185
Magnesite	35	0.08	1.33	43	0.4	4.50	0.295	0.2	-170	0.911	0.5681
Nitrogen	14	0.56	4.38	13	1.2	21.71	0.202	0.47	-176	0.910	0.1770
Alumina	59	0.3	3.40	26	0.7	9.78	0.347	0.43	-179	0.906	0.4465
Molybdenum	17	0.36	2.77	36	0.7	12.29	0.226	0.51	-188	0.901	0.4214
Tungsten	27	.23	2.13	17	.7	7.27	0.294	0.33	-232	0.878	0.3494
Sulfur	20	0.25	2.11	16	0.8	9.19	0.230	0.31	-250	0.868	0.2273
Salt	19	0.47	3.99	20	1	20	0.200	0.47	-250	0.869	0.3468
Cobalt	24	0.2	1.89	15	0.7	6.66	0.284	0.29	-256	0.865	0.3584
Talc	1	0.01	1	17	0.5	4.12	0.243	0.02	-333	0.825	0.2900

The use of the pattern equation creates a relationship between α and *n* that can be evaluated and compared to origin shifts produced by independent patent and production activity best-fit derivations. A graphical representation, such as Fig. 12, of the relative scale, or distance, of the origin shift can be made, using a ratio of the shift and the origin, x_0, of the production data, indicating an absolute amount that the patent or activity driving force has on the other. This ratio, called the Origin Ratio, composes the x-axis of Fig. 12 and is defined as

$$\text{Origin Ratio} = (x_0 + OS)/x_0 \qquad (3)$$

where x_0 equals the production data origin and OS is the shift in origin of the best-fit patent data. The origin ratio is dimensionless since x_0 and OS are both in years which are then cancelled out. The y-axis of Fig. 12 is the drive ratio of the material and is expressed as

$$\text{Drive Ratio} = (\alpha^n)_a/(\alpha^n)_p \qquad (4)$$

where $(\alpha^n)_a$ equals the modified patent best-fit variable alpha to the n power, which is the same as the alpha and n from the production activity best fit equation, and $(\alpha^n)_p$ is equal to the independent patent best-fit variable alpha raised to the power n, in both cases n, being best-fit variables. The drive ratio is dimensionless as well since $(\alpha^n)_p$ is generated from a best fit equation having data with patents as units. Likewise, $(\alpha^n)_a$ results from a modified patent equation, that is used to generate the origin shift, having units of patents. These units cancel each other upon calculation of the ratio. Such a curve with the origin ratio on the x-axis and the drive ratio on the y-axis may effectively represent innovative behavior.

Table 6 presents the α and n values for the independent activity and patent data and the original origin shifts and origin ratio derived for predicted Stage III materials in Section 4 as well as α^n and drive ratios. The drive ratio generally becomes progressively larger than one, as the origin ratio grows larger than one, which represents the origin shift moving away from zero in a positive shift direction. Likewise, the drive ratio approaches zero as the origin ratio becomes progressively smaller away from one, which is representative of the origin shift moving further in the negative direction from zero as shown in Figs. 12(a, b and c) below. The figures show the calculated positions for all those materials that possess a shift in origin. Note that the activity of nitrogen is possibly being driven the most by its patents since its ratio is nearest to zero for materials whose activity is driven by patents. Similarly, the patents of silver may be driven the most by its activity because its ratio is farthest from one for materials whose patents are driven by activity.

Three patterns emerge from the best-fit analysis shown in Table 6. The first is that when a positive origin shift is indicated, the drive ratio is always above one (the ratio is always less than one and approaches zero when the origin shift is negative). Second, when n_a is divided by n_p the result is always less then one for materials that have negative shifts in origin and the result is always one or greater for materials with a positive origin shift. While n_a is the value for the n variable for the activity best-fit evaluation, n_p is the value for the independent patent best-fit evaluation. The ratio between them may be indicative of the driving force of the material. Lastly, as the origin ratios move away from one in either direction the modified patent R^2, which is generated by patent data being run with the common pattern equation production parameters, generally becomes smaller than one. As indicated in Table 6 and on Fig. 12(a) materials such as talc, sulfur, cobalt and salt have origin ratios the farthest below one and lower modified R^2 than do materials with ratios nearer to one. In the same way silver, and manganese have the highest origin ratios and have R^2's less than materials with origin ratios near to one. This could indicate that materials approach Stage IV when they reach origin ratio extremes and enter stage IV when modified R^2 values become too small to support an origin shift or origin ratio.

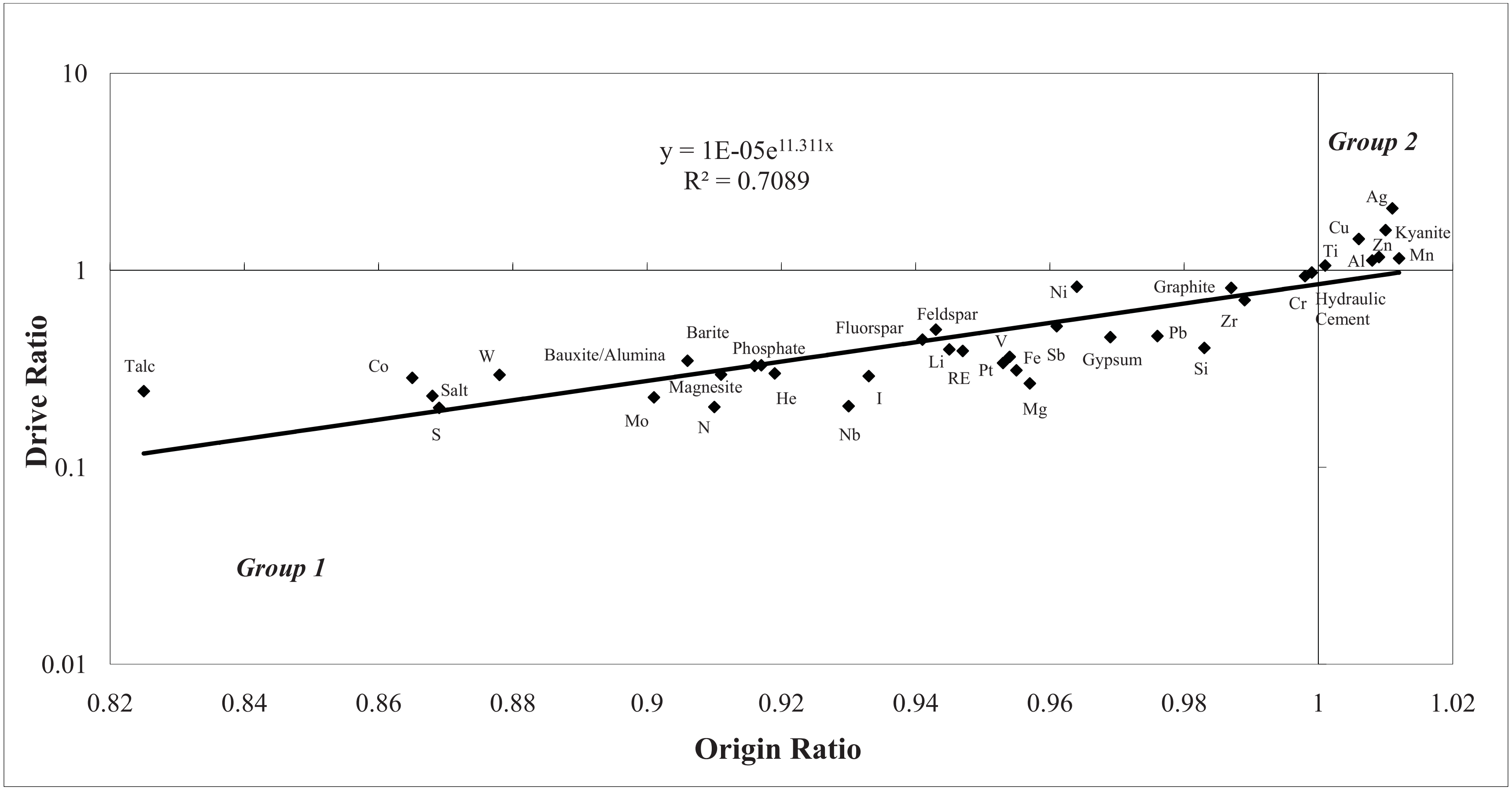


Figure 12(a). Engineering Materials Origin vs. Drive Ratio. Origin Ratio vs. Drive Ratio displaying relative strength of driving force of either patents or production activity. The driving force of nitrogen is strongest for a material whose production activity is driven by its patents since its ratio is farthest below one. The driving force of silver is strongest for a material whose patents are possibly driven by its production activity since its ratio is farthest above one. Alternately, the difference could be couched in terms of a hypothesis that elements like Niobium are driven by technical reasons or in other words, the innovation is highly technically influenced whereas the influence of new material technology on innovation diminishes for materials like Kyanite and Cu. Note also that the cross over point occurs at 1 (y-axis). The origin shift is the shift described in section 3 between the best-fit activity and best-fit patent evaluations for each material using the common pattern equation (1).

Fig. 12(a) appears to divide the materials evaluated into two groups. Group 1 is composed of materials whose patent activity is driving their production as suggested by the lag in production. The remaining materials in Group 2, are those in which patenting is driven by production suggested, conversely, by a lag in patenting. Stage IV materials do not fit into either of these groups and are possibly commodities in the full sense of the word whose pricing is fully set by demand and supply and with no supplier having a technological edge and no driving force associated with them.

Group 1 materials, according to their drive ratios had more than one patent published per normalized unit of production where patents may be thought to *drive* production activity. Nitrogen, for example, had one patent published per 0.202 normalized units of production. Group 2 materials had less than one patent published per normalized unit of production where the patents are possibly *driven* by production. For instance, silver had one patent published per 2.060 normalized units of production according to its drive ratio. In other words for each normalized unit of nitrogen production, 4.95 patents are found to be driving the production and for each normalized unit of silver production 0.49 patents are being driven by that unit of production. These results may be interpreted to mean that Group 1 is more innovatively active since more patents are required to drive one unit of production than Group 2 where production drives patents. Group 2 still is still innovatively active, but not as much as Group 1.

Alternatively, Fig. 12(b) presents materials whose production activity R^2 values are higher than 0.85 as opposed to Fig. 12(a) that includes all calculated values. The overall R^2 for the equation of the plot for 12(b) is higher than that of 12(a) indicating that higher best-fit R^2 values may predict a more accurate picture of what materials are in Stage III of their life cycles.

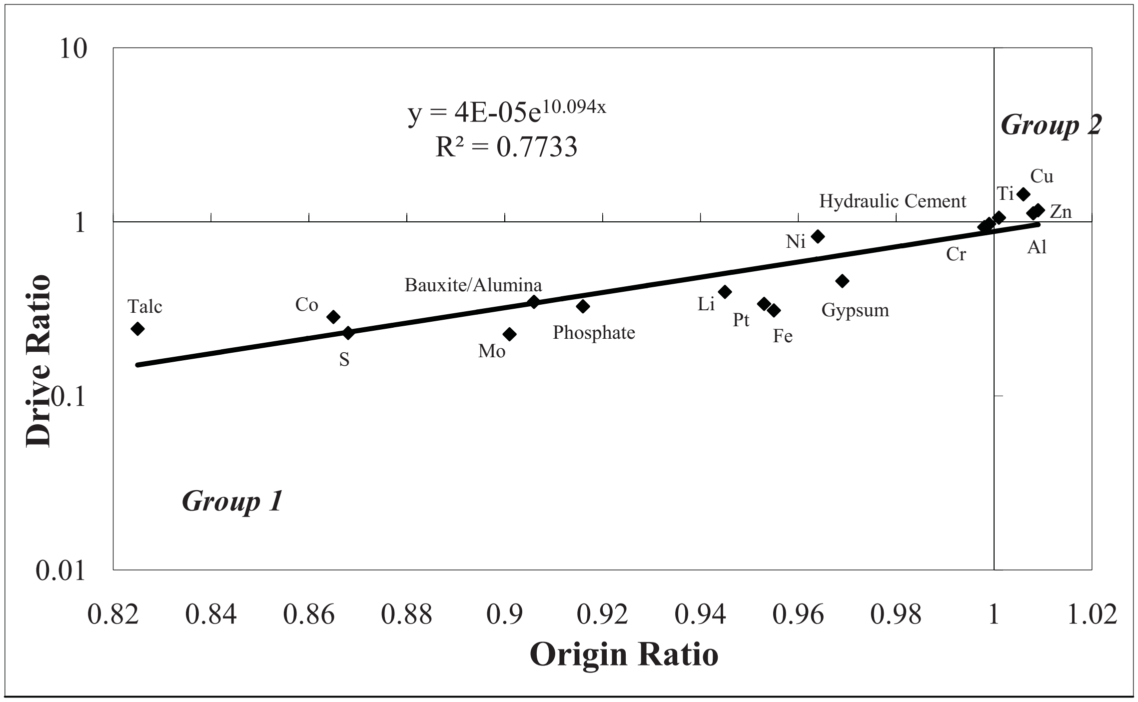


Figure 12(b). Engineering Materials With R^2 Over 0.85 Origin Ratio vs. Drive Ratio. Displays relative strength of driving force of either patents or production activity of materials with production activity R^2 values of over 0.85. This figure has higher overall R^2 value than Fig. 12(a) and crosses y-axis near one.

Figure 12(a) presents all materials whose data were capable of revealing best-fit R^2 values for their production data, then an R^2 value and an origin shift for their patent data when plugged into the same best-fit equation. An origin shift presents strong evidence of a Stage III material since a shift in origin displays driving or driven innovation and innovative activity is most strongly associated with Stage III. Better evidence of Stage III may be presented when a best-fit equation is run with the patent data first, resulting in a second patent R^2 value. Then the production data is plugged into the equation, leading to a second production R^2 and resulting origin shift. For the thirty-eight materials in Table 6, evaluation as just described led to twenty-one materials having new R^2 values for patents and production as well as a new origin shift in the opposite direction of the original as shown in Table 6. The data and evaluations of the remaining seventeen materials would not support a second set of R^2 values.

Table 7. Origin Ratios, Shifts and R^2. 1st production and patent R^2 represent the case where a production best-fit equation and R^2 were established then patent data was plugged into the equation resulting in a patent R^2 and an origin shift. Likewise, 2nd production and patent R^2 represent the case where a patent best-fit equation and R^2 were established first, rather than production as was done first previously, then production data was plugged into the equation resulting in a production R^2 and an origin shift. The 2nd shifts for all materials were in the opposite directions than the 1st shifts. The Avg. shift is the average of the absolute values of the two shifts, 1st and 2nd, with the sign of the 1st shift being employed in all cases for consistency. As a convention the sign chosen was the same as the 1st shift, but could be the sign of the 2nd if all are kept consistent.

Material	Production (1st) R^2	Modified Patent (1st) R^2	Shift (1st)	Patent (2nd) R^2	Modified Production (2nd) R^2	Shift (2nd)	Avg. Shift	Origin Ratio
Aluminum	0.9818	0.9658	(+)15	0.9554	0.9562	(-)17	*(+)16*	1.008
Antimony	0.7192	0.7644	(-)75	0.6640	0.9076	(+)65	*(-)70*	0.961
Bauxite	0.9521	0.4465	(-)179	0.9074	0.3453	(+)50	*(-)114.5*	0.906
Chromium	0.9731	0.9320	(+)3	0.9368	0.9698	(+)4	*(-)3.5*	0.998
Copper	0.9576	0.9320	(+)11	0.9416	0.9728	(-)13	*(+)12*	1.006
Feldspar	0.7833	0.4073	(-)108	0.7775	0.9789	(+)48	*(-)78*	0.943
Graphite	0.8122	0.9045	(-)24	0.9617	0.6803	(+)21	*(-)22.5*	0.987
Gypsum	0.8740	0.7123	(-)59	0.9543	0.6674	(+)42	*(-)50.5*	0.969
Hyd. Cem.	0.9743	0.9280	(-)1	0.9326	0.9732	(+)2	*(-)1.5*	0.999
Iron	0.8599	0.6888	(-)89	0.9329	0.0501	(+)49	*(-)69*	0.953
Kyanite	0.8387	0.8825	(+)20	0.9040	0.9293	(-)28	*(+)24*	1.010
Lead	0.5368	0.7303	(-)41	0.9172	0.1267	(+)40	*(-)40.5*	0.979
Manganese	0.5782	0.9666	(+)23	0.9132	0.7614	(-)36	*(+)29.5*	1.012
Nickel	0.9823	0.7331	(-)69	0.9502	0.7436	(+)41	*(-)55*	0.964
Platinum	0.9539	0.6065	(-)90	0.9121	0.9370	(+)48	*(-)69*	0.953
Rare Earths	0.8256	0.4483	(-)101	0.8152	0.8547	(+)43	*(-)72*	0.947
Silicon	0.6029	0.8980	(-)30	0.6195	0.6801	(+)31	*(-)30.5*	0.984
Silver	0.5027	0.3484	(+)21	0.7582	0.5563	(-)51	*(+)36*	1.011
Titanium	0.8600	0.9630	(+)1	0.9620	0.8774	(-)3	*(+)2*	1.001
Zinc	0.8805	0.9669	(+)18	0.9617	0.9650	(-)24	*(+)21*	1.009
Zirconium	0.6913	0.9536	(-)21	0.8964	0.4545	(+)17	*(-)19*	0.989

Table 7 contains two sets of two R^2 values and their resulting origin shifts and ratios as well as the average of the absolute values of the shifts. Origin shifts and R^2 values were sought by evaluating the production data first, then plugging in the patent data and then doing the same using the patent data first. In this way, four R^2 values are obtained as well as two origins, which have opposite signs. The opposite signs indicate that in one case the production or patents are the driving force and in the other case they are the driven force. For example, aluminum's 1st R^2 values indicate that its production is driving its patents by the positive origin shift. The 2nd R^2 values, on the other hand, reveal that the patents are being driven by the production as shown by the negative shift in origin. Each set of R^2 values is revealing the same behavior, but from opposite directions. This leads to the averaging of the absolute value of the shifts, which may reveal a more accurate picture of the materials origin shift, innovative behavior and reaffirm the material as Stage III.

Figure 12(c) presents the shifts of the materials found in Table 7 and another method to express the drive ratio and evidence of Stage III. The results in it are similar to Fig. 12(a) and 12(b) with an exponential Drive Ratio/Origin Ratio plot that crosses the logarithmic y-axis near one and a fairly constant slope. The three Drive Ratio/Origin Ratio plots indicate materials that are in Stage III of their life cycles due to the presence of innovative driving forces coupled with the idea that innovative behavior is strongest in Stage III.

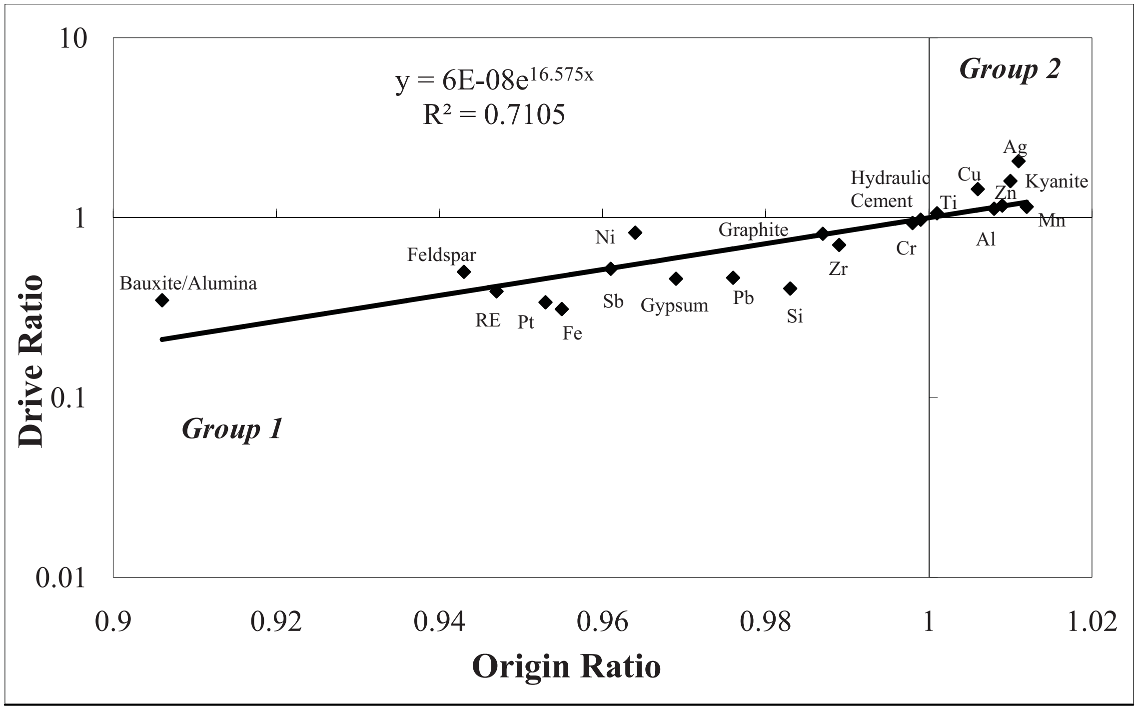


Figure 12(c). Engineering Materials With Two R^2 and Origin Shifts Origin Ratio vs. Drive Ratio. Displays relative strength of driving force of either patents or production activity of materials with two sets of two R^2 values and two origin shifts. Again, the plot crosses the y-axis near one and an overall R^2 value near that of Fig. 12(a).

Section 6: Energy Sources

An important goal of this dissertation is the determination of whether energy sources behave in a similar pattern as do engineering materials and if they can be evaluated in a like manner. Due to climate change and scarcity of energy resources there is a great interest in the development, diffusion and innovation of renewable, sustainable and carbon friendly forms of energy as well as policies that may be adopted by governments to utilize these clean energy sources [92-126]. The application of life cycle, best-fit and origin shift analyses as well as correlation theory to such energy sources would be a valuable addition to the understanding of their behavior. Accordingly, these procedures were applied to the energy sources listed in Table 2. Following the application of correlation theory, best-fit and origin shift analyses to engineering materials the same procedures were performed on the energy sources in Table 2. Due to the availability of consistent and continuous data sets, United States production for energy sources was chosen. Worldwide statistics were not available for the years to be researched on a complete basis and for many of the systems investigated there was no data.

Data Collection

The patent data for energy sources and materials was collected from the European Patent Office (EPO) web site in the same manner as described previously for engineering materials. Worldwide searches of patent counts per year were performed for each energy source using keywords in the titles and abstracts of published patents. Worldwide patent counts were made, rather than patent counts from only the USPTO, due to the existence of patent treaties which result in the effects of the innovation, that are represented by patents, being more global in scope. The global scope would lead to U.S. innovation relating to the U.S. production of these energy sources being affected by the honoring of patents from other

PCT member nations making worldwide patent counts legitimate for the purposes of this dissertation.

Production activity data for these systems and materials were collected from the U.S. Energy Information Administration (EIA), which is affiliated with the United States Department of Energy [91]. The data found on this site from this agency is consistent and complete for the years and energy sources required. The energy source production data for all energy sources is reported in billion or quadrillion Btu and then converted to kilo joules (kJ). Detailed production definitions can be found in Appendix 4.

Patent and Production Activity Data Correlation

The selected energy sources were subjected to the same correlation evaluations that were performed above on engineering materials. Correlation was sought between data sets relating to the production of kJ for energy sources, per year, and data sets composed of patents published per year for the same energy source. As with the evaluated engineering materials, a coefficient constant, r, and $100r^2$ were generated for each energy source listed in Table 8 below. Comparative plots of the generated production and activity were generated as well and can illustrate graphically the extent of any correlation that is present. Examples of such graphical illustration are found in Figs. 13 and 14. Figure 13 presents the correlation between the production activity and patents of wind energy and reveals a strong correlation and coefficient, r, of 0.9681. Figure 14 represents the correlation of the production activity and patent data of U.S. oil energy production and indicates a lack of correlation or coefficient, r, of -0.4862.

Table 8 reveals that there exists some degree of correlation for the production and patent data sets for energy sources except for U.S. oil energy. A relationship is thus exhibited between the production and patenting or innovation of energy resources allowing an assumption that changes in one data set cause or are caused by changes in the other set of data as was shown for engineering materials. Further analysis of this data is thereby more reliable due to this proven correlative relationship. It is also apparent that energy sources behave in a similar manner as engineering materials when correlation theory is applied.

Table 8. Energy Sources Correlation Coefficients *r* and *100r*^{2}. Some correlation between production and patents exists to some degree for all energy sources except U.S. oil energy.

Material	Overall Correlation Coefficient *r*	(100) r^2
US Biofuel Energy	0.9469	89.67%
US Biomass Energy	0.5624	31.63%
US Coal Energy	0.8235	67.82%
US Fossil Fuel Energy	0.5956	35.50%
US Geothermal Energy	0.6660	44.36%
US Hydroelectric Energy	0.3617	13.0%
US Natural Gas Energy	0.4728	22.36%
US Nuclear Energy	0.8541	72.95%
US Oil Energy	-0.4862	-23.64%
US Renewable Energy	0.4030	16.24%
US Solar Energy	0.4786	27.90%
US Total Energy	0.8064	65.02%
US Wind Energy	0.9681	93.72%
US Wood Energy	0.8271	68.40%

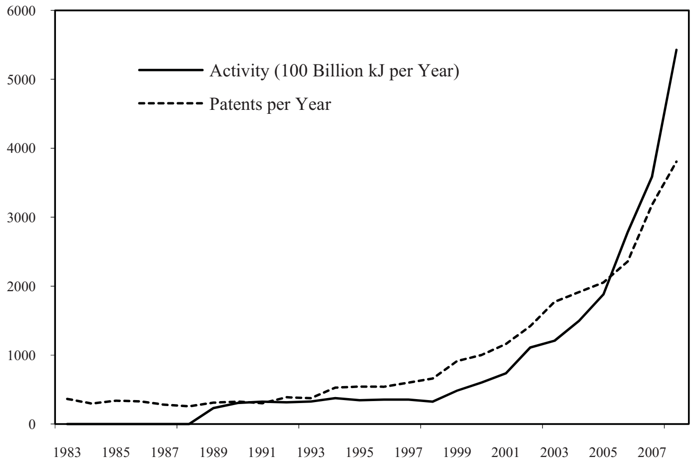


Figure 13. **U.S. Wind Energy Activity and Patents.** A strong correlation is illustrated by this figure. The calculated correlation coefficient was 0.9681. Data scaled to fit on the same figure.

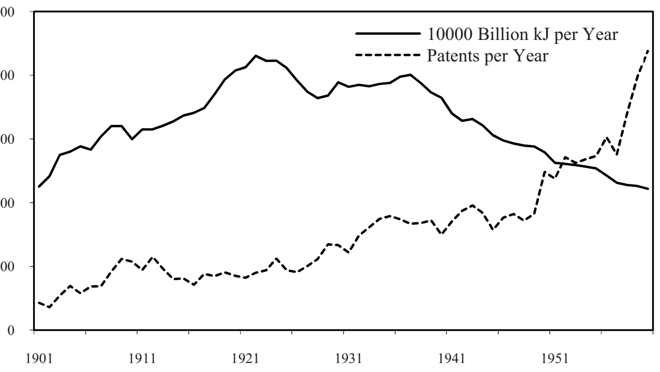


Figure 14. U.S. Oil Energy Activity and Patents. No correlation is exhibited in this figure with the two curves showing little resemblance. The calculated correlation coefficient was -0.4862. Data scaled to fit on the same figure.

Best-Fit

The best-fit common pattern equation (1) was applied, using a MatLab program, to energy sources data in an identical manner as was employed with engineering materials. As was the case with engineering materials, energy sources produced similar four-stage life cycles for production and patent data sets. Figure 15 displays a typical long–term four-stage life cycle for the production activity of U.S. hydroelectric energy. Stages I-IV are all present as well as a Stage II hump and "valley of death."

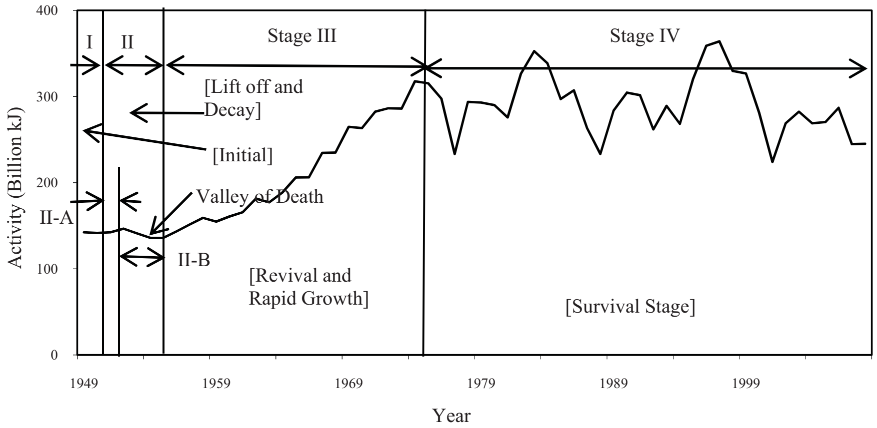


Figure 15. U.S Hydroelectric Energy. Illustration of a typical long-term life cycle for an energy source. The plot indicates the division of the life cycle into four stages that is common to engineering materials and specifically here to U.S. hydroelectric energy production.

Wind Energy as an Example. The common pattern equation and best-fit analysis were applied to fourteen energy sources as described in Section 4 for engineering materials. Wind energy serves as a good example of best-fit applied to energy sources. Figure 16 represents best-fit analysis for the production data of U.S. wind energy in thousands of kJ. The curve of the actual activity reveals that wind energy is likely in Stage III of its life cycle. Stages I-II are present along with a probable Stage III and rapid growth. There is no sign of leveling off or onset of the survival mode of Stage IV. A good R^2 of 0.8516 is present indicating a good fit. Figure 17 is composed of the best-fit analysis for the patent data of wind power. The life cycle for the patent data is also appears to be in Stage III as depicted by the strong rapid growth phase existing to the present. The patent data also has a good R^2 of 0.8183. All of the parameters in Figs. 16 and 17 are the same except for the origin, which has shifted negatively to 1961 for the patent data from the 1983 origin of the production data.

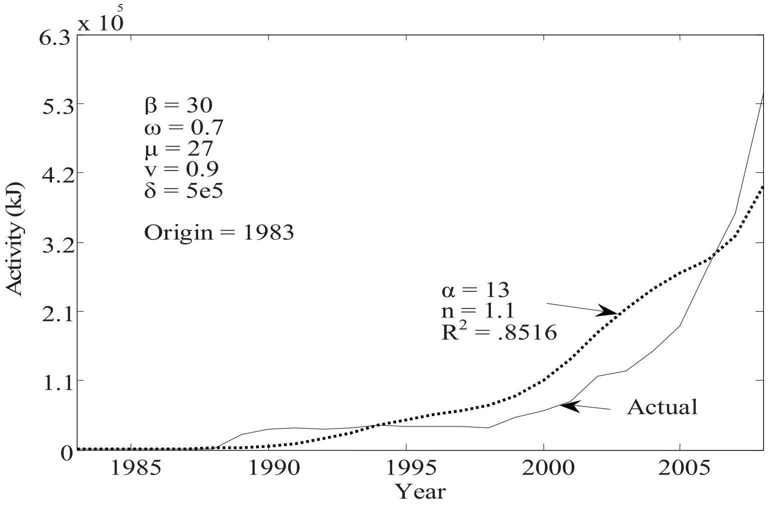


Figure 16. EIA U.S. Wind Energy Production. Fitted wind energy production activity curve with best-fit parameters and R^2 value and origin. The data is from EIA U.S. wind power production in kJ per year [91]. Shown in the figure are both the actual data curve and a best-fit curve.

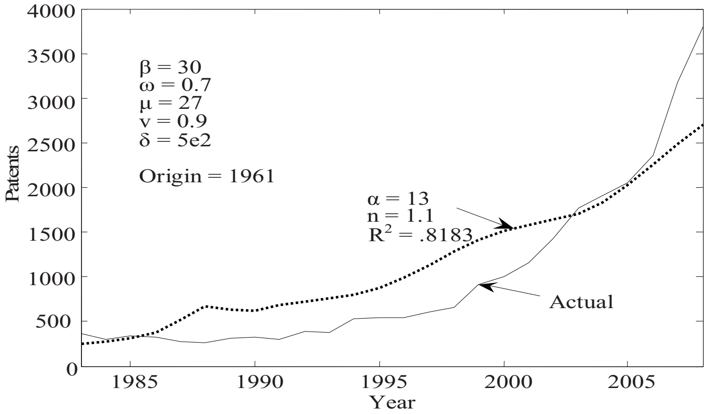


Figure 17. EPO Worldwide Patent Search: Wind and (Power or Energy) in Title or Abstract by Date of Publication. Wind energy modified patent curve with best-fit parameters and R^2 value and origin. The data is from the European Patent Office worldwide patents containing wind and (energy or power) in the title or abstract of the patent by date of publication. Parameters are the same as for the wind power production activity curve with only a shift in the origin.

The origin of 1961 for the wind energy patent best-fit curve signifies a 22-year lag for the production activity data when compared to patenting data. Twenty-two years after the patent data met a point in its life cycle, the activity data crossed the same normalized position in its own life cycle, which suggests that the patenting or innovative activity associated with wind energy is driving the production of the wind energy.

Table 9 below contains the individual origins and the origin shifts between the patent and activity curves for each of the energy sources evaluated. Wind, fossil fuel, solar, renewable, total, natural gas and coal energy displayed negative shifts of origin of 22, 38, 93, 97, 331, 392 and 428 years respectively. Such negative shifts indicate that the patenting curve reached a point in its life cycle a number of years before the production curve reached the same point in its life cycle. This could indicate that patenting or innovative behavior is *driving* production and displaying the constructive side of the innovative process. Figure 18 shows the negative 22 year origin shift for U.S. wind energy production. For wind power, a specific point that was reached by its activity production life cycle in 1990 was reached by its patenting plot in 1978. The innovative behavior, represented by patents, thus occurred before the production of the wind energy. It could be then said that the innovation is causing or *driving* the production and that the innovation is strong and constructive which may be the case in a new technology where new processes and innovation are creating a need for new production.

Likewise, Table 9 shows that biofuel, biomass, geothermal and nuclear energy have positive shifts of 7, 8, 20 and 36 years, respectively, indicating that the patent curve reached a point in its life cycle a certain number of years after the production curve of the system reached the same point in its life cycle. This could indicate that the production of the energy source happens before the patenting or innovation and is being *driven* by the production. Such a behavior can be seen as an example of the destructive side of the innovative process. Figure 19 is an example of a positive origin shift of 20 years in U.S. geothermal energy. For geothermal energy, a certain point reached in the life cycle of the production activity that was reached in 1982, was likewise reached by the patenting plot in 2002. The patenting occurred twenty years after the production and thus was caused by or is being *driven* by the production of the system. Less strong innovative activity and the negative aspect of the innovative process is displayed in a case such as this and may occur in an older technology where innovation is being employed to better utilize production.

As with engineering materials, there are a number of indicators that point towards the life cycle stage that the energy source is in. Strong correlation is the first indicator of possible Stage III (Table 3), which is illustrated by a comparative graphical plot of the production and patent data. At times the plots relating to correlation reveal curves with Stage III features.

Positive best-fit R^2 values for either or both the production activity and patent data of an energy source are indicators of a possible Stage III as well. Such R^2 values are produced for curves that have Stage III life cycle attributes as shown in Fig. 3. Due to the fact that the span of years for most energy sources is comparatively short when compared to engineering materials and the common pattern equation does not function optimally, lower values of R^2 are acceptable here where they would not for engineering materials.

The lower values of R^2 attainable for energy sources may be explained by the fact that the pattern equation is attempting to create a best-fit for a material or source with Stage III features. Sources with Stage I and II features may still generate an R^2 albeit a lower one. Stage IV sources need parabolic alphas and would not generate an R^2 with a linear alpha as have been employed here. Possibly, at the least, R^2 values generated for energy materials may suggest sources that are not in Stage IV but may be in Stage I, II or III.

Table 9. Energy Source Production and Patent R^2 values, correlation coefficient (*r*), origins, origin shifts and Stages. Energy sources are listed in order of descending Production R^2 values. As with engineering materials, an origin shift indicates the presence of a system in Stage III of its life cycle. Strong correlation and R^2 values near one are indicators of possible overall Stage III, but are not definitive evidence. Negative Production R^2 values, no correlation and lack of origin shift are indicative of Stage IV production energy sources. (* Indicates sources using Equation (2) for same scaling reasons as when used with engineering materials in Section 4.)

Energy Source	Production R^2	Independent Patent R^2	Modified Patent R^2	Correlation *r*	Production Origin	Patent Origin	Origin Shift	Stage
US Biofuel Energy	0.9024	0.8037	0.7881	0.9469	1981	1988	(+)7 years	III
US Coal Energy*	0.8547	0.5431	0.1697	0.8235	1949	1521	(-)428 years	III
US Wind Energy	0.8516	0.9097	0.8183	0.9681	1983	1961	(-)22 years	III
US Renewable Energy*	0.7404	0.3748	0.1237	0.4030	1949	1852	(-)97 years	III
US Biomass Energy*	0.7154	0.6243	0.6839	0.5624	1949	1957	(+)8 years	III
US Nuclear Energy	0.7142	0.1540	0.1758	0.8541	1957	1993	(+)36 years	III
US Geothermal Energy	0.6273	0.7138	0.4764	0.660	1960	1980	(+)20 years	III
US Total Energy*	0.3703	0.6511	0.2801	0.8064	1949	1618	(-)331 years	III
US Fossil Fuel Energy*	0.1995	0.7868	0.6993	0.5956	1949	1911	(-)38 years	III
US Solar Energy	0.1186	0.6355	0.4413	0.4786	1984	1891	(-)93 years	III
US Natural Gas Energy*	0.0989	0.8949	0.2094	0.4728	1949	1557	(-)392 years	III
US Wood Energy*	0.3728	0.9312	-	0.8271	1949	-	No Shift	IV
US Hydroelectric Energy*	0.1357	0.8470	-	0.3617	1949	-	No Shift	IV
US Oil Energy	Negative	0.5041	-	-0.4862	1949	-	No Shift	IV

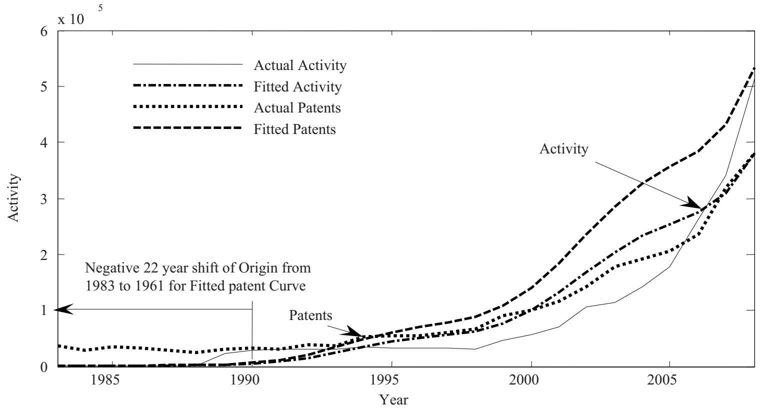


Figure 18. **U.S. Wind Energy Best-Fit Activity and Patents.** Plot showing the origin shift of patent and activity best-fit curves for wind energy. The shift is negative, indicating patent activity occurring before production activity and thus possibly driving the production. All parameters for the pattern equation are identical for the patent and production activity curves except for the difference in the origin that result in the negative origin shift.

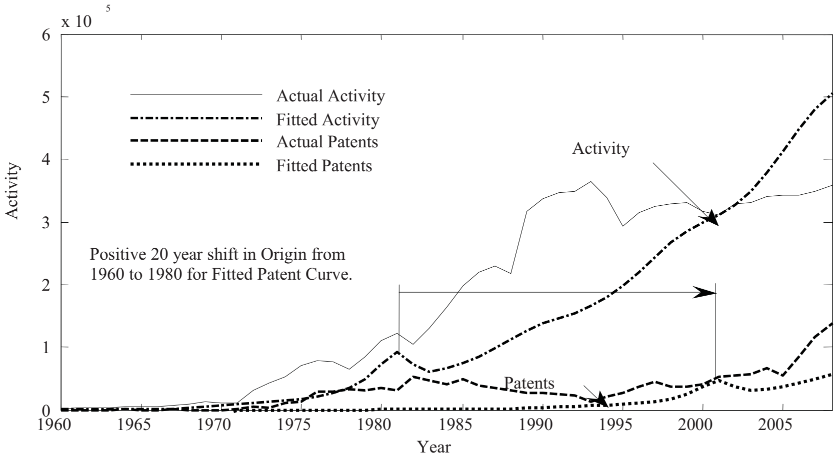


Figure 19. U.S. Geothermal Energy Best-Fit Activity and Patents. Plot depicting the origin shift of patent and activity best-fit curves for geothermal energy. The shift is positive, indicating patent activity occurring after production activity and thus possibly being driven by the production. All parameters for the pattern equation are identical for the patent and production activity curves except for the origins (the matching results in the positive origin shift).

Best-Fit, Origin Shift and Innovation

As with engineering materials the best-fit approach can be applied to comparisons of energy sources activity and patent data with patent and origin shifts, allowing inferences to be made concerning the relationship of innovations to production for these energy sources. The best-fit equation and program were applied to all of the studied energy sources' activity and patent data independently. This analysis was performed successfully on the energy sources listed below in Table 10. Table 10 presents the α and n values for the independent activity and patent data and the original origin shifts and resulting origin ratios, $(x_0 + OS)/x_0$, derived for Stage III energy sources as well as α^n and the drive ratios, again defined as $(\alpha^n)_{activity}$ / $(\alpha^n)_{patent}$.. Similar to the drive ratio for engineering materials, the drive ratio generally becomes progressively larger than one, as the origin ratio becomes larger than one representing the origin shift moving away from zero in a positive shift direction. The drive ratio also approaches zero as the origin ratio becomes progressively smaller than one which is the result of the origin shift moving further in the negative direction from zero as shown in Fig. 20 below.

Table 10. Energy source α and n parameters, drive ratio and origin shifts, origin ratios and modified R^2. Alpha and n are from the pattern equation. Ratio of α^n indicates strength of the driving force of the material. The farther the ratio is from one, in either direction, the greater the driving force. A positive origin shift could indicate patents being driven by production. A negative origin shift suggests production being driven by patents. Note that (n_a/n_p) is less than one for production sources with negative shifts in origin and one or above for sources with positive origin shifts. Modified R^2 generally becomes smaller then one as the origin ratio moves farther from one.

	α_a	n_a	α_a^n	α_p	n_p	α_p^n	Drive Ratio	n_a/n_p	Origin Shift	Origin Ratio	Modified R^2
Nuclear	13	1.3	28.06	16	1	16	1.75	1.3	+36	1.018	0.1758
Geothermal	17	0.8	9.65	31	0.5	9.65	1.73	1.6	+20	1.010	0.4764
Biomass	12	1	12	14	0.9	10.75	1.12	1.11	+8	1.004	0.6839
Biofuel	15	1.2	25.78	22	0.9	16.15	1.60	1.33	+7	1.004	0.7881
Wind	13	1.1	16.80	13	1.5	46.87	0.36	0.73	-22	0.989	0.8183
Fossil Fuel	36	0.29	2.83	41	1	41	0.069	0.29	-38	0.981	0.6993
Solar	37	0.7	12.52	39	1.4	168.9	0.074	0.5	-93	0.953	0.4413
Renewables	1	0.09	1	14	0.5	3.74	0.267	0.18	-97	0.950	0.1237
Total Energy	46	0.34	3.68	12	1.2	19.73	0.186	0.283	-331	0.830	0.2801
Nat. Gas	22	0.2	1.86	32	0.9	22.63	0.082	0.22	-392	0.799	0.2094
Coal	28	0.2	1.95	17	1	17	0.115	0.2	-428	0.780	0.1697

As with engineering materials the use of the pattern equation in the case of energy sources creates a relationship between α and n that can be evaluated and compared to origin shifts produced by independent patent and production activity best-fit derivations. A graphical representation, such as Fig. 20, of the relative scale, or distance, of the origin shift can be made, indicating an absolute amount that the patent or activity driving force has on the other. Such a curve may effectively represent innovation behavior. Noted is that the activity of fossil fuel power is possibly being driven the most by its patents since its drive ratio is nearest to zero for systems whose activity is driven by patents. Similarly, the patents of nuclear power may be driven the most by its activity because its ratio is farthest from one for energy sources whose patents are driven by activity

Again, as with engineering materials three patterns emerge from the best-fit analysis for energy sources shown in Table 10. The first is that when a positive origin shift is indicated, the drive ratio is always above one (the ratio is always less than one and approaches zero when the origin shift is negative). Second, when n_a is divided by n_p the resulting ratio is always less than one for energy sources that have negative shifts in origin and the resulting ratio is always one or above for energy sources with a positive origin shift. Lastly, as the origin ratios move away from one in either direction the modified patent R^2, which is generated by patent data being run with the common pattern equation production parameters, generally becomes smaller than one. As indicated in Table 10 and on Fig. 20 energy sources such as coal and natural gas energy have origin ratios the farthest below one and lower modified R^2 than do sources with ratios nearer to one. In the same way nuclear energy has the highest origin ratio and has an R^2 less than sources with origin ratios near to one. This could indicate that energy sources may approach Stage IV when they reach origin ratio extremes and enter stage IV when modified R^2 values become too small to support an origin shift or origin ratio in a manner similar to engineering materials.

Fig. 20 appears to divide the energy sources evaluated into two groups. Group 1, containing coal, natural gas, wind, renewable, fossil fuel, solar and total energy, is composed of energy sources whose patent activity is driving their production as suggested by the lag in production. Biomass, biofuel, geothermal and nuclear energy are in Group 2, in which patenting is driven by production suggested, conversely, by a lag in patenting.

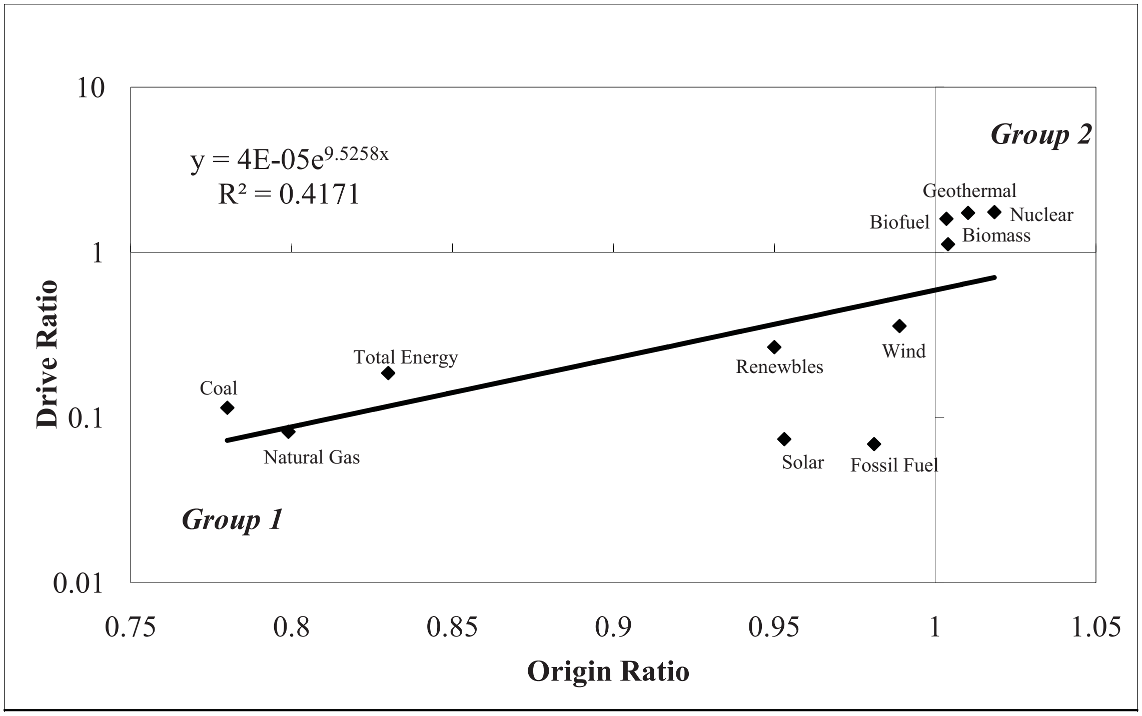


Figure 20. E**nergy Source Origin Ratio vs. Drive Origin.** Displays relative strength of driving force of either patents or production activity.

Group 1 energy sources, according to their drive ratios had more than one patent published per normalized unit of production where patents may be thought to *drive* production activity. U.S. fossil fuel energy, for example, had one patent published per 0.069 normalized units of production. Group 2 energy sources had less than one patent published per normalized unit of production where the patents are possibly *driven* by production. U.S. nuclear energy had one patent published per 1.75 normalized units of production according to its drive ratio. In other words for each normalized unit of fossil fuel energy production, 14.5 patents were found to drive the production and for each normalized unit of nuclear energy production 0.57 patents are being driven. These results may be interpreted to mean that Group 1 has more innovation associated with it since more patents are required to drive one unit of production than Group 2 where production drives patents. Group 2 is still innovatively active, but not as much as Group 1. And, like engineering materials, the presence of an origin shift in energy sources indicates constructive or destructive innovation, which is a classic feature of Stage III and thereby strongly points towards the presence of a Stage III source or at least an energy source that is not in Stage IV. It is possible that Stage I or II is in evidence for materials such as solar and wind energy that have had shorter life cycles and produce low R^2 values. These energy sources may be in the opening stages of their long-term life cycles. Their origin shifts indicate the presence of constructive or destructive innovation which could exist in Stages I and II as well as they do in Stage III, though to a lesser degree. In such cases an origin shift is good if not definite evidence of the presence of Stage III, but it is strong evidence of the absence of Stage IV.

Energy Materials

This section contains correlation, best-fit and origin shift analysis data for the production and patents of energy producing materials, in tons, barrels or cubic feet, of coal, natural gas, oil and uranium rather than energy (kJ) produced by them, which was done for energy sources above. The production data is from the EIA web site [91] and the patent data is from the EPO site [80]. All data gathering techniques, correlation, best-fit and origin shift analyses were carried out in an identical manner as for engineering materials and energy sources. Energy materials behaved in a similar manner as engineering and materials. Details concerning the gathered data and evaluations for energy materials can be found in Appendix 5. These four materials all exhibit Stage III behavior with origin shifts.

Table 11. Production and Patent R^2 values, correlation coefficients (r), origins, origin shifts and Stage for each evaluated energy materials. Equation 2 was used in all cases.

Energy Source	Production R^2	Independent Patent R^2	Modified Patent R^2	Correlation r	Production Origin	Patent Origin	Origin Shift	Stage
US Coal	0.7142	0.7523	0.6276	0.8368	1900	1870	(-)30 years	III
US Natural Gas	0.3701	0.9332	0.2536	0.6982	1936	1610	(-)326 years	III
US Oil	0.2334	0.9243	0.4524	0.5402	1900	1920	(+)20 years	III
US Uranium	0.1256	0.0159	.0154	0.6265	1949	1819	(-)130 years	III

Table 12. Energy material α and n parameters, drive ratio and origin shifts and ratios for energy materials. Materials arrange by descending modified R^2.

	α_a	n_a	α_a^n	α_p	n_p	α_p^n	Drive Ratio	n_a/n_p	Origin Shift	Origin Ratio	Modified R^2
Coal	15	0.6	5.08	23	0.7	8.98	0.566	0.86	-30	0.984	0.6276
Oil	24	0.7	9.25	33	0.6	8.14	1.14	1.17	+20	1.011	0.4524
Nat. Gas	17	0.23	1.92	15	0.8	8.73	0.220	0.288	-326	0.832	0.2536
Uranium	2	0.29	1.22	10	0.3	1	0.61	0.97	-130	0.94	.0154

Table 11 reveals that oil has a positive origin shift and therefore in the destructive mode of innovation while coal, natural gas and uranium have negative shifts and are in the creative mode of the innovation process. Table 12 continues the trends displayed by engineering materials and energy sources of positive origin shifts producing origin ratios and drive ratios over one and negative shifts producing ratios below one. The modified R^2 also tends to be farther from one the larger the shift in origin is.

Figure 21 shows that oil is in group 2 and natural gas, coal and uranium are in group 1. By comparison in Fig. 20, nuclear energy is in group 2 while coal and natural gas energy are in Group 1 and oil energy is in Stage IV with no origin shift. No pattern emerges since only two of the materials have the same direction of shift as its energy counterpart. Similar behavior is exhibited, though, for energy systems as has been revealed for engineering materials and energy sources.

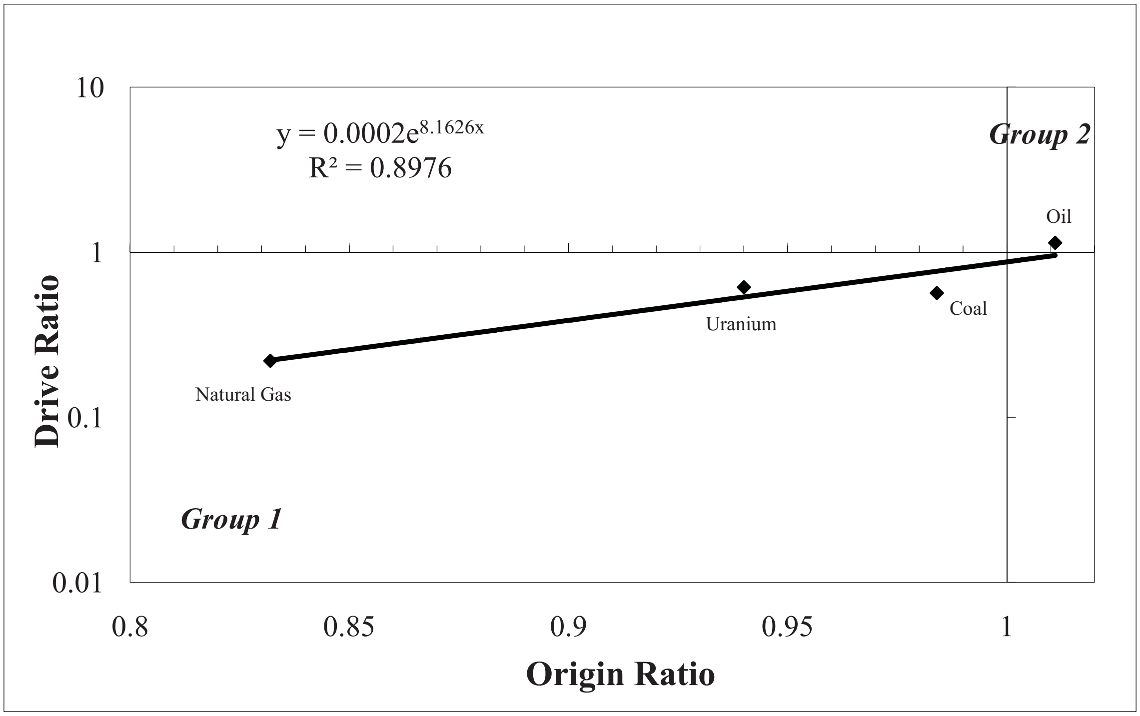


Figure 21. Energy Materials Origin Ratio vs. Drive Ratio. Displays relative strength of driving force of either patents or production activity for energy materials. R^2 is high probably due to only four points being in the plot.

Engineering Material Connection

In several cases the best-fit and correlation evaluations of energy sources revealed a connection between such energy sources that are predicted to be in Stage III, or innovatively active and engineering materials that are also innovatively active, or in Stage III, of their life cycles. Table 13 give examples of energy sources and the engineering materials that are both being innovated and helping to innovate the energy source. Vanadium and silicon are Stage III materials in the constructive mode and are commonly used in products related to solar and wind power production [90]. Other materials such as graphite, nickel, cobalt, silver, manganese, the rare earths and lithium, which are in Stage III, are being innovated largely in support of energy production and storage. Even Stage IV materials (cadmium, selenium, fluorspar) are being innovated in the energy generation field [90]. In three cases innovatively active energy sources, coal energy, nuclear energy and natural gas energy use for fuel, coal, uranium and natural gas that are also in Stage III. With energy resources declining worldwide and environmental concerns, it seems logical that materials are being innovatively employed to meet energy requirements in an environmentally friendly manner resulting in Stage III growth and Stage IV stability for these materials. It appears that where the need for innovative energy sources arises the innovative behavior of engineering materials that might fill that need rise as well.

Table 13. Examples of energy sources and the engineering materials that are innovatively active possibly due to their usage in the related energy source [90].

Energy source	Related Material	Usage
Solar Energy	Vanadium	Vanadium Redox Batteries (large power storage)
"	Silicon, Selenium	Solar Cells
Wind Energy	Vanadium	Vanadium Redox Batteries (large power storage)
Nuclear Energy	Fluorspar	Nuclear Fuel Additive
"	Uranium	Fuel
Renewable Energy	Graphite	Fuel Cells, Batteries
"	Nickel, Rare Earths, Cobalt	Rechargeable Batteries
"	Lithium, Cadmium, Lead	Batteries
"	Manganese	Dry Cell Batteries
"	Silver	Battery Electrodes
Coal Energy	Coal	Fuel
Natural Gas Energy	Natural Gas	Fuel

Table 14. Comparison of origin shifts, origin ratios and drive ratios of energy sources and the engineering and energy materials that are related to them [90].

	Origin Shift	Origin Ratio	Drive Ratio
Solar Energy	**-93 years**	**0.953**	**0.074**
Vanadium	-90 years	0.954	0.363
Silicon	-30 years	0.985	0.435
Wind Energy	**-22 years**	**0.989**	**0.36**
Vanadium	-90 years	0.954	0.363
Nuclear energy	**+36 years**	**1.018**	**1.75**
Uranium	-130 years	0.94	0.61
Fluorspar	-113 years	0.941	0.444
Coal Energy	**-428 years**	**0.780**	**0.115**
Coal	-30 years	0.984	0.57
Natural Gas Energy	**-392 years**	**0.799**	**0.082**
Natural Gas	-326 years	0.832	0.22
Renewable Energy	**-97 years**	**0.950**	**0.267**
Graphite	-24 years	0.987	0.813
Nickel	-69 years	0.964	0.824
Rare Earths	-101 years	0.947	0.389

Cobalt	-256 years	0.865	0.284
Lithium	-106 years	0.945	0.396
Lead	-41 years	0.978	0.434
Manganese	+23 years	1.012	1.418
Silver	+21 years	1.011	2.060

Table 14 indicates that in a majority of cases the origin shift direction of the materials follows that of their particular related energy source. Likewise, the origin and drive ratios are higher or lower than one for the material as that of its related energy source. Nuclear energy is the only obvious exception to this pattern, however it has only two materials to compare it with. The degree of the shift or ratio of the materials seem to have little relation to that of the energy sources. It still can be said that innovatively active, or Stage III, energy sources utilize or are partially enabled by engineering and energy materials that are also innovatively active

Energy Source and Engineering Material Result Comparison

The application of correlation theory and best-fit analysis to energy sources as was applied to engineering materials has disclosed that energy sources behave in a similar manner to engineering materials. In both cases, correlation theory has revealed that production and patent data have a relationship to each other and that changes in one set of data have an impact on changes in the other data set. Energy sources have been shown to display the same four-stage life cycle exhibited by engineering materials in both production and patent data. Origin shift and innovative patterns are found in each case as well. Positive shifts are always found where the drive ratio is greater than one and negative when the drive ratio is less than one. Also, the ratio produced by dividing n_a by n_p is less than one where a negative origin shift is found and one or above where a positive origin shift exists.

The drive ratio versus origin shift plots (Figs. 12 (a-c), 20 and 21) for energy sources, engineering materials and energy materials all reveal a possible connection to the dual nature of innovation as proposed by Schumpeter [55]. Engineering materials and energy sources with drive ratios below one indicate production drive by innovation and the constructive nature of the innovative process. Energy sources and engineering materials with drive ratios above one represent the destructive facet of the innovative process where production drives innovation as measured by patents. Innovation is present in both instances but is stronger on the constructive side. Finally, Stage III is indicated in both engineering materials and energy sources where a shift in origin is found though best-fit analysis.

Section 7: Analysis

Schumpeterian economic theory posits the idea that innovation propels capitalistic economies through a process of "Creative Destruction" where innovation constantly destroys the old while it creates anew [55]. Patents, being analogous to innovation, may be considered as tools to carry out this process of "Creative Destruction." Patents can be used to prevent innovation or deny the right to compete when used to protect property rights by blocking the technical innovation of others in the same industry. This is the destructive side of patents. The creative side is illustrated by the use of innovation to overcome protective patents, which result in more patents and new innovative products. Numerical and graphical proof that patents can indicate and measure the destructive and creative functions that innovation can exhibit is offered here.

Correlation

Correlation, to some degree, was shown to exist between patent and activity data for forty-eight of fifty evaluated engineering materials and thirteen of fourteen energy sources. Thus, statistically, the number of patents published, in reference to an engineering material or energy source, is often correlated at least to some degree to the amount of production for that material or energy source on a yearly basis. Materials and energy sources with strong correlation (Al, Cr, Ni, wind power, e.g.) often appeared to be in Stage III of their life cycles while those with weak or no correlation (Hg, Be, As, hydroelectric power, e.g.) are commonly considered to be in Stage IV. The correlation coefficient *r* gives evidence that variations in one of the data sets, activity or patent, can be attributed to variations in the other data set. In other words, change in one set of data drives the change in the other set. Comparisons of the production and patent data are thus more relevant due to the relationship that exists between them, which correlation theory indicates. Best-fit analysis can aid in determining which data came first and thus, drove the change in the other set.

Best-Fit

The best-fit equation and program can identify the four stages in the life of the production and patent data of an engineering material or an energy source. Most innovative activity occurs during Stage III and appears to diminish or cease at the onset of Stage IV, making the identification of these stages an important objective. The curves and coefficients produced via correlation analysis are a start in identifying the stage of a material or system. There is an obvious flattening of the curves during Stage IV when compared to Stage III. If the correlation curve flattens for an extended period and the correlation coefficient drops, the material or system is likely in Stage IV. Another indicator of the stage of a material or system is its R^2 value. The materials and systems studied here show that, in general, Stage III items have R^2 values for production and patenting data approaching one for engineering materials and positive R^2 values for energy sources and materials. The strongest and most obvious Stage III materials and systems have R^2 values approaching one generated from the production, modified patent and independent patent best-fit evaluations such as nickel, aluminum and wind power. Stage IV is very strongly indicated when R^2 is negative or near negative such as for cadmium, arsenic, beryllium and fossil fuel power whose generated life cycle curves back up this inference. The combination of no correlation, a negative or near negative R^2 and life cycle curves that illustrate a steep sustained drop off of production, as for mercury, may indicate a Stage V or “ Final Death” where innovative activity is very low again reaching the initial starting levels of its Stage 1.

Stage V

As suggested previously in section 2, a Stage V may exist in the life cycle of materials. Figure 22 below shows a proposed Stage V occurring after Stage IV for mercury. Stage V exhibits a steady decline in production with no clear sign from the data of revival as exists in Stages III or IV. With no clear sign of revival, Stage V can be called the “Final Death” stage. Such “final” death may be due solely to resource depletion. However, environmental and health concerns for toxic substances, such as asbestos, mercury and beryllium could also explain a decrease in production [90]. A final explanation for death could be the replacement of a material with another less costly one or the successful innovating around a toxic or expensive material thereby causing a decrease in production. While the onset of Stage V may be caused by resource depletion, the materials investigated here that display Stage V behavior are asbestos, beryllium and mercury, which are toxic substances with environmental concerns attached to them. Arsenic and cadmium, also toxic materials, are now Stage IV but seem to be approaching Stage V. Such environmental concerns seem to be a more likely cause, rather than resource depletion, for the onset of Stage V according to the results of this study.

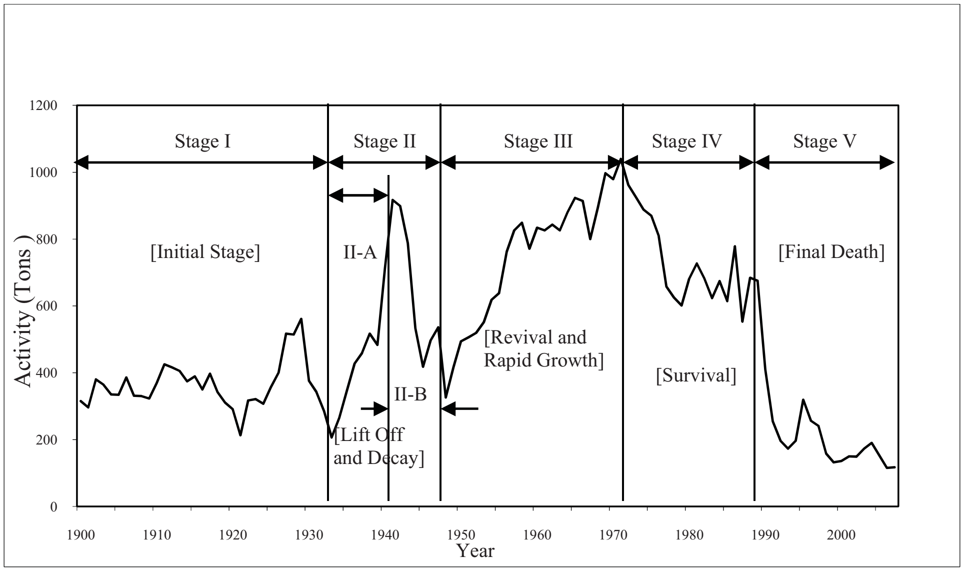


Figure 22. Mercury Production Life Cycle. The life cycle curve for mercury depicting it as a Stage V material. This figure identifies the four stages as discussed in Section 2 and shown in Fig. 3. Also shown is the possible Stage V or "Final Death Stage". Here Stage V begins around 1988 and is identified by a steep decline in production with little clear sign from the production data for any future stabilization or revival as is often displayed in Stages III and IV. Stage V could indicate resource depletion or less demand for the material or innovating away from the material due to environmental or toxicity concerns such as exist with asbestos and mercury. Activity is in tens of tons.

Origin Shift

The best-fit analysis of the data can confirm and further identify the time frames where Stages III and IV may exist. The best-fit equation was applied to the patent data of each engineering material and energy source with the same pattern equation and parameters, as was previously done to the production data. A change or shift was sought in the data origin in these modified patent best-fit equations. Positive and negative shifts were each found for engineering materials and energy sources. A negative shift implies that the patenting occurs previous to the activity and therefore variations in the patents may drive change in the activity. A positive origin shift indicates that activity occurs first and variations in it possibly drive variations in the patents. Also, the presence of an origin shift indicates Stage III since a shift possibly predicts the mode or direction of innovative activity and such activity is strongest in Stage III, which in these materials and systems is backed, for the most part, by Stage III type curves, good correlations and high R^2 values.

Driving Force

Driving force behavior can be illustrated by best-fit analysis and comparisons of α and n parameters with origin ratios of these thirty-eight materials and twelve energy sources. Nitrogen appears to be, amongst the engineering materials studied here, the one whose patents most drive its production activity. Silver, on the other hand, is the material whose activity drives its patenting the most. Nitrogen, along with the other group 1 materials (Fig. 12(a)), have a drive ratio less than the universal constant n_0 of one and could be thought to be in the creative mode of the innovative process where patents and innovation spur production and economic growth. Silver and the remaining group 2 materials are in the destructive or negative mode of the innovative process with drive ratios above the universal constant, n_0, of one where patents could be used as protection of property rights and as a result stifle innovation and possibly economic growth. Materials with low drive ratios may be in the position of being farthest into the creative part of the innovative process due to their use in the electronics, metallurgical or other high-tech industries [90]. Patenting and innovation are very focused for materials in these areas. High drive ratio materials are used for a wide variety of applications in lower-tech industries [90]. The activity of such materials may be driving the patenting because the variety of products made from them are less cutting-edge and high-tech than those of a material, such as nickel, whose patents drive its production activity.

Examples of the uses of specific engineering materials seem to support the idea that negative origin shifts and high alpha ratios indicate more innovative activity while positive shifts indicate less. Aluminum, copper, manganese, titanium and zinc are used in a great variety of applications and lack a narrow focus of innovation and patenting though they do have some high-tech applications [90]. Materials with negative origin shifts, or low origin ratios, and low alpha ratios often have application in very focused, high-tech and currently highly innovative areas. Nickel is used for super alloys, aerospace and rechargeable batteries [90]. Silicon is employed in solar cells and semiconductors, the rare earths are important in rechargeable batteries and electronics and iodine is a component of LCDs, which are very important in the electronics industry [90]. Though there are some anomalies, the general pattern illustrated is that that lower alpha ratios and lower origin ratios are signs of innovatively stronger materials while less innovative materials have higher ratios and shifts.

U.S. fossil fuel energy appears to be the energy source whose patents most drive its production while U.S. nuclear power is the energy source whose patents are most driven by its production. As with engineering materials, the group 1 energy sources of renewable, wind, coal, natural gas, fossil fuel, solar and total energy, have drive ratios less that the universal constant, n_0, of one and are systems that appear to be relatively high-tech and in currently highly innovative areas [92-99, 106-110]. Group 2 energy sources, biofuel, biomass, nuclear and geothermal energy, have drive ratios above the universal constant of one also in the same manner of engineering materials and could be said to be in less high-tech areas [100-105]. Energy sources in group 1 could be said to be in the constructive phase of innovation since their production is being drive by innovation as measured by patents while those in group 2, where production drives innovation, are in the destructive segment of the innovative process.

Origin ratios below one represent negative origin shifts and the constructive mode of the innovative process. However, some engineering materials and energy sources seem not to have the cutting edge applications that would merit a high degree of innovation but are nonetheless in Group 1. Materials such as talc, salt and sulfur and the energy sources of coal and total energy have some of the lowest origin ratios of those evaluated. These five materials and energy sources and others with low origin ratios also, in general, also have lower modified patent R^2 values as shown in Figs. 6 and 10 than do those with origin ratios near one. Such relatively poorer fits of patent data to production activity best-fit parameters may indicate that the resulting innovative activity is mainly to keep the production afloat instead of developing new innovative uses of or improvements to the material or energy source. A material or energy source may enter Stage IV when the modified patent R^2 becomes so low that it cannot generate a shift in origin and thereby an origin ratio. Such a point could illustrate where innovation can no longer keep the production afloat and Stage IV sets in.

Origin ratios above one indicate the destructive aspect of the innovative process where production is driving the patenting. Engineering materials and energy sources in Group 2 have drive ratios above one, origin shifts above one and modified patent R^2 values that decrease from one as the origin shift grows larger than one. Silver and nuclear energy are the material and energy source, respectively, that have the highest origin ratio and lowest R^2 value for group 2 materials and energy sources. Silver and nuclear energy may be nearest to having no innovation for production to drive and thus to Stage IV. This may be the case since as the R^2 values decrease in Group 2 they will not be able to produce an origin shift or ratio.

Analysis of the driving force may reveal two means that a material or energy source may leave Stage III and enter Stage IV. Stage IV seems to be approached when a material or energy sources nears either end of the trend lines of Figs. 12(a-c) and 20. In either case it appears that the driving force is losing the driven production or patenting. In Group 2 the materials or energy sources at the extreme of the trend lines have production with little innovation to drive, are not innovatively active, leave Stage III and becomes commodities. With Group 1, materials or sources at the extreme of the trend lines, have little production for the innovative activity to drive and may also enter Stage IV.

Life Cycle Stage Change

The results generated by the processes described here are not static for the tested materials and sources but instead are of a fluid nature. The *r*, R^2, stage, origin shift or driving force of a material can change over time. A previous study of twelve metals, utilizing production and patent data for the years 1900-2004 produced results that in some cases were quite different from the results generated in this dissertation which covers the years 1900-2007 [127]. Table 15 indicates that of the twelve metals evaluated in the previous study, four of them (iron, manganese, molybdenum and tungsten), changed from being Stage IV to Stage III.

Table 15. Comparison of the current 1900-2007 results with previous results for twelve metals for the years 1900-2004 [92]. The stage in the life cycle of the material as well as its origin shift and *r* and R^2 values for each span of years are recorded.

Result Changes Between 1900-2004 and 1900-2007 Data								
Material	**Estimated Stage**		**Correlation *r***		**Production Best-Fit R^2**		**Origin Shift**	
	2004	**2007**	**2004**	**2007**	**2004**	**2007**	**2004**	**2007**
Aluminum	III	III	.9623	.9652	.9801	.9818	+15	+15
Chromium	III	III	.9483	.9495	.9690	.9731	-2	-3
Copper	III	III	.9430	.9507	.9397	.9576	+11	+11
Iron	IV	III	.8682	.8741	.5162	.8599	-	-89
Magnesium	III	III	.8817	.9078	.6467	.7502	-79	-83
Manganese	IV	III	.6312	.6835	.6140	.5728	-	-23
Molybdenum	IV	III	.9184	.9289	.9430	.9538	-	-188
Nickel	III	III	.9525	.9563	.9676	.9823	-57	-69
Titanium	III	III	.9011	.9150	.8303	.8600	+2	+1
Tungsten	IV	III	.7587	.7419	.5528	.6449	-	-232
Zinc	III	III	.9249	.9387	.8655	.8805	+26	+18
Zirconium	III	III	.8900	.9239	.5520	.6913	-22	-21

Manganese production for the years 1900-2004 is displayed in Fig. 23. In 2004 Mn was in Stage IV with its production oscillating after peak production in 1976. 2004 production had not reached the peak production of 1976. Production was rising and falling during these Stage IV years of 1976-2004 with no clear signs of a continual rise in production.

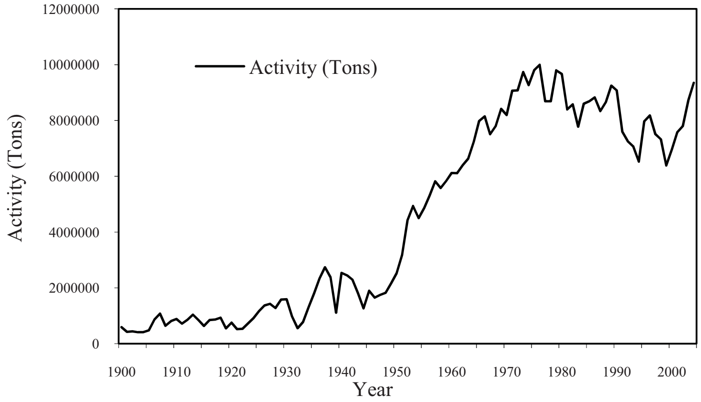


Figure 23. Manganese production activity covering the years 1900-2004. In 2004 Mn was in Stage IV, or the survival stage, with production oscillating and not rising or dropping permanently over time. 2004 production was 9,350,000 tons and not above the peak production of 10,000 tons in 1976.

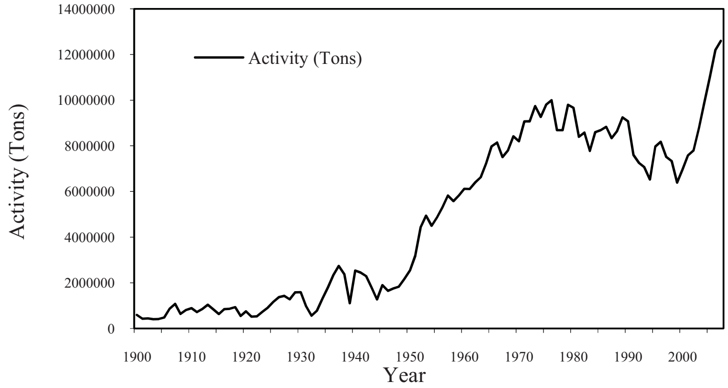


Figure 24. Manganese production activity covering the years 1900-2007. In 2007 Mn is in Stage III. Oscillations in production have stopped with a continual rise in production from 1999 –2007. 2007 production was 12,600,000 tons. 1976 production was surpassed in 2005.

Figure 24 shows manganese production for the years 1900-2007. Indicated is a steady continuous rise in production from 1976 to 2007. The peak production of 1976 was surpassed in 2005 with increases until 2007 where Mn re-entered Stage III. Production plots graphically illustrate Stage III features and Stage III is possibly further indicated by the presence of an origin shift and a linear alpha in its best-fit equation rather than a parabolic alpha, which is required for Stage IV materials [2]. It is possible that in another span of three years these materials could return to Stage IV due to decline in production or oscillation caused by resources depletion or economic and environmental forces. If there is a steady rise in the production data over the last few years evaluated, the material or system will likely be in Stage III. If there is steady decline or no change in production data over the last few years of production, Stage IV is probably present. The stage depends on whether the material or system is in the peak or valley of the oscillating production data at the most recent date.

Relevance

The processes and evaluations presented in this dissertation set forth original and important tools that can possibly be used for the prediction of the innovative behavior of engineering materials and energy sources. Each step in the evaluation process presented here provides a certain level of predictive ability for the more efficient usage of ever more scarce natural resources. Also, the use of these procedures allow for the wiser and more profitable allocation of monetary resources that in light of the present economic environment, are vital for financial stability for individuals, corporations and nations.

Correlation theory provides the first predictive tool. As has been demonstrated, resources such as engineering materials and energy sources in almost every case tested, display some degree of correlation. This means a change in one of the data sets, such as production, was statistically the result of changes in the patent data set or vice versa. From this, it can be suggested that if an individual or group has information that reveals probable future increases in production, such as governmental stimulus monies available for production of energy sources, it may be profitable to participate in future innovation, since, if correlation is high for the material or system the patenting curve will follow the trend of the production curve. Likewise, if it is announced that governmental funds will be available for innovative activity applied to renewable energy it could signal an opportunity to provide resources for the production of renewable energy if there is strong correlation since the increase in production will mirror the increase in innovation. If production is predicted to drop in the future due to resource depletion, environmental concerns or global conditions it can be inferred that innovation will decline as well and decisions concerning development can be based upon this knowledge.. The stronger that the correlation between the production and patenting data of a material or system is, will make any development or research decisions more logical and intelligent.

Best-fit analysis and the identification of the long-term life cycles of materials and system also provide tools in the allocation of natural and economic resources. It has previously been proven that metals and non-metals have four-stage life cycles, and above, it has been shown that energy sources also have a four-stage life cycle similar to metals and non-metals allowing for identical evaluation. The common pattern equation (Eq. 1) and best-fit analysis can be used to show the life cycle of engineering materials and energy sources by the plots generated as well as the R^2 values calculated. Determining the likely life cycle point that a material or system is in currently allows for intelligent development and allocation decisions. Development of a material or system found to be in Stage III of its production life cycle would be a more logical choice than development of a Stage IV material. Stage III materials are in a time of rapid growth while those in Stage IV are in survival mode with little growth. If growth occurs in a Stage IV it is probably for the short term due to the oscillations in activity existing in this stage. A Stage IV material may return to Stage III or it may fall into a possible Stage V. There is thus far more risk in allocating resources in Stage IV materials than in Stage III. However, Stage IV materials often offer opportunities in the innovation around or in replacement of them, which again is an example of the destructive side of the innovative process.

Indicators of a Stage III engineering material and energy source are firstly strong correlation between the data sets. Other indications of Stage III are R^2 values near one for engineering materials and positive for energy sources in regards to production activity and patenting best-fit evaluation, while the presence of an origin shift is final evidence of the presence of Stage III. It is suggested here that the presence of an origin shift in the patent data of a material confirms the presence of Stage III that is predicted by the previously mentioned indicators. In all cases for engineering materials and energy sources, the models proposed in this dissertation have shown that when Stage III seems to be likely, that an origin shift is in existence.

The origin shifts produced by best-fit analysis offer a possible time frame in which the allocation of monetary resources for research and development may more safely take place. If a material or system experiences a negative origin shift in patent best-fit, its patenting or innovation occurs before its production at an identical point in their respective life cycles. This suggests that if a material or system is in Stage III and the innovative activity happens X number of years previous to the production, then when the production life cycle curve enters Stage IV, the innovative activity won't reach that same point in its life cycle for that X number of years. This outcome possibly gives a window of X number of years to consider innovation relating to that material.

On the other hand if there is a positive shift in the patent best-fit origin the innovative activity reaches a point in its life cycle after the production activity crosses the same point in its life cycle. It may be less profitable to invest time and money on a material or system if this is the case. Consideration may be needed to spend less on the production for a material whose innovative activity has reached Stage IV a number of years before its production has. If innovation is declining there may be less of a reason to continue further production.

U.S. wind power, for example, has a strong correlation coefficient of 0.9681, a high best-fit R^2 of 0.8561, is likely in Stage III and has a negative origin shift of 22 years. Development of wind power is likely a good decision. It is in Stage III, or rapid growth stage and has production that is being driven by its innovation, where the constructive side of the innovative process exists and the universal constant, n_0, and drive ratio are below one, as indicted by the negative origin shift in patent data. Twenty-two years before the production data of wind power reached a specific point in its life cycle, its patent data reached that same point. In other words, 22 years after the production of wind power reaches the survival stage (Stage IV), the innovative behavior, as measured by the patent data will reach a like point in its life cycle. Such gives a possible 22 year window to safely allocate resources for the development of wind power after it has reached Stage IV in its production.

The evaluation of kyanite, on the other hand, produced a positive 20 year shift in its patent data origin indicating that innovative activity in this case is being driven by production. Twenty years after the production curve reaches a certain point in its life cycle the patenting data will reach the same point in its life cycle. The destructive side of the innovation process is present and innovation will still be present but to a lesser degree than where constructive innovation exists. With kyanite, or other materials or systems with positive origin shifts, an individual, company or nation might want to be more cautious about allocating resources since there will be less innovative activity and the production will reach Stage IV before the patenting data. More information would be needed to make an intelligent choice. If it is foreseen, with kyanite, that its production Stage IV will last 20 years or longer it may still be profitable to invest resources in it. In such a case opportunities will be present in innovating around the technology or in replacement of it or to use present production.

It is strongly believed that presented above is a powerful method for the evaluation of the relationship of engineering materials and energy sources, which can be employed, for the allocation of scarce economic and natural resources. Varying fields such as engineering, economics, law and business will all benefit from the predictive value that this model provides.

Conclusion and Summary: The study presented in this paper has shown that patents are a good measure of technical innovation for engineering materials and energy sources. For Stage III materials and energy sources, the patents mirror and behave similarly to the production activity as described by the life cycle platform (1-3,83). Correlation theory and best-fit analysis when applied to the fifty engineering materials and fourteen energy sources studied provide several indicators that when combined can suggest the stage of a material or system and the driving force of the innovative activity of the material or system. Stage III is generally indicated by a life cycle curve that is still growing, strong correlation and a production and patenting data R^2 values near one. The existence of an origin shift verifies the existence of Stage III for engineering materials and energy sources. Even more, a negative origin shift and low drive ratio points towards the strongest innovative activity for a Stage III material or system, while a positive shift and higher ratio indicates not as strong innovative activity.

Although not conclusively established as the sole reason, the dual nature of Schumpeterian innovation is possibly also highlighted when comparing the patents and production of the various substances. It has been found that the life cycle stage of a material or energy source, as well as the relative extent of the driving force acting upon that item's production can be determined. When the drive ratio of a material or system is below the universal constant n_0, of one, the material or substance may be in the creative mode of innovation where patents and innovation spur economic growth. When the drive ratio is greater than one, or n_0, the destructive side of the innovative process might be present. The y-axis of the plots shown in Figs. 12(a-c) and 20, which correlate the driving force to origin shift, appears to always be at 1 when the origin shift is 0, thus perhaps indicating that there is one universal constant, common to the life cycle of all engineering materials and energy sources.

Appendix 1: Correlation

The correlation, or sample correlation coefficient, r, is calculated with the equation,

$$r = S_{xy}/(S_{xx} * S_{yy})^{1/2} \qquad \text{(A1.1)},$$

where

$$S_{xx} = \sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2 / n \qquad \text{(A1.2)}$$

$$S_{yy} = \sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2 / n \qquad \text{(A1.3)}$$

$$S_{xy} = \sum_{i=1}^{n} x_i y_i - (\sum_{i=1}^{n} x_i)\ (\sum_{i=1}^{n} y_i) / n \qquad \text{(A1.4)}$$

and n is equal to the number of pairs of x and y in the data set. As an example, the correlation coefficient will be determined for the accumulated data concerning aluminum. In the case of aluminum, 108 data entries were made for activity and patents, x and y respectively, giving an n value of 108. For aluminum,

$\Sigma x = 833134000$, $\Sigma y = 486253$, $\Sigma x^2 = 1.6e16$, $\Sigma y^2 = 5.81e9$ and $\Sigma xy = 9.43e12$.

Calculating, using equations A1.2, A1.3 and A1.4 and the above values,

$S_{xx} = 16e16 - (833134000)^2/108 = 9.559e15$,

$S_{yy} = 5.81e9 - (486253)^2/108 = 3.62e9$ and

$S_{xy} = 9.43e12 - \{833134000) * (486253)\}/108 = 5.68e12$.

By substitution of the above values into the Eq. (A1.1), $\boldsymbol{r = S_{xy} / (S_{xx} * S_{yy})^{1/2}}$ we get

$$5.68e12 / (9.559e15 * 3.62e9)^{1/2} = 0.965222$$

which indicates a good correlation between the activity and patent data. The *r* value of 0.9652 can be squared then multiplied by 100 resulting in 93.17 suggesting that 93.17% of the variations in the patent numbers can be attributed to corresponding differences in the activity data [81-83]. Table A1.1 below displays the results calculated above and Fig. A1.1 shows a comparison of aluminum activity and patent data. Each material was treated in the same manner.

Table A1.1. Correlation Eq.(A1.1) terms calculated from Table A3.1 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**100r^2**
833134000	486253	1.6E+16	5.81E+09	9.43E+12	9.559E+15	3.62E+09	5.68E+12	**0.965222**	**93.16534**

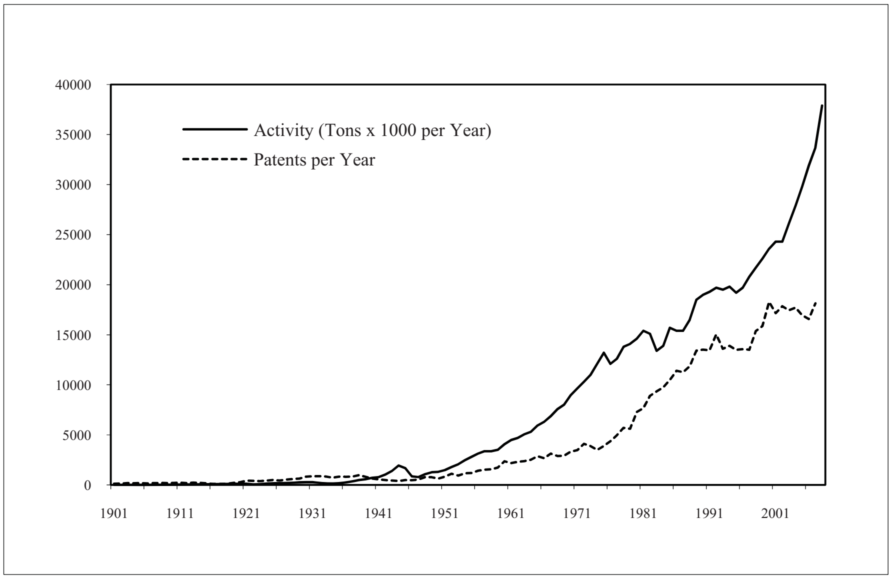


Figure A1.1. Aluminum activity and patent data illustrating correlation.

Appendix 2: MatLab

Program A2.1: MatLab program template used for Best-Fit analysis [2]. Common pattern equation (1) is contained within the program. Individual parameters, x (activity), y and r (years) entered for each material. A plot with individual curves, displaying the actual activity values and fitted data are produced as well as an R^2 value is produced by this program.

```
clear all;
% %START USER INPUTS
%~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
   year=[];%please input the years in the brackets.  separate individual values by a comma and separate lines by '.....'
           %example [1990, 1991.....
           %        1992]
   activity=[];%please input the years in the brackets.  separate individual values by a comma and separate lines by '.....'
              %example [2.8, 3.6.....
              %         4.8]

   %constants
   %Please choose the values for the parameters below
   %~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
   a= ;        %alpha
   b= ;        %Beta
   u= ;        %mu "u" is the location parameter. It gives the position of the mean
   v= ;        %nu "v" is the scale factor, which controls the width of  peak
   const= ;    %delta
   c= ;        %omega
   x0=;        %origin of the data
   n= ;        %power exponent

   r= [];        %choose years where you want to predict
             %syntax: (1) r=<start year>:<increment>:<end year>;
             %       (2) r=[1900, 1901, 1903, ...,2000];


% %END USER INPUTS
%~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

% From data
plot(year,activity*1e3,'r'); %plots (Year VS Activity)

hold on; %to plot two graphs in the same figure


% From Equation
x=r-x0; %normalized years
R2=0; %non-linear R^2 value intialized to zero

% EQUATIONS
z=const*(exp((x-u)./v).*exp(-exp((x-u)./v)))/v;
%calculation of the additive part in the equation
```

```
y=x.^n.*[(a^n.*x.^2)+(b^n*sin(c*x))]+z;
%calulation of the complete equation

plot(r,y,'b');
%plotting the equation

xlabel('Years'); ylabel('Activity');


%Calculation of R2
actmeany=sum(y)/length(y);

for i=1:length(y)
   SStot=(activity*1e3-actmeany).^2;
   SSreg=(y-activity*1e3).^2;
end
R2=1-(sum(SSreg)/sum(SStot));
disp(R2);
%displaying the R^2 value
```

Program A2.2: Zinc Production MatLab Program. The years 1900-2007 are entered for the year and "r" inputs while the production data for each year is entered in the activity input. The parameters a, b, u, v, const, c, x0 and n (*α, β, μ, ν, δ, ω, x0 and n* respectively)are entered as well. Running the program results in a plot and an R^2 value. The best-fit is the curve with an R^2 value closest to one indicating the best estimate of the equation parameters [2]. Each material was evaluated in the same manner.

```
clear all;
% %START USER INPUTS
%~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
   year=[1900, 1901, 1902, 1903, 1904, 1905, 1906, 1907, 1908, 1909, 1910, 1911, 1912, 1913, 1914, 1915,
1916, 1917, 1918, 1919, 1920.....
      1921, 1922, 1923, 1924, 1925, 1926, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934, 1935, 1936, 1937,
1938, 1939, 1940.....
      1941, 1942, 1943, 1944, 1945, 1946, 1947, 1948, 1949, 1950, 1951, 1952, 1953, 1954, 1955, 1956, 1957,
1958, 1959, 1960.....
      1961, 1962, 1963, 1964, 1965, 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977,
1978, 1979, 1980.....
      1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997,
1998, 1999, 2000.....
      2001, 2002, 2003, 2004, 2005, 2006, 2007];%please input the years in the brackets.  separate individual
values by a comma and separate lines by '.....'
         %example [1990, 1991.....
         %        1992]
   activity=[479, 510, 547, 574, 629, 660, 704, 738, 723, 775, 810, 895, 971, 939, 795, 760, 882, 901, 849, 719,
682, 464, 730.....
      889, 986, 1190, 1410, 1420, 1360, 1320, 1260, 904, 709, 892, 1060, 1210, 1330, 1470, 1420, 1500, 1470,
1590, 1630, 1830, 1870.....
      1470, 1440, 1600, 1690, 1730, 2150, 2360, 2590, 2670, 2660, 2900, 3110, 3150, 2950, 3020, 3090, 3490,
3570, 3660, 4030, 4310.....
      4500, 4840, 4970, 5340, 5460, 5520, 5440, 5710, 5780, 5850, 5690, 5920, 5850, 5990, 5950, 5950, 6130,
6280, 6520, 6760, 6840, 7190.....
      6770, 6820, 7150, 7270, 7250, 6910, 7050, 7280, 7480, 7540, 7570, 7960, 8770, 8910, 8880, 9520, 9590,
9930, 10000, 10900 ];%please input the years in the brackets.  separate individual values by a comma and
separate lines by '.....'
```

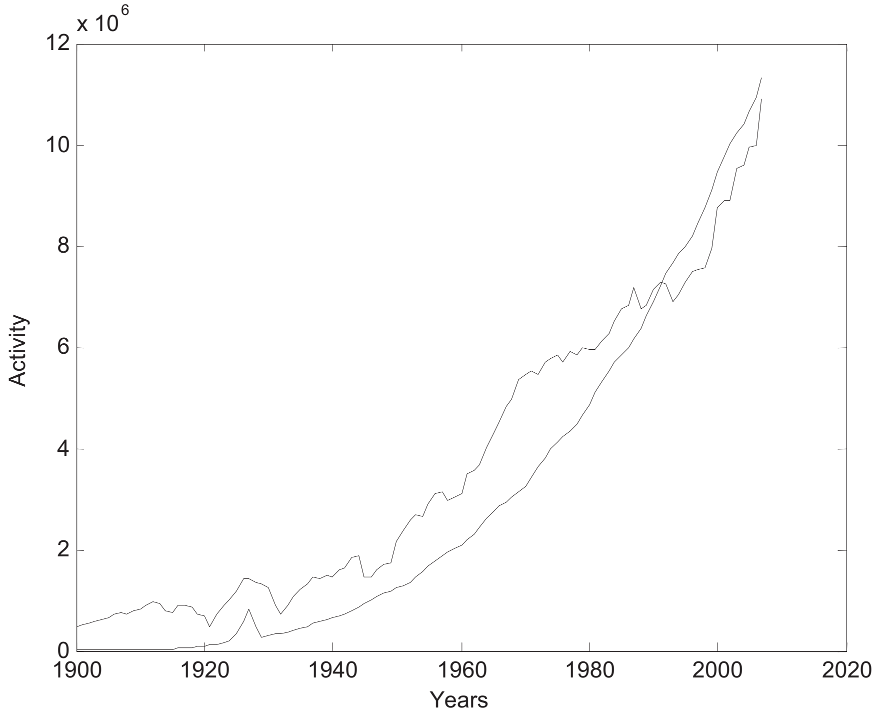
```
                %example [2.8, 3.6.....
                %        4.8] 86

   %constant
   %Please choose the values for the parameters below
   %~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
   a= 20;        %alpha
   b= 30;        %Beta
   u= 27;        %mu "u" is the location parameter. It gives the position of the mean
   v= 0.9;        %nu "v" is the scale factor, which controls the width of  peak
   const= 1.5e6;     %delta
   c= 0.7;        %omega
   x0= 1900;       %origin of the data
   n= 0.9;        %power exponent

   r= [1900, 1901, 1902, 1903, 1904, 1905, 1906, 1907, 1908, 1909, 1910, 1911, 1912, 1913, 1914, 1915, 1916,
1917, 1918, 1919, 1920.....
      1921, 1922, 1923, 1924, 1925, 1926, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934, 1935, 1936, 1937,
1938, 1939, 1940.....
      1941, 1942, 1943, 1944, 1945, 1946, 1947, 1948, 1949, 1950, 1951, 1952, 1953, 1954, 1955, 1956, 1957,
1958, 1959, 1960.....
      1961, 1962, 1963, 1964, 1965, 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977,
1978, 1979, 1980.....
      1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997,
1998, 1999, 2000.....
      2001, 2002, 2003, 2004, 2005, 2006, 2007]       %choose years where you want to predict
              %syntax: (1) r=<start year>:<increment>:<end year>;
              %       (2) r=[1900, 1901, 1903, ...,2000];


% %END USER INPUTS
%~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

% From data
plot(year,activity.*1e3,'r'); %plots (Year VS Activity)

hold on; %to plot two graphs in the same figure


% From Equation
x=r-x0; %normalized years
R2=0; %non-linear R^2 value intialized to zero

% EQUATIONS
z=const*(exp((x-u)./v).*exp(-exp((x-u)./v)))./v;
%calculation of the additive part in the equation

y=x.^n.*[(a^n.*x.^2)+(b^n.*x.*sin(c*x))]+z;
%calulation of the complete equation

plot(r,y,'b');
%plotting the equation

xlabel('Years'); ylabel('Activity');


%Calculation of R2
actmeany=sum(y)/length(y);
```

```
for i=1:length(y)
    SStot=(activity*1e3-actmeany).^2;
    SSreg=(y-activity*1e3).^2;
end
R2=1-(sum(SSreg)/sum(SStot));
disp(R2);
%displaying the R^2 value
```

Program A2.3: Data resulting from program A2.2 composed of “r” values, an R^2 of 0.8805 and an actual and best-fit curve plot.

```
r =

  Columns 1 through 9

        1900        1901        1902        1903        1904        1905        1906        1907        1908

  Columns 10 through 18

        1909        1910        1911        1912        1913        1914        1915        1916        1917

  Columns 19 through 27

        1918        1919        1920        1921        1922        1923        1924        1925        1926

  Columns 28 through 36

        1927        1928        1929        1930        1931        1932        1933        1934        1935

  Columns 37 through 45

        1936        1937        1938        1939        1940        1941        1942        1943        1944

  Columns 46 through 54

        1945        1946        1947        1948        1949        1950        1951        1952        1953

  Columns 55 through 63

        1954        1955        1956        1957        1958        1959        1960        1961        1962

  Columns 64 through 72

        1963        1964        1965        1966        1967        1968        1969        1970        1971

  Columns 73 through 81

        1972        1973        1974        1975        1976        1977        1978        1979        1980

  Columns 82 through 90

        1981        1982        1983        1984        1985        1986        1987        1988        1989

  Columns 91 through 99
```

```
      1990      1991      1992      1993      1994      1995      1996      1997      1998

  Columns 100 through 108

      1999      2000      2001      2002      2003      2004      2005      2006      2007

    0.8805
```



Appendix 3: Engineering Material Data

Table A3.1. Aluminum Activity[3] and Patents[4]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	6800	117	**1927**	220000	539	**1954**	2810000	1170	**1981**	15100000	7673
1901	6800	129	**1928**	258000	592	**1955**	3140000	1189	**1982**	13400000	8912
1902	7900	143	**1929**	280000	644	**1956**	3370000	1420	**1983**	13900000	9348
1903	8500	187	**1930**	272000	841	**1957**	3370000	1531	**1984**	15700000	9747
1904	10000	177	**1931**	220000	868	**1958**	3510000	1567	**1985**	15400000	10485
1905	13000	187	**1932**	153000	876	**1959**	4060000	1729	**1986**	15400000	11407
1906	17000	155	**1933**	142000	848	**1960**	4490000	2372	**1987**	16500000	11271
1907	22000	181	**1934**	170000	735	**1961**	4700000	2181	**1988**	18500000	11856
1908	17000	207	**1935**	259000	832	**1962**	5060000	2300	**1989**	19000000	13416
1909	30000	187	**1936**	360000	824	**1963**	5320000	2379	**1990**	19300000	13523
1910	45000	197	**1937**	482000	827	**1964**	5940000	2519	**1991**	19700000	13455
1911	46000	233	**1938**	579000	984	**1965**	6310000	2871	**1992**	19500000	15034
1912	58000	192	**1939**	720000	823	**1966**	6880000	2668	**1993**	19800000	13599
1913	65000	233	**1940**	787000	635	**1967**	7570000	3129	**1994**	19200000	13897
1914	69000	213	**1941**	1040000	563	**1968**	8020000	2895	**1995**	19700000	13498
1915	78000	159	**1942**	1400000	491	**1969**	8970000	2917	**1996**	20800000	13572
1916	106000	116	**1943**	1950000	436	**1970**	9650000	3325	**1997**	21700000	13505
1917	123000	117	**1944**	1690000	397	**1971**	10300000	3480	**1998**	22600000	15369
1918	128000	119	**1945**	870000	486	**1972**	11000000	4112	**1999**	23600000	15872
1919	121000	199	**1946**	790000	473	**1973**	12100000	3884	**2000**	24300000	18286
1920	125000	279	**1947**	1080000	548	**1974**	13200000	3496	**2001**	24300000	17164
1921	70000	429	**1948**	1270000	784	**1975**	12100000	3908	**2002**	26100000	17853
1922	87000	409	**1949**	1310000	776	**1976**	12600000	4373	**2003**	27900000	17453
1923	141000	389	**1950**	1490000	637	**1977**	13800000	4961	**2004**	29800000	17721
1924	168000	435	**1951**	1800000	837	**1978**	14100000	5705	**2005**	31900000	16944
1925	178000	501	**1952**	2060000	1124	**1979**	14600000	5620	**2006**	33700000	16577
1926	195000	449	**1953**	2470000	936	**1980**	15400000	7279	**2007**	37900000	18141

Table A3.2. Correlation Eq.(A1.1) terms calculated from Table A3.1 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	100r^2
833134000	486253	1.6E+16	5.81E+09	9.43E+12	9.559E+15	3.62E+09	5.68E+12	**0.965222**	**93.16534**

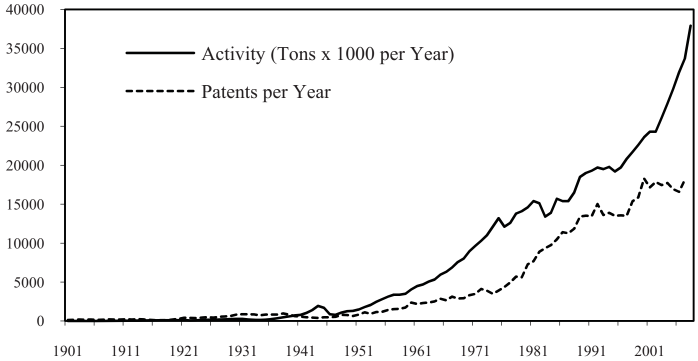


Figure A3.1. Aluminum: Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[3] Activity represents world production of aluminum, defined at usgs.gov as "…world primary aluminum production. Data are reported in the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[4] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Aluminum, Al and aluminium were used as keywords found in the patent title or abstract by year of publication.

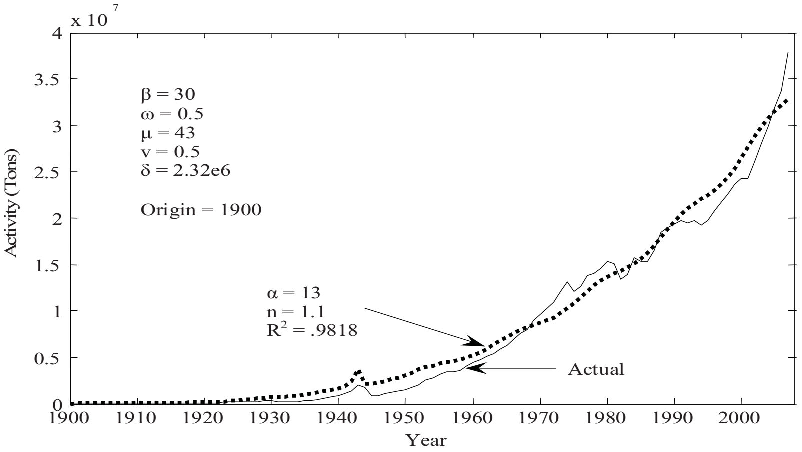

Figure A3.2. **USGS World Aluminum Production.** World aluminum production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

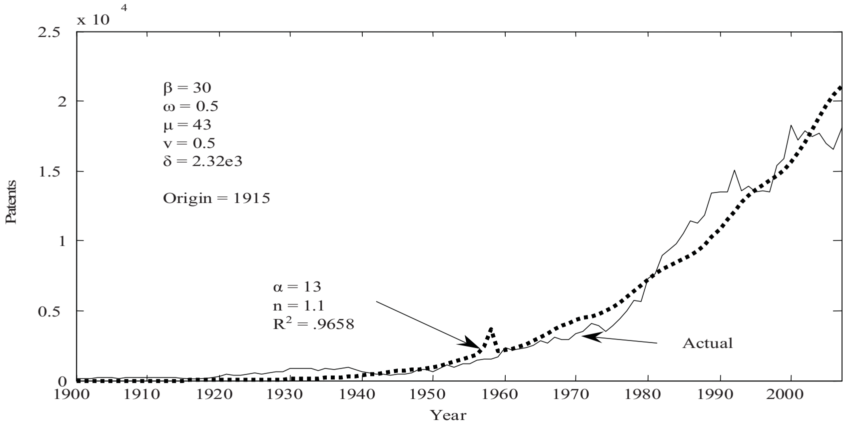

Figure A3.3. EPO Worldwide Patent Search: Aluminum, Al or Aluminum in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

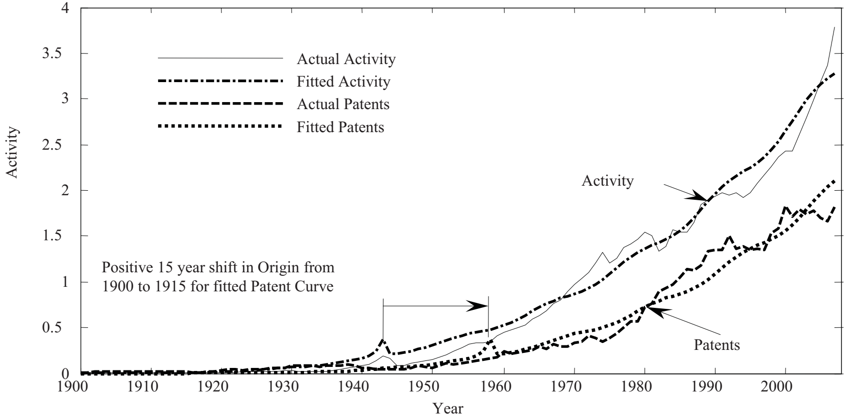

Figure A3.4. Aluminum Best-Fit Activity and Patents. Illustrates aluminum best-fit origin shift.

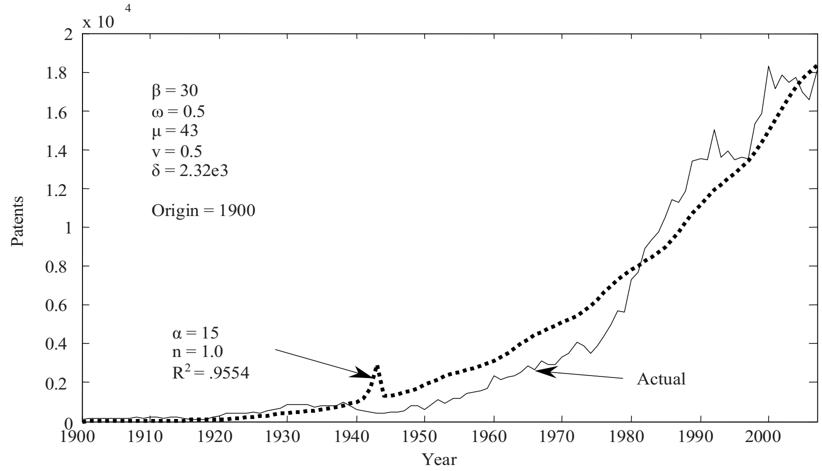

Figure A3.5. **Aluminum Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.3. Antimony Activity[5] and Patents[6]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**	28000	50	**1954**	39900	103	**1981**	59200	350
1901			**1928**	28500	51	**1955**	46300	83	**1982**	53800	366
1902			**1929**	31600	64	**1956**	53300	130	**1983**	48400	373
1903			**1930**	23600	86	**1957**	50800	116	**1984**	53400	401
1904			**1931**	15600	82	**1958**	46300	139	**1985**	55000	443
1905			**1932**	17300	67	**1959**	53300	119	**1986**	59900	401
1906	14500	19	**1933**	20200	68	**1960**	53300	225	**1987**	56100	367
1907	15000	17	**1934**	22600	61	**1961**	51900	192	**1988**	64400	439
1908	16000	15	**1935**	29800	64	**1962**	53700	201	**1989**	68400	479
1909	15000	15	**1936**	35300	78	**1963**	58000	227	**1990**	60400	496
1910	15000	22	**1937**	38600	101	**1964**	63000	254	**1991**	64700	515
1911	15500	34	**1938**	33900	79	**1965**	63000	313	**1992**	76000	518
1912	24200	26	**1939**	38800	50	**1966**	61400	217	**1993**	73000	509
1913	24500	22	**1940**	46300	66	**1967**	58400	243	**1994**	106000	537
1914	23600	21	**1941**	49000	51	**1968**	61500	220	**1995**	103000	487
1915	43200	13	**1942**	51400	36	**1969**	66200	198	**1996**	156000	504
1916	81600	8	**1943**	53200	32	**1970**	70000	187	**1997**	155000	530
1917	57200	13	**1944**	36000	27	**1971**	64100	208	**1998**	117000	548
1918	30800	18	**1945**	27000	52	**1972**	68100	243	**1999**	108000	597
1919	11800	13	**1946**	26000	56	**1973**	69300	209	**2000**	118000	625
1920	29000	19	**1947**	38000	42	**1974**	70500	209	**2001**	157000	656
1921	18300	27	**1948**	45000	64	**1975**	67900	262	**2002**	118000	778
1922	18900	31	**1949**	37000	64	**1976**	69200	305	**2003**	116000	700
1923	17600	30	**1950**	50000	57	**1977**	72200	296	**2004**	142000	649
1924	17500	33	**1951**	65000	57	**1978**	68800	279	**2005**	171000	618
1925	25500	44	**1952**	44500	86	**1979**	71900	268	**2006**	173000	586
1926	29000	51	**1953**	33600	63	**1980**	67200	371	**2007**	170000	621

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[5] Activity represents world production of antimony, defined at usgs.gov as "…world mine production in terms of antimony content. U.S. production is withheld and not available in the total for the years 1985-92 and 2000 to the most recent. Data are reported in the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[6] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Antimony and stibium were used as keywords found in the patent title or abstract by year of publication.

Table A3.4. Correlation Eq.(A1.1) terms calculated from Table A3.3 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
5899990	22160	4.79E+11	9177362	1.94E+09	1.565E+11	4630458	7.25E+08	**0.851817**	**72.55915**

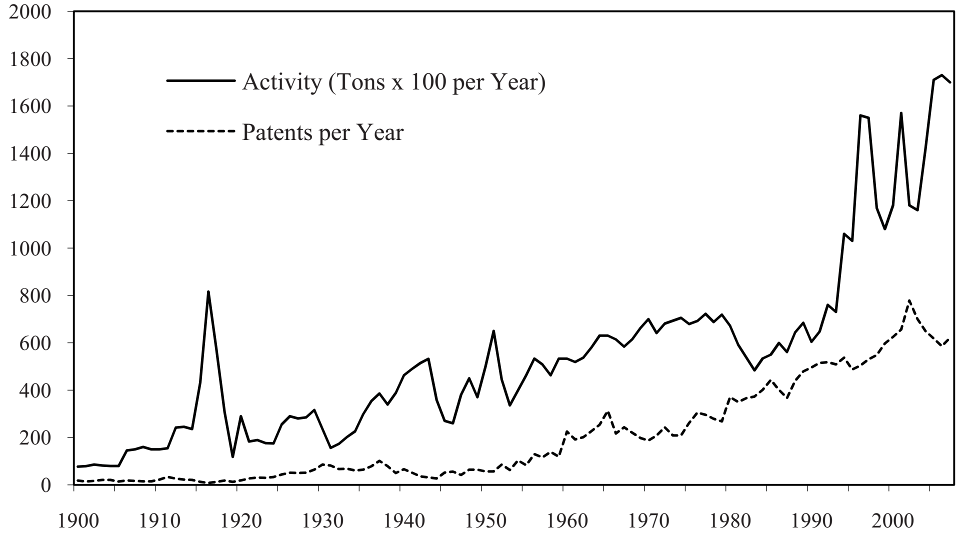

Figure A3.6. Antimony: Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

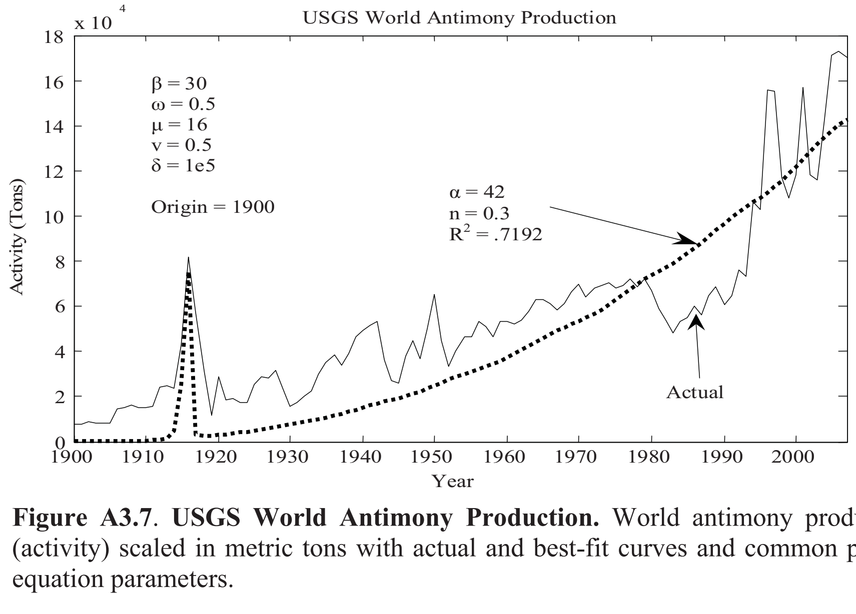

Figure A3.7. **USGS World Antimony Production.** World antimony production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

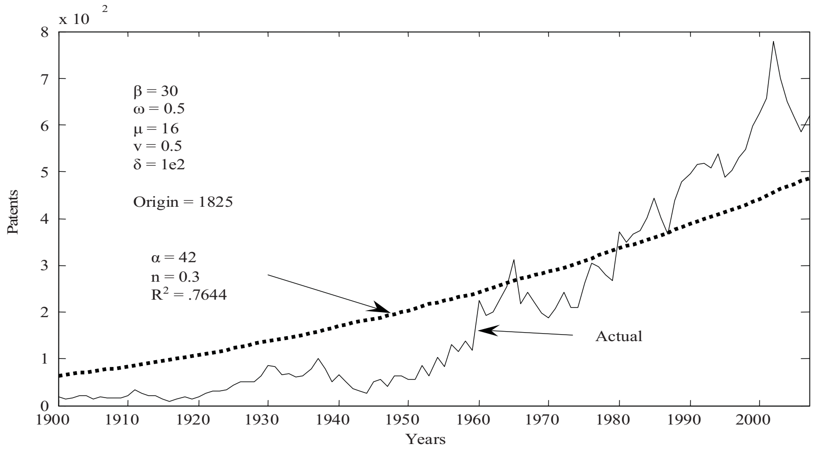

Figure A3.8. EPO Worldwide Patent Search: Antimony or Stibium in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

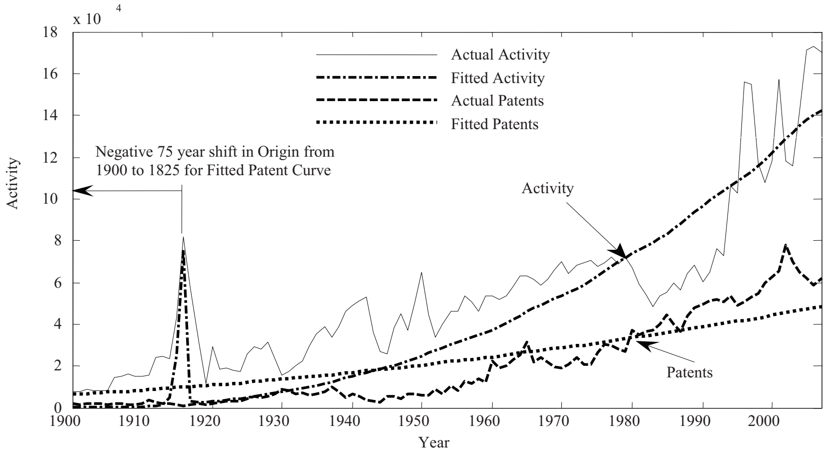

Figure A3.9. Antimony Best-Fit Activity and Patents. Illustrates antimony best-fit origin shift.

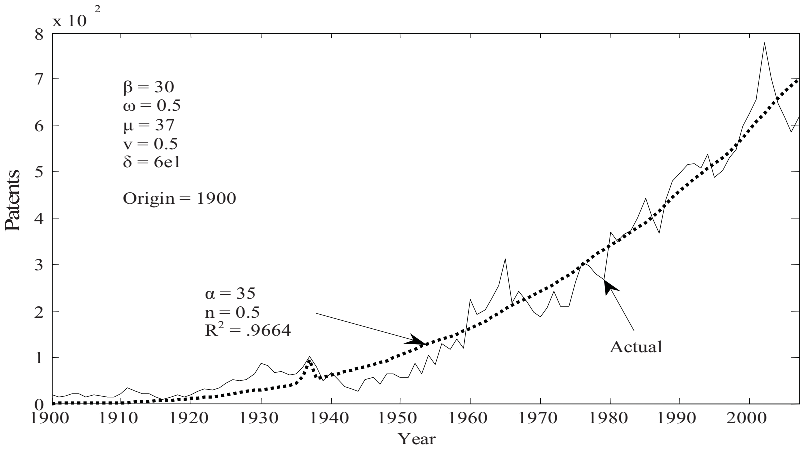

Figure A3.10. **Antimony Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.5. Arsenic Activity[7] and Patents[8]

Year	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**
1900			**1927**	39900	42	**1954**	26100	34	**1981**	33100	228
1901			**1928**	43200	58	**1955**	30900	41	**1982**	34500	281
1902			**1929**	46000	42	**1956**	33700	62	**1983**	31900	275
1903			**1930**	49600	59	**1957**	30900	62	**1984**	35600	334
1904			**1931**	51000	59	**1958**	27500	57	**1985**	40300	439
1905			**1932**	51500	45	**1959**	32100	54	**1986**	39600	435
1906			**1933**	27300	46	**1960**	39400	102	**1987**	47200	423
1907			**1934**	38200	40	**1961**	40500	93	**1988**	40400	500
1908			**1935**	41600	51	**1962**	34100	79	**1989**	49400	492
1909			**1936**	42200	42	**1963**	36600	121	**1990**	40400	436
1910	6810	17	**1937**	42400	57	**1964**	39900	103	**1991**	34800	457
1911	12800	12	**1938**	52200	44	**1965**	38600	135	**1992**	34700	497
1912	27600	17	**1939**	42800	42	**1966**	39500	117	**1993**	31900	349
1913	13400	13	**1940**	40400	32	**1967**	44600	115	**1994**	35400	321
1914	11500	6	**1941**	46000	34	**1968**	46400	104	**1995**	35600	287
1915	13300	5	**1942**	47700	14	**1969**	37700	108	**1996**	32500	237
1916	13300	8	**1943**	50200	19	**1970**	37500	105	**1997**	31800	253
1917	16400	3	**1944**	51800	8	**1971**	37800	100	**1998**	30500	358
1918	23200	11	**1945**	42100	37	**1972**	31400	143	**1999**	31600	365
1919	19000	15	**1946**	31800	32	**1973**	35200	111	**2000**	47500	406
1920	27900	12	**1947**	42400	20	**1974**	37200	94	**2001**	45000	370
1921	16200	15	**1948**	40900	34	**1975**	30700	105	**2002**	44700	387
1922	23500	20	**1949**	26500	26	**1976**	26100	134	**2003**	69700	364
1923	47300	30	**1950**	35700	20	**1977**	23200	119	**2004**	57800	421
1924	47200	26	**1951**	47400	19	**1978**	23300	182	**2005**	60000	461
1925	50300	37	**1952**	37100	41	**1979**	22400	127	**2006**	61200	391
1926	41100	46	**1953**	20600	23	**1980**	23600	240	**2007**	55900	451

Table A3.6. Correlation Eq.(A1.1) terms calculated from Table A3.5 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**100r^2**
3579210	14344	1.44E+11	4431828	5.84E+08	1.344E+10	2332335	59759598	**0.337535**	**11.39299**

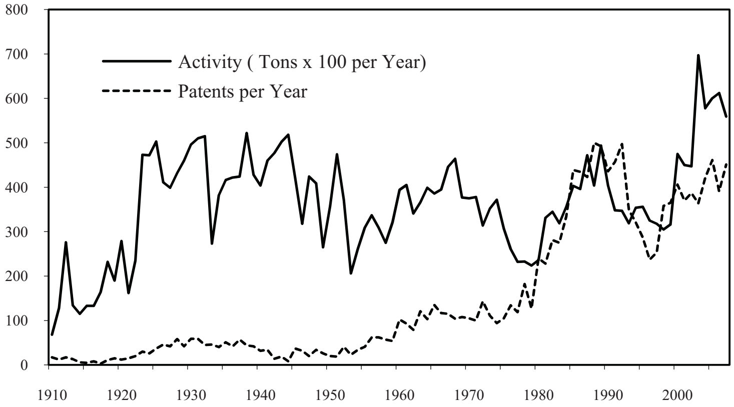

Figure A3.11. Arsenic: Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[7] Activity represents world production of antimony, defined at usgs.gov as "…world production of arsenic trioxide in terms of arsenic content. Data are not available for the years 1906-09. Data are from the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[8] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Arsenic was used as a keyword found in the patent title or abstract by year of publication.

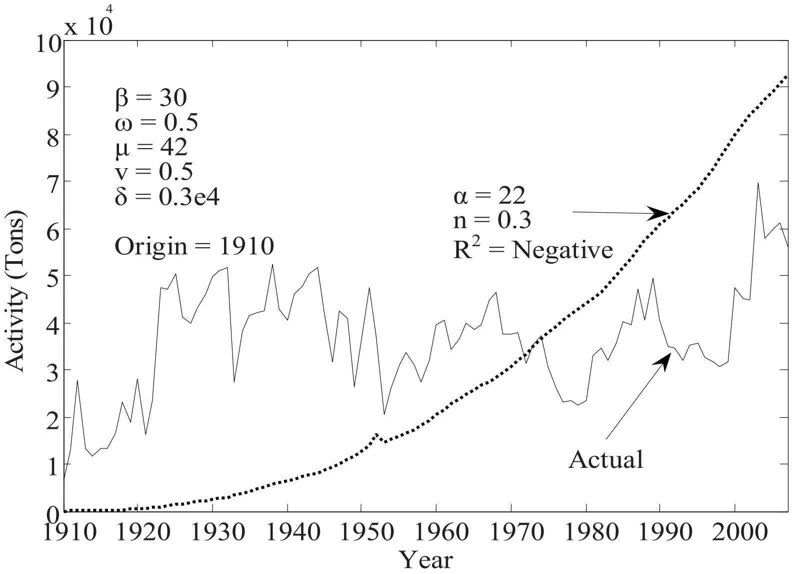

Figure A3.12. **USGS World Arsenic Production.** World arsenic production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters. *R²* has a negative value indicating Stage IV. No best-fit for the patent data was obtainable.

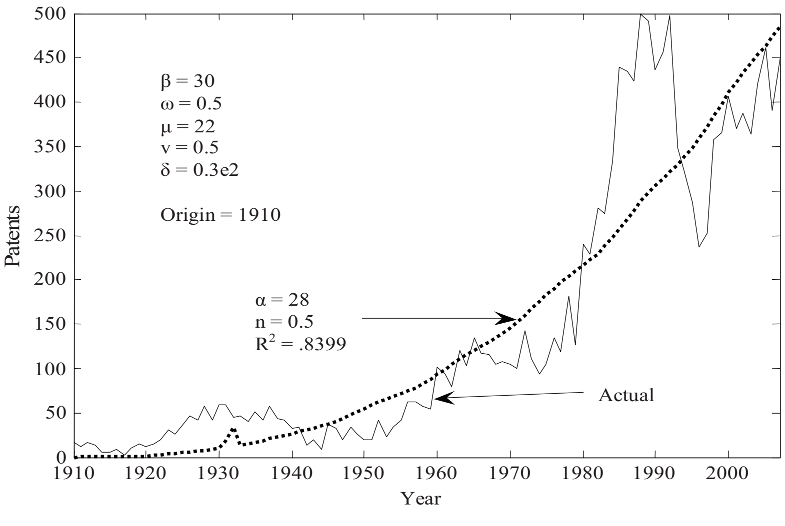

Figure A3.13. Arsenic Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.7. Asbestos[9] Activity[10] and Patents[11]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	20600	104	**1927**	342000	209	**1954**	1510000	189	**1981**	4350000	324
1901	30500	117	**1928**	354000	189	**1955**	1770000	197	**1982**	4560000	325
1902	28400	154	**1929**	400000	205	**1956**	1810000	215	**1983**	4430000	313
1903	34300	183	**1930**	339000	245	**1957**	1890000	231	**1984**	4310000	272
1904	41100	180	**1931**	235000	238	**1958**	1860000	198	**1985**	4250000	254
1905	56000	154	**1932**	186000	276	**1959**	2050000	184	**1986**	4030000	213
1906	64700	126	**1933**	249000	232	**1960**	2210000	274	**1987**	4240000	203
1907	66300	133	**1934**	271000	240	**1961**	2510000	245	**1988**	4320000	220
1908	14100	146	**1935**	337000	229	**1962**	2410000	263	**1989**	4240000	337
1909	73600	130	**1936**	460000	207	**1963**	2510000	276	**1990**	4010000	324
1910	84700	135	**1937**	556000	247	**1964**	2770000	328	**1991**	3530000	304
1911	114000	150	**1938**	413000	246	**1965**	2810000	344	**1992**	3350000	333
1912	117000	156	**1939**	425000	182	**1966**	2970000	289	**1993**	2520000	269
1913	145000	166	**1940**	428000	155	**1967**	2910000	392	**1994**	2250000	221
1914	106000	153	**1941**	528000	144	**1968**	3010000	379	**1995**	2180000	201
1915	117000	128	**1942**	509000	131	**1969**	3270000	344	**1996**	2100000	207
1916	142000	91	**1943**	575000	118	**1970**	3490000	419	**1997**	2150000	153
1917	141000	78	**1944**	546000	94	**1971**	3580000	424	**1998**	1980000	192
1918	144000	94	**1945**	573000	127	**1972**	3780000	451	**1999**	1850000	149
1919	181000	136	**1946**	680000	144	**1973**	4190000	397	**2000**	2110000	157
1920	193000	168	**1947**	816000	155	**1974**	4160000	359	**2001**	2060000	111
1921	91100	203	**1948**	930000	224	**1975**	4140000	429	**2002**	2320000	141
1922	136000	198	**1949**	884000	209	**1976**	4770000	439	**2003**	2400000	140
1923	201000	171	**1950**	1290000	126	**1977**	4790000	444	**2004**	2330000	138
1924	198000	185	**1951**	1420000	157	**1978**	4690000	386	**2005**	2250000	126
1925	312000	195	**1952**	1420000	172	**1979**	4760000	249	**2006**	2180000	149
1926	329000	175	**1953**	1420000	173	**1980**	4700000	333	**2007**	2200000	349

Table A3.8. Correlation Eq.(A1.1) terms calculated from Table A3.7 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
187587400	23886	5.93E+14	6179482	5.28E+10	2.672E+14	896695	1.13E+10	**0.728794**	**53.11403**

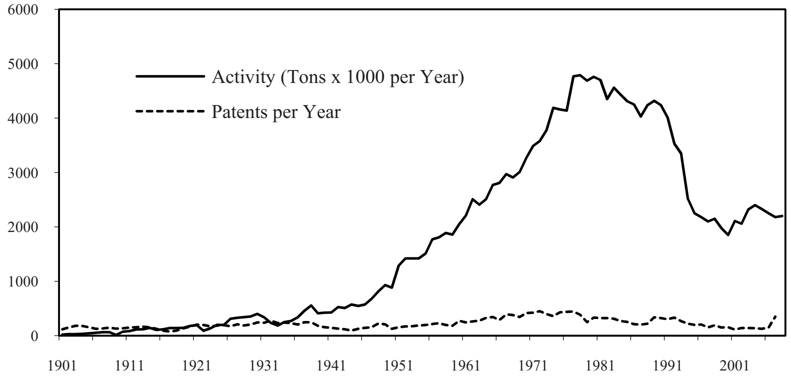

Figure A3.14 Asbestos: Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[9] Fibrous amphibole mineral [128].

[10] Activity represents world production of asbestos, defined at usgs.gov as "…world mine production of asbestos. Data for the years 1900-04 include only Canada and the United States. For the years 1904-12 data include Canada, The United States and Russia. World asbestos mine production data are from the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[11] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Asbestos was used as a keyword found in the patent title or abstract by year of publication.

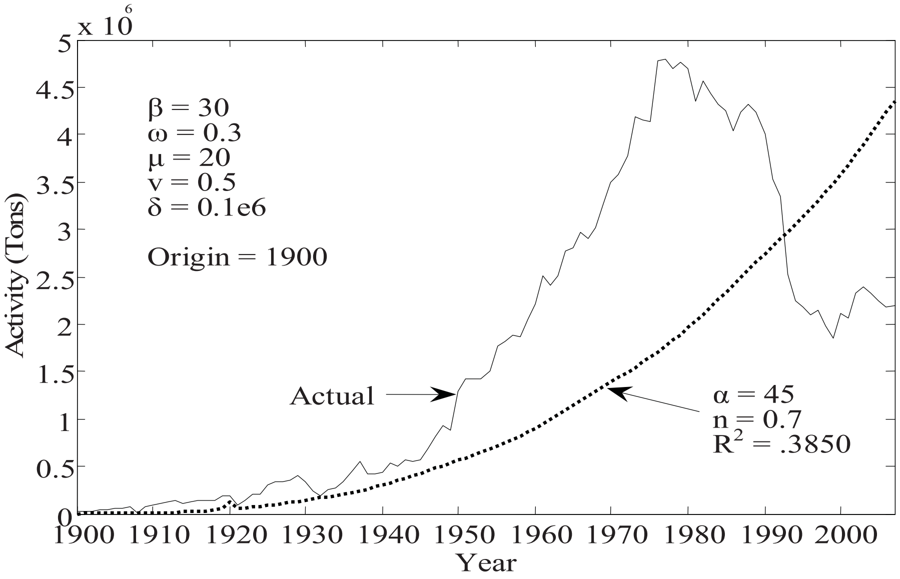

Figure A3.15. **USGS World Asbestos Production.** World asbestos production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters. No best-fit for the patent data was obtainable.

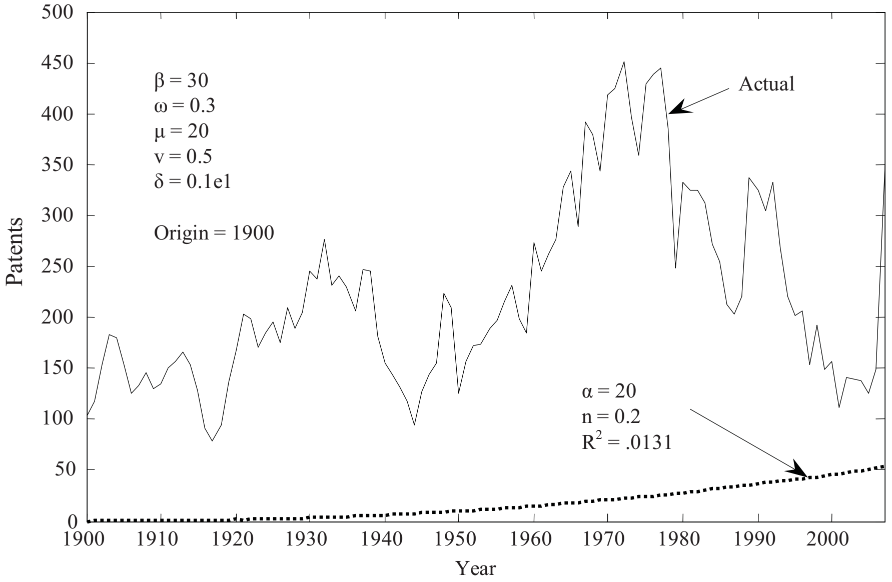

Figure A3.16. Asbestos Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.9. Barite[12] Activity[13] and Patents[14]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**	536000	0	**1954**	2080000	4	**1981**	8310000	39
1901			**1928**	635000	0	**1955**	2420000	0	**1982**	7400000	45
1902			**1929**	677000	1	**1956**	2700000	1	**1983**	5470000	61
1903			**1930**	592000	0	**1957**	3340000	0	**1984**	5910000	72
1904			**1931**	468000	1	**1958**	2480000	1	**1985**	6160000	68
1905			**1932**	368000	0	**1959**	2700000	0	**1986**	4790000	92
1906			**1933**	439000	1	**1960**	2710000	0	**1987**	4810000	110
1907			**1934**	770000	0	**1961**	2820000	0	**1988**	5660000	64
1908			**1935**	726000	0	**1962**	3080000	1	**1989**	5820000	101
1909			**1936**	854000	0	**1963**	2880000	0	**1990**	5870000	95
1910			**1937**	992000	0	**1964**	3170000	1	**1991**	5570000	98
1911			**1938**	975000	1	**1965**	3540000	4	**1992**	4840000	105
1912			**1939**	961000	1	**1966**	3690000	2	**1993**	4470000	103
1913			**1940**	959000	0	**1967**	3570000	3	**1994**	4470000	139
1914			**1941**	1030000	0	**1968**	3420000	0	**1995**	4830000	120
1915			**1942**	1000000	1	**1969**	3850000	0	**1996**	6060000	126
1916			**1943**	1010000	0	**1970**	3940000	0	**1997**	6690000	135
1917			**1944**	1120000	1	**1971**	3730000	1	**1998**	5750000	126
1918			**1945**	964000	1	**1972**	3960000	10	**1999**	6160000	139
1919	359000	0	**1946**	1110000	0	**1973**	4750000	7	**2000**	6560000	157
1920	453000	0	**1947**	1360000	0	**1974**	4870000	5	**2001**	6740000	135
1921	242000	0	**1948**	1210000	0	**1975**	5010000	10	**2002**	6160000	128
1922	414000	1	**1949**	1340000	1	**1976**	5360000	13	**2003**	6780000	167
1923	445000	0	**1950**	1450000	0	**1977**	5960000	16	**2004**	7760000	149
1924	487000	2	**1951**	1670000	0	**1978**	7000000	18	**2005**	8110000	156
1925	536000	1	**1952**	1780000	1	**1979**	7170000	25	**2006**	7960000	133
1926	527000	0	**1953**	1960000	1	**1980**	7600000	52	**2007**	7630000	119

Table A3.10. Correlation Eq.(A1.1) terms calculated from Table A3.9 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	100r^2
304959000	3171	1.59E+15	365171	1.96E+10	5.406E+14	252190.8	8.74E+09	**0.748629**	**56.04449**

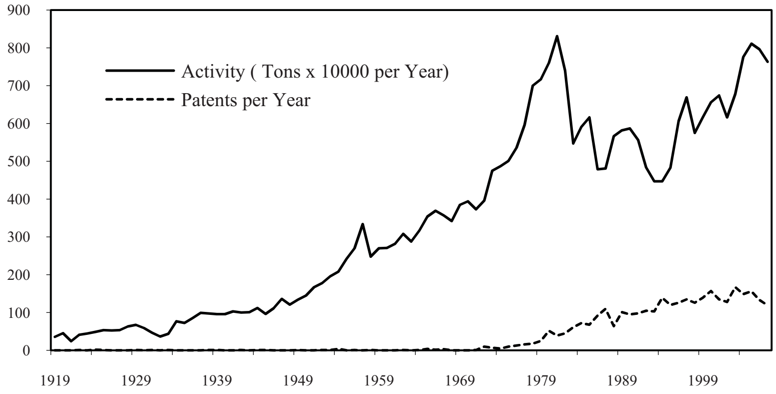

Figure A3.17. Barite: Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[12] Orthorhombic mineral form of barium sulfate [128].

[13] Activity represents world production of barite, defined at usgs.gov as "…world crude barite production. Data are not available for the years 1900-12 and 1914-1918. Data are reported in the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[14] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Barite, baryte or barium sulphate were used as keywords found in the patent title or abstract by year of publication.

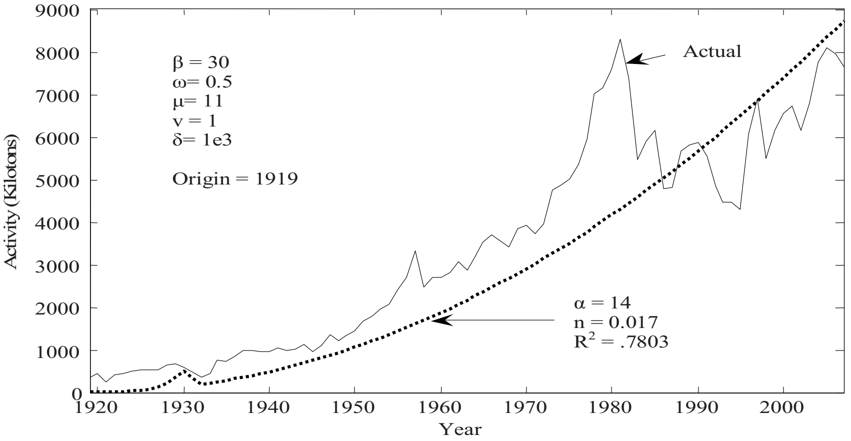

Figure A3.18. **USGS World Barite Production.** World barite production (activity) scaled in metric kilotons with actual and best-fit curves and common pattern equation parameters. No best-fit for the patent data was obtainable.

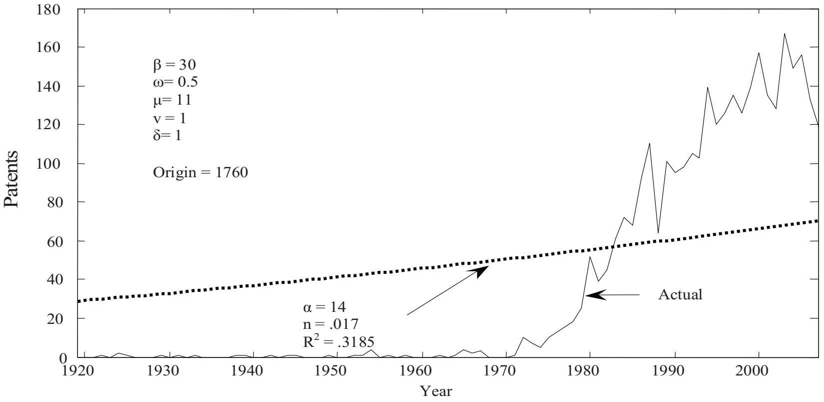

Figure A3.19. EPO Worldwide Patent Search: Barite, Baryte or Barium Sulphate in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

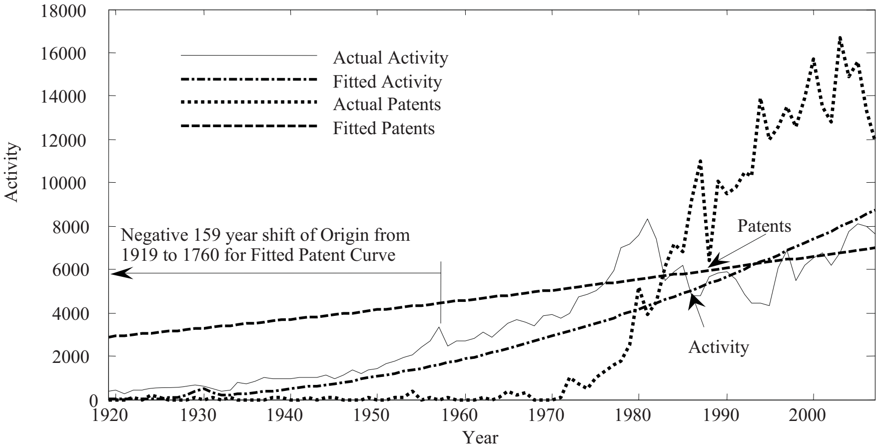

Figure A3.20. Barite Best-Fit Activity and Patents. Illustrates barite best-fit origin shift.

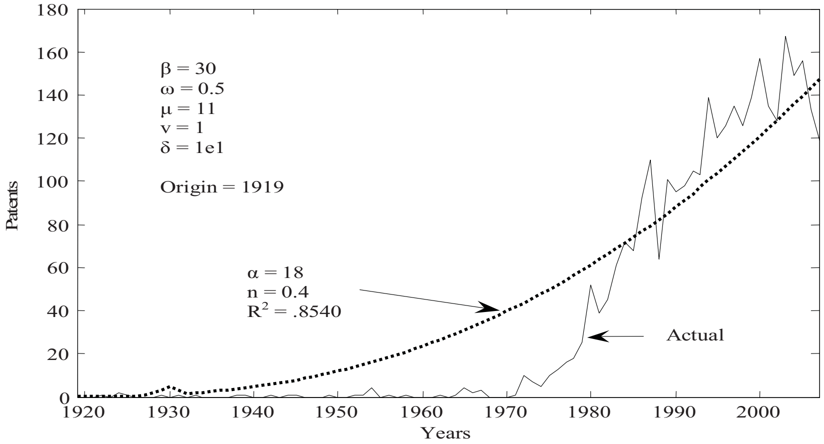

Figure A3.21. Barite Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.11. Bauxite/Alumina[15] Activity[16] and Patents[17]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y patent	Yr.	x (activity)	y patent
1900	88000	19	**1927**	1880000	80	**1954**	16200000	278	**1981**	85300000	1466
1901	106000	21	**1928**	2030000	95	**1955**	17800000	260	**1982**	79300000	1605
1902	136000	16	**1929**	2150000	81	**1956**	18800000	331	**1983**	78700000	1674
1903	189000	26	**1930**	1630000	127	**1957**	20500000	374	**1984**	87200000	1854
1904	133000	27	**1931**	1150000	103	**1958**	21400000	432	**1985**	84200000	1895
1905	159000	19	**1932**	1000000	107	**1959**	23100000	414	**1986**	88200000	2162
1906	201000	20	**1933**	1100000	102	**1960**	27600000	581	**1987**	91600000	2004
1907	269000	22	**1934**	1330000	100	**1961**	29400000	434	**1988**	97400000	2207
1908	243000	37	**1935**	1770000	109	**1962**	31100000	435	**1989**	103000000	3058
1909	275000	28	**1936**	2830000	124	**1963**	30700000	453	**1990**	113000000	2794
1910	356000	27	**1937**	3750000	113	**1964**	33400000	502	**1991**	111000000	2652
1911	425000	23	**1938**	3870000	143	**1965**	37400000	595	**1992**	105000000	2795
1912	435000	20	**1939**	4340000	100	**1966**	40700000	542	**1993**	110000000	2463
1913	539000	39	**1940**	4390000	93	**1967**	44600000	619	**1994**	106000000	2447
1914	236000	28	**1941**	6110000	84	**1968**	46000000	616	**1995**	112000000	2331
1915	321000	35	**1942**	8360000	63	**1969**	51800000	520	**1996**	117000000	2266
1916	701000	16	**1943**	14000000	49	**1970**	57800000	644	**1997**	122000000	2218
1917	1030000	19	**1944**	6960000	75	**1971**	62100000	692	**1998**	123000000	2562
1918	818000	15	**1945**	3430000	80	**1972**	64900000	872	**1999**	129000000	2611
1919	569000	37	**1946**	4360000	95	**1973**	70400000	783	**2000**	136000000	2687
1920	901000	45	**1947**	6320000	125	**1974**	79600000	786	**2001**	137000000	2331
1921	318000	47	**1948**	8360000	143	**1975**	74800000	966	**2002**	144000000	2347
1922	701000	43	**1949**	8230000	159	**1976**	77400000	1101	**2003**	153000000	2478
1923	1200000	33	**1950**	8180000	143	**1977**	81900000	1113	**2004**	164000000	2346
1924	1160000	43	**1951**	10900000	144	**1978**	81000000	1142	**2005**	179000000	2219
1925	1380000	81	**1952**	12800000	220	**1979**	85500000	1018	**2006**	199000000	2110
1926	1380000	57	**1953**	13800000	184	**1980**	89200000	1513	**2007**	202000000	2198

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[15] Aluminum ore and aluminum oxide [128].

[16] Activity represents world production of bauxite, defined at usgs.gov as "…world mine production of bauxite is reported on a 'dried bauxite equivalents' basis. U.S. bauxite production data are withheld from the total for the years 1989 to the most recent. Alumina world production data is reported as 'quantity produced' (alumina), for the years 1968-71, and as 'calcined alumina equivalents' for the years after 1971. All data are reported in the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[17] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Bauxite or alumina were used as keywords found in the patent title or abstract by year of publication.

Table A3.12. Correlation Eq.(A1.1) terms calculated from Table A3.9 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
4.731E+09	83680	5.05E+17	1.6E+08	8.62E+12	2.974E+17	95135138	4.95E+12	**0.930961**	**86.66877**

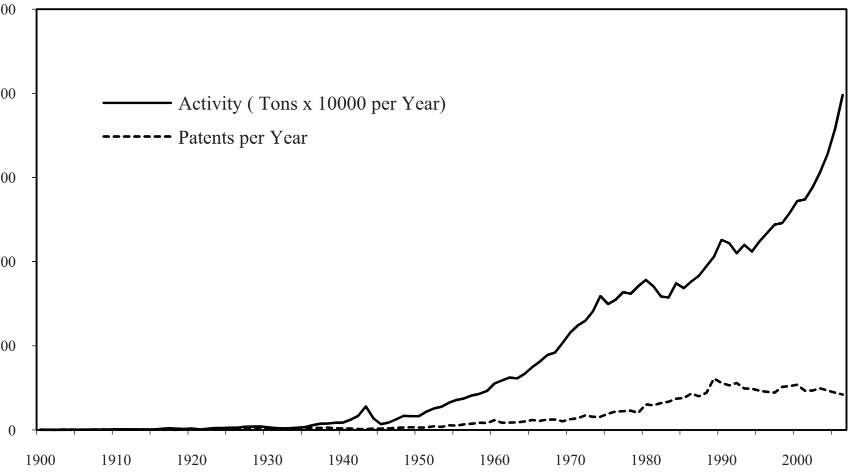

Figure A3.22. Bauxite and Alumina Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

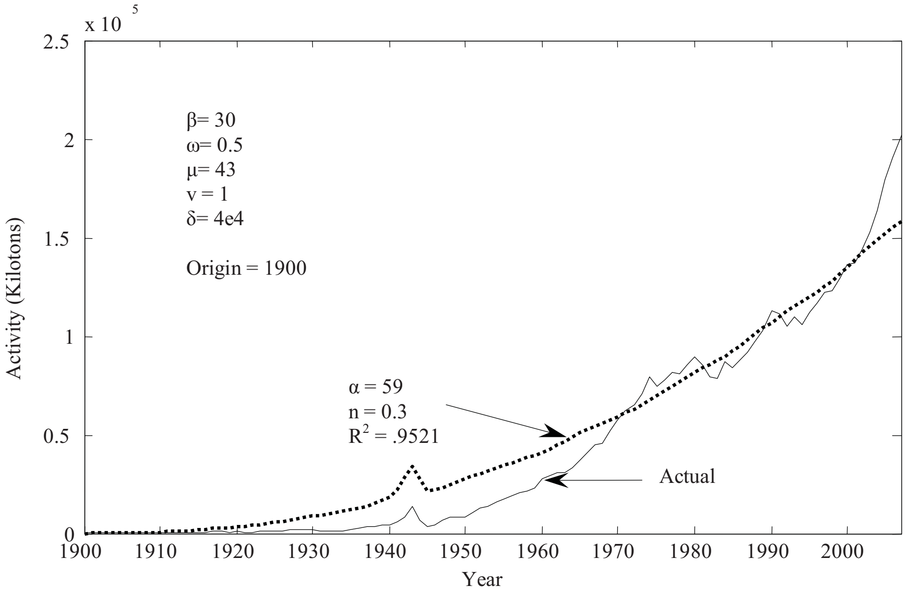

Figure A3.23. **USGS World Bauxite/Alumina Production.** World bauxite/alumina production (activity) scaled in metric kilotons with actual and best-fit curves and common pattern equation parameters.

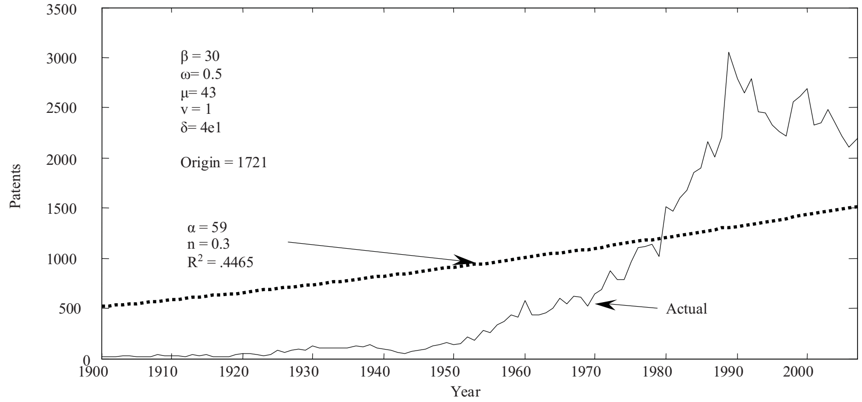

Figure A3.24. EPO Worldwide Patent Search: Bauxite or Alumina in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

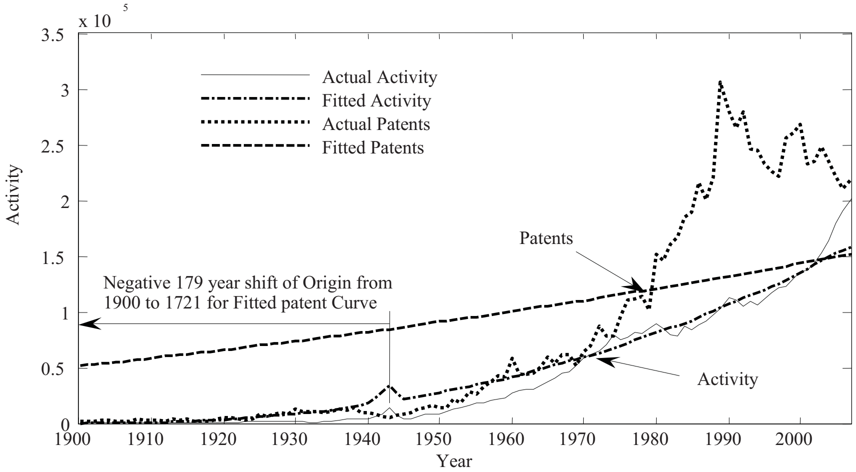

Figure A3.25. Bauxite/Alumina Best-Fit Activity and Patents. Illustrates bauxite/Alumina best-fit origin shift.

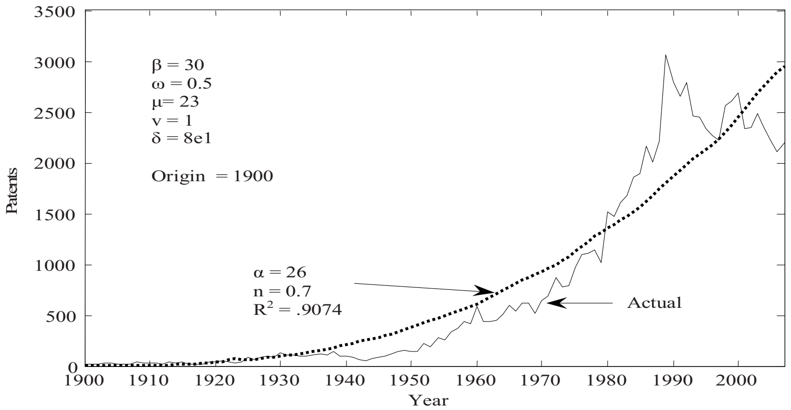

Figure A3.26. Bauxite/Alumina Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.13 Beryllium Activity[18] and Patents[19]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**	279	54	**1981**	385	80
1901			**1928**			**1955**	323	43	**1982**	327	115
1902			**1929**			**1956**	468	64	**1983**	366	111
1903			**1930**			**1957**	410	74	**1984**	359	107
1904			**1931**			**1958**	279	87	**1985**	326	125
1905			**1932**			**1959**	406	83	**1986**	356	124
1906			**1933**			**1960**	446	117	**1987**	345	102
1907			**1934**			**1961**	468	133	**1988**	332	114
1908			**1935**	16	71	**1962**	399	133	**1989**	301	112
1909			**1936**	17	50	**1963**	265	149	**1990**	284	103
1910			**1937**	15	52	**1964**	178	178	**1991**	263	107
1911			**1938**	42	72	**1965**	222	144	**1992**	278	115
1912			**1939**	36	104	**1966**	165	152	**1993**	243	117
1913			**1940**	87	79	**1967**	197	183	**1994**	218	137
1914			**1941**	164	58	**1968**	263	168	**1995**	247	118
1915			**1942**	120	43	**1969**	322	144	**1996**	255	101
1916			**1943**	218	31	**1970**	249	145	**1997**	276	114
1917			**1944**	118	29	**1971**	210	156	**1998**	289	160
1918			**1945**	39	33	**1972**	157	148	**1999**	248	133
1919			**1946**	68	58	**1973**	144	151	**2000**	202	163
1920			**1947**	57	55	**1974**	126	140	**2001**	120	169
1921			**1948**	99	67	**1975**	119	124	**2002**	101	161
1922			**1949**	183	68	**1976**	93	100	**2003**	107	170
1923			**1950**	269	33	**1977**	103	103	**2004**	111	128
1924			**1951**	243	76	**1978**	105	110	**2005**	137	116
1925			**1952**	301	65	**1979**	96	81	**2006**	179	97
1926			**1953**	298	44	**1980**	373	97	**2007**	179	123

Table A3.14. Correlation Eq.(A1.1) terms calculated from Table A3.13 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	100r^2
16089	7671	4540781	923695	1729386	994809.48	117609.5	38718.62	**0.113195**	**1.281319**

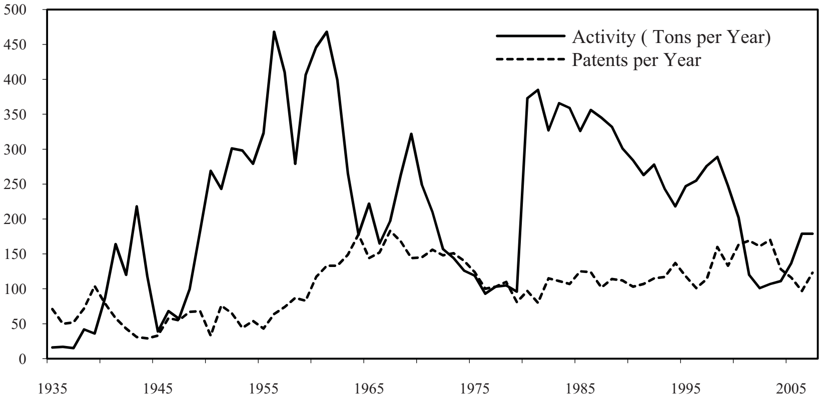

Figure A3.27. Beryllium Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[18] Activity represents world production of beryllium, defined at usgs.gov as "…the estimated beryllium content of beryllium-bearing ores produced throughout the world. World mine production data are based on a beryllium metal equivalent of 4 percent Be in beryl and bertrandite ores, reported as equivalent to beryl ore containing 11 percent BeO. Data are not available prior to the year 1935. U.S. production data for the years 1964-67 and 1969-79 are not available and are not included in the total. Data are from the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[19] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Beryllium was used as the keyword found in the patent title or abstract by year of publication.

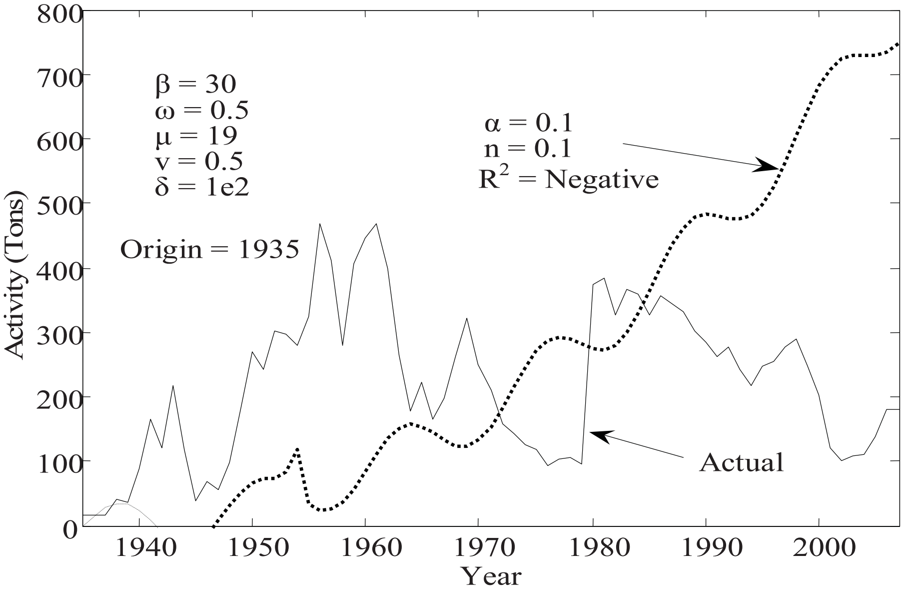

Figure A3.28. **USGS World Beryllium Production.** World beryllium production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters. R^2 has a negative value indicating Stage IV. No best-fit for the patent data was obtainable.

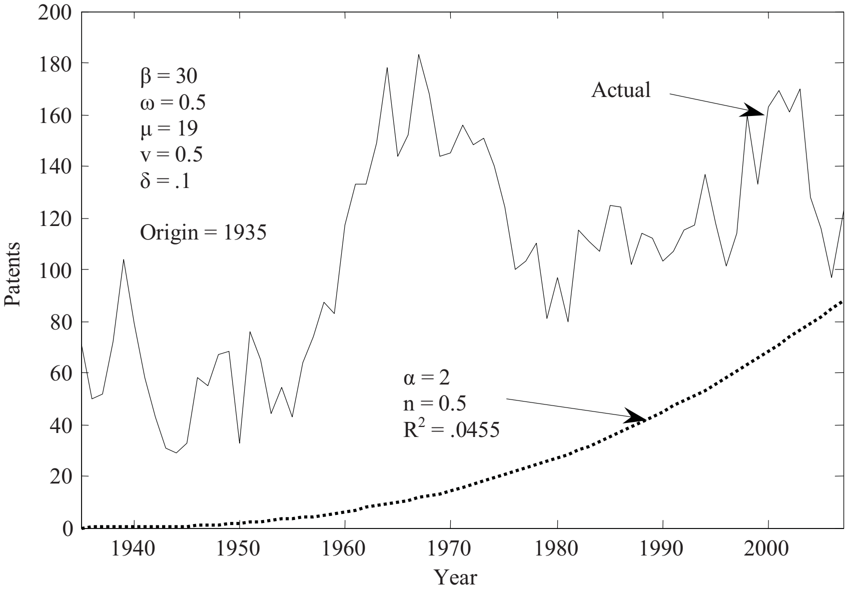

Figure A3.29. Beryllium Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.15 Bismuth Activity[20] and Patents[21]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**	1680	57	**1981**	3750	236
1901			**1928**			**1955**	1910	43	**1982**	4110	215
1902			**1929**			**1956**	2400	60	**1983**	3980	259
1903			**1930**			**1957**	2270	66	**1984**	3480	240
1904			**1931**			**1958**	2090	61	**1985**	4410	207
1905			**1932**			**1959**	2270	77	**1986**	3660	234
1906			**1933**			**1960**	2400	124	**1987**	3170	221
1907			**1934**			**1961**	2590	107	**1988**	3220	261
1908			**1935**			**1962**	3040	110	**1989**	3650	339
1909			**1936**			**1963**	2530	110	**1990**	3440	497
1910			**1937**	700	46	**1964**	2890	149	**1991**	3230	385
1911			**1938**	1000	51	**1965**	2960	134	**1992**	2870	506
1912			**1939**	1300	47	**1966**	3110	118	**1993**	3550	472
1913			**1940**	1400	39	**1967**	3380	124	**1994**	3410	430
1914			**1941**	1400	43	**1968**	3770	122	**1995**	3430	387
1915			**1942**	1700	15	**1969**	3760	94	**1996**	3600	457
1916			**1943**	1400	14	**1970**	3720	103	**1997**	4490	468
1917			**1944**	1200	18	**1971**	3830	129	**1998**	3990	504
1918			**1945**	1100	32	**1972**	4000	132	**1999**	5490	545
1919			**1946**	940	22	**1973**	3720	132	**2000**	3760	542
1920			**1947**	1500	26	**1974**	4820	135	**2001**	4420	570
1921			**1948**	1500	45	**1975**	3980	153	**2002**	4600	603
1922			**1949**	1500	35	**1976**	3940	145	**2003**	5100	651
1923			**1950**	1400	31	**1977**	4480	157	**2004**	5600	665
1924			**1951**	1770	32	**1978**	4250	155	**2005**	5400	602
1925			**1952**	1770	37	**1979**	3420	162	**2006**	5700	588
1926			**1953**	2090	34	**1980**	3610	221	**2007**	6300	671

Table A3.16. Correlation Eq.(A1.1) terms calculated from Table A3.15 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
222300	15502	8.17E+08	6186822	62618120	120900631	2802146	14081576	**0.765053**	**58.53064**

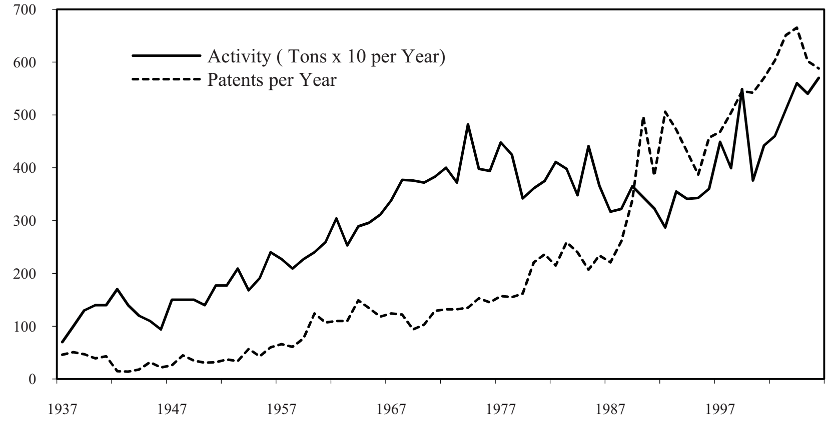

Figure A3.30. Bismuth Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[20] Activity represents world production of bismuth, defined at usgs.gov as "…bismuth content of world mine production. Data were not available prior to 1912 or for the years 1922-36. Data for the years 1912-21 and 1972-2003 exclude U.S. production. Data are from the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]. Data for 2004 is an unpublished revision published by the Commodity Specialist." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[21] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Bismuth was used as the keyword found in the patent title or abstract by year of publication.

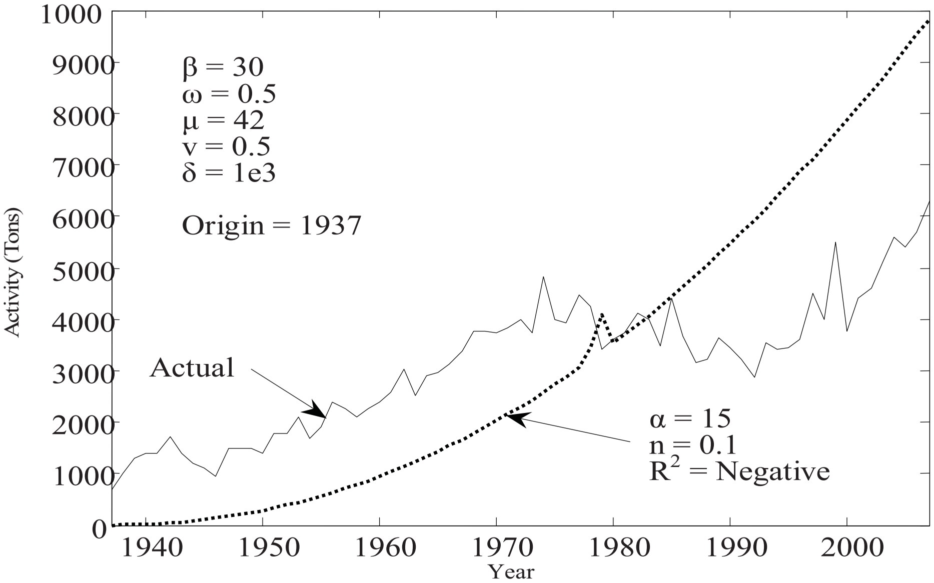

Figure A3.31. **USGS World Bismuth Production.** World bismuth production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters. R^2 has a negative value indicating possible Stage IV. No best-fit for the patent data was obtainable.

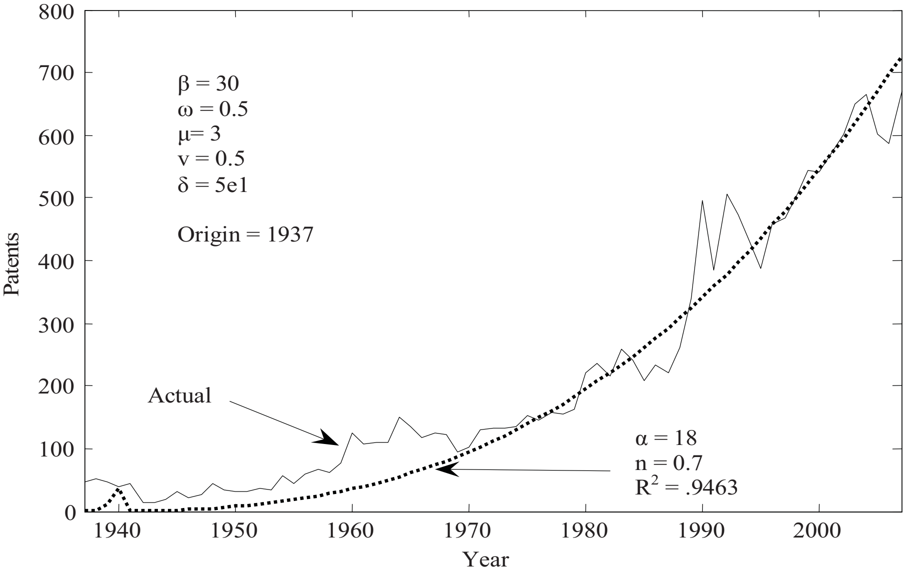

Figure A3.32. Bismuth Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.17 Boron Activity[22] and Patents[23]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**			**1981**	2560000	796
1901			**1928**			**1955**			**1982**	2270000	946
1902			**1929**			**1956**			**1983**	2240000	1126
1903			**1930**			**1957**			**1984**	2510000	1147
1904			**1931**			**1958**			**1985**	2510000	1425
1905			**1932**			**1959**			**1986**	2510000	1383
1906			**1933**			**1960**			**1987**	2690000	1536
1907			**1934**			**1961**			**1988**	2990000	1705
1908			**1935**			**1962**			**1989**	2990000	1899
1909			**1936**			**1963**			**1990**	2910000	1759
1910			**1937**			**1964**	172000	412	**1991**	2960000	1785
1911			**1938**			**1965**	189000	466	**1992**	2670000	2097
1912			**1939**			**1966**	209000	435	**1993**	2640000	1691
1913			**1940**			**1967**	221000	437	**1994**	3810000	1737
1914			**1941**			**1968**	232000	378	**1995**	4020000	1543
1915			**1942**			**1969**	251000	359	**1996**	4330000	1558
1916			**1943**			**1970**	257000	400	**1997**	4580000	1537
1917			**1944**			**1971**	284000	410	**1998**	4570000	1764
1918			**1945**			**1972**	314000	489	**1999**	4460000	1902
1919			**1946**			**1973**	342000	422	**2000**	4600000	2147
1920			**1947**			**1974**	328000	385	**2001**	4740000	2182
1921			**1948**			**1975**	354000	473	**2002**	4580000	2319
1922			**1949**			**1976**	2340000	505	**2003**	4750000	2342
1923			**1950**			**1977**	2730000	498	**2004**	4960000	2140
1924			**1951**			**1978**	2660000	549	**2005**	4840000	1990
1925			**1952**			**1979**	2520000	553	**2006**	3580000	1926
1926			**1953**			**1980**	2610000	782	**2007**	3840000	2089

Table A3.18. Correlation Eq.(A1.1) terms calculated from Table A3.17 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
112123000	54424	4E+14	88106536	1.81E+11	1.143E+14	20788996	4.24E+10	**0.869138**	**75.54004**

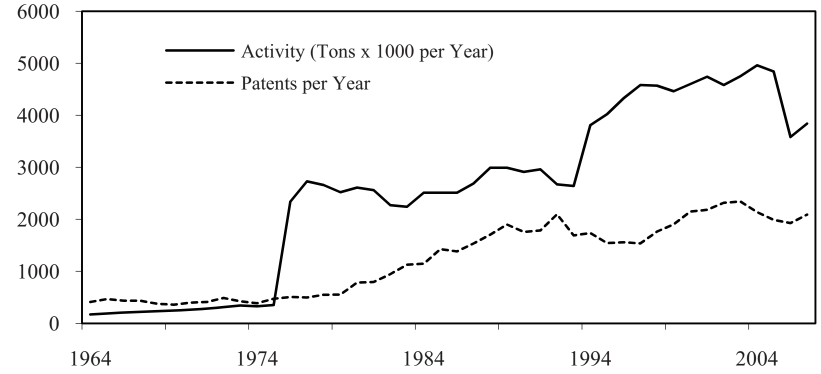

Figure A3.33. Boron Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[22] Activity represents world production of boron, defined at usgs.gov as "…world mine production. For most years, world mine production data are reported in gross weight. Data could not be converted to contained B_2O_3 because various boron units are used when reporting the minerals and compounds of boron. World production data are not reported for the years 1914-64. Data reported in the MR [*Minerals Resources of the United* States] and MYB [*Minerals Yearbook*] cover the years 1900-13 and 1976 to the most recent and are all gross weight data. Data for the years 1964-75 are calculated B_2O_3 content and are reported in the 1975 and 1980 MFP [*Mineral Facts and Problems*]. World production data from 2006 to most recent does not include U.S. data." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[23] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Boron was used as the keyword found in the patent title or abstract by year of publication.

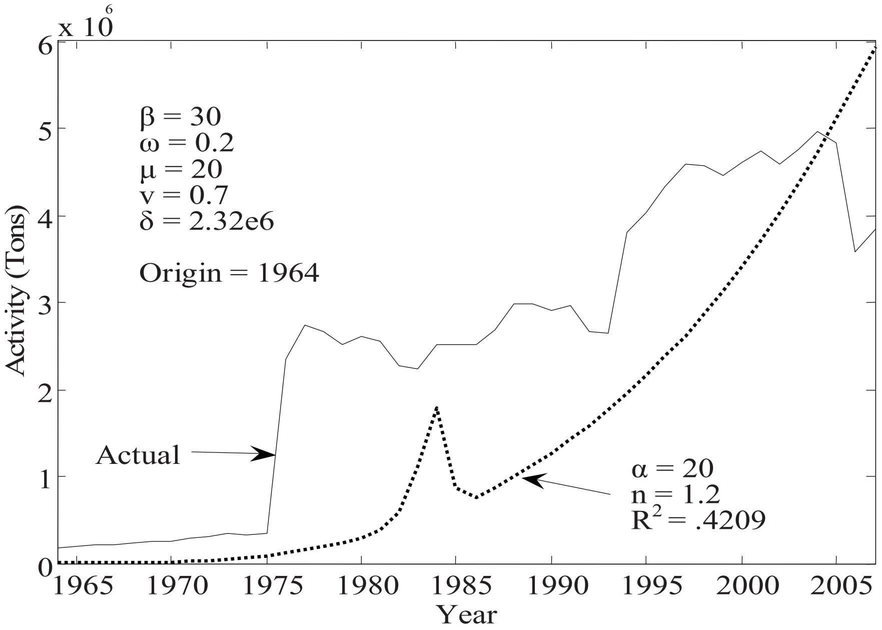

Figure A3.34. **USGS World Production.** World boron production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters. No best-fit for the patent data was obtainable.

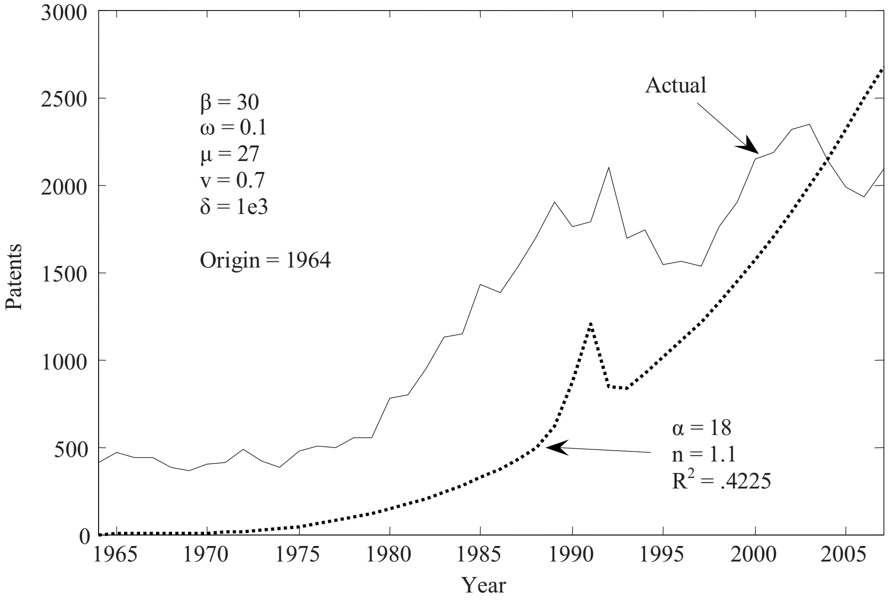

Figure A3.35. Boron Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.19 Cadmium Activity[24] and Patents[25]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	14	5	**1927**	661	39	**1954**	7300	185	**1981**	17400	672
1901	13	8	**1928**	1500	65	**1955**	8390	211	**1982**	16400	760
1902	13	6	**1929**	2180	70	**1956**	9070	242	**1983**	17600	809
1903	17	10	**1930**	2480	80	**1957**	9390	275	**1984**	19600	892
1904	25	6	**1931**	1230	104	**1958**	9800	241	**1985**	19100	941
1905	25	6	**1932**	1040	87	**1959**	10200	252	**1986**	19100	1039
1906	21	11	**1933**	1950	115	**1960**	11100	399	**1987**	19000	1070
1907	39	17	**1934**	2480	124	**1961**	11700	326	**1988**	21900	1171
1908	37	12	**1935**	3150	136	**1962**	11700	318	**1989**	21400	1316
1909	39	16	**1936**	3390	146	**1963**	11800	351	**1990**	20200	1223
1910	43	10	**1937**	3970	127	**1964**	12700	418	**1991**	20900	1241
1911	55	7	**1938**	4010	155	**1965**	11900	450	**1992**	19600	1516
1912	67	14	**1939**	4580	140	**1966**	13000	428	**1993**	18700	1565
1913	62	7	**1940**	5220	139	**1967**	13200	499	**1994**	18200	1615
1914	80	8	**1941**	5220	92	**1968**	15000	458	**1995**	20100	1829
1915	78	11	**1942**	5030	44	**1969**	17600	429	**1996**	18900	2010
1916	119	3	**1943**	5380	48	**1970**	16500	476	**1997**	20300	2132
1917	172	7	**1944**	5320	45	**1971**	15400	468	**1998**	20200	2491
1918	165	13	**1945**	4760	75	**1972**	16700	502	**1999**	20000	2439
1919	89	11	**1946**	4050	93	**1973**	17200	467	**2000**	20300	3090
1920	81	24	**1947**	4930	85	**1974**	17300	408	**2001**	20000	3045
1921	54	20	**1948**	4870	127	**1975**	15200	423	**2002**	17800	3566
1922	128	28	**1949**	5220	148	**1976**	17000	458	**2003**	18400	3272
1923	248	27	**1950**	6010	115	**1977**	18300	474	**2004**	18700	3225
1924	245	26	**1951**	6070	130	**1978**	17300	543	**2005**	20200	2898
1925	4116	46	**1952**	6170	163	**1979**	18700	397	**2006**	19900	2743
1926	960	33	**1953**	7060	135	**1980**	18200	633	**2007**	20400	2295

Table A3.20. Correlation Eq.(A1.1) terms calculated from Table A3.19 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
1010886	64815	1.62E+10	1.22E+08	1.16E+09	6.721E+09	83019689	5.53E+08	**0.740132**	**54.77951**

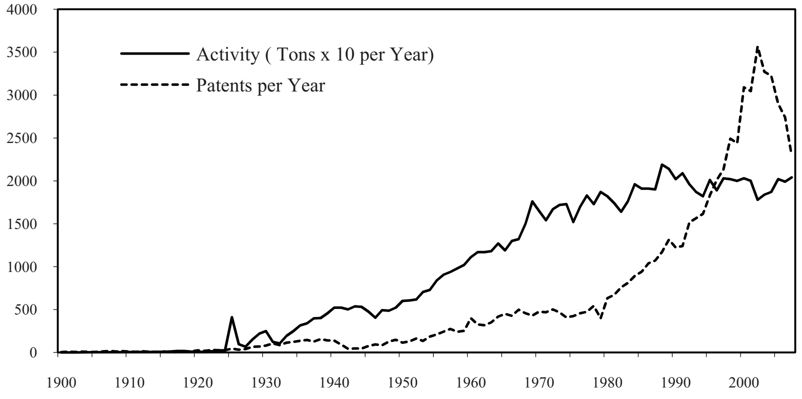

Figure A3.36. Cadmium Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[24] Activity represents world production of cadmium, defined at usgs.gov as "…world refinery production of cadmium. World production begins in 1932. Data prior to 1932 are production data from selected countries. Data are from the MR [*Minerals Resources of the United* States] and MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[25] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Cadmium or Cd were used as keywords found in the patent title or abstract by year of publication.

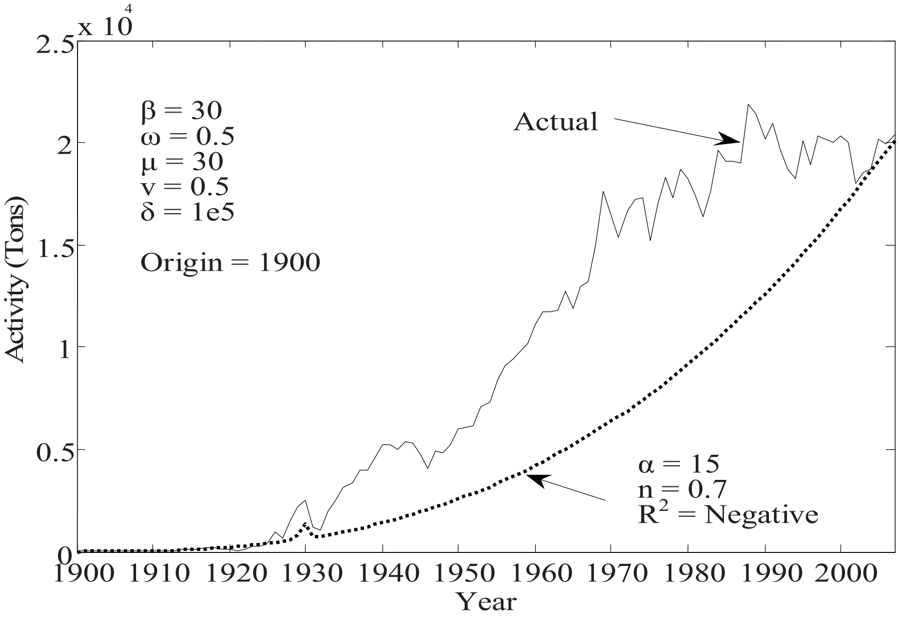

Figure A3.37. **USGS World Cadmium Production.** World cadmium production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters. R^2 has a negative value indicating possible Stage IV. No best-fit for the patent data was obtainable.

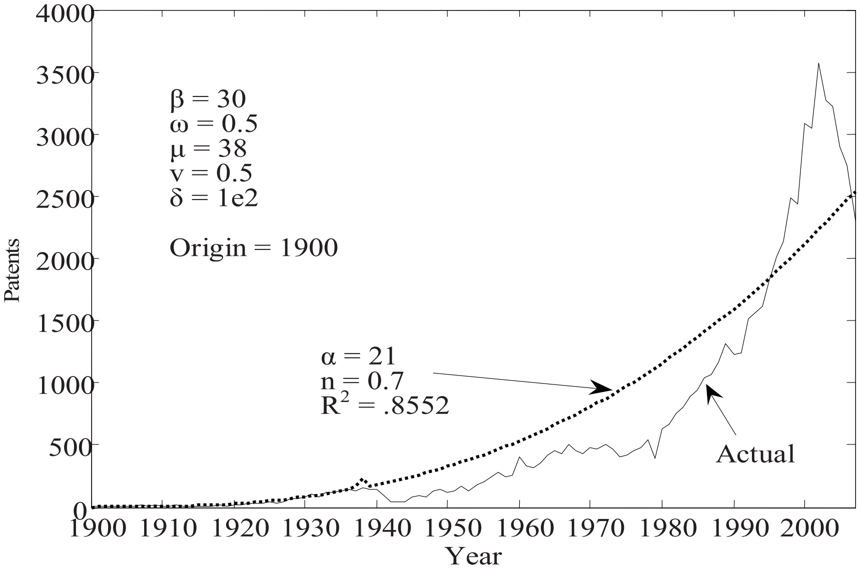

Figure A3.38. Cadmium Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.21. Chromium Activity[26] and Patents[27]

Year	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**
1900	16500	42	**1927**	124000	222	**1954**	924000	413	**1981**	2550000	2850
1901	27900	36	**1928**	140000	289	**1955**	1040000	479	**1982**	2390000	3420
1902	26400	44	**1929**	197000	326	**1956**	1200000	526	**1983**	2540000	3693
1903	29500	42	**1930**	173000	391	**1957**	1370000	601	**1984**	2950000	3649
1904	36600	48	**1931**	127000	458	**1958**	1130000	578	**1985**	3180000	4006
1905	44500	57	**1932**	101000	413	**1959**	1150000	582	**1986**	3530000	4428
1906	49700	45	**1933**	123000	342	**1960**	1250000	836	**1987**	3450000	4546
1907	34700	55	**1934**	183000	385	**1961**	1220000	739	**1988**	3870000	4563
1908	20700	48	**1935**	241000	441	**1962**	1280000	732	**1989**	4320000	5068
1909	33300	42	**1936**	317000	359	**1963**	1170000	777	**1990**	3950000	4750
1910	33600	61	**1937**	392000	415	**1964**	1290000	833	**1991**	4060000	4776
1911	25100	67	**1938**	362000	439	**1965**	1490000	968	**1992**	3420000	5239
1912	38000	65	**1939**	347000	361	**1966**	1360000	863	**1993**	3080000	5130
1913	45500	62	**1940**	457000	270	**1967**	1430000	1083	**1994**	3090000	5336
1914	48500	49	**1941**	509000	247	**1968**	1560000	1042	**1995**	4530000	5225
1915	57400	53	**1942**	637000	207	**1969**	1670000	1003	**1996**	3660000	5028
1916	87000	39	**1943**	542000	177	**1970**	1910000	1176	**1997**	4330000	4872
1917	81300	52	**1944**	411000	173	**1971**	2000000	1309	**1998**	4460000	5380
1918	96500	48	**1945**	318000	190	**1972**	1970000	1462	**1999**	4810000	5286
1919	52900	62	**1946**	352000	214	**1973**	2030000	1341	**2000**	4750000	5708
1920	53200	76	**1947**	521000	246	**1974**	2230000	1242	**2001**	3740000	5690
1921	41400	122	**1948**	644000	331	**1975**	2530000	1383	**2002**	4510000	6275
1922	43300	153	**1949**	650000	332	**1976**	2430000	1530	**2003**	4770000	5887
1923	63500	178	**1950**	720000	239	**1977**	2600000	1759	**2004**	5480000	5989
1924	90200	129	**1951**	823000	290	**1978**	2990000	1916	**2005**	5810000	5331
1925	95300	160	**1952**	963000	430	**1979**	2590000	1976	**2006**	5850000	5383
1926	112000	174	**1953**	1130000	327	**1980**	2830000	2836	**2007**	6620000	5703

Table A3.22 Correlation Eq.(A1.1) terms calculated from Table A3.21 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**$100r^2$**
169232500	173719	5.73E+14	7.2E+08	6.21E+11	3.074E+14	4.4E+08	3.49E+11	**0.949454**	**90.14634**

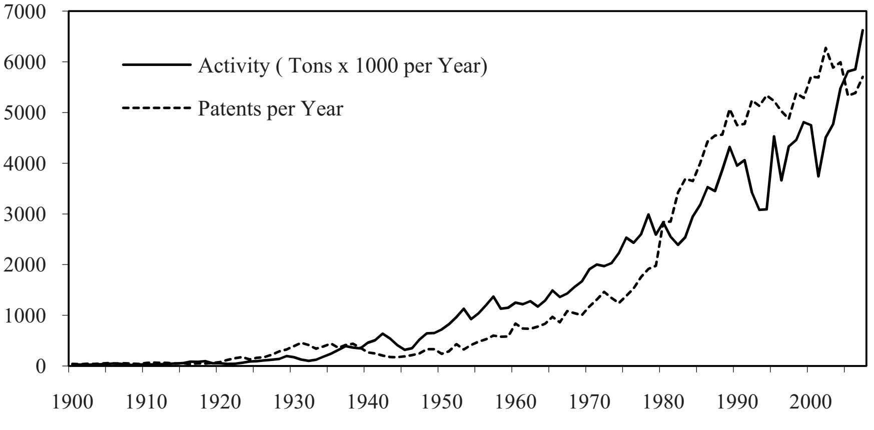

Figure A3.39. Chromium Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[26] Activity represents world production of chromium, defined at usgs.gov as "…an estimate of world chromite ore mine production measured in contained chromium. World production reported in gross weight was converted to contained chromium by assuming that its chromic oxide content was the same as that of chromite ore imported into the United States. Before content of chromite ore was reported, a time-averaged value was used." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[27] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Chromium, Cr or Chrome were used as keywords found in the patent title or abstract by year of publication.

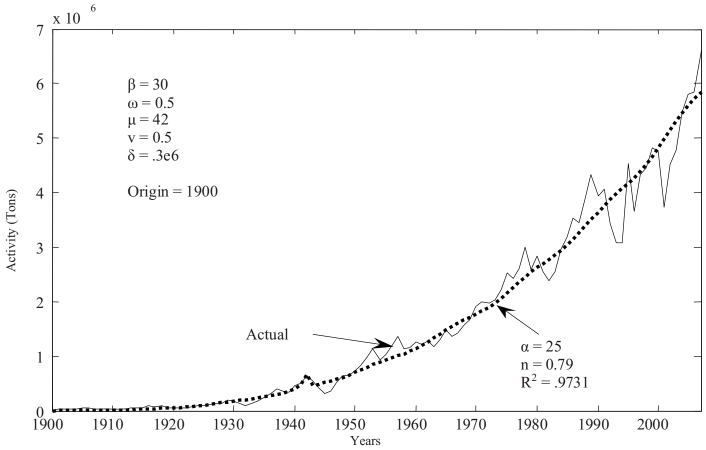

Figure A3.40. **USGS World Chromium Production.** World chromium production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

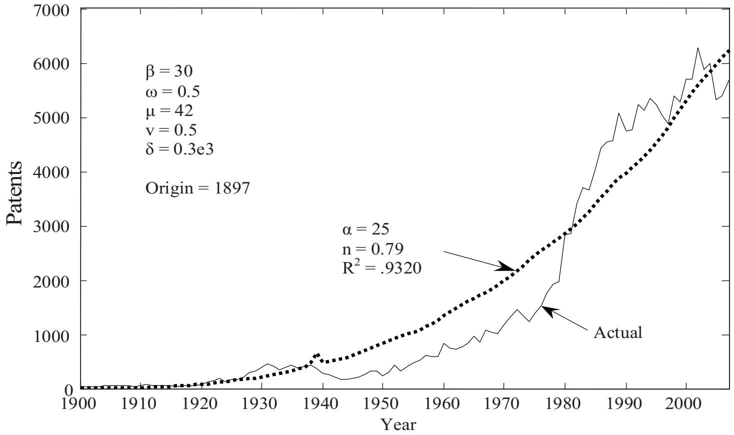

Figure A3.41. EPO Worldwide Patent Search: Chromium , Cr or Chrome in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

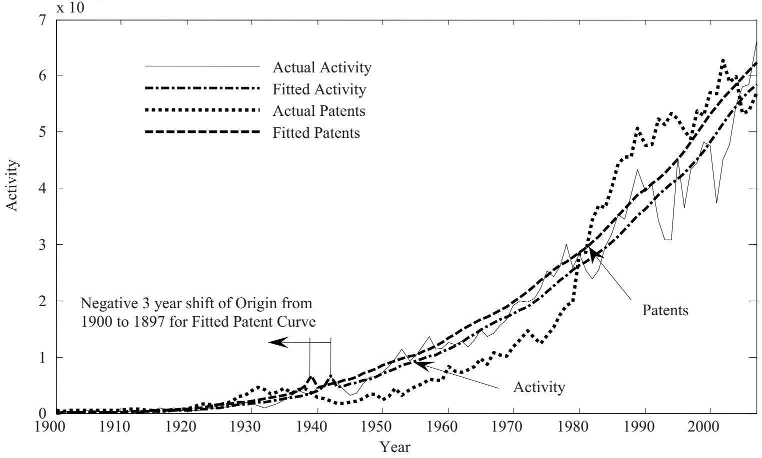

Figure A3.42 Chromium Best-Fit Activity and Patents. Illustrates best-fit origin shift.

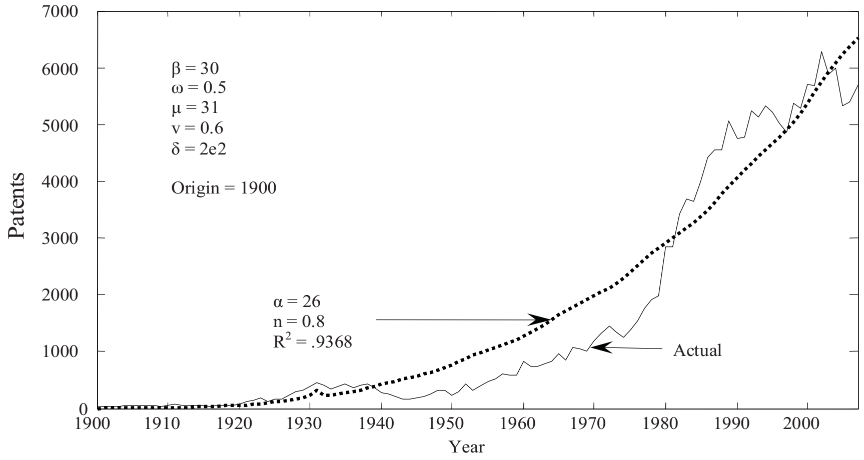

Figure A3.43. **Chromium Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.23 Cobalt Activity[28] and Patents[29]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**	1180	72	**1954**	13100	298	**1981**	30700	1018
1901	180	11	**1928**	1180	99	**1955**	13300	319	**1982**	24600	1044
1902	540	9	**1929**	1360	127	**1956**	14400	388	**1983**	37900	1094
1903	640	8	**1930**	1270	151	**1957**	14400	431	**1984**	40900	1086
1904	540	9	**1931**	910	205	**1958**	12600	389	**1985**	47400	1109
1905	450	8	**1932**	1090	180	**1959**	14800	401	**1986**	50200	1098
1906	450	15	**1933**	1270	173	**1960**	14200	511	**1987**	41200	1117
1907	910	11	**1934**	1450	169	**1961**	14400	449	**1988**	43800	1099
1908	1360	15	**1935**	2000	182	**1962**	17100	457	**1989**	42900	1169
1909	1450	8	**1936**	2720	151	**1963**	14500	417	**1990**	42300	1117
1910	1000	19	**1937**	3800	191	**1964**	17800	467	**1991**	33300	1092
1911	820	13	**1938**	4500	199	**1965**	19000	526	**1992**	28000	1234
1912	860	7	**1939**	4500	187	**1966**	21800	441	**1993**	21900	1216
1913	820	16	**1940**	5000	120	**1967**	20500	469	**1994**	18000	1106
1914	360	19	**1941**	4000	129	**1968**	19600	457	**1995**	24500	1144
1915	230	22	**1942**	3500	66	**1969**	20200	396	**1996**	26200	1186
1916	410	12	**1943**	4200	60	**1970**	24200	415	**1997**	27400	1338
1917	360	16	**1944**	3900	60	**1971**	25100	440	**1998**	35300	1655
1918	450	16	**1945**	4700	90	**1972**	24800	610	**1999**	32700	1637
1919	360	24	**1946**	3500	143	**1973**	29400	620	**2000**	37900	1899
1920	360	25	**1947**	5000	129	**1974**	30900	563	**2001**	47900	1892
1921	180	33	**1948**	6100	181	**1975**	30800	727	**2002**	50700	1998
1922	820	29	**1949**	5900	181	**1976**	21400	726	**2003**	52900	2011
1923	640	37	**1950**	7170	179	**1977**	21500	765	**2004**	58600	1853
1924	1090	38	**1951**	8440	183	**1978**	26800	913	**2005**	63400	1716
1925	1090	56	**1952**	10100	282	**1979**	29900	859	**2006**	65900	1634
1926	820	41	**1953**	11300	189	**1980**	31300	981	**2007**	65500	1749

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[28] Activity represents world mine production of cobalt, defined at usgs.gov as "…cobalt content of refined products or the cobalt content, recoverable cobalt content, or recovered cobalt content of mined ores, concentrates, or intermediate products depending on the producing country and year…..Data for the years 1901-36 are from IC [*U.S. Bureau of Mines Information* Circular] 8103. Data for the years 1937 to the most recent are from the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[29] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Cobalt was used as the keyword found in the patent title or abstract by year of publication.

Table A3.24. Correlation Eq.(A1.1) terms calculated from Table A3.23 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**$100r^2$**
1777030	56341	6.21E+10	63953703	1.92E+09	3.258E+10	34287270	9.8E+08	**0.926925**	**85.91898**

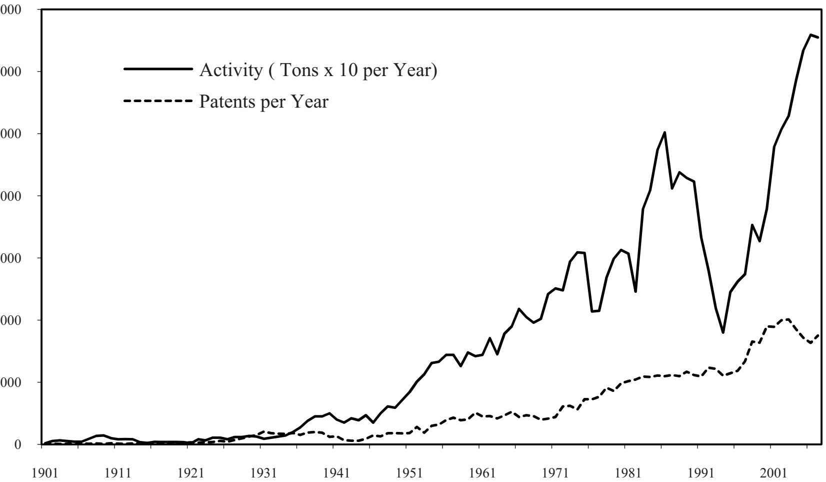

Figure A3.44 Cobalt Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

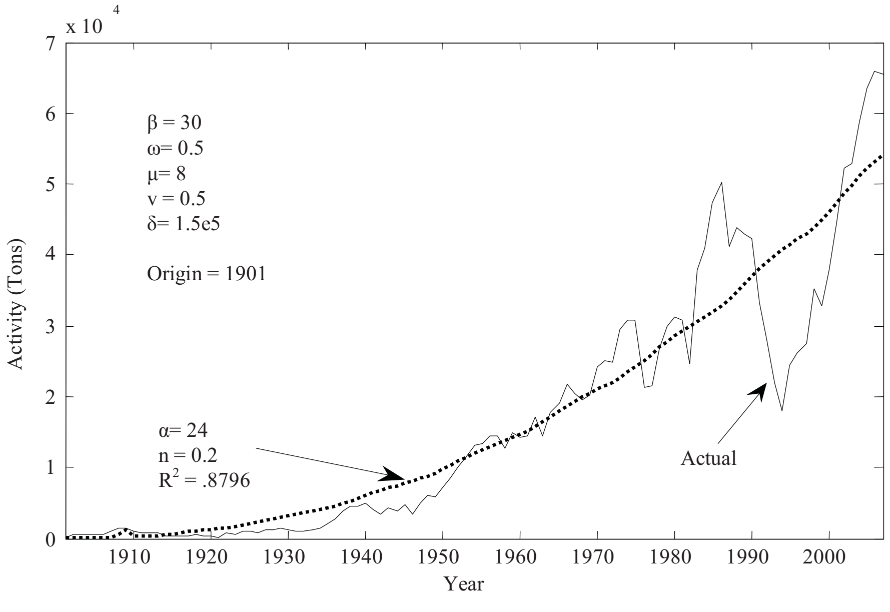

Figure A3.45. USGS World Cobalt Production. World cobalt production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

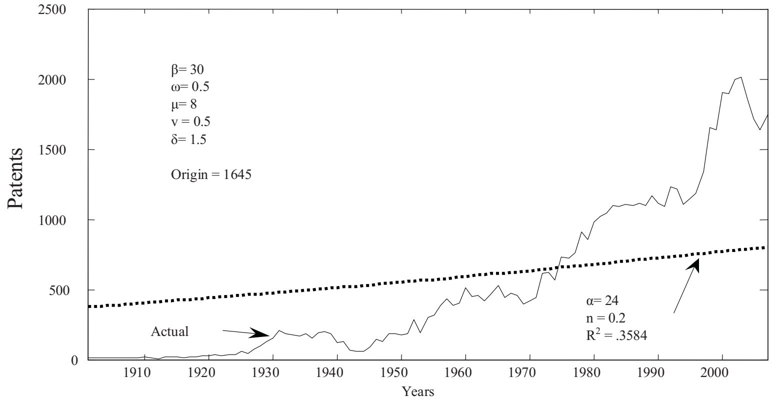

Figure A3.46. EPO Worldwide Patent Search: Cobalt in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

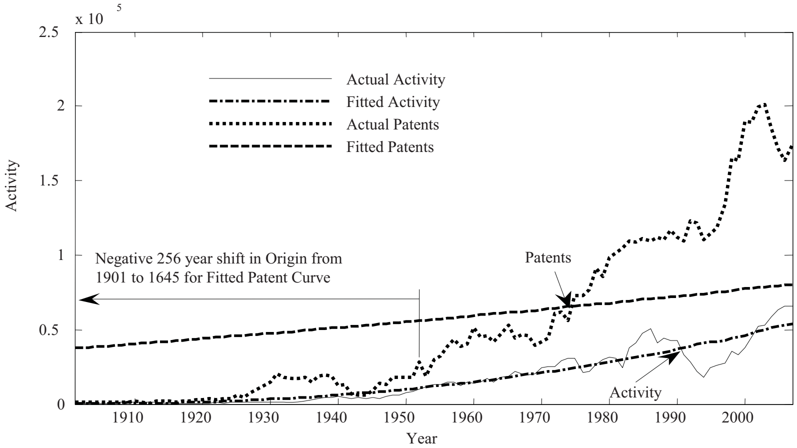

Figure A3.47 Cobalt Best-Fit Activity and Patents. Illustrates best-fit origin shift.

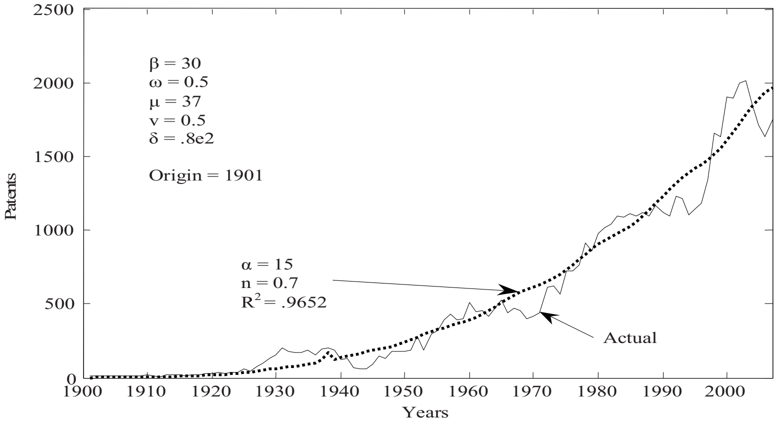

Figure A3.48. Cobalt Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.25. Copper Activity[30] and Patents[31]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	495000	165	**1927**	1520000	447	**1954**	2640000	773	**1981**	7690000	4182
1901	526000	169	**1928**	1730000	511	**1955**	2900000	824	**1982**	7580000	4673
1902	555000	186	**1929**	1950000	538	**1956**	3200000	964	**1983**	7610000	4684
1903	596000	232	**1930**	1610000	640	**1957**	3300000	1016	**1984**	7810000	5125
1904	660000	221	**1931**	1400000	773	**1958**	3190000	896	**1985**	7990000	5574
1905	713000	236	**1932**	909000	646	**1959**	3430000	925	**1986**	7940000	6094
1906	724000	198	**1933**	1050000	611	**1960**	3940000	1301	**1987**	8240000	5766
1907	721000	254	**1934**	1280000	601	**1961**	4090000	1190	**1988**	8720000	7025
1908	744000	257	**1935**	1500000	695	**1962**	4220000	1100	**1989**	9040000	9723
1909	828000	219	**1936**	1720000	675	**1963**	4290000	1255	**1990**	9200000	8660
1910	858000	200	**1937**	2290000	670	**1964**	4450000	1335	**1991**	9330000	8422
1911	890000	194	**1938**	1990000	749	**1965**	4660000	1548	**1992**	9470000	9392
1912	1000000	218	**1939**	2130000	637	**1966**	4580000	1424	**1993**	9490000	8266
1913	996000	241	**1940**	2400000	560	**1967**	4630000	1806	**1994**	9500000	8197
1914	938000	197	**1941**	2480000	430	**1968**	5010000	1751	**1995**	10000000	7604
1915	1060000	182	**1942**	2590000	322	**1969**	5520000	1677	**1996**	11000000	7831
1916	1420000	125	**1943**	2620000	316	**1970**	5900000	1992	**1997**	11500000	7423
1917	1430000	117	**1944**	2460000	300	**1971**	5940000	2066	**1998**	12100000	8551
1918	1430000	120	**1945**	2110000	368	**1972**	6540000	2404	**1999**	12800000	8868
1919	994000	228	**1946**	1780000	451	**1973**	6920000	2240	**2000**	13200000	10521
1920	959000	234	**1947**	2130000	490	**1974**	7100000	2049	**2001**	13700000	10566
1921	558000	310	**1948**	2210000	673	**1975**	6740000	2235	**2002**	13600000	11246
1922	884000	260	**1949**	2140000	649	**1976**	7260000	2526	**2003**	13800000	11222
1923	1270000	310	**1950**	2380000	495	**1977**	7420000	2820	**2004**	14700000	11303
1924	1360000	327	**1951**	2490000	576	**1978**	7280000	2840	**2005**	15000000	10065
1925	1530000	386	**1952**	2570000	731	**1979**	7350000	2710	**2006**	15100000	9776
1926	1510000	368	**1953**	2600000	564	**1980**	7200000	3820	**2007**	15400000	10130

Table A3.26. Correlation Eq.(A1.1) terms calculated from Table A3.25 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
510898000	289648	4.27E+15	2.04E+09	2.82E+12	1.851E+15	1.26E+09	1.45E+12	**0.950672**	**90.37776**

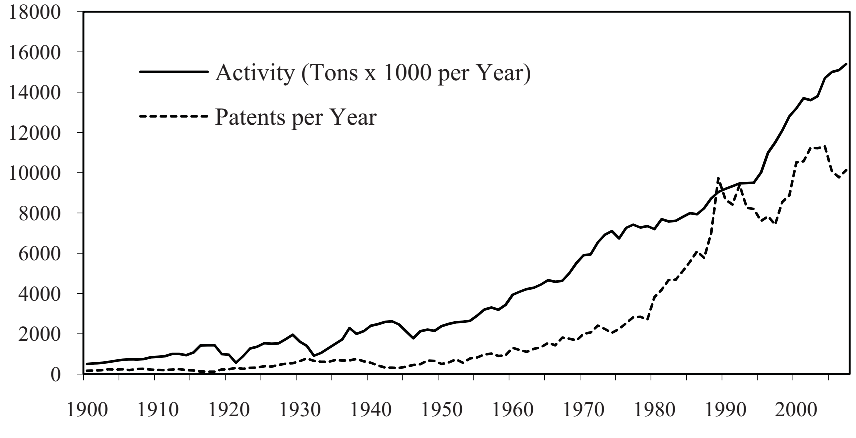

Figure A3.49 Copper Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[30] Activity represents world production of copper, defined at usgs.gov as follows. "World mine production is based on a compilation of available data published in the MR and the MYB and generally reflects the copper content of concentrates, precipitates, and electrowon copper. For some countries, including the United States, recoverable copper content is used. For other countries, such as Chile, data includes copper content of non-duplicative mine and metal products produced from domestic ores and concentrates." (usgs.gov) Data is in metric tons, as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[31] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Copper or Cu were used as keywords found in the patent title or abstract by year of publication.

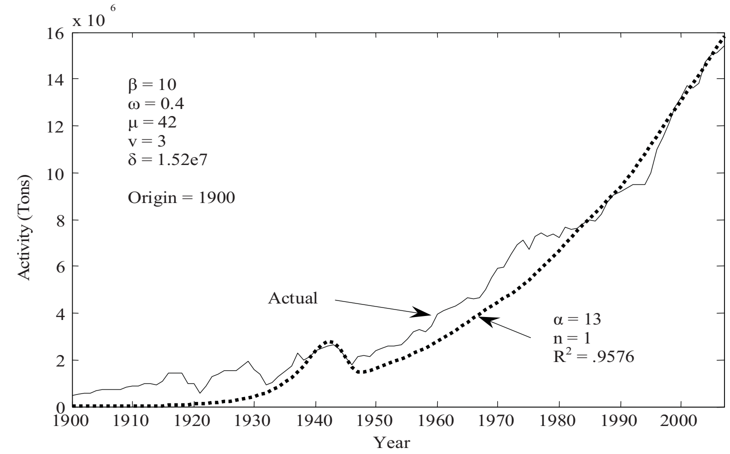

Figure A3.50. **USGS World Copper Production.** World copper production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

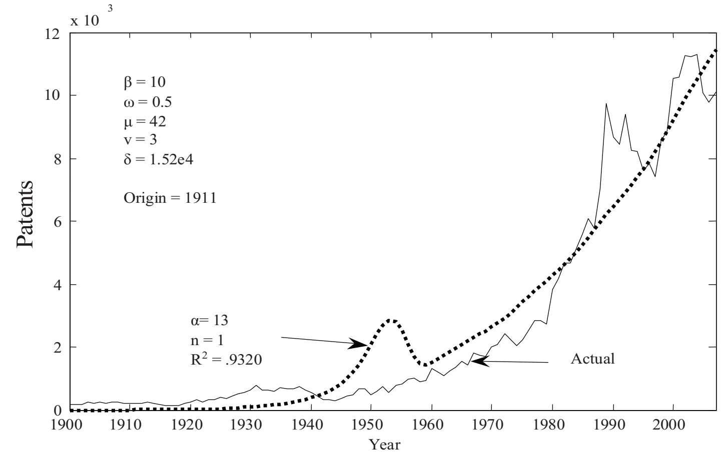

Figure A3.51. EPO Worldwide Patent Search: Copper or Cu in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

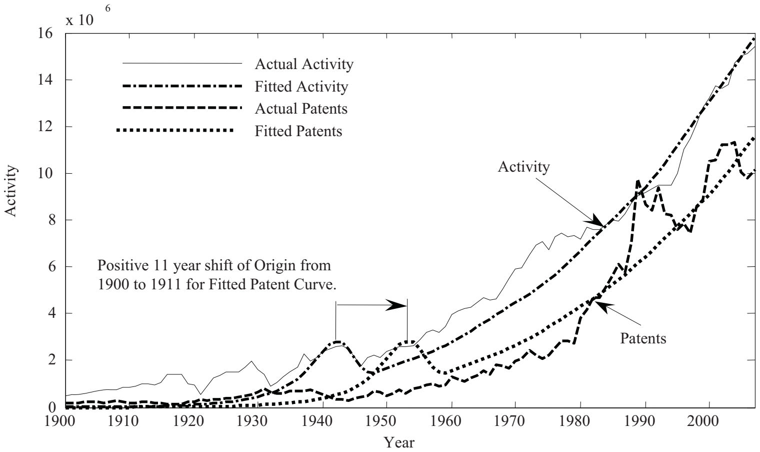

Figure A3.52. Copper Best-Fit Activity and Patents. Illustrates best-fit origin shift.

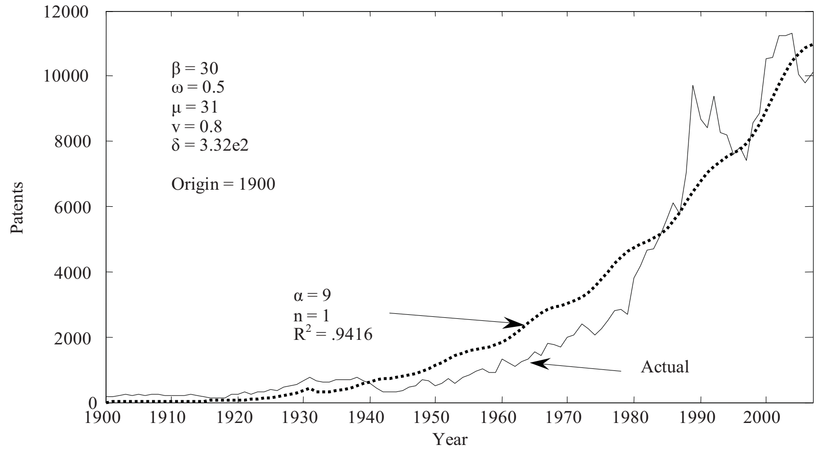

Figure A3.53. **Copper Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.27 Feldspar[32] Activity[33] and Patents[34]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**	340000	0	**1954**	945000	5	**1981**	3230000	18
1901			**1928**	366000	4	**1955**	1070000	7	**1982**	3520000	18
1902			**1929**	331000	3	**1956**	1130000	3	**1983**	3590000	16
1903			**1930**	284000	5	**1957**	1260000	5	**1984**	3790000	22
1904			**1931**	239000	2	**1958**	1210000	9	**1985**	4030000	23
1905			**1932**	189000	3	**1959**	1370000	6	**1986**	4120000	30
1906			**1933**	258000	3	**1960**	1570000	6	**1987**	4380000	14
1907			**1934**	280000	2	**1961**	1630000	11	**1988**	4840000	31
1908	150000	4	**1935**	316000	6	**1962**	1630000	6	**1989**	5180000	55
1909	168000	3	**1936**	381000	7	**1963**	1710000	8	**1990**	5990000	44
1910	179000	2	**1937**	426000	8	**1964**	1890000	5	**1991**	5670000	53
1911	210000	0	**1938**	320000	5	**1965**	2010000	9	**1992**	5990000	56
1912	206000	1	**1939**	390000	4	**1966**	2150000	10	**1993**	6170000	52
1913	156000	4	**1940**	400000	2	**1967**	2040000	18	**1994**	6490000	62
1914	193000	3	**1941**	475000	13	**1968**	2240000	20	**1995**	7910000	48
1915	155000	3	**1942**	440000	5	**1969**	2450000	10	**1996**	8290000	60
1916	168000	3	**1943**	440000	2	**1970**	2530000	17	**1997**	8650000	64
1917	174000	6	**1944**	465000	2	**1971**	2550000	22	**1998**	9330000	62
1918	136000	7	**1945**	500000	1	**1972**	2720000	12	**1999**	9980000	79
1919	108000	8	**1946**	675000	5	**1973**	2770000	21	**2000**	9540000	103
1920	207000	10	**1947**	700000	10	**1974**	3010000	16	**2001**	11800000	99
1921	167000	9	**1948**	770000	4	**1975**	2630000	13	**2002**	14100000	99
1922	208000	12	**1949**	660000	8	**1976**	2800000	20	**2003**	13600000	124
1923	250000	8	**1950**	721000	9	**1977**	2940000	13	**2004**	15100000	119
1924	362000	3	**1951**	793000	3	**1978**	3030000	16	**2005**	16200000	83
1925	314000	6	**1952**	803000	9	**1979**	3110000	14	**2006**	17600000	80
1926	345000	3	**1953**	793000	4	**1980**	3200000	17	**2007**	18100000	111

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[32] Silicate minerals linked with potassium, sodium and calcium [128].

[33] Activity represents world production of feldspar, defined at usgs.gov as "…the quantity of feldspar that was produced annually throughout the world as reported in the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]. World production does not include production data for nepheline syenite" Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[34] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Feldspar was used as the keyword found in the patent title or abstract by year of publication.

Table A3.28. Correlation Eq.(A1.1) terms calculated from Table A3.27 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**$100r^2$**
301396000	2168	2.62E+15	133006	1.8E+10	1.707E+15	86003.76	1.15E+10	**0.949019**	**90.06377**

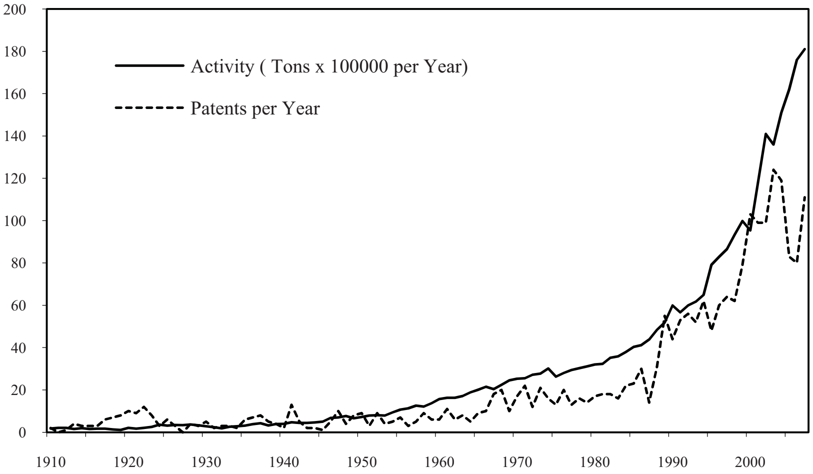

Figure A3.54. Feldspar Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

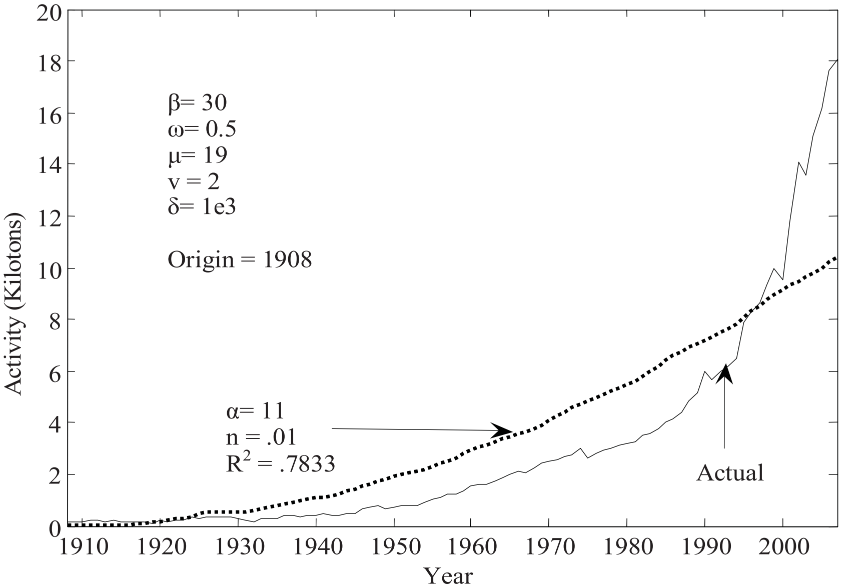

Figure A3.55. **USGS World Feldspar Production.** World feldspar production (activity) scaled in metric kilotons with actual and best-fit curves and common pattern equation parameters.

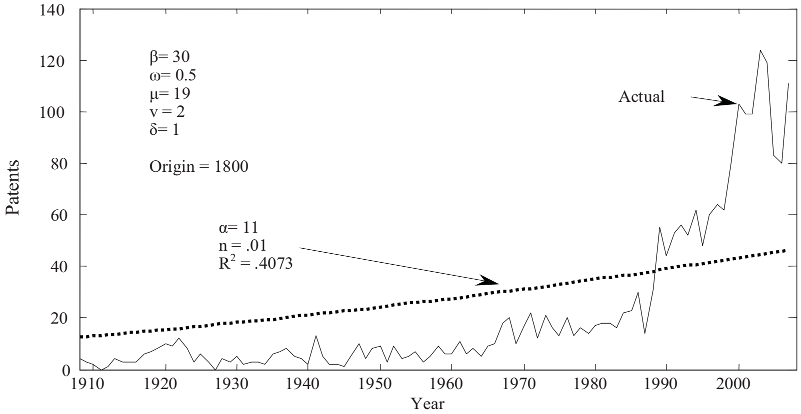

Figure A3.56. EPO Worldwide Patent Search: Feldspar in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

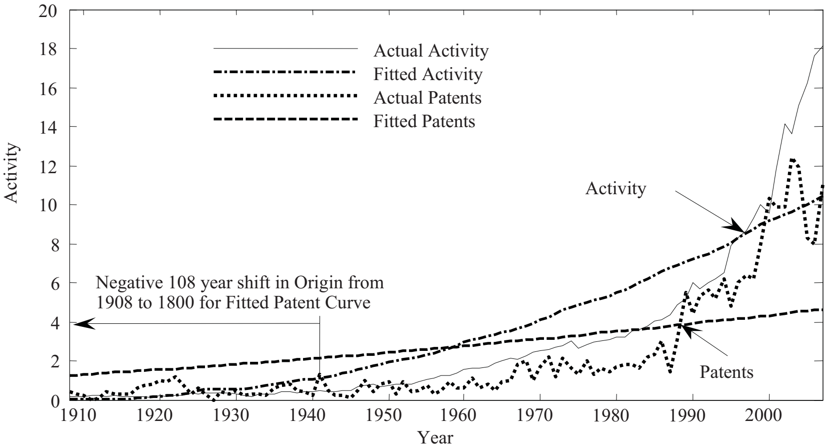

Figure A3.57. Feldspar Best-Fit Activity and Patents. Illustrates best-fit origin shift.

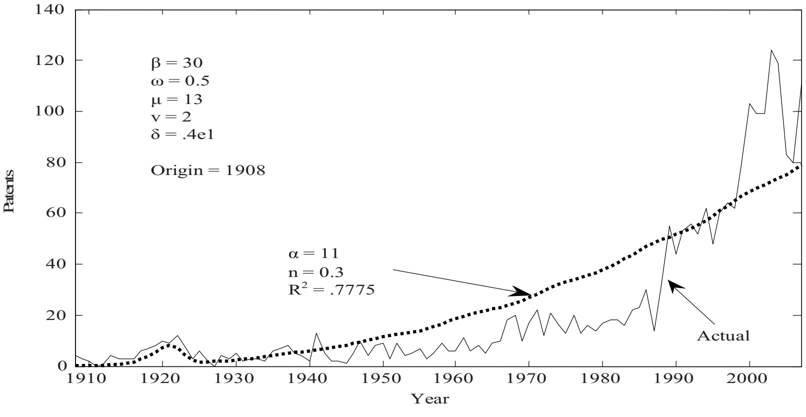

Figure A3.58. Feldspar Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.29 Fluorspar[35] Activity[36] and Patents[37]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**	317000	6	**1954**	1220000	7	**1981**	5100000	37
1901			**1928**	345000	11	**1955**	1410000	13	**1982**	4530000	31
1902			**1929**	376000	5	**1956**	1700000	7	**1983**	4230000	41
1903			**1930**	291000	7	**1957**	1830000	5	**1984**	4830000	36
1904			**1931**	166000	8	**1958**	1840000	12	**1985**	4980000	20
1905			**1932**	128000	11	**1959**	1720000	21	**1986**	4850000	28
1906			**1933**	229000	8	**1960**	2020000	17	**1987**	4600000	35
1907			**1934**	286000	6	**1961**	2060000	18	**1988**	5280000	45
1908			**1935**	340000	7	**1962**	2150000	12	**1989**	5560000	34
1909			**1936**	455000	8	**1963**	2150000	18	**1990**	5120000	29
1910			**1937**	519000	16	**1964**	2460000	9	**1991**	4300000	49
1911			**1938**	456000	16	**1965**	2770000	26	**1992**	4120000	44
1912			**1939**	577000	15	**1966**	2840000	19	**1993**	4180000	32
1913	171000	4	**1940**	616000	8	**1967**	3170000	23	**1994**	3750000	24
1914	121000	3	**1941**	698000	6	**1968**	3640000	19	**1995**	4040000	51
1915	163000	0	**1942**	883000	9	**1969**	3890000	13	**1996**	4180000	46
1916	201000	0	**1943**	1040000	9	**1970**	4190000	16	**1997**	4180000	53
1917	279000	1	**1944**	1040000	0	**1971**	4760000	21	**1998**	4430000	77
1918	313000	1	**1945**	674000	10	**1972**	4530000	24	**1999**	4300000	67
1919	196000	2	**1946**	524000	8	**1973**	4580000	28	**2000**	4450000	74
1920	264000	3	**1947**	655000	3	**1974**	4860000	19	**2001**	4590000	79
1921	92500	8	**1948**	795000	6	**1975**	4520000	22	**2002**	4450000	79
1922	208000	1	**1949**	710000	10	**1976**	4320000	21	**2003**	4850000	122
1923	215000	12	**1950**	844000	19	**1977**	4380000	38	**2004**	5230000	89
1924	255000	5	**1951**	1030000	7	**1978**	4670000	35	**2005**	5280000	101
1925	263000	9	**1952**	1180000	10	**1979**	4610000	34	**2006**	5330000	95
1926	310000	8	**1953**	1210000	5	**1980**	5010000	31	**2007**	5690000	84

Table A3.30. Correlation Eq.(A1.1) terms calculated from Table A3.29 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
233165500	2321	9.38E+14	117819	9.19E+09	3.654E+14	61113.31	3.5E+09	**0.739928**	**54.74942**

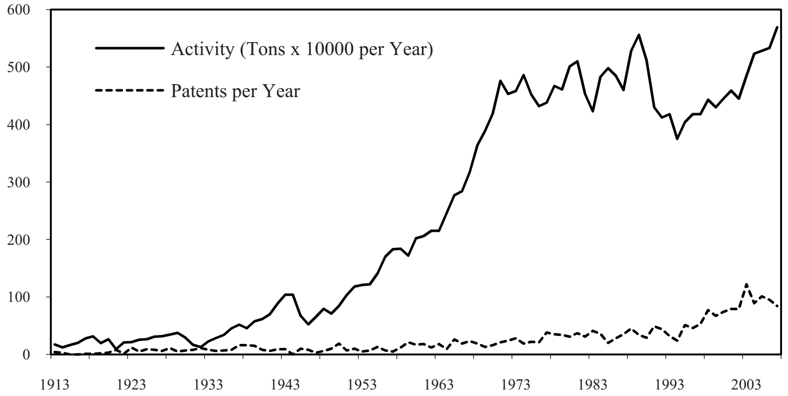

Figure A3.59. Fluorspar Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[35] Fluorite or a mineral form of calcium fluoride [128].

[36] Activity represents world production of fluorspar, defined at usgs.gov as "…data for the years 1913 to the most recent represent the total estimated quantities of fluorspar that were produced annually throughout the world. Data were recorded from the MR [*Mineral resources of the United States*] and the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[37] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Fluorspar or fluorite were used as keywords found in the patent title or abstract by year of publication.

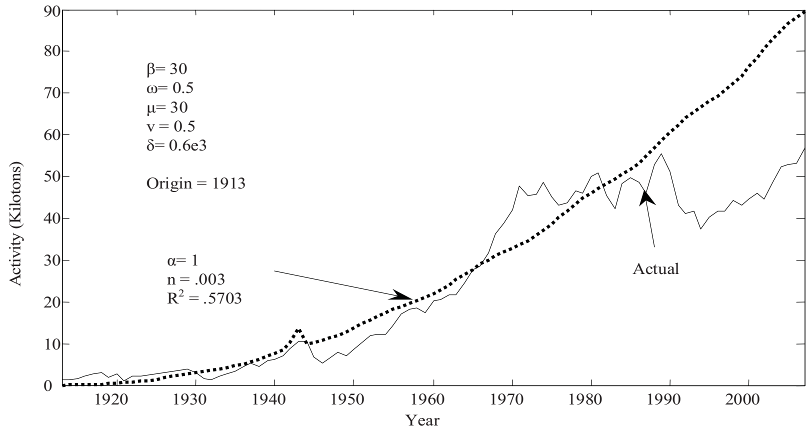

Figure A3.60. USGS World Fluorspar Production. World fluorspar production (activity) scaled in metric kilotons with actual and best-fit curves and common pattern equation parameters.

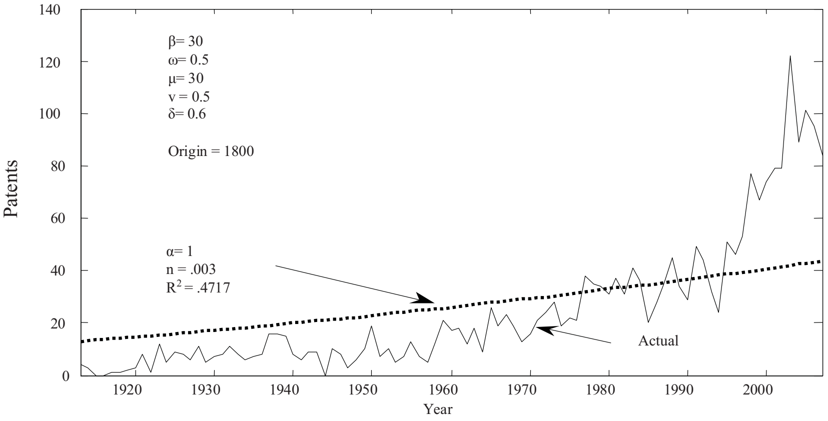

Figure A3.61. EPO Worldwide Patent Search: Fluorspar or Fluorite in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

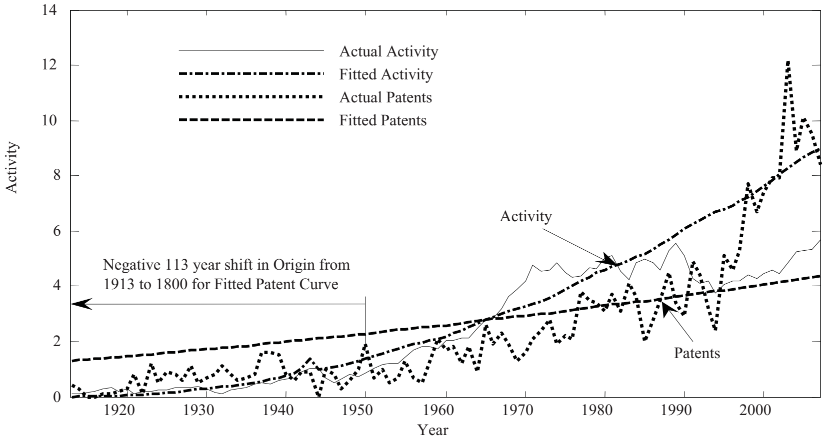

Figure A3.62. Fluorspar Best-Fit Activity and Patents. Illustrates best-fit origin shift.

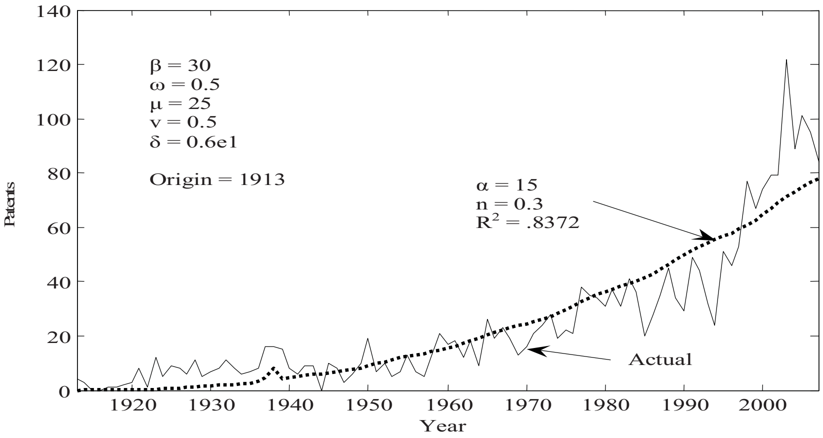

Figure A3.63. Fluorspar Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.31 Gold Activity[38] and Patents[39]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	386	54	**1927**	597	70	**1954**	965	65	**1981**	1280	634
1901	395	45	**1928**	603	73	**1955**	947	90	**1982**	1340	752
1902	451	50	**1929**	609	87	**1956**	978	100	**1983**	1400	867
1903	496	53	**1930**	648	81	**1957**	1020	11	**1984**	1460	866
1904	526	48	**1931**	695	84	**1958**	1050	108	**1985**	1530	898
1905	575	45	**1932**	754	76	**1959**	1130	97	**1986**	1610	1072
1906	608	42	**1933**	793	80	**1960**	1190	180	**1987**	1660	1071
1907	623	45	**1934**	841	82	**1961**	1230	167	**1988**	1870	1204
1908	668	44	**1935**	924	91	**1962**	1290	188	**1989**	2010	1348
1909	687	39	**1936**	1030	75	**1963**	1340	242	**1990**	2180	1442
1910	689	51	**1937**	1100	77	**1964**	1390	262	**1991**	2160	1418
1911	699	34	**1938**	1170	89	**1965**	1440	324	**1992**	2260	1530
1912	705	42	**1939**	1230	81	**1966**	1450	321	**1993**	2280	1315
1913	694	46	**1940**	1310	52	**1967**	1420	364	**1994**	2260	1410
1914	663	41	**1941**	1080	57	**1968**	1440	301	**1995**	2230	1280
1915	704	22	**1942**	1120	31	**1969**	1450	360	**1996**	2290	1250
1916	685	30	**1943**	896	25	**1970**	1480	404	**1997**	2450	1268
1917	631	22	**1944**	813	31	**1971**	1450	412	**1998**	2500	1466
1918	578	24	**1945**	762	34	**1972**	1390	481	**1999**	2570	1533
1919	550	28	**1946**	860	35	**1973**	1350	454	**2000**	2590	1763
1920	507	32	**1947**	900	58	**1974**	1250	381	**2001**	2600	1746
1921	498	38	**1948**	932	52	**1975**	1200	454	**2002**	2550	1891
1922	481	42	**1949**	964	66	**1976**	1210	436	**2003**	2540	1958
1923	554	52	**1950**	879	66	**1977**	1210	427	**2004**	2420	1869
1924	592	52	**1951**	883	64	**1978**	1210	521	**2005**	2470	1710
1925	591	59	**1952**	868	84	**1979**	1210	522	**2006**	2430	1643
1926	602	56	**1953**	864	75	**1980**	1220	639	**2007**	2380	1839

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[38] Activity represents world production of gold, defined at usgs.gov as "…World gold production data for the years 1900–26 are from reported estimates by Ridgeway (1929). World gold production data for the years 1927 to the most recent are from the MYB in the "Salient gold statistics" and "Gold: World production by country" tables. Updated values for world gold production for the years 1929–50 reflect revised estimates by the USGS gold commodity specialist for some countries." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[39] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Gold was used as the keyword found in the patent title or abstract by year of publication.

Table A3.32. Correlation Eq.(A1.1) terms calculated from Table A3.31 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
131193	48266	2.02E+08	57810854	9.5481495E+07	42538212	36240421	36850372	**0.938546**	**88.08688898**

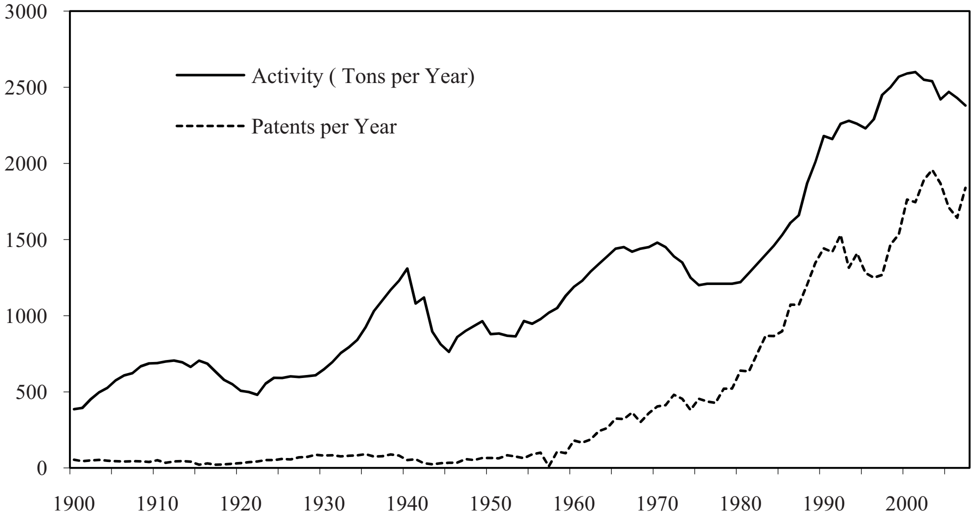

Figure A3.64. Gold Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

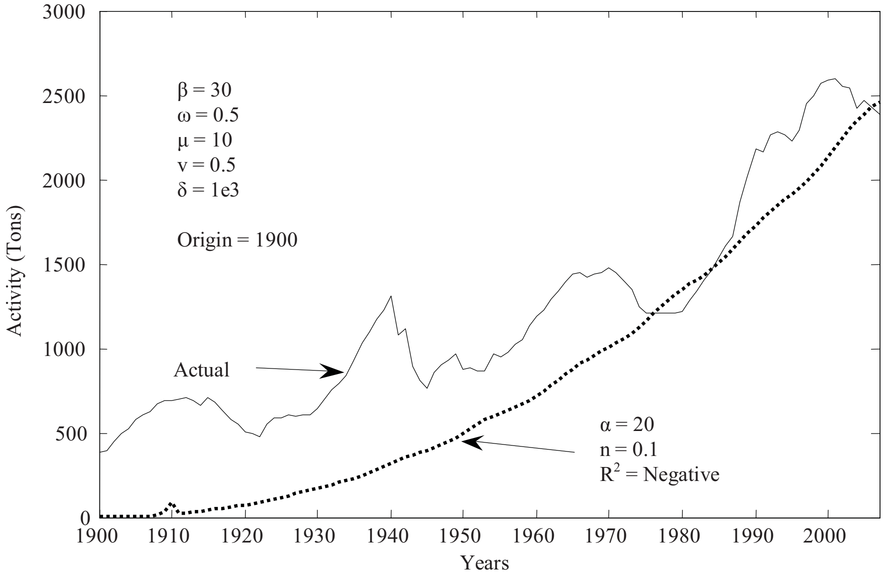

Figure A3.65. **USGS World Gold Production.** World gold production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters. R^2 is negative possibly indicating Stage IV. No best-fit for the patent data was obtainable.

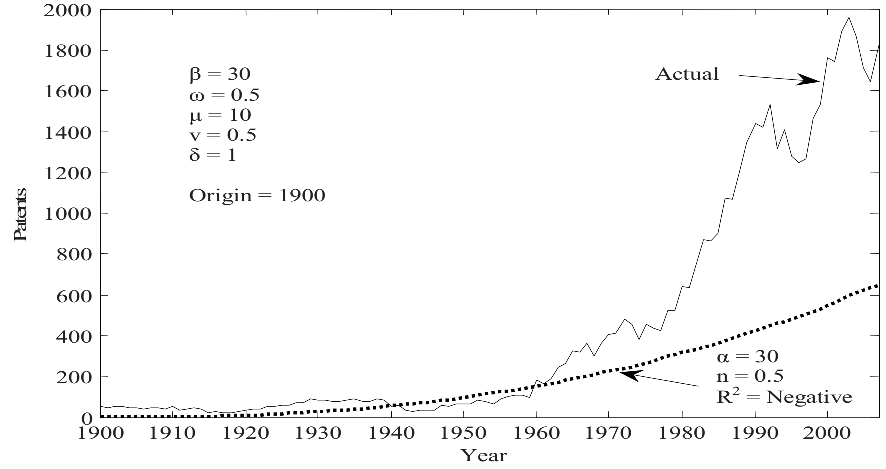

Figure A3.66. Gold Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.33. Graphite[40] Activity[41] and Patents[42]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	81600	29	**1927**	154000	100	**1954**	168000	177	**1981**	589000	1070
1901	77100	20	**1928**	150000	93	**1955**	272000	217	**1982**	562000	1185
1902	81600	24	**1929**	150000	93	**1956**	263000	217	**1983**	604000	1303
1903	77100	29	**1930**	118000	100	**1957**	372000	271	**1984**	625000	1305
1904	77100	38	**1931**	77100	125	**1958**	318000	253	**1985**	584000	1307
1905	90700	52	**1932**	72600	119	**1959**	372000	312	**1986**	625000	1407
1906	104000	46	**1933**	86200	102	**1960**	435000	447	**1987**	643000	1440
1907	109000	44	**1934**	109000	90	**1961**	413000	403	**1988**	575000	1418
1908	95300	51	**1935**	145000	124	**1962**	535000	433	**1989**	1010000	1744
1909	95300	43	**1936**	150000	103	**1963**	679000	402	**1990**	946000	1566
1910	95300	33	**1937**	159000	123	**1964**	620000	439	**1991**	771000	1528
1911	109000	43	**1938**	177000	122	**1965**	607000	456	**1992**	670000	1643
1912	118000	42	**1939**	222000	116	**1966**	484000	423	**1993**	648000	1447
1913	136000	46	**1940**	254000	92	**1967**	358000	536	**1994**	517000	1509
1914	104000	28	**1941**	231000	66	**1968**	437000	520	**1995**	584000	1517
1915	113000	36	**1942**	272000	57	**1969**	376000	498	**1996**	555000	1546
1916	172000	20	**1943**	277000	67	**1970**	393000	608	**1997**	685000	1450
1917	209000	29	**1944**	263000	55	**1971**	394000	595	**1998**	651000	1666
1918	181000	25	**1945**	136000	56	**1972**	361000	671	**1999**	692000	1839
1919	122000	36	**1946**	95300	78	**1973**	395000	584	**2000**	846000	1940
1920	118000	54	**1947**	122000	106	**1974**	497000	549	**2001**	816000	1796
1921	90700	81	**1948**	163000	137	**1975**	451000	568	**2002**	932000	2004
1922	104000	78	**1949**	168000	117	**1976**	449000	621	**2003**	999000	1966
1923	95300	70	**1950**	159000	103	**1977**	493000	640	**2004**	1020000	2072
1924	95300	79	**1951**	195000	122	**1978**	534000	824	**2005**	1040000	2078
1925	122000	83	**1952**	177000	166	**1979**	626000	609	**2006**	1020000	1835
1926	136000	67	**1953**	168000	132	**1980**	597000	1008	**2007**	1110000	1922

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[40] Natural Graphite [78].

[41] Activity represents world production of graphite, defined at usgs.gov as follows. "….were reported in the MR [*Minerals Resources of the United States*] and the MYB [*Minerals Yearbook*]." (usgs.gov) Data is in metric tons, as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[42] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Graphite was used as the keyword found in the patent title or abstract by year of publication.

Table A3.34. Correlation Eq.(A1.1) terms calculated from Table A3.33 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**100r^2**
39677600	60774	2.3E+13	79940074	4.06E+10	8.438E+12	45741194	1.82E+10	**0.928652**	**86.23946**

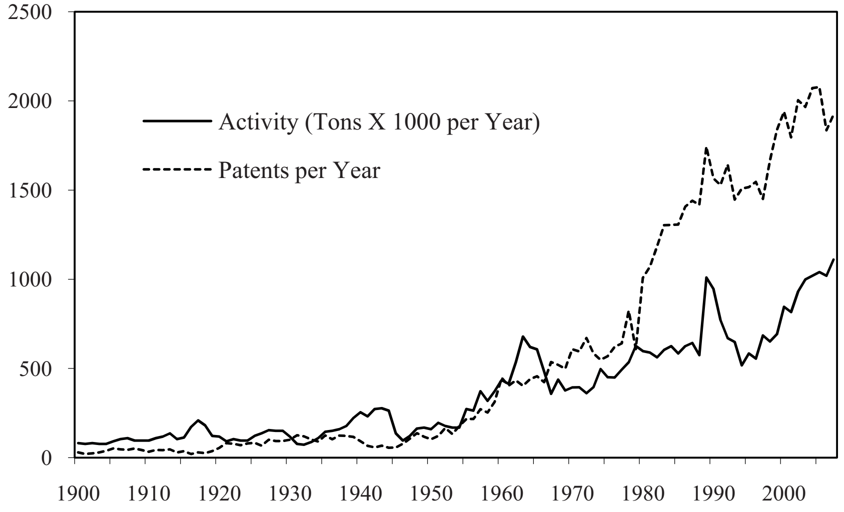

Figure A3.67. Graphite Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

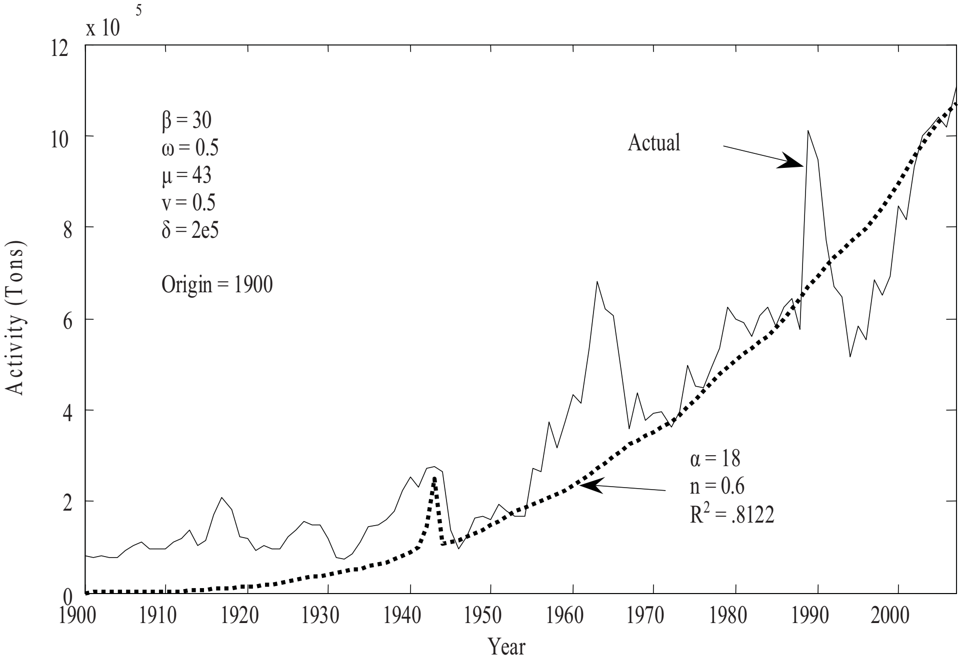

Figure A3.68. **USGS World Graphite Production**. World graphite production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

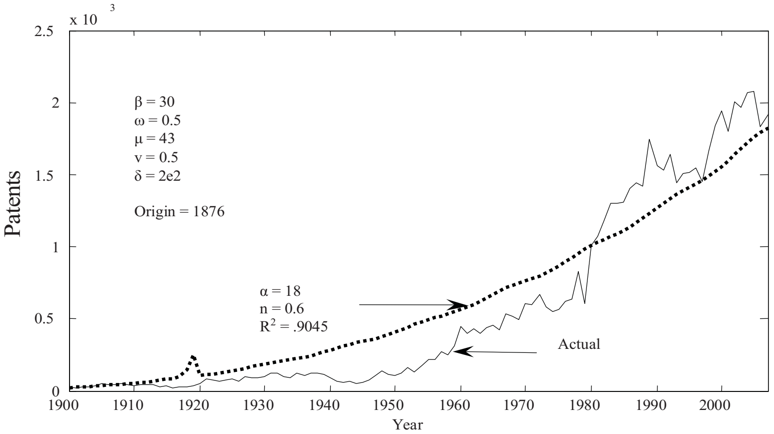

Figure A3.69. EPO worldwide Patent Search: Graphite in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

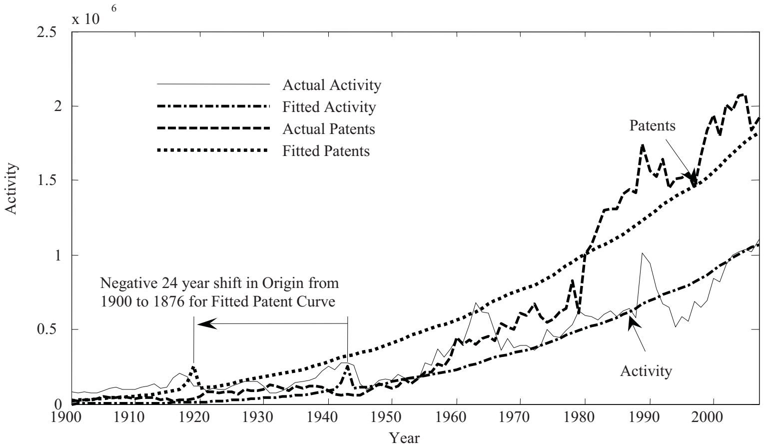

Figure A3.70. Graphite Best-Fit Activity and Patents. Illustrates best-fit origin shift.

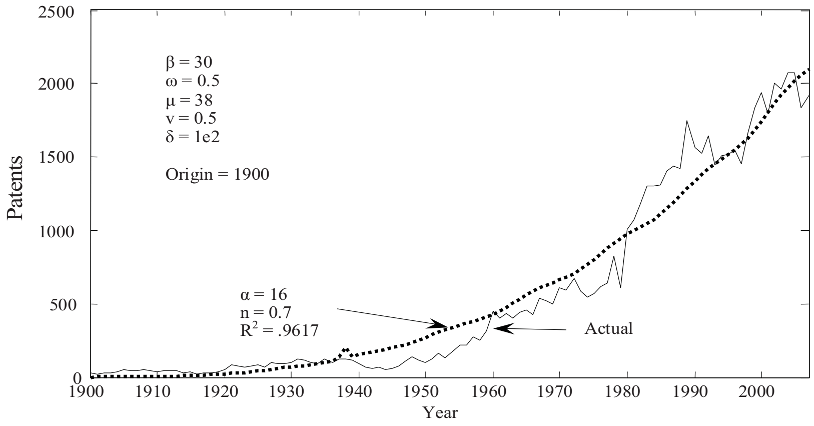

Figure A3.71. **Graphite Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.35 Gypsum[43] Activity[44] and Patents[45]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y
1900			**1927**	11200000	35	**1954**	28000000	31	**1981**	76200000	374
1901			**1928**	11800000	19	**1955**	32100000	26	**1982**	72500000	342
1902			**1929**	12500000	37	**1956**	33500000	31	**1983**	80700000	385
1903			**1930**	11900000	46	**1957**	34200000	40	**1984**	85800000	337
1904			**1931**	9400000	46	**1958**	37800000	35	**1985**	87000000	336
1905			**1932**	7800000	49	**1959**	43100000	46	**1986**	88200000	317
1906			**1933**	7400000	54	**1960**	40000000	37	**1987**	93000000	325
1907			**1934**	7900000	35	**1961**	40500000	33	**1988**	101000000	355
1908			**1935**	8300000	45	**1962**	43500000	40	**1989**	104000000	427
1909			**1936**	9400000	31	**1963**	45500000	42	**1990**	104000000	409
1910			**1937**	7790000	30	**1964**	46800000	50	**1991**	100000000	421
1911			**1938**	6030000	44	**1965**	48000000	64	**1992**	98800000	531
1912			**1939**	8030000	23	**1966**	48700000	48	**1993**	97200000	451
1913			**1940**	7940000	29	**1967**	46200000	75	**1994**	96300000	465
1914			**1941**	8960000	14	**1968**	49400000	78	**1995**	98400000	488
1915			**1942**	9350000	19	**1969**	52200000	66	**1996**	104000000	522
1916			**1943**	8480000	13	**1970**	51600000	64	**1997**	107000000	629
1917			**1944**	8400000	17	**1971**	53100000	119	**1998**	104000000	678
1918			**1945**	9800000	12	**1972**	57600000	126	**1999**	109000000	703
1919			**1946**	14400000	17	**1973**	61500000	94	**2000**	108000000	735
1920			**1947**	16500000	24	**1974**	61400000	132	**2001**	105000000	778
1921			**1948**	21200000	17	**1975**	59200000	142	**2002**	111000000	764
1922			**1949**	19000000	13	**1976**	66100000	219	**2003**	114000000	751
1923			**1950**	22600000	19	**1977**	74500000	328	**2004**	120000000	774
1924	9700000	13	**1951**	18400000	25	**1978**	77800000	420	**2005**	122000000	781
1925	10700000	26	**1952**	24100000	18	**1979**	80400000	336	**2006**	125000000	772
1926	11300000	28	**1953**	25400000	21	**1980**	78400000	384	**2007**	152400000	784

Table A3.36. Correlation Eq.(A1.1) terms calculated from Table A3.35 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
4.521E+09	18559	3.73E+17	9503115	1.77E+12	1.292E+17	5402681	7.7E+11	**0.921142**	**84.85017**

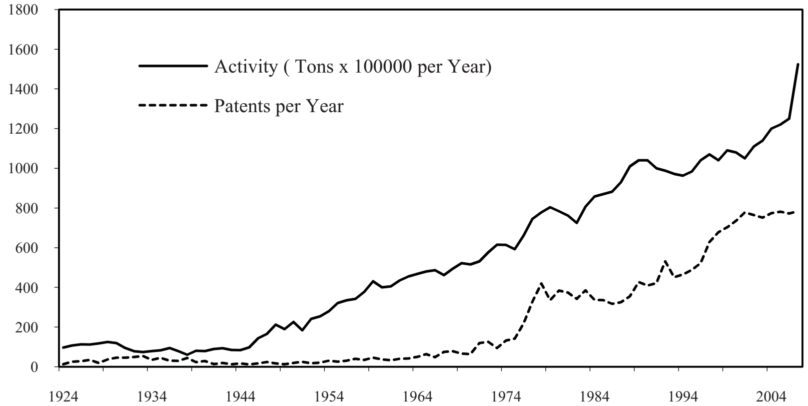

Figure A3.72. Gypsum Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[43] Monoclinic mineral form of hydrated calcium sulphate.

[44] Activity represents world production of gypsum, defined at usgs.gov as "…mine production of crude gypsum. Data are not available prior to 1924. Data are recorded in the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[45] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Gypsum was used as the keyword found in the patent title or abstract by year of publication.

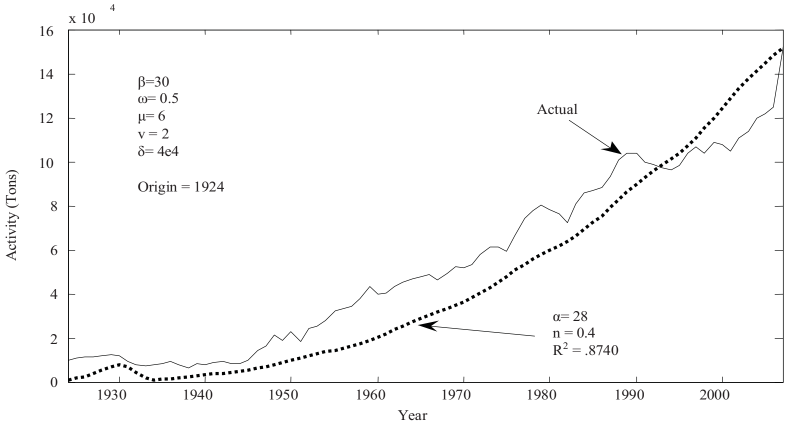

Figure A3.73. **USGS World Gypsum Production.** World gypsum production (activity)scaled in metric kilotons with actual and best-fit curves and common pattern equation parameters. No best-fit for the patent data was obtainable.

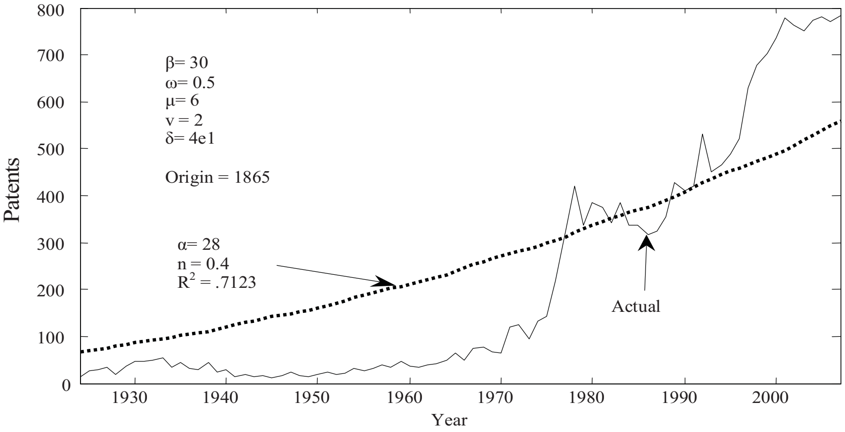

Figure A3.74. EPO Worldwide Patent Search: Gypsum in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

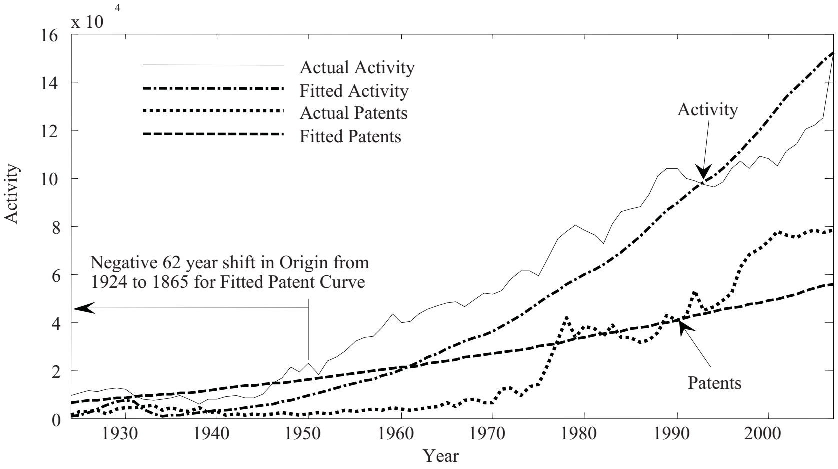

Figure A3.75. Graphite Best-Fit Activity and Patents. Illustrates best-fit origin shift.

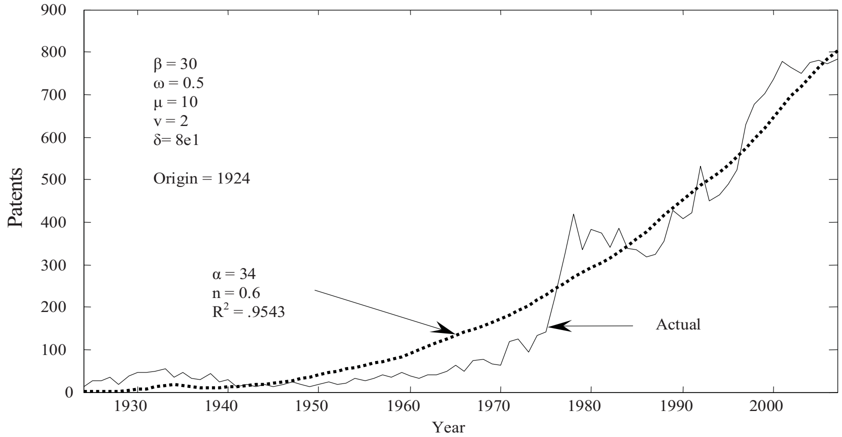

Figure A3.76. Gypsum Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.37. Helium Activity[46] and Patents[47]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**	914	27	**1981**	5580	198
1901			**1928**			**1955**	1060	50	**1982**	1830	270
1902			**1929**			**1956**	1170	58	**1983**	3480	256
1903			**1930**			**1957**	1400	49	**1984**	8570	309
1904			**1931**			**1958**	1600	64	**1985**	9750	371
1905			**1932**			**1959**	2290	58	**1986**	10000	355
1906			**1933**			**1960**	3080	100	**1987**	11600	429
1907			**1934**			**1961**	3490	90	**1988**	13300	406
1908			**1935**	49	21	**1962**	3420	103	**1989**	14800	548
1909			**1936**	22.4	16	**1963**	10800	122	**1990**	15600	420
1910			**1937**	23.1	15	**1964**	19400	110	**1991**	15900	426
1911			**1938**	29.2	21	**1965**	21000	147	**1992**	16900	561
1912			**1939**	30.1	17	**1966**	22100	130	**1993**	16900	453
1913			**1940**	45.3	10	**1967**	22700	169	**1994**	17900	525
1914			**1941**	77.5	3	**1968**	22500	157	**1995**	18800	396
1915			**1942**	159	6	**1969**	22500	174	**1996**	18800	397
1916			**1943**	558	2	**1970**	22200	173	**1997**	23400	376
1917			**1944**	608	1	**1971**	22400	165	**1998**	22700	484
1918			**1945**	454	10	**1972**	20200	203	**1999**	22900	478
1919			**1946**	279	10	**1973**	16000	212	**2000**	19800	571
1920			**1947**	337	12	**1974**	4900	179	**2001**	17900	564
1921			**1948**	303	14	**1975**	5870	177	**2002**	18500	665
1922			**1949**	264	10	**1976**	7120	156	**2003**	24400	594
1923			**1950**	390	13	**1977**	7830	140	**2004**	26100	555
1924			**1951**	537	19	**1978**	8400	176	**2005**	27100	481
1925			**1952**	693	31	**1979**	8890	158	**2006**	28100	436
1926			**1953**	772	31	**1980**	7560	181	**2007**	28900	428

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[46] Activity represents world production of helium, defined at usgs.gov as follows. "….World production data for the years 1935–71 were recorded from the MYB. World production data for the years 1972 to the most recent were recorded from the MCS. World production data for the years 1935 to the most recent represent the summed quantity of total U.S. helium production and the total estimated production capacity of all other helium-producing countries. For the years 1935–62, world production is equal to U.S. production." Data is in metric tons, as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[47] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Helium was used as the keyword found in the patent title or abstract by year of publication.

Table A3.38. Correlation Eq.(A1.1) terms calculated from Table A3.37 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
755934.6	15742	1.43E+10	6148154	2.62E+08	6.425E+09	2753489	99225238	**0.745984**	**55.64915**

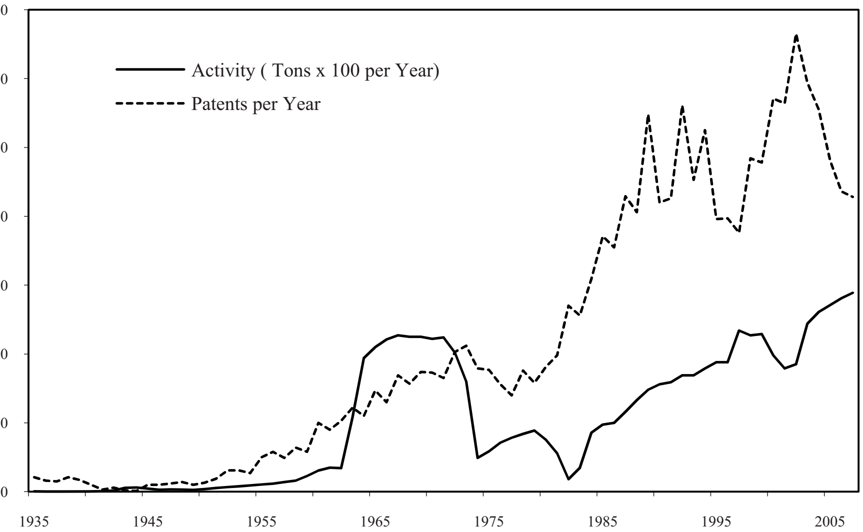

Figure A3.77. Helium Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

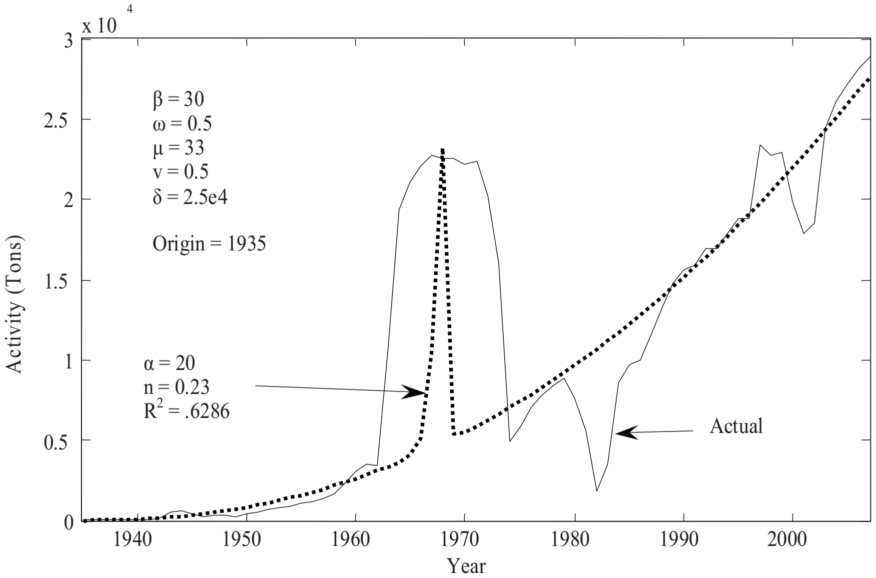

Figure A3.78. **USGS World Helium Production.** World helium production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

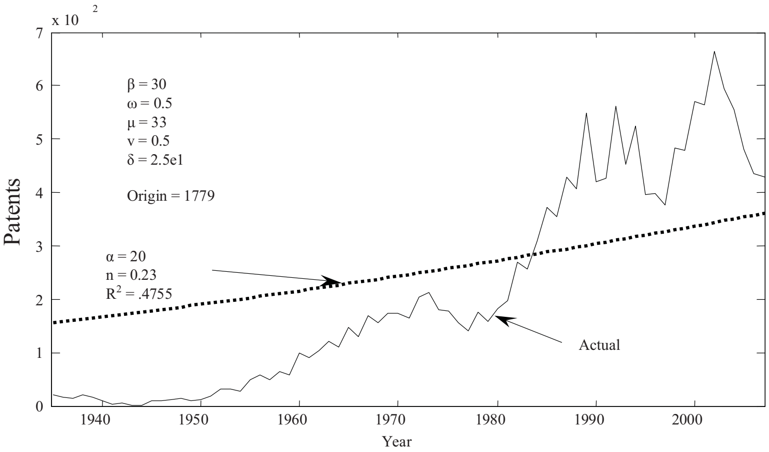

Figure A3.79. EPO Worldwide Patent Search: Helium in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

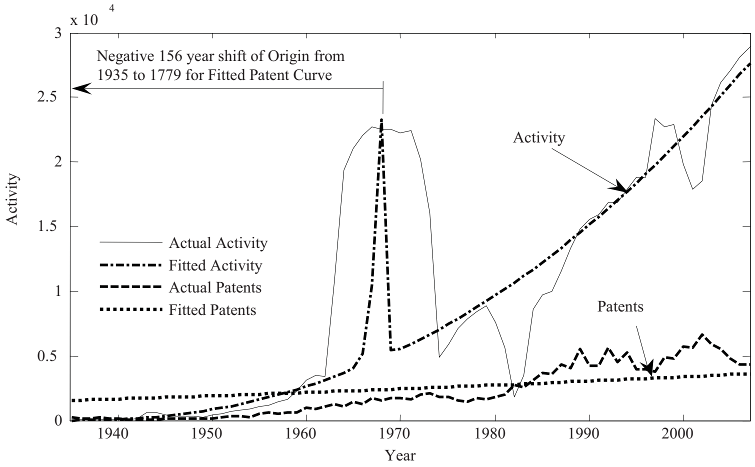

Figure A3.80. Helium Best-Fit Activity and Patents. Illustrates best-fit origin shift.

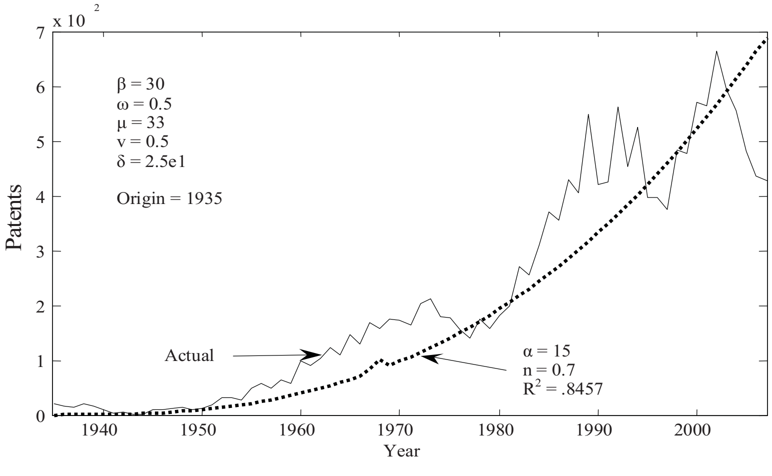

Figure A3.81. **Helium Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.39 Hydraulic Cement[48] Activity[49] and Patents[50]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (pat)
1900			**1927**	67800000	13	**1954**	194900000	17	**1981**	886700000	73
1901			**1928**	72200000	11	**1955**	217300000	17	**1982**	887400000	102
1902			**1929**	74900000	16	**1956**	235400000	10	**1983**	916600000	96
1903			**1930**	72300000	12	**1957**	246900000	13	**1984**	941100000	124
1904			**1931**	62100000	15	**1958**	262500000	13	**1985**	959400000	103
1905			**1932**	49300000	21	**1959**	294300000	21	**1986**	1.008E+09	92
1906			**1933**	48200000	22	**1960**	316500000	26	**1987**	1.053E+09	114
1907			**1934**	58300000	20	**1961**	333200000	18	**1988**	1.118E+09	99
1908			**1935**	65400000	24	**1962**	358500000	19	**1989**	1.042E+09	152
1909			**1936**	62800000	12	**1963**	378000000	22	**1990**	1.043E+09	150
1910			**1937**	82700000	18	**1964**	415600000	20	**1991**	1.185E+09	183
1911			**1938**	85900000	23	**1965**	433400000	32	**1992**	1.123E+09	174
1912			**1939**	93000000	16	**1966**	464200000	22	**1993**	1.291E+09	207
1913			**1940**	81000000	7	**1967**	479800000	30	**1994**	1.37E+09	213
1914			**1941**	88000000	9	**1968**	515200000	28	**1995**	1.445E+09	212
1915			**1942**	80900000	7	**1969**	543100000	26	**1996**	1.493E+09	154
1916			**1943**	71200000	9	**1970**	571800000	29	**1997**	1.547E+09	197
1917			**1944**	54900000	18	**1971**	590000000	37	**1998**	1.54E+09	185
1918			**1945**	49500000	6	**1972**	661000000	34	**1999**	1.6E+09	226
1919			**1946**	72500000	4	**1973**	702000000	39	**2000**	1.66E+09	203
1920			**1947**	85800000	4	**1974**	703200000	49	**2001**	1.75E+09	200
1921			**1948**	102000000	13	**1975**	702200000	53	**2002**	1.85E+09	219
1922			**1949**	115000000	12	**1976**	735400000	65	**2003**	2.02E+09	211
1923			**1950**	133000000	11	**1977**	797100000	68	**2004**	2.19E+09	228
1924			**1951**	149000000	5	**1978**	853000000	77	**2005**	2.35E+09	207
1925			**1952**	161000000	6	**1979**	872400000	39	**2006**	2.55E+09	209
1926	62400000	11	**1953**	178000000	12	**1980**	883100000	66	**2007**	2.77E+09	197

Table A3.40. Correlation Eq.(A1.1) terms calculated from Table A3.39 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
5.573E+10	5777	7.39E+19	867369	7.71E+12	3.604E+19	460372.3	3.79E+12	**0.929922**	**86.4755**

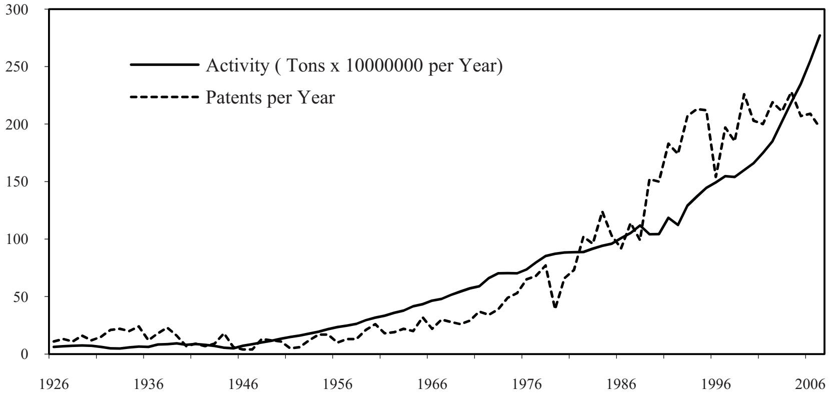

Figure A3.82. Hydraulic Cement Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[48] Portland, natural, masonry, and slag or pozzolanic cement [78].

[49] Activity represents world production of hydraulic cement, defined at usgs.gov as "…recorded from the MYB [*Minerals Yearbook*] and MR [*Minerals Resources of the United States*]. World production statistics were not available from 1900-1925" Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[50] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Hydraulic and cement were used as the keywords found in the patent title or abstract by year of publication.

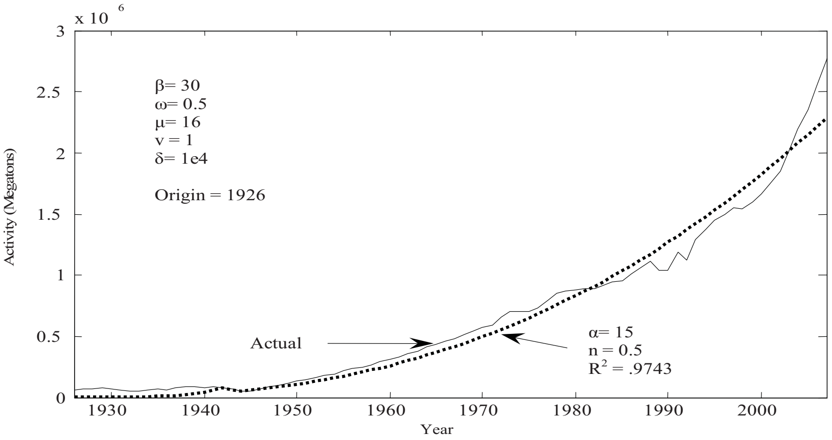

Figure A3.83. **USGS World Hydraulic Cement Production.** World hydraulic cement production scaled in metric megatons with actual and best-fit curves and common pattern equation parameters.

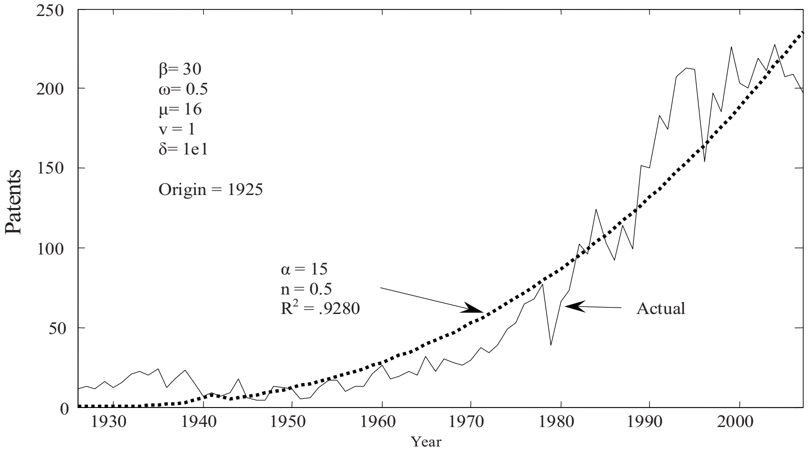

Figure A3.84. EPO Worldwide Patent Search: Hydraulic Cement in Title or Abstract by date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

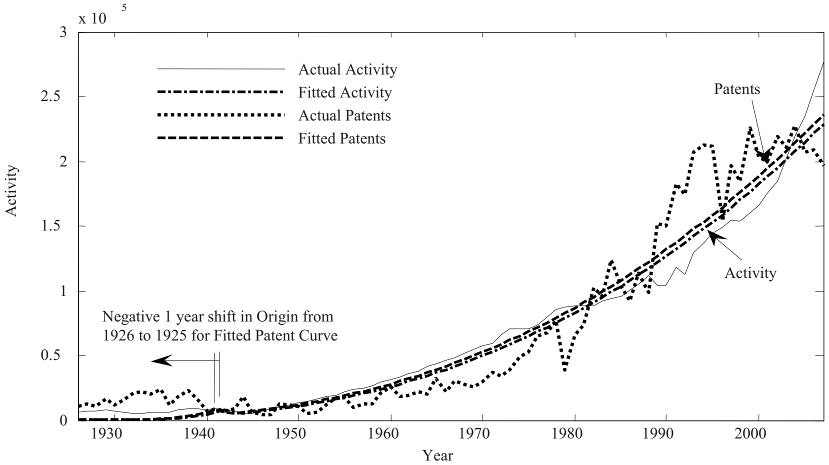

Figure A3.85. Hydraulic Cement Best-Fit activity and Patents. Illustrates best-fit origin shift.

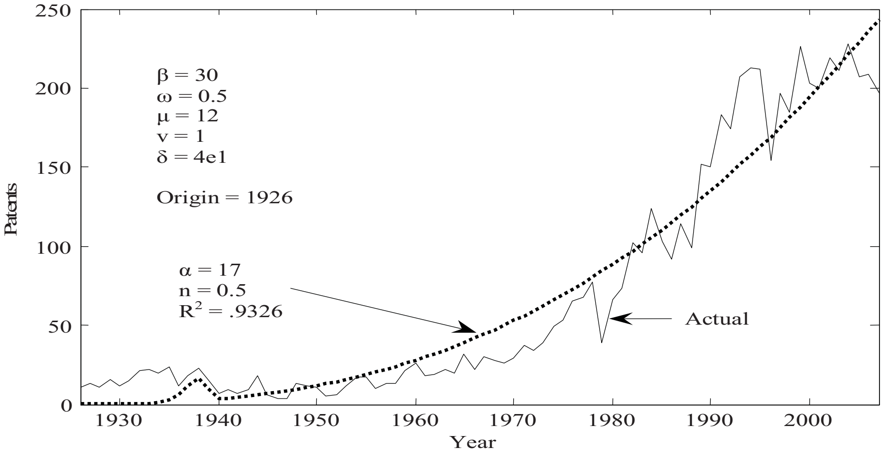

Figure A3.86. Hydraulic Cement Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.41 Iodine Activity[51] and Patents[52]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**			**1981**	12000	443
1901			**1928**			**1955**			**1982**	12300	452
1902			**1929**			**1956**			**1983**	12500	466
1903			**1930**			**1957**			**1984**	12400	387
1904			**1931**			**1958**			**1985**	12800	482
1905			**1932**			**1959**			**1986**	13000	496
1906			**1933**			**1960**	3030	143	**1987**	12700	490
1907			**1934**			**1961**	3360	147	**1988**	14900	587
1908			**1935**			**1962**	3410	131	**1989**	16300	642
1909			**1936**			**1963**	3580	171	**1990**	16000	643
1910			**1937**			**1964**	4190	207	**1991**	17300	538
1911			**1938**			**1965**	4480	254	**1992**	16500	626
1912			**1939**			**1966**	5560	177	**1993**	16100	602
1913			**1940**			**1967**	5250	232	**1994**	14300	654
1914			**1941**			**1968**	5290	195	**1995**	13400	669
1915			**1942**			**1969**	7070	188	**1996**	14100	681
1916			**1943**			**1970**	8260	211	**1997**	15700	689
1917			**1944**			**1971**	9360	167	**1998**	18600	795
1918			**1945**			**1972**	9740	228	**1999**	18400	701
1919			**1946**			**1973**	10900	209	**2000**	19500	823
1920			**1947**			**1974**	10400	184	**2001**	20700	679
1921			**1948**			**1975**	10800	205	**2002**	21000	779
1922			**1949**			**1976**	11000	265	**2003**	24600	858
1923			**1950**			**1977**	10300	296	**2004**	24800	732
1924			**1951**			**1978**	10400	282	**2005**	26500	773
1925			**1952**			**1979**	11100	242	**2006**	26700	719
1926			**1953**			**1980**	11600	482	**2007**	25700	738

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[51] Activity represents world production of iodine, defined at usgs.gov as "World production data for the years 1960-75, are reported in the mine production table of the CDS [*Commodity Data Summaries*]. Data for the years 1976 to the most recent are reported in the world production table of the MYB [*Minerals Yearbook*]. Excludes production in the U.S. in 2006." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[52] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Iodine was used as a keyword found in the patent title or abstract by year of publication.

Table A3.42. Correlation Eq.(A1.1) terms calculated from Table A3.41 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**100r^2**
614500	21168	1.01E+10	12351438	3.46E+08	2.228E+09	3016350	74640680	**0.910526**	**82.90567**

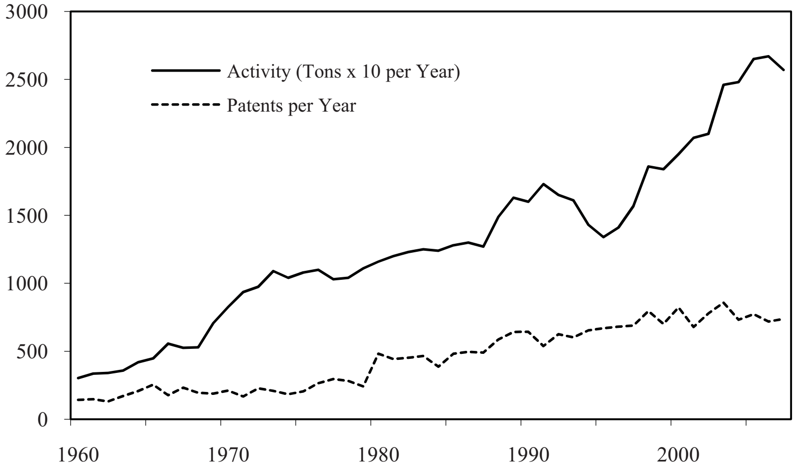

Figure A3.87. Iodine Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

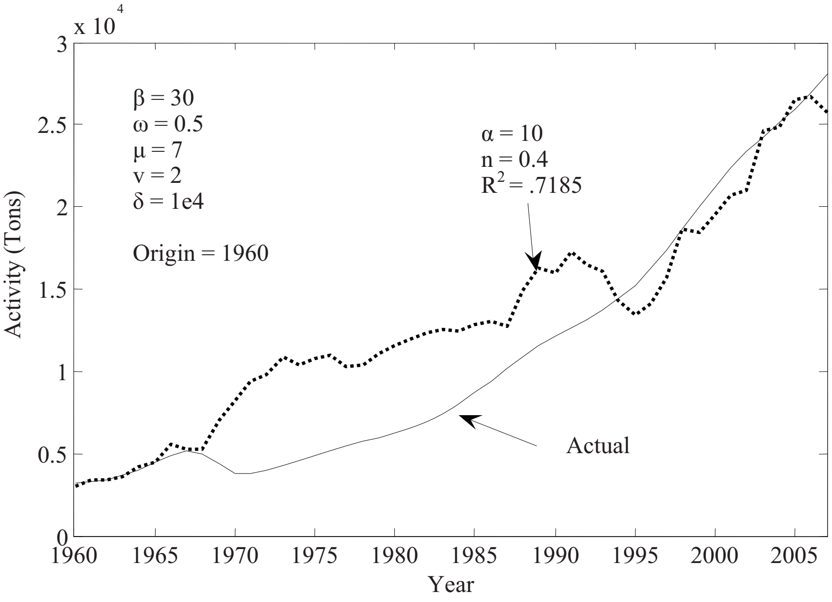

Figure A3.88. **USGS World Iodine Production.** World iodine production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

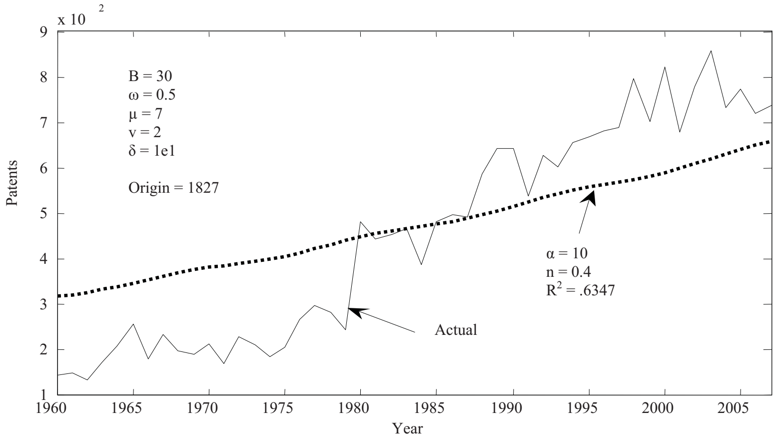

Figure A3.89. EPO Worldwide Patent Search: Iodine in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

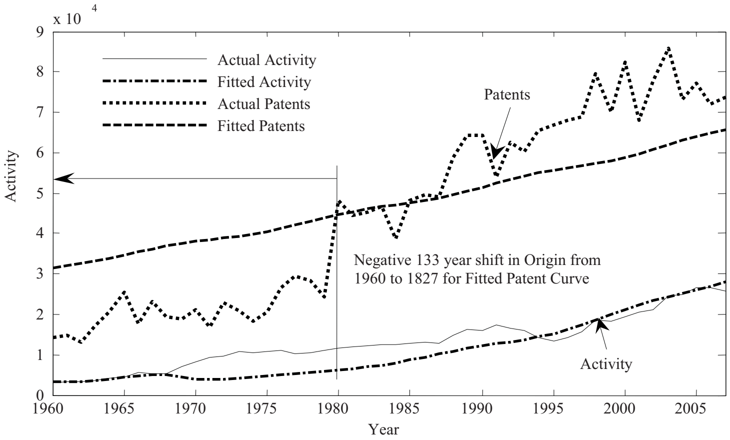

Figure A3.90. Iodine Best-Fit Activity and Patents. Illustrates best-fit origin shift.

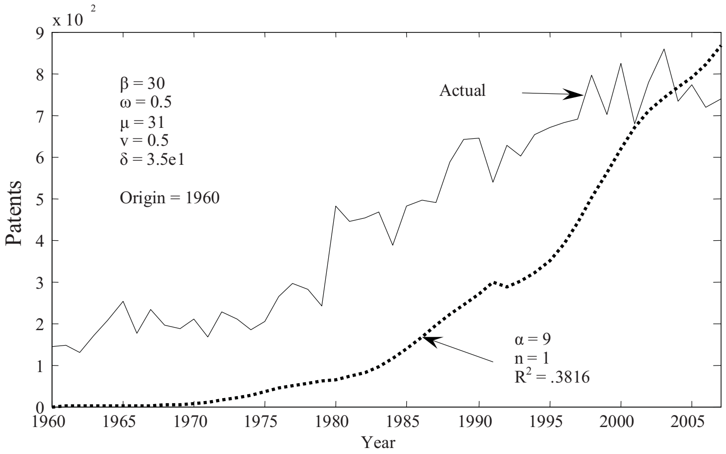

Figure A3.91. Iodine Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.43 Iron Activity[53] and Patents[54]

Year	x (activity)	y pat.	Year	x (activity)	y (patent)	Year	x (activity)	y (pat.)	Yr.	x (activity)	y (pat.)
1900			**1927**	171000000	922	**1954**	405000000	954	**1981**	858000000	6201
1901			**1928**	174000000	909	**1955**	369000000	1088	**1982**	781000000	7271
1902			**1929**	201000000	964	**1956**	395000000	1320	**1983**	740000000	7605
1903			**1930**	179000000	1130	**1957**	434000000	1215	**1984**	829000000	7745
1904	95500000	717	**1931**	119000000	1281	**1958**	405000000	1123	**1985**	861000000	8070
1905	116000000	662	**1932**	76200000	1121	**1959**	439000000	1103	**1986**	864000000	8961
1906	100000000	590	**1933**	91200000	964	**1960**	522000000	1525	**1987**	903000000	8758
1907	135000000	598	**1934**	120000000	910	**1961**	503000000	1341	**1988**	967000000	9147
1908	109000000	580	**1935**	138000000	965	**1962**	508000000	1337	**1989**	1.01E+09	10130
1909	126000000	548	**1936**	170000000	876	**1963**	523000000	1466	**1990**	983000000	9728
1910	142000000	521	**1937**	212000000	912	**1964**	583000000	1469	**1991**	956000000	9348
1911	133000000	474	**1938**	162000000	999	**1965**	621000000	1741	**1992**	925000000	10660
1912	151000000	464	**1939**	204000000	828	**1966**	636000000	1482	**1993**	953000000	9741
1913	177000000	555	**1940**	204000000	698	**1967**	623000000	1837	**1994**	992000000	9994
1914	118000000	442	**1941**	220000000	493	**1968**	679000000	1772	**1995**	1.03E+09	9689
1915	116000000	351	**1942**	235000000	434	**1969**	713000000	1638	**1996**	1.02E+09	9529
1916	139000000	256	**1943**	231000000	368	**1970**	769000000	2067	**1997**	1.07E+09	9576
1917	142000000	265	**1944**	203000000	376	**1971**	787000000	2198	**1998**	1.05E+09	10732
1918	127000000	288	**1945**	162000000	445	**1972**	778000000	2446	**1999**	1.02E+09	10700
1919	110000000	433	**1946**	154000000	455	**1973**	846000000	2341	**2000**	1.07E+09	11910
1920	124000000	550	**1947**	187000000	535	**1974**	898000000	2283	**2001**	1.04E+09	11425
1921	73000000	746	**1948**	219000000	821	**1975**	902000000	2528	**2002**	1.1E+09	12041
1922	104000000	723	**1949**	223000000	904	**1976**	899000000	2790	**2003**	1.21E+09	11430
1923	136000000	710	**1950**	251000000	680	**1977**	841000000	3792	**2004**	1.36E+09	11736
1924	130000000	699	**1951**	294000000	769	**1978**	847000000	4042	**2005**	1.54E+09	11190
1925	151000000	823	**1952**	297000000	1106	**1979**	903000000	4149	**2006**	1.82E+09	11033
1926	155000000	800	**1953**	338000000	732	**1980**	891000000	6089	**2007**	2.03E+09	11840

Table A3.44. Correlation Eq.(A1.1) terms calculated from Table A3.43 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	100r^2
5.485E+10	357718	4.74E+19	2.87E+09	3.41E+14	1.852E+19	1.64E+09	1.52E+14	**0.874126**	**76.40968**

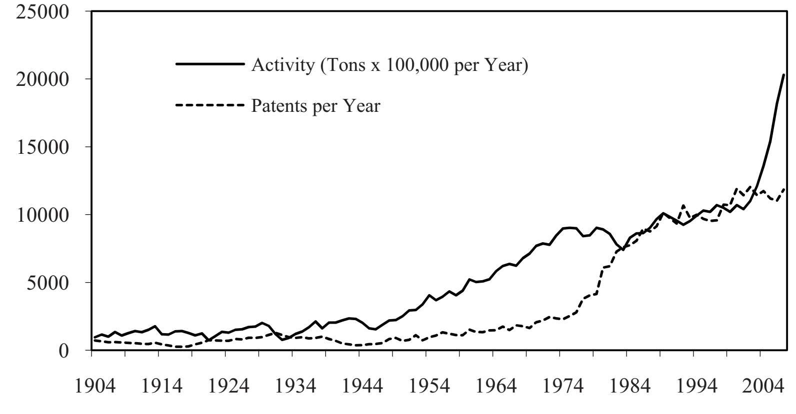

Figure A3.92. Iron Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[53] Activity represents world production of iron, defined at usgs.gov as "…the world production of iron ore, iron ore concentrates, and iron ore agglomerates. For the years 1913–22, world production is reported as "production in principal countries." A graph of the time series for world production gives a smooth curve when the category name changes, indicating that major producers were included. World production data were recorded from the MR [*Minerals Resources of the United States*] and the MYB [*Minerals Yearbook*]. "Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[54] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Iron of Fe were used as keyword founds in the patent title or abstract by year of publication.

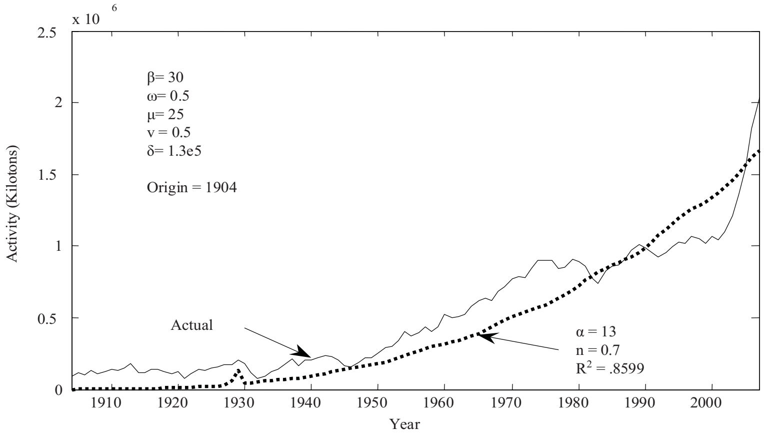

Figure A3.93. **USGS World Iron Production.** World iron production (activity) scaled in metric kilotons with actual and best-fit curves and common pattern equation parameters.

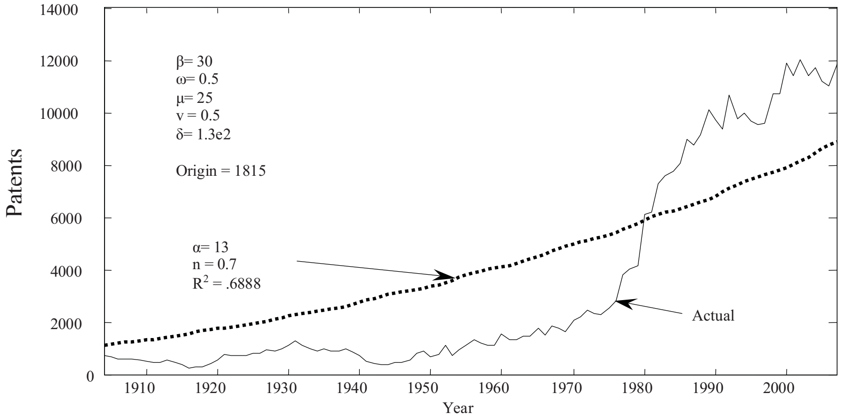

Figure A3.94. EPO Worldwide Patent Search: Iron or Fe in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

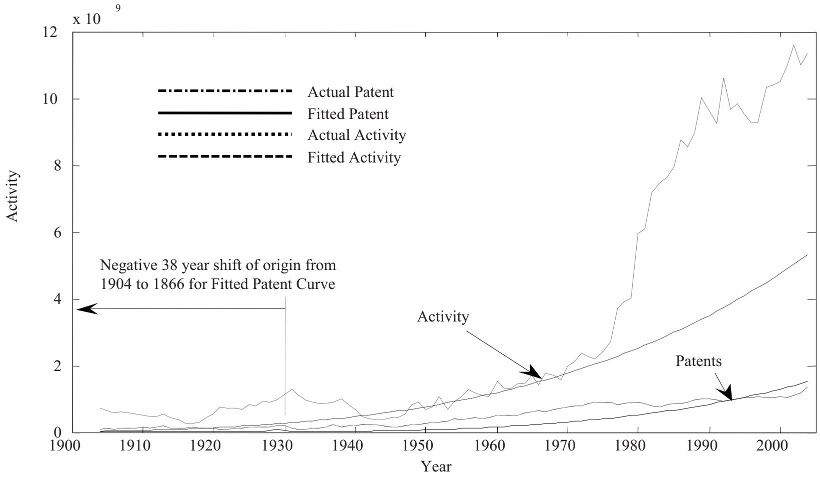

Figure A3.95. Iron Best-Fit Activity and Patents. Illustrates best-fit origin shift.

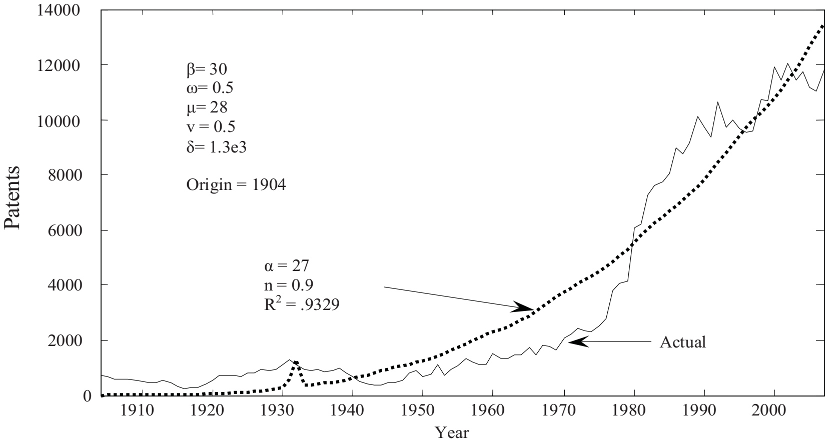

Figure A3.96. Iron Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.45 Kyanite[55] Activity[56] and Patents[57]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**	73000	3	**1981**	330000	120
1901			**1928**	2300	0	**1955**	38000	0	**1982**	290000	132
1902			**1929**	3700	0	**1956**	58000	1	**1983**	240000	140
1903			**1930**	8800	1	**1957**	82000	1	**1984**	280000	122
1904			**1931**	3500	1	**1958**	76000	4	**1985**	340000	114
1905			**1932**	5700	0	**1959**	77000	3	**1986**	300000	114
1906			**1933**	4500	1	**1960**	95000	3	**1987**	340000	121
1907			**1934**	9700	0	**1961**	130000	3	**1988**	380000	133
1908			**1935**	20000	0	**1962**	130000	3	**1989**	410000	154
1909			**1936**	25000	1	**1963**	120000	8	**1990**	400000	137
1910			**1937**	27000	0	**1964**	120000	7	**1991**	310000	146
1911			**1938**	29000	1	**1965**	120000	8	**1992**	320000	142
1912			**1939**	15000	0	**1966**	130000	11	**1993**	270000	118
1913			**1940**	13000	0	**1967**	130000	7	**1994**	280000	147
1914			**1941**	22000	3	**1968**	120000	4	**1995**	280000	150
1915			**1942**	25000	1	**1969**	140000	6	**1996**	300000	163
1916			**1943**	23000	0	**1970**	200000	10	**1997**	350000	152
1917			**1944**	15000	1	**1971**	190000	6	**1998**	460000	170
1918			**1945**	15000	1	**1972**	180000	13	**1999**	360000	207
1919			**1946**	23000	4	**1973**	200000	12	**2000**	406000	209
1920			**1947**	43000	0	**1974**	180000	13	**2001**	424000	201
1921			**1948**	46000	0	**1975**	190000	33	**2002**	391000	182
1922			**1949**	61000	2	**1976**	230000	33	**2003**	386000	202
1923			**1950**	58000	2	**1977**	250000	29	**2004**	456000	211
1924			**1951**	73000	0	**1978**	240000	43	**2005**	450000	189
1925			**1952**	67000	2	**1979**	290000	69	**2006**	444000	176
1926			**1953**	47000	2	**1980**	350000	123	**2007**	443000	170

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[55] Includes synthetic mullite and kyanite [78].

[56] Activity represents world production of kyanite, defined at usgs.gov as "…data for the years 1928-60 are from the "World Production" table in the 1960 MYB [*Minerals Yearbook*]. World production data for the years 1961–70 were from the "World Mine Production" table in the CDS. World production for the years 1971–2002 were from the MCS[*Mineral Commodity Summaries*]. Data for the years 2003 to the most recent are unpublished revisions made by the Commodity Specialist." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[57] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Kyanite or aluminum silicate were used as keywords found in the patent title or abstract by year of publication.

Table A3.46. Correlation Eq.(A1.1) terms calculated from Table A3.45 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
14464200	4701	4.36E+12	712065	1.66E+09	1.748E+12	435822.5	8.07E+08	**0.92419**	**85.4127**

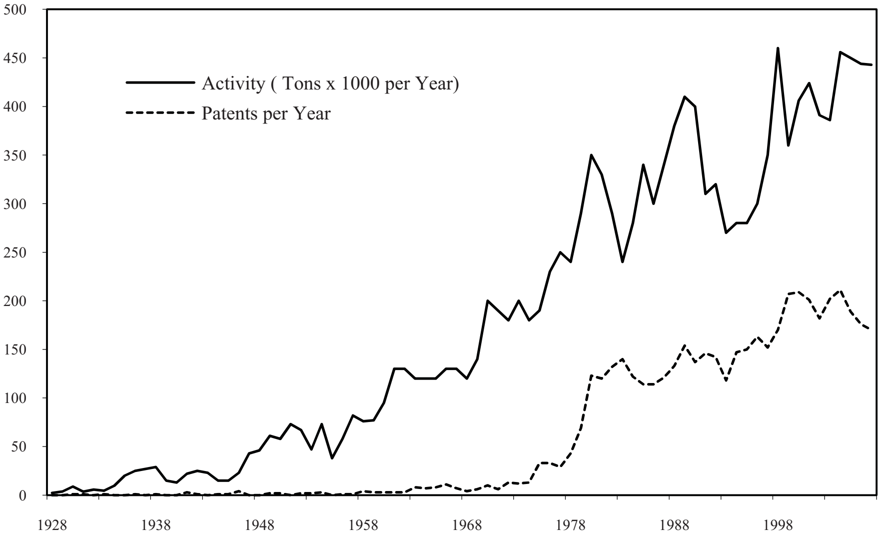

Figure A3.97. Kyanite Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

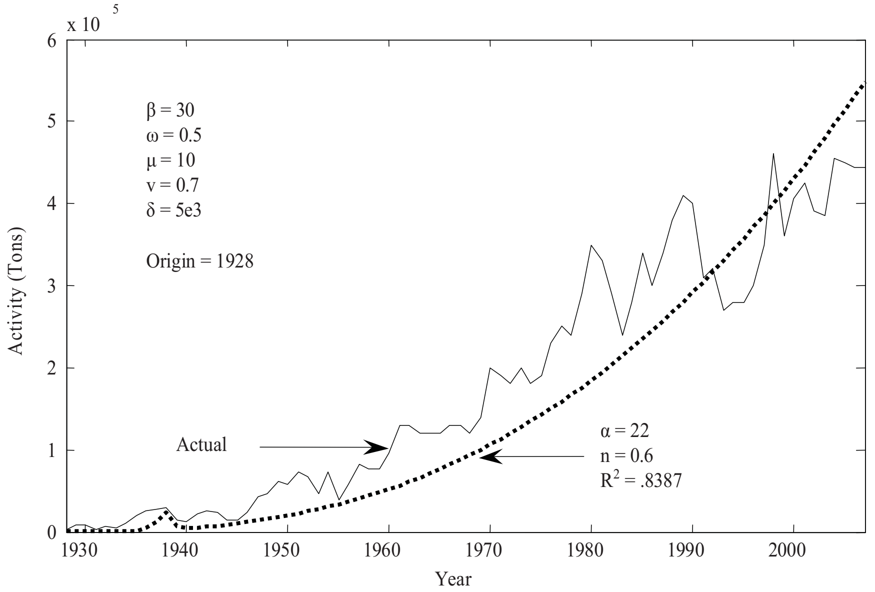

Figure A3.98. **USGS World Kyanite Production.** World kyanite production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

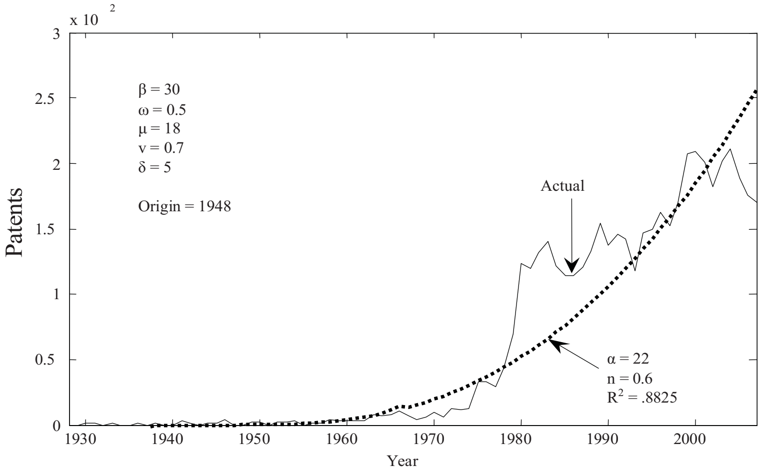

Figure A3.99. EPO Worldwide Patent Search: Kyanite or Aluminum Silicate in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

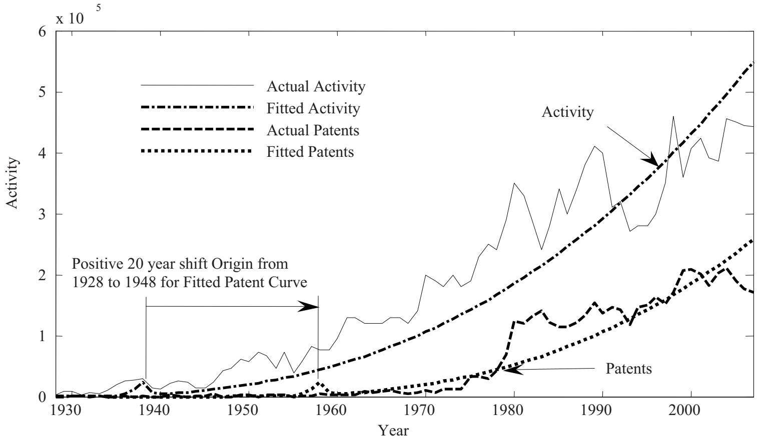

Figure A3.100. Kyanite Best-Fit Activity and Patents. Illustrates best-fit origin shift.

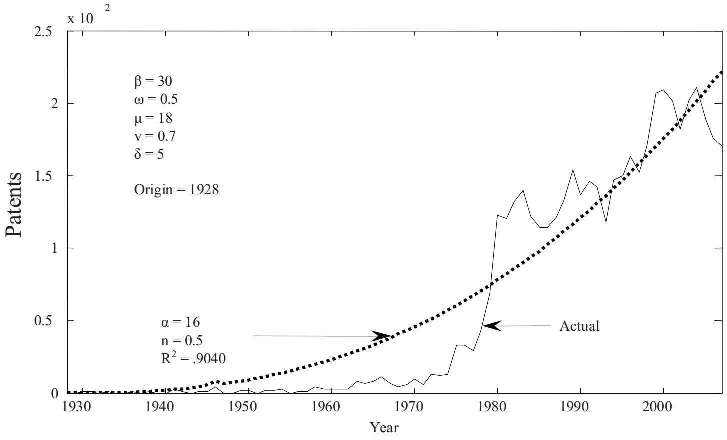

Figure A3.101. **Kyanite Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.47 Lead Activity[58] and Patents[59]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	749000	231	**1927**	1540000	594	**1954**	2000000	796	**1981**	3350000	5204
1901	800000	220	**1928**	1680000	595	**1955**	2010000	839	**1982**	3450000	6114
1902	850000	250	**1929**	1610000	605	**1956**	2400000	982	**1983**	3350000	6262
1903	900000	340	**1930**	1520000	793	**1957**	2380000	1093	**1984**	3200000	7004
1904	950000	307	**1931**	1260000	792	**1958**	2350000	919	**1985**	3390000	7531
1905	1000000	294	**1932**	1050000	785	**1959**	2320000	955	**1986**	3240000	8034
1906	1040000	283	**1933**	1040000	687	**1960**	2390000	1342	**1987**	3430000	7876
1907	993000	334	**1934**	1200000	679	**1961**	2390000	1173	**1988**	3420000	8485
1908	1280000	281	**1935**	1380000	691	**1962**	2510000	1174	**1989**	3400000	10449
1909	1060000	272	**1936**	1470000	746	**1963**	2560000	1228	**1990**	3370000	10534
1910	1100000	297	**1937**	1590000	720	**1964**	2530000	1305	**1991**	3260000	10354
1911	1110000	324	**1938**	1700000	824	**1965**	2700000	1535	**1992**	3200000	11860
1912	1160000	310	**1939**	1740000	687	**1966**	2850000	1212	**1993**	2900000	10598
1913	1150000	342	**1940**	1700000	631	**1967**	2870000	1447	**1994**	2800000	10758
1914	1100000	290	**1941**	1600000	467	**1968**	3010000	1396	**1995**	2710000	9998
1915	1000000	243	**1942**	1500000	409	**1969**	3240000	1380	**1996**	2920000	9867
1916	950000	184	**1943**	1400000	383	**1970**	3390000	1580	**1997**	3100000	9596
1917	900000	178	**1944**	1300000	314	**1971**	3490000	1700	**1998**	3060000	10648
1918	800000	169	**1945**	1250000	375	**1972**	3450000	2118	**1999**	3080000	10770
1919	764000	294	**1946**	1030000	438	**1973**	3490000	2027	**2000**	3200000	11815
1920	804000	323	**1947**	1310000	575	**1974**	3490000	1824	**2001**	3120000	11672
1921	783000	452	**1948**	1380000	791	**1975**	3440000	1917	**2002**	2850000	12153
1922	972000	428	**1949**	1370000	782	**1976**	3690000	2179	**2003**	3150000	11756
1923	1080000	464	**1950**	1640000	601	**1977**	3410000	2817	**2004**	3200000	11619
1924	1220000	489	**1951**	1600000	663	**1978**	3460000	2986	**2005**	3520000	11626
1925	1410000	549	**1952**	1810000	888	**1979**	3510000	3674	**2006**	3650000	11748
1926	1470000	554	**1953**	1870000	680	**1980**	3520000	5202	**2007**	3770000	12083

Table A3.48. Correlation Eq.(A1.1) terms calculated from Table A3.47 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
232875000	339111	6.09E+14	2.86E+09	1.04E+12	1.064E+14	1.79E+09	3.06E+11	**0.701272**	**49.17827**

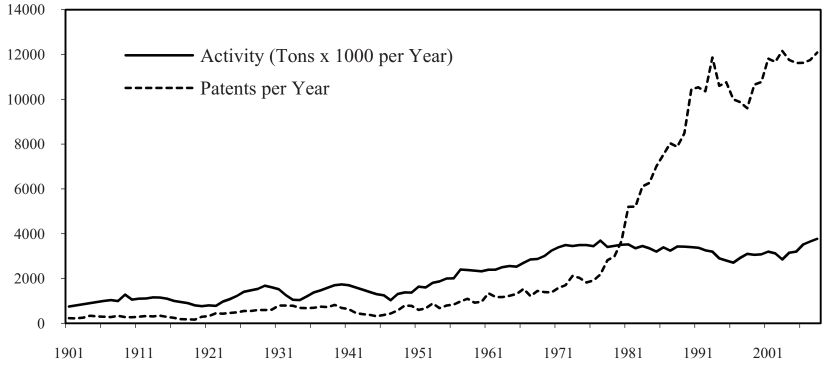

Figure A3.102. Lead Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[58] Activity represents world production of lead, defined at usgs.gov as "…contained lead in world smelter production for the years 1900–54 and for world mine production for the years 1955–98. Data were from the MYB and MR for the years 1900–73 and the MCS for the years 1974 to the most recent. World production data were for contained lead in world smelter production originating from ores and may include secondary lead when inseparable. Blank cells in the worksheet indicate that data were not available for the years 1901–05, 1914–18, 1926, 1937, and 1940–44." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[59] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Lead or Pb were used as keywords found in the patent title or abstract by year of publication.

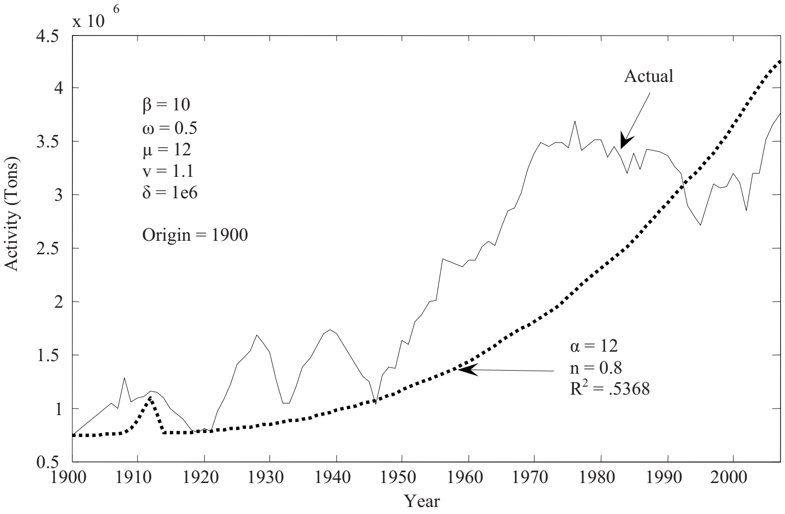

Figure A3.103. **USGS World Lead Production.** World lead production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

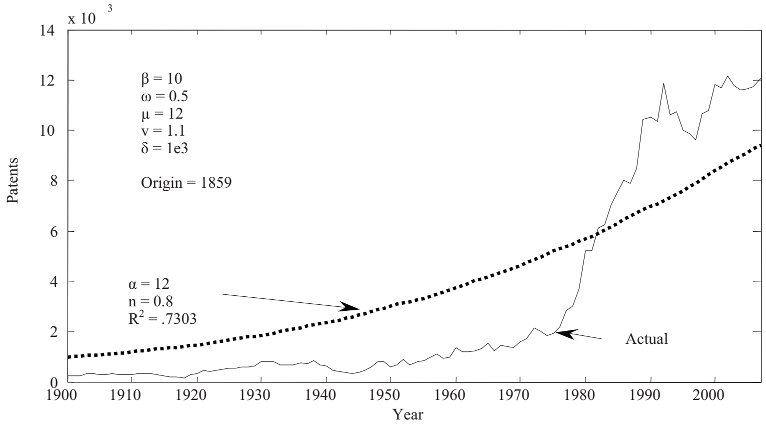

Figure A3.104. EPO Worldwide Patent Search: Lead or Pb in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

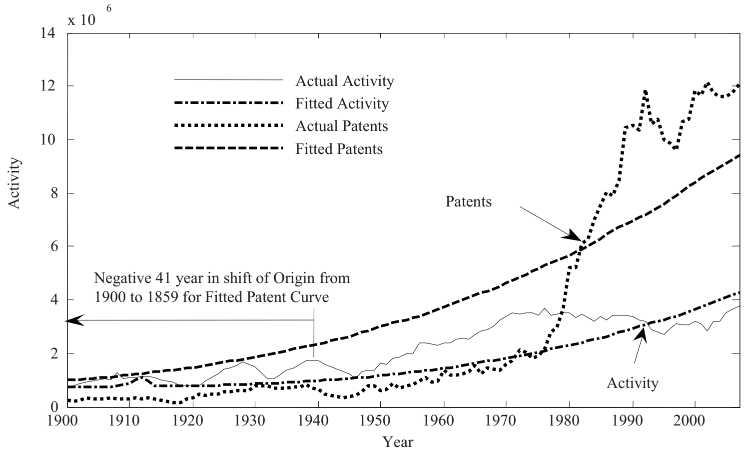

Figure A3.105. Lead Best-Fit Activity and Patents. Illustrates best-fit origin shift.

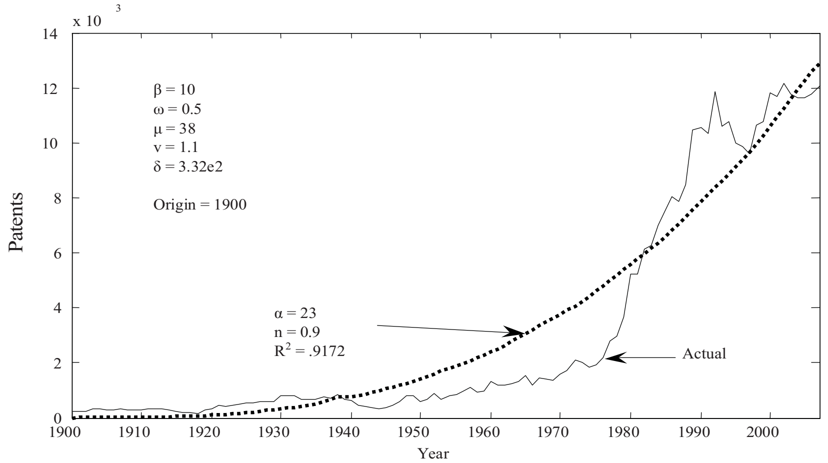

Figure A3.106. **Lead Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.49 Lithium Activity[60] and Patents[61]

Year	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**
1900			**1927**	5260	15	**1954**	93200	174	**1981**	90200	1025
1901			**1928**	5970	20	**1955**	86000	193	**1982**	83600	1230
1902			**1929**	3140	19	**1956**	105000	268	**1983**	93700	1332
1903			**1930**	3030	25	**1957**	111000	265	**1984**	108000	1335
1904			**1931**	679	50	**1958**	87800	288	**1985**	122000	1427
1905			**1932**	690	40	**1959**	62400	296	**1986**	132000	1496
1906			**1933**	738	50	**1960**	87100	427	**1987**	139000	1450
1907			**1934**	1200	42	**1961**	57200	392	**1988**	154000	1499
1908			**1935**	1540	55	**1962**	47300	401	**1989**	173000	1690
1909			**1936**	2060	34	**1963**	49500	372	**1990**	163000	1664
1910			**1937**	3280	32	**1964**	64000	418	**1991**	149000	1660
1911			**1938**	2510	43	**1965**	68500	507	**1992**	156000	1824
1912			**1939**	3060	51	**1966**	3450	407	**1993**	127000	1761
1913			**1940**	3440	56	**1967**	7590	482	**1994**	128000	1954
1914			**1941**	4400	36	**1968**	63700	469	**1995**	177000	2078
1915			**1942**	6990	17	**1969**	68000	459	**1996**	214000	2196
1916			**1943**	9180	19	**1970**	73100	553	**1997**	213000	2504
1917			**1944**	15600	20	**1971**	73400	524	**1998**	178000	3181
1918			**1945**	2830	28	**1972**	19700	605	**1999**	188000	3389
1919			**1946**	4540	43	**1973**	79300	521	**2000**	204000	4013
1920			**1947**	5350	69	**1974**	113000	525	**2001**	210000	4197
1921			**1948**	4540	99	**1975**	122000	570	**2002**	219000	4578
1922			**1949**	6270	77	**1976**	75000	655	**2003**	252000	4450
1923			**1950**	18000	92	**1977**	74300	611	**2004**	262000	4468
1924			**1951**	25200	94	**1978**	81900	687	**2005**	345000	4514
1925	3730	13	**1952**	25500	158	**1979**	76000	580	**2006**	395000	4987
1926	4530	17	**1953**	57800	155	**1980**	92800	945	**2007**	388000	5149

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[60] Activity represents world production of lithium, defined at usgs.gov as "…data are in gross tons of lithium minerals and brine. Since 1967, lithium production was reported as ore and ore concentrates from mines and lithium carbonate from brine deposits. World production data for the years 1966–67 do not include data 4 from Rhodesia (Zimbabwe) and some other African countries. Zimbabwe was by far the largest producer at the time. After 1954, world production does not include U.S. production. Data were not available for the years 1900–24." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[61] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Lithium or Li were used as keywords found in the patent title or abstract by year of publication.

Table A3.50. Correlation Eq.(A1.1) terms calculated from Table A3.49 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**100r^2**
7236797	85114	1.29E+12	2.43E+08	1.69E+10	6.635E+11	1.56E+08	9.43E+09	**0.927197**	**85.96949**

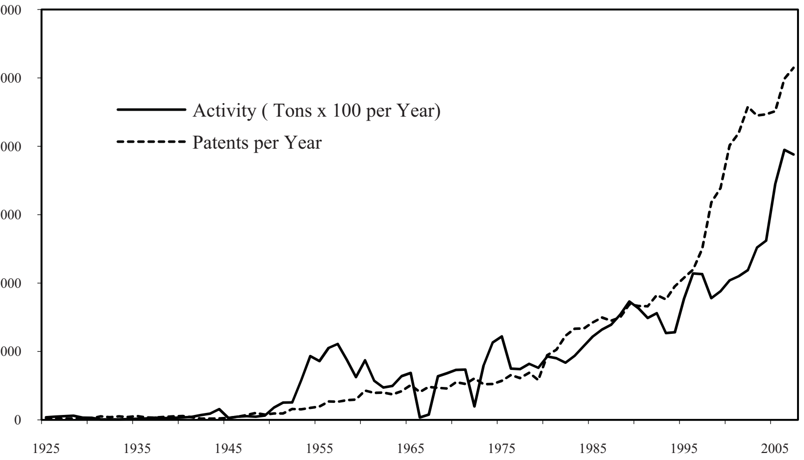

Figure A3.107. Lithium Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

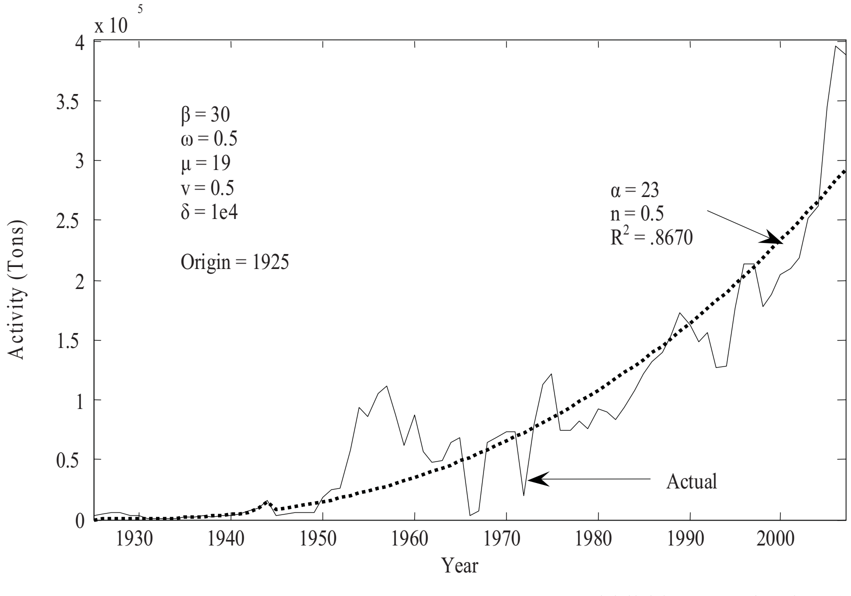

Figure A3.108. USGS World Lithium Production. World lithium production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

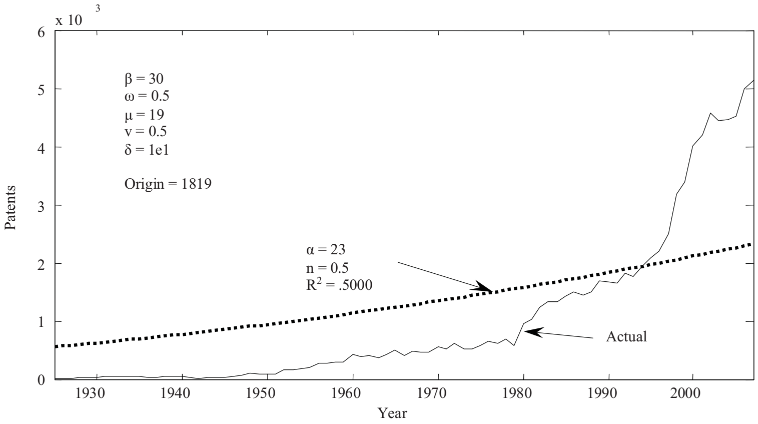

Figure A3.109. EPO Worldwide Patent Search: Lithium or Li in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

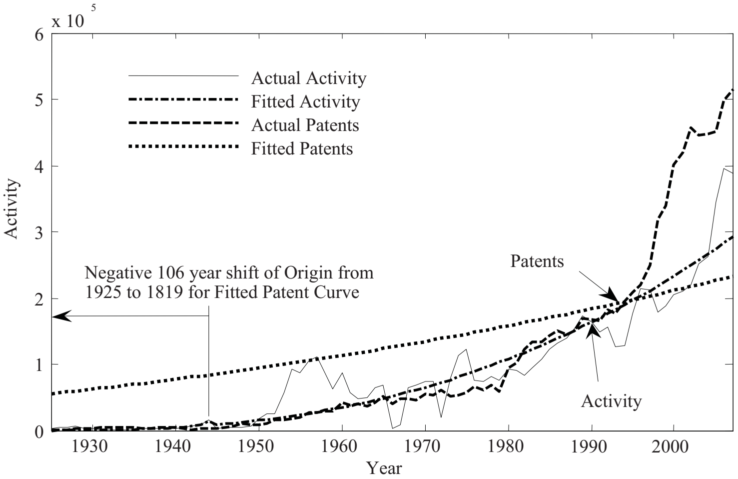

Figure A3.110. Lithium Best-Fit Activity and Patents. Illustrates best-fit origin shift.

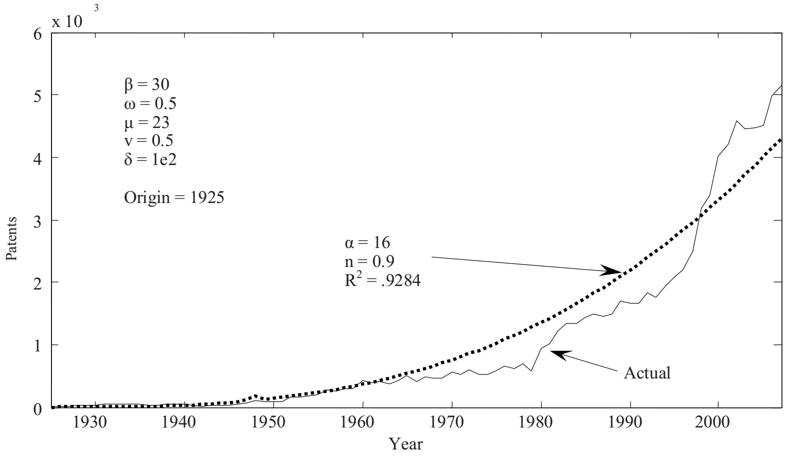

Figure A3.111. Lithium Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.51 Magnesite[62] Activity[63] and Patents[64]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y
1900			**1927**	833000	29	**1954**	1650000	86	**1981**	11300000	86
1901			**1928**	827000	31	**1955**	1930000	85	**1982**	11400000	80
1902			**1929**	1060000	36	**1956**	2360000	112	**1983**	11300000	137
1903			**1930**	834000	59	**1957**	2470000	120	**1984**	11800000	100
1904			**1931**	691000	73	**1958**	2330000	122	**1985**	12200000	105
1905			**1932**	697000	59	**1959**	3740000	105	**1986**	12300000	140
1906			**1933**	883000	49	**1960**	6820000	123	**1987**	12000000	125
1907			**1934**	1160000	51	**1961**	7250000	79	**1988**	12000000	131
1908			**1935**	1440000	61	**1962**	7440000	84	**1989**	12000000	155
1909			**1936**	1590000	58	**1963**	8980000	81	**1990**	10500000	147
1910			**1937**	2000000	58	**1964**	9540000	93	**1991**	9790000	159
1911			**1938**	1700000	68	**1965**	10000000	109	**1992**	10200000	152
1912			**1939**	2000000	47	**1966**	10100000	67	**1993**	8280000	164
1913	556000	11	**1940**	2000000	52	**1967**	10200000	91	**1994**	9020000	151
1914	434000	9	**1941**	2000000	44	**1968**	10700000	62	**1995**	10600000	195
1915	307000	10	**1942**	2300000	36	**1969**	9630000	76	**1996**	11000000	159
1916	599000	8	**1943**	2400000	30	**1970**	8720000	87	**1997**	10100000	160
1917	753000	5	**1944**	2000000	21	**1971**	8970000	65	**1998**	11400000	200
1918	364000	6	**1945**	1200000	31	**1972**	8830000	86	**1999**	9830000	234
1919	284000	9	**1946**	1200000	41	**1973**	9070000	77	**2000**	12700000	227
1920	576000	16	**1947**	1600000	42	**1974**	9870000	86	**2001**	11100000	210
1921	384000	19	**1948**	2400000	62	**1975**	9640000	108	**2002**	14100000	190
1922	536000	25	**1949**	2700000	59	**1976**	9070000	115	**2003**	14100000	237
1923	514000	22	**1950**	1330000	59	**1977**	9960000	103	**2004**	16500000	233
1924	491000	20	**1951**	1650000	53	**1978**	10200000	96	**2005**	15100000	254
1925	716000	20	**1952**	1520000	70	**1979**	10900000	70	**2006**	15000000	216
1926	716000	29	**1953**	1780000	58	**1980**	11500000	105	**2007**	15200000	246

Table A3.52. Correlation Eq.(A1.1) terms calculated from Table A3.51 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	100r^2
581715000	8632	5.91E+15	1160874	7.7E+10	2.353E+15	376543.2	2.41E+10	**0.81084**	**65.7462**

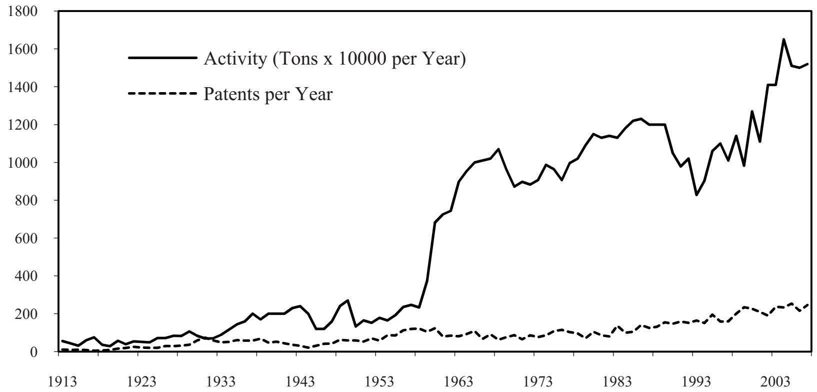

Figure A3.112. Magnesite Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[62] Magnesium carbonate.

[63] Activity represents world production of magnesite, defined at usgs.gov as "…metric tons gross weight of magnesite (magnesium carbonate) produced. Data were from the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]. Blank cells for the years 1900–12 in the worksheet indicate that data were not available." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[64] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Magnesium and carbonate were used as the keywords found in the patent title or abstract by year of publication.

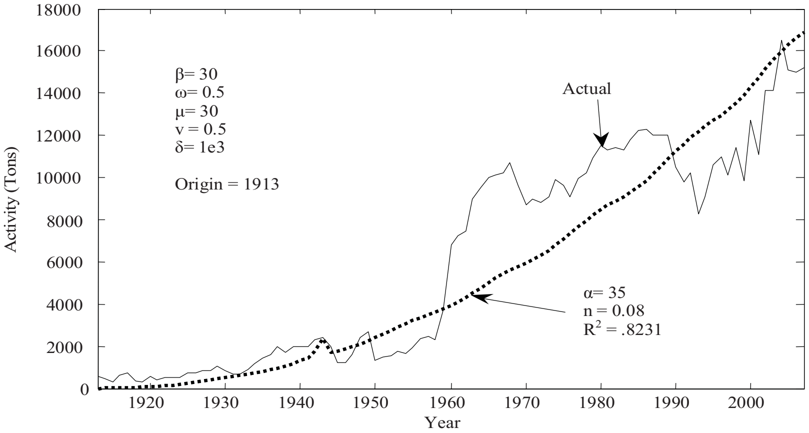

Figure A3.113. **USGS World Magnesite Production.** World magnesite production (activity) scaled in metric kilotons with actual and best-fit curves and common pattern equation parameters.

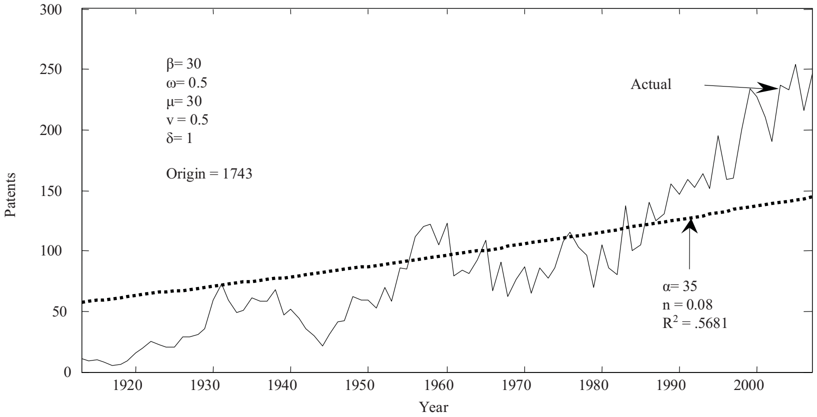

Figure A3.114. EPO Worldwide Patent Search: Magnesium and Carbonate in title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

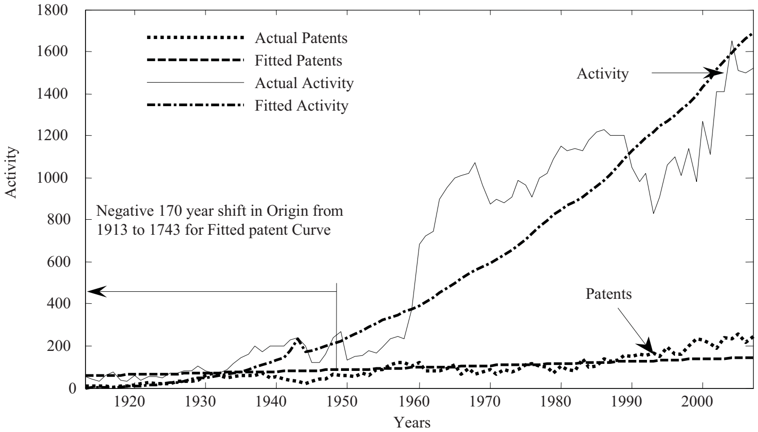

Figure A3.115. Magnesite Best-Fit Activity and Patents. Illustrates best-fit origin shift.

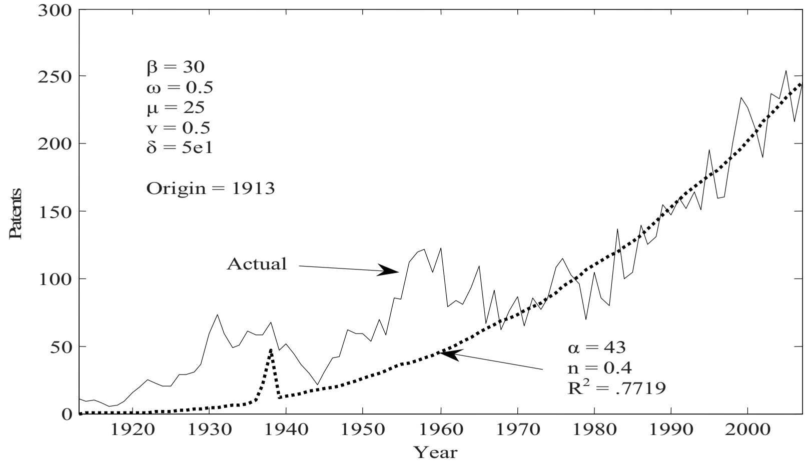

Figure A3.116. Magnesite Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.53 Magnesium Activity[65] and Patents[66]

Year	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**
1900			**1927**			**1954**	119000	524	**1981**	308000	2253
1901			**1928**			**1955**	121000	602	**1982**	254000	2491
1902			**1929**			**1956**	103000	697	**1983**	260000	2604
1903			**1930**			**1957**	117000	728	**1984**	328000	2737
1904			**1931**			**1958**	71200	752	**1985**	325000	2881
1905			**1932**			**1959**	74700	731	**1986**	322000	3224
1906			**1933**			**1960**	92900	969	**1987**	324000	3142
1907			**1934**			**1961**	105000	859	**1988**	334000	3375
1908			**1935**			**1962**	134000	787	**1989**	344000	3832
1909			**1936**			**1963**	143000	858	**1990**	354000	3732
1910			**1937**	19600	431	**1964**	151000	947	**1991**	342000	3975
1911			**1938**	23900	529	**1965**	162000	1022	**1992**	295000	4133
1912			**1939**	29400	436	**1966**	163000	901	**1993**	269000	3901
1913			**1940**	37800	416	**1967**	185000	1090	**1994**	282000	4356
1914			**1941**	59800	365	**1968**	189000	1025	**1995**	395000	4331
1915			**1942**	105000	308	**1969**	198000	938	**1996**	378000	4300
1916			**1943**	238000	245	**1970**	220000	1107	**1997**	384000	4314
1917			**1944**	218000	232	**1971**	232000	1103	**1998**	396000	5485
1918			**1945**	62000	276	**1972**	234000	1324	**1999**	341000	6298
1919			**1946**	24000	253	**1973**	240000	1150	**2000**	422000	7313
1920			**1947**	32000	326	**1974**	130000	1009	**2001**	420000	6851
1921			**1948**	31000	450	**1975**	235000	1214	**2002**	432000	7207
1922			**1949**	34000	396	**1976**	249000	1319	**2003**	509000	7560
1923			**1950**	45600	330	**1977**	257000	1398	**2004**	595000	7770
1924			**1951**	82600	399	**1978**	288000	1780	**2005**	622000	7583
1925			**1952**	150000	514	**1979**	307000	1698	**2006**	689000	7695
1926			**1953**	153000	408	**1980**	316000	2339	**2007**	749000	7980

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[65] Activity represents world production of magnesium, defined at usgs.gov as "…primary magnesium produced. Data were from the MR [*Minerals Resources of the United States*] and the MYB [*Minerals Yearbook*]. Blank cells in the worksheet indicate that data were not available for the years 1915–36." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[66] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Magnesium or Mg were used as keywords found in the patent title or abstract by year of publication.

Table A3.54. Correlation Eq.(A1.1) terms calculated from Table A3.53 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
16855500	166508	5.84E+12	7.74E+08	6.36E+10	1.837E+12	3.84E+08	2.41E+10	**0.907816**	**82.41297**

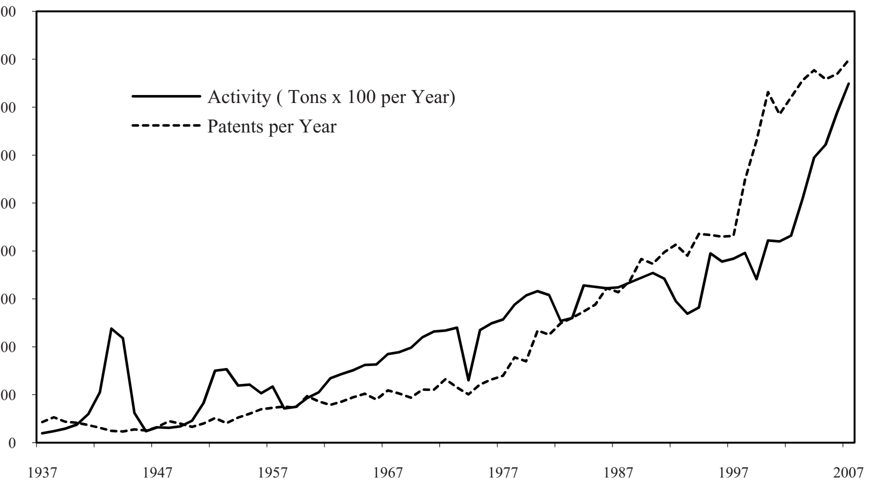

Figure A3.117. Magnesium Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

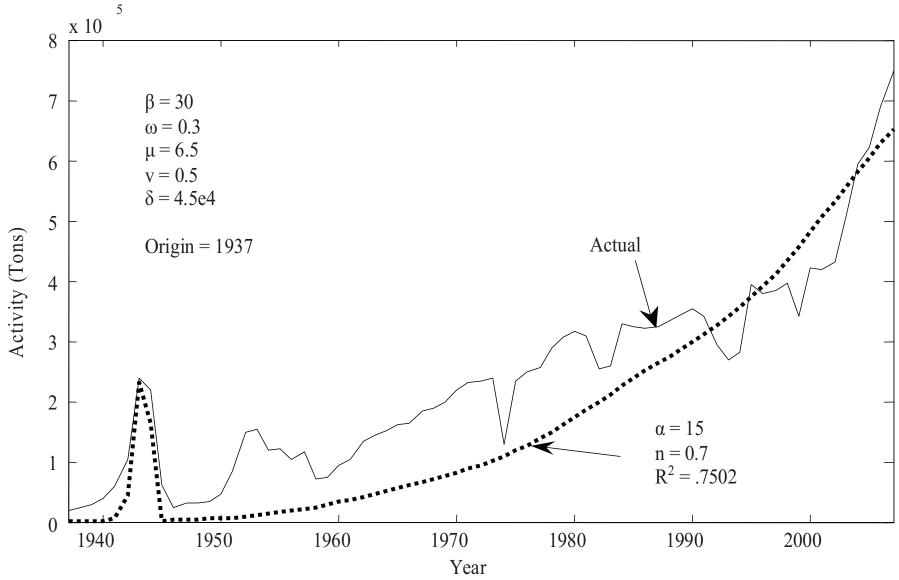

Figure A3.118. USGS World Magnesium Production. World magnesium production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

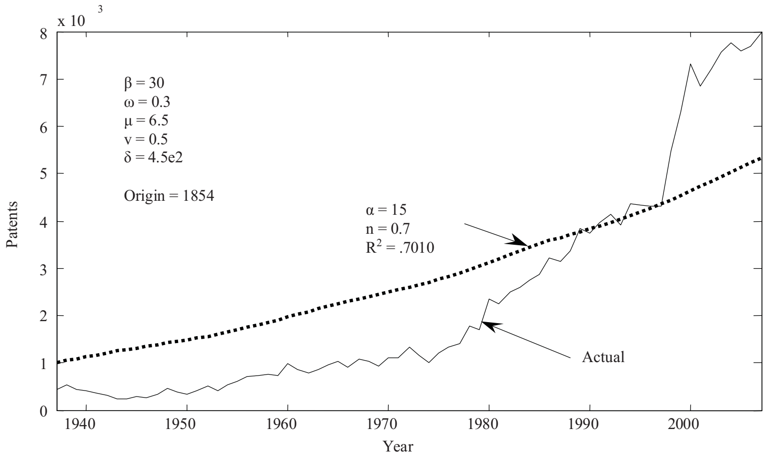

Figure A3.119. EPO Worldwide Patent Search: Magnesium or Mg in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

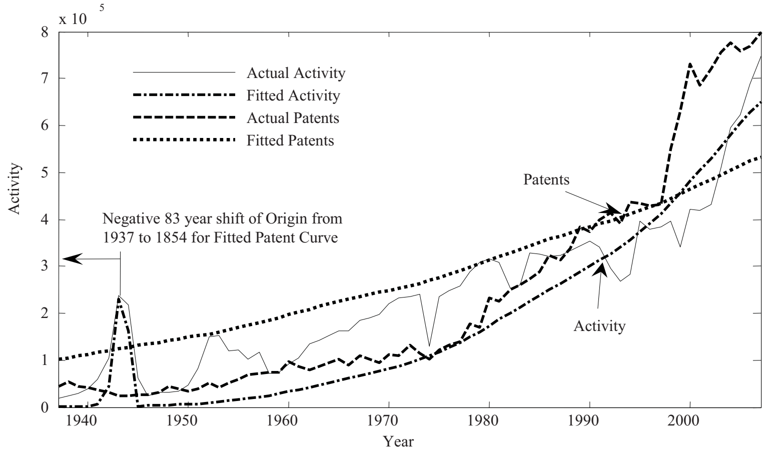

Figure A3.120. Magnesium Best-Fit Activity and Patents. Illustrates best-fit origin shift.

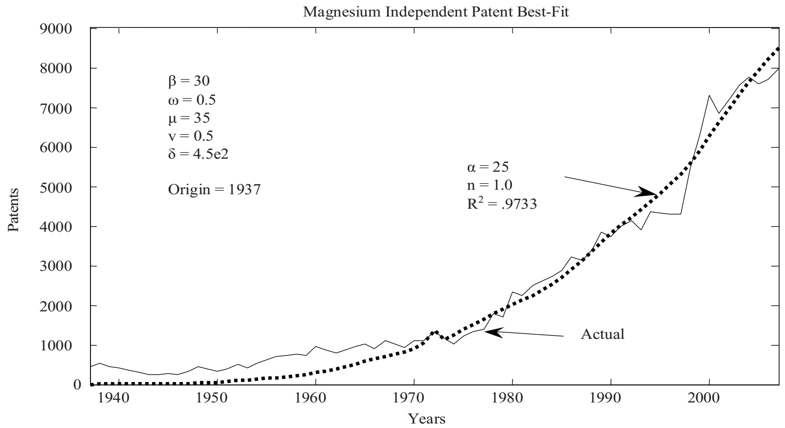

Figure A3.121. Magnesium Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.55 Manganese Activity[67] and Patents[68]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	592000	38	**1927**	1430000	116	**1954**	4500000	261	**1981**	8400000	2258
1901	429000	25	**1928**	1280000	156	**1955**	4870000	310	**1982**	8580000	2589
1902	441000	45	**1929**	1580000	200	**1956**	5310000	410	**1983**	7780000	2587
1903	411000	51	**1930**	1590000	199	**1957**	5820000	406	**1984**	8600000	2599
1904	416000	49	**1931**	982000	247	**1958**	5580000	341	**1985**	8690000	2851
1905	481000	30	**1932**	559000	225	**1959**	5830000	386	**1986**	8830000	3190
1906	868000	50	**1933**	779000	206	**1960**	6120000	549	**1987**	8340000	3161
1907	1080000	42	**1934**	1310000	212	**1961**	6110000	463	**1988**	8650000	3325
1908	641000	40	**1935**	1800000	243	**1962**	6400000	448	**1989**	9250000	3684
1909	811000	43	**1936**	2340000	211	**1963**	6630000	491	**1990**	9080000	3774
1910	888000	45	**1937**	2740000	252	**1964**	7240000	478	**1991**	7600000	3671
1911	719000	48	**1938**	2380000	270	**1965**	7980000	569	**1992**	7260000	4360
1912	856000	53	**1939**	1110000	239	**1966**	8150000	520	**1993**	7070000	4245
1913	1040000	58	**1940**	2540000	174	**1967**	7510000	649	**1994**	6530000	4308
1914	840000	56	**1941**	2450000	168	**1968**	7800000	558	**1995**	7970000	4425
1915	636000	41	**1942**	2290000	114	**1969**	8420000	517	**1996**	8180000	4390
1916	850000	24	**1943**	1800000	112	**1970**	8200000	608	**1997**	7520000	4454
1917	864000	18	**1944**	1270000	102	**1971**	9070000	656	**1998**	7330000	4862
1918	934000	28	**1945**	1900000	107	**1972**	9080000	804	**1999**	6390000	4836
1919	550000	56	**1946**	1650000	162	**1973**	9740000	739	**2000**	6960000	5767
1920	754000	65	**1947**	1750000	163	**1974**	9270000	697	**2001**	7580000	5658
1921	523000	90	**1948**	1830000	223	**1975**	9810000	783	**2002**	7800000	6277
1922	535000	87	**1949**	2160000	229	**1976**	10000000	893	**2003**	8790000	5973
1923	731000	94	**1950**	2530000	161	**1977**	8690000	1006	**2004**	9900000	6080
1924	919000	99	**1951**	3180000	202	**1978**	8690000	1333	**2005**	11000000	5517
1925	1170000	98	**1952**	4440000	284	**1979**	9800000	1411	**2006**	12200000	5514
1926	1370000	83	**1953**	4940000	194	**1980**	9670000	2051	**2007**	12600000	6018

Table A3.56. Correlation Eq.(A1.1) terms calculated from Table A3.55 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	100r^2
510129000	141337	3.8E+15	5.59E+08	1.16E+12	1.394E+15	3.74E+08	4.94E+11	**0.683516**	**46.71938**

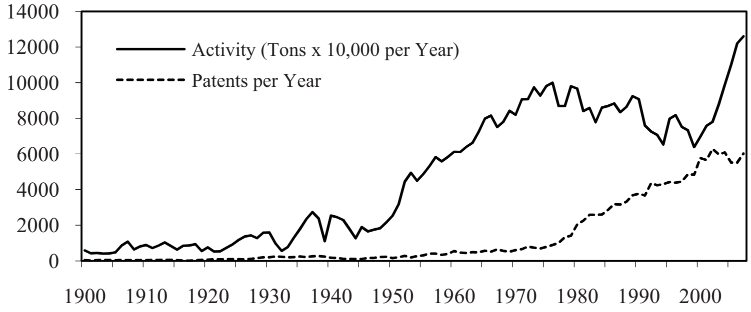

Figure A3.122. Manganese Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[67] Activity represents world production of manganese, defined at usgs.gov as "…contained manganese of world manganese mine production. For the period 1900–50, the reported values were calculated by multiplying gross weight (adjusted to metric tons) reported in Materials Survey—Manganese (U.S. Bureau of Mines and U.S. Geological Survey, 1952) by 0.45 (45 percent). The 45-percent-content estimate was used for consistency with what appears to have been used for the oldest years given in Mineral Facts and Problems. For the period 1951–63, the reported values were calculated by multiplying the gross weight (adjusted to metric tons) reported in MYB series by 0.45. For the period 1964–79, the reported values were taken directly from the values (adjusted to metric tons) reported in the MFP. For the years 1980 to the most recent, the reported values were taken directly from the values published in MYB world production table data series. In more recent years, the manganese content figure has been closer to 35 percent." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[68] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Manganese or Mn were used as keywords found in the patent title or abstract by year of publication.

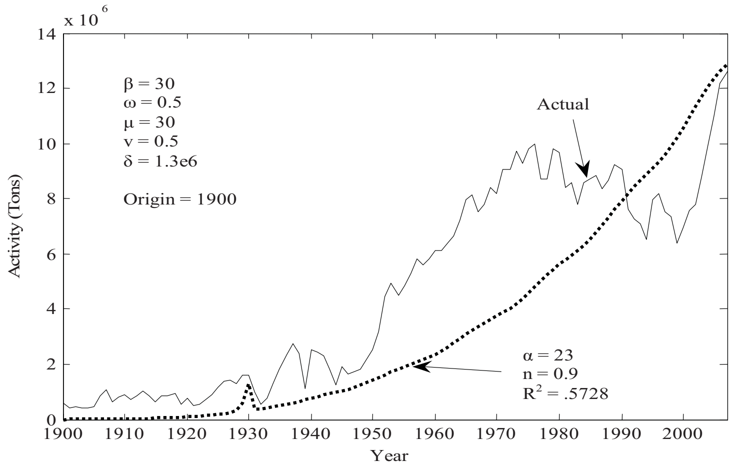

Figure A3.123. USGS World Manganese production. World manganese production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

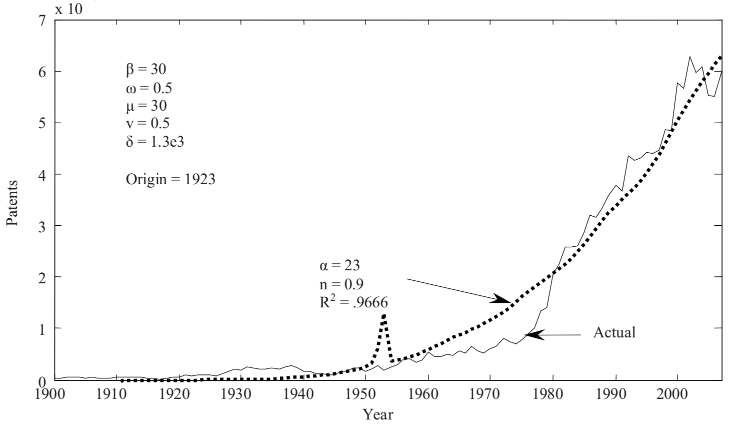

Figure A3.124. EPO Worldwide Patent Search: Manganese or Mn in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

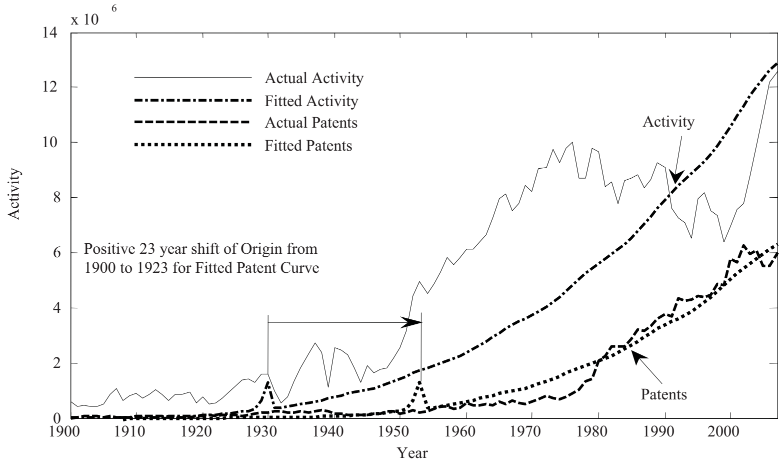

Figure A3.125. Manganese Best-Fit Activity and Patents. Illustrates best-fit origin shift.

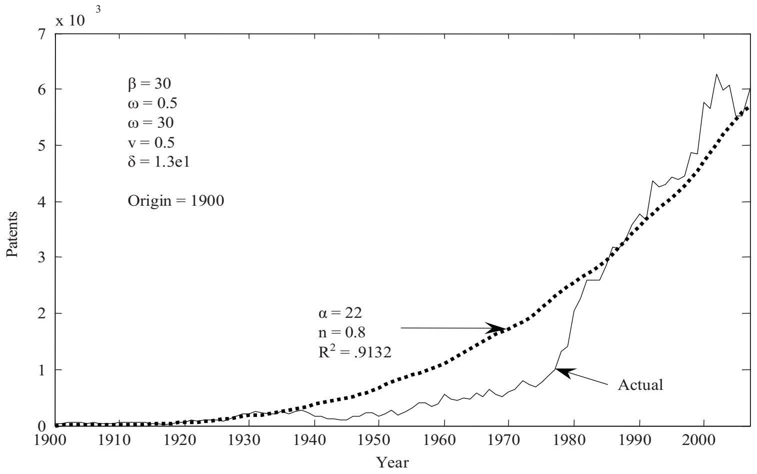

Figure A3.126. Manganese Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.57 Mercury Activity[69] and Patents[70]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y
1900	3150	82	**1927**	5170	216	**1954**	6180	277	**1981**	7270	757
1901	2960	80	**1928**	5140	212	**1955**	6380	310	**1982**	6820	896
1902	3800	61	**1929**	5610	256	**1956**	7620	350	**1983**	6230	919
1903	3640	104	**1930**	3760	333	**1957**	8260	342	**1984**	6740	921
1904	3350	140	**1931**	3420	396	**1958**	8490	285	**1985**	6140	1037
1905	3340	151	**1932**	2850	383	**1959**	7710	328	**1986**	7780	1020
1906	3860	147	**1933**	2060	349	**1960**	8340	429	**1987**	5530	890
1907	3310	118	**1934**	2650	371	**1961**	8260	380	**1988**	6840	904
1908	3300	125	**1935**	3460	366	**1962**	8430	364	**1989**	6750	953
1909	3230	112	**1936**	4270	343	**1963**	8260	401	**1990**	4100	893
1910	3690	129	**1937**	4590	362	**1964**	8800	445	**1991**	2540	894
1911	4250	137	**1938**	5170	463	**1965**	9230	458	**1992**	1960	942
1912	4160	136	**1939**	4830	299	**1966**	9140	439	**1993**	1730	922
1913	4050	142	**1940**	7130	280	**1967**	8000	516	**1994**	1960	911
1914	3740	110	**1941**	9170	194	**1968**	8950	502	**1995**	3190	880
1915	3890	100	**1942**	8990	165	**1969**	9970	447	**1996**	2560	797
1916	3500	67	**1943**	7870	138	**1970**	9790	505	**1997**	2410	887
1917	3970	51	**1944**	5330	108	**1971**	10400	475	**1998**	1580	1009
1918	3420	50	**1945**	4180	131	**1972**	9620	571	**1999**	1320	955
1919	3100	80	**1946**	4960	134	**1973**	9250	552	**2000**	1360	1000
1920	2910	118	**1947**	5360	184	**1974**	8880	526	**2001**	1500	901
1921	2130	140	**1948**	3260	276	**1975**	8700	554	**2002**	1490	1061
1922	3170	156	**1949**	4160	255	**1976**	8090	583	**2003**	1730	1068
1923	3210	161	**1950**	4940	192	**1977**	6580	590	**2004**	1900	1076
1924	3070	134	**1951**	5060	232	**1978**	6250	642	**2005**	1520	1111
1925	3560	202	**1952**	5190	296	**1979**	6010	554	**2006**	1150	1151
1926	4000	190	**1953**	5510	243	**1980**	6810	756	**2007**	1170	1157

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[69] Activity represents world production of mercury, defined at usgs.gov as "…from the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]. Mercury production data for the United States, primarily as a byproduct of gold, copper, and zinc mining, were withheld from world mine production data for the years 1993–97 and were not available for the years 1998 to the most recent." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[70] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Mercury or Hg were used as the keywords found in the patent title or abstract by year of publication.

Table A3.58. Correlation Eq.(A1.1) terms calculated from Table A3.51 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
545520	48893	3.43E+09	33904655	2.3702068E+08	672858667	11770160	-9943296	**-0.11173**	**1.248402059**

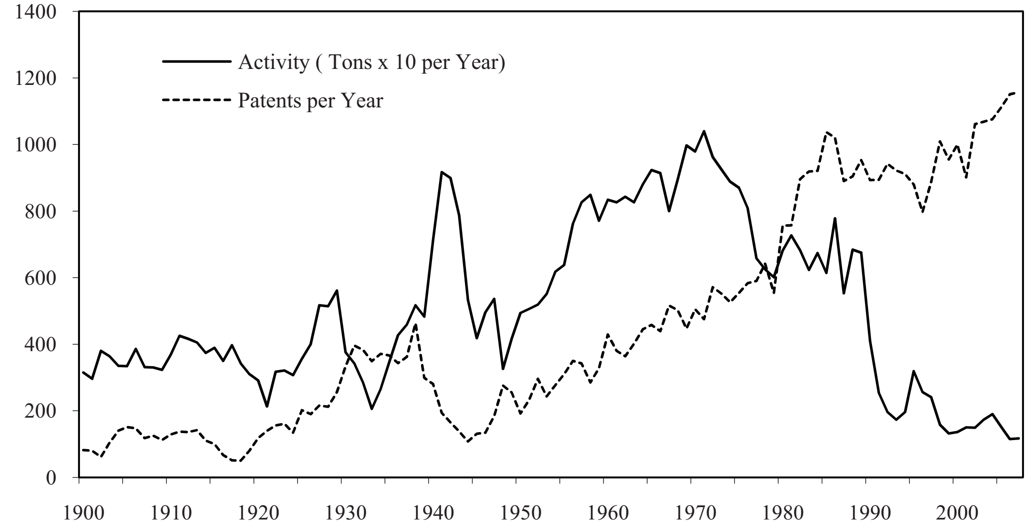

Figure A3.127. Mercury Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

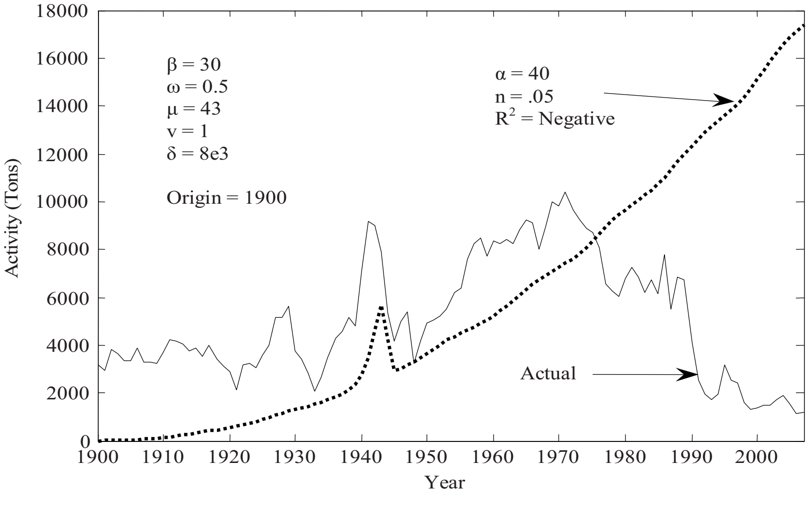

Figure A3.128. USGS World Mercury Production. World mercury production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters. Negative R^2 as well as non-linear α indicate possible Stage IV. No best-fit for the patent data was obtainable. Lack of correlation and Stage IV make meaningful activity best-fit impossible.

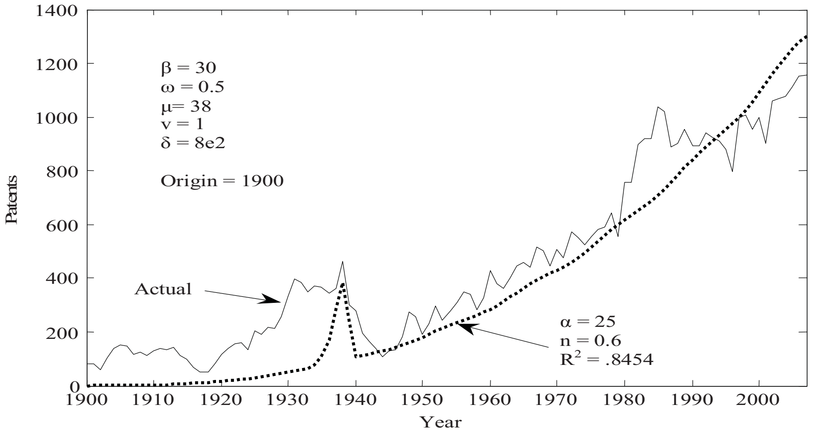

Figure A3.129. Mercury Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.59 Molybdenum Activity[71] and Patents[72]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y
1900	10	4	**1927**	1220	72	**1954**	29700	206	**1981**	109000	1675
1901	22	1	**1928**	1720	109	**1955**	34000	281	**1982**	95000	1978
1902	46	2	**1929**	2000	93	**1956**	31900	279	**1983**	63800	2046
1903	148	4	**1930**	1910	163	**1957**	34600	337	**1984**	97700	2039
1904	62	4	**1931**	1590	197	**1958**	26200	339	**1985**	98400	2330
1905	91	8	**1932**	1320	177	**1959**	32400	338	**1986**	93200	2483
1906	91	12	**1933**	2990	152	**1960**	40400	464	**1987**	99500	2574
1907	91	25	**1934**	5130	139	**1961**	33600	394	**1988**	113000	2454
1908	136	20	**1935**	6530	149	**1962**	26900	445	**1989**	136000	2786
1909	91	8	**1936**	9030	140	**1963**	34000	524	**1990**	127000	2631
1910	91	18	**1937**	14800	173	**1964**	35300	509	**1991**	115000	2496
1911	91	25	**1938**	16400	207	**1965**	44700	610	**1992**	114000	2764
1912	181	16	**1939**	15600	202	**1966**	56700	568	**1993**	99200	2734
1913	91	23	**1940**	17400	114	**1967**	64300	658	**1994**	108000	2898
1914	136	18	**1941**	20300	107	**1968**	65700	652	**1995**	136000	2897
1915	272	11	**1942**	29000	72	**1969**	72300	668	**1996**	127000	2757
1916	454	13	**1943**	31600	72	**1970**	82300	723	**1997**	138000	2683
1917	590	13	**1944**	21500	64	**1971**	77600	706	**1998**	135000	3019
1918	816	14	**1945**	16300	72	**1972**	79300	900	**1999**	129000	2983
1919	408	10	**1946**	10800	112	**1973**	81700	838	**2000**	135000	3541
1920	181	27	**1947**	14000	109	**1974**	84200	681	**2001**	133000	3430
1921	45	31	**1948**	13600	149	**1975**	81800	746	**2002**	122000	3892
1922	45	46	**1949**	11400	145	**1976**	88700	763	**2003**	131000	3748
1923	136	36	**1950**	14500	110	**1977**	95100	871	**2004**	159000	3939
1924	272	52	**1951**	20300	141	**1978**	100000	1043	**2005**	186000	3538
1925	680	75	**1952**	22600	205	**1979**	104000	1057	**2006**	184000	3410
1926	816	52	**1953**	28400	153	**1980**	111000	1588	**2007**	205000	3652

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[71] Activity represents world production of molybdenum, defined at usgs.gov as "…world mine production of ores and concentrates. For the years 1900–04, data are from Sutolov (1983, p.251-252)[*Sutolov, Alexander, ed., [1983], Statistical summary 1900-1982, in Internet molybdenum yearbook 1983, v. V of Internet molybdenum encyclopedia: Santiago, Chile, Alexander Sutolov Internet Publications, p. 248-297.*]. For the years 1905 to the most recent, data are from the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[72] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Molybdenum or Mo were used as the keywords found in the patent title or abstract by year of publication.

Table A3.60. Correlation Eq.(A1.1) terms calculated from Table A3.59 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	100r^2
5395233	98731	5.77E+11	2.45E+08	1.13E+10	3.078E+11	1.55E+08	6.42E+09	**0.928979**	**86.30013**

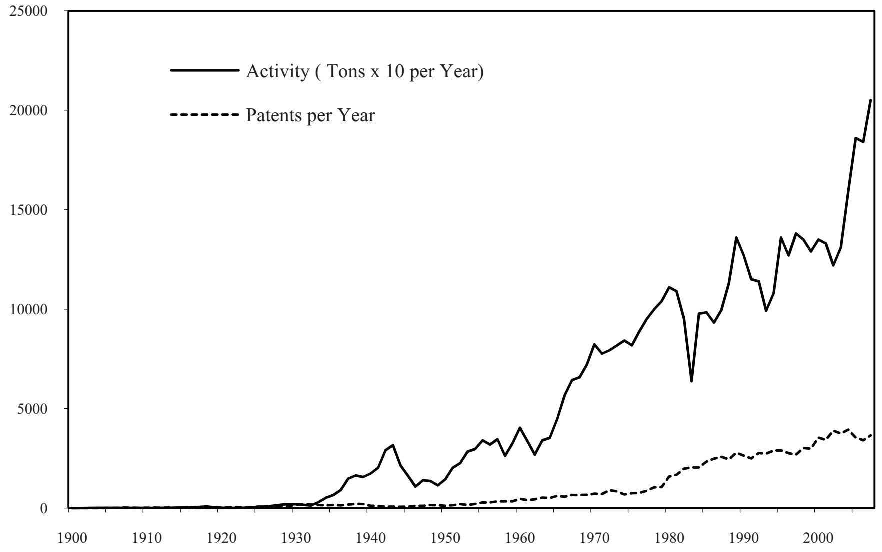

Figure A3.130. Molybdenum Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

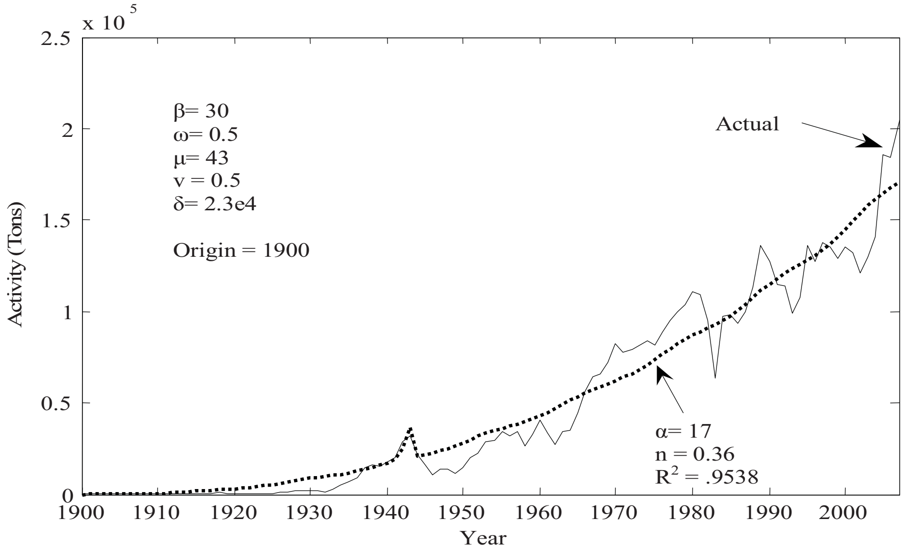

Figure A3.131. USGS World Molybdenum Production. World molybdenum production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

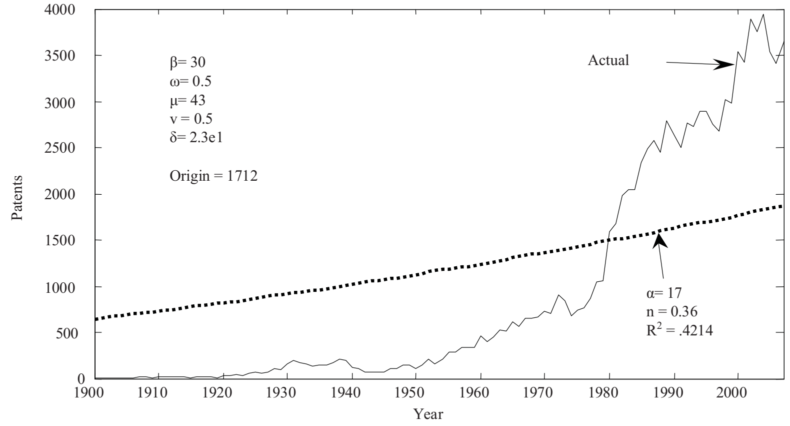

Figure A3.132. EPO Worldwide Patent Search: Molybdenum or Mo in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

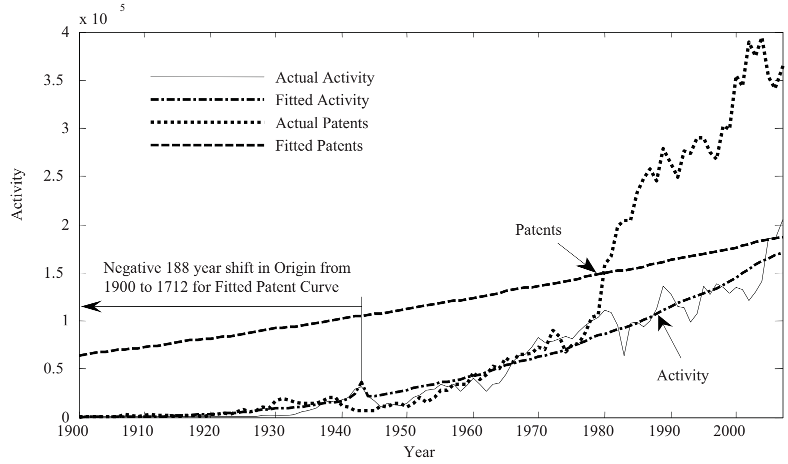

Figure A3.133. Molybdenum Best-Fit Activity and Patents. Illustrates best-fit origin shift.

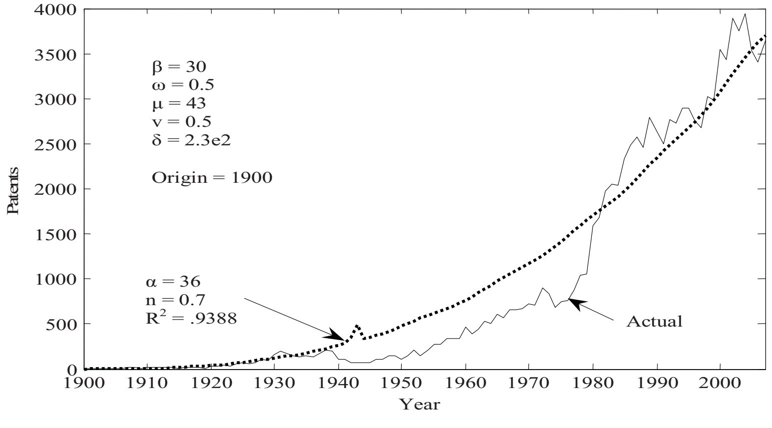

Figure A3.134. Molybdenum Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.61 Nickel Activity[73] and Patents[74]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	9290	37	**1927**	34500	248	**1954**	216000	566	**1981**	726000	3617
1901	11400	37	**1928**	50300	338	**1955**	239000	646	**1982**	621000	4294
1902	12200	48	**1929**	56300	353	**1956**	259000	744	**1983**	673000	4681
1903	10200	54	**1930**	54200	455	**1957**	286000	818	**1984**	773000	4916
1904	10500	56	**1931**	36300	533	**1958**	224000	776	**1985**	813000	5360
1905	15600	57	**1932**	21800	452	**1959**	285000	843	**1986**	852000	5639
1906	16000	54	**1933**	46300	402	**1960**	320000	1108	**1987**	891000	5552
1907	16300	68	**1934**	71600	388	**1961**	361000	1091	**1988**	952000	5850
1908	14900	76	**1935**	77400	441	**1962**	357000	1033	**1989**	987000	6489
1909	17000	79	**1936**	93400	399	**1963**	339000	1070	**1990**	974000	6108
1910	23100	73	**1937**	120000	434	**1964**	371000	1160	**1991**	1010000	5879
1911	25200	80	**1938**	115000	496	**1965**	425000	1394	**1992**	1010000	6657
1912	27900	68	**1939**	122000	438	**1966**	412000	1323	**1993**	928000	6006
1913	32200	98	**1940**	140000	359	**1967**	449000	1670	**1994**	932000	6218
1914	30000	83	**1941**	162000	290	**1968**	497000	1560	**1995**	1040000	5949
1915	39100	75	**1942**	158000	203	**1969**	487000	1591	**1996**	1060000	5906
1916	45500	48	**1943**	167000	207	**1970**	628000	1815	**1997**	1140000	5780
1917	46200	37	**1944**	157000	167	**1971**	637000	1841	**1998**	1180000	6605
1918	47600	53	**1945**	145000	214	**1972**	611000	2189	**1999**	1170000	6597
1919	23100	76	**1946**	123000	282	**1973**	710000	1986	**2000**	1290000	7656
1920	35700	111	**1947**	140000	290	**1974**	770000	1807	**2001**	1350000	7387
1921	10400	161	**1948**	151000	410	**1975**	802000	2057	**2002**	1350000	7636
1922	11800	142	**1949**	146000	437	**1976**	792000	2315	**2003**	1370000	7602
1923	31100	143	**1950**	145000	360	**1977**	828000	2402	**2004**	1420000	7542
1924	35300	130	**1951**	132000	410	**1978**	658000	2717	**2005**	1490000	6815
1925	37100	186	**1952**	146000	573	**1979**	686000	2657	**2006**	1580000	6717
1926	33900	179	**1953**	198000	454	**1980**	779000	3660	**2007**	1660000	7025

Table A3.62. Correlation Eq.(A1.1) terms calculated from Table A3.61 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
46347690	221664	4.19E+13	1.14E+09	2.13E+11	2.198E+13	6.86E+08	1.17E+11	**0.956269**	**91.44502**

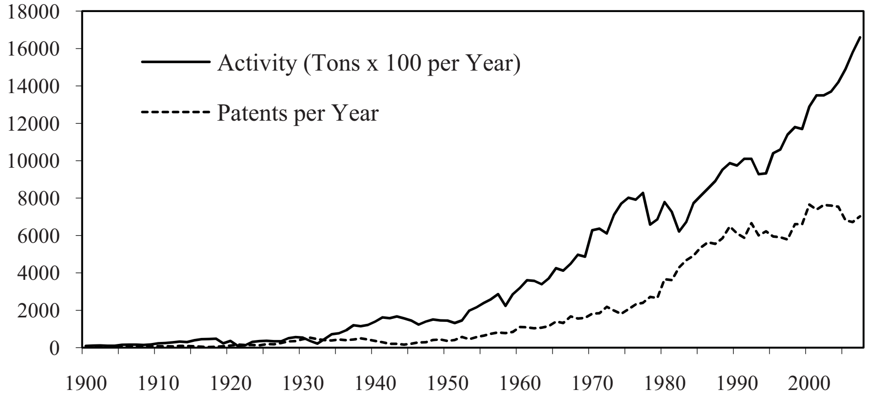

Figure A3.135. Nickel Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[73] Activity represents world production of nickel, defined at usgs.gov as "…mine production and is reported as recoverable nickel contained in the ore mined. Where actual mine output was not available, data related to a more highly processed form were used to indicate the minimum magnitude of mine output. In 1953, production data for countries once comprising the former Soviet Union were included for the first time. Data are sourced as follows: 1900–29, MS50 [*Materials Survey- Nickel 1950*]; and 1930 to the most recent year, MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[74] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Nickel or Ni were used as keywords found in the patent title or abstract by year of publication.

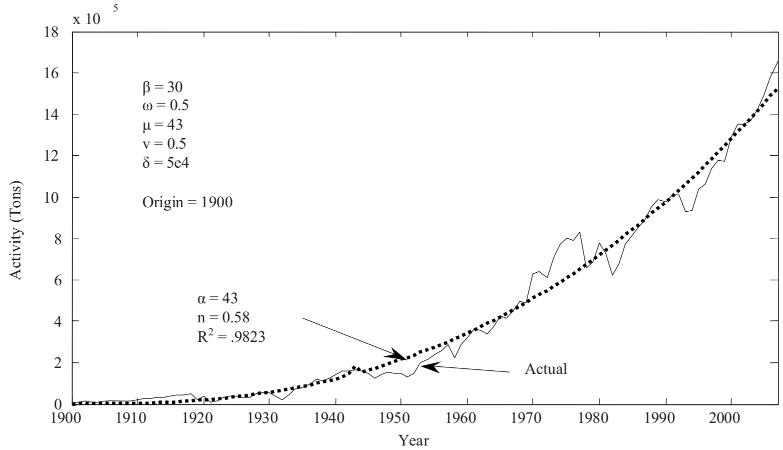

Figure A3.136. USGS World Nickel Production. World nickel production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

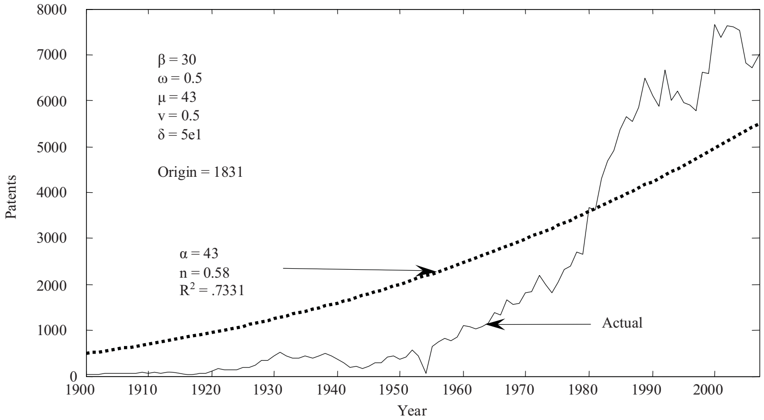

Figure A3.137. EPO Worldwide Patent search: Nickel or Ni in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

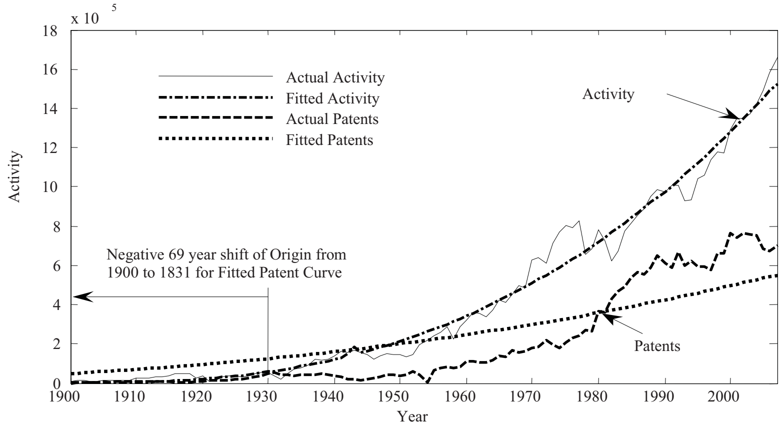

Figure A3.138. Nickel Best-Fit Activity and Patents. Illustrates best-fit origin shift.

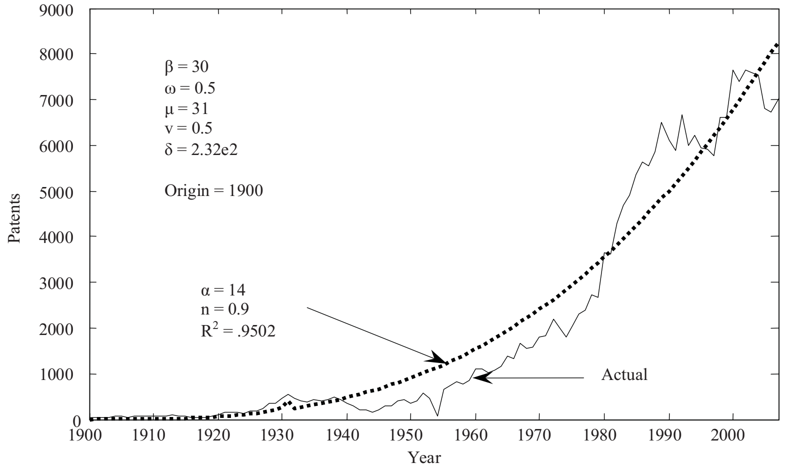

Figure A3.139. Nickel Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.63 Niobium Activity[75] and Patents[76]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**			**1981**	14800	671
1901			**1928**			**1955**			**1982**	10600	873
1902			**1929**			**1956**			**1983**	8580	1034
1903			**1930**			**1957**			**1984**	13900	993
1904			**1931**			**1958**			**1985**	14800	1107
1905			**1932**			**1959**			**1986**	14600	1282
1906			**1933**			**1960**			**1987**	9360	1325
1907			**1934**			**1961**			**1988**	16900	1453
1908			**1935**			**1962**			**1989**	14100	1591
1909			**1936**			**1963**			**1990**	15300	1567
1910			**1937**			**1964**	2480	181	**1991**	15700	1484
1911			**1938**			**1965**	3120	282	**1992**	15300	1828
1912			**1939**			**1966**	5060	275	**1993**	12400	1905
1913			**1940**			**1967**	5150	296	**1994**	15700	1934
1914			**1941**			**1968**	4950	270	**1995**	15600	1819
1915			**1942**			**1969**	6610	302	**1996**	16200	1711
1916			**1943**			**1970**	8460	314	**1997**	20500	1656
1917			**1944**			**1971**	3740	342	**1998**	26200	1797
1918			**1945**			**1972**	5950	380	**1999**	24600	1729
1919			**1946**			**1973**	14700	308	**2000**	24800	1981
1920			**1947**			**1974**	9340	292	**2001**	31100	1928
1921			**1948**			**1975**	7860	361	**2002**	33000	2423
1922			**1949**			**1976**	9470	335	**2003**	40400	2286
1923			**1950**			**1977**	8800	408	**2004**	41900	2385
1924			**1951**			**1978**	9670	445	**2005**	60300	2021
1925			**1952**			**1979**	14000	448	**2006**	51200	2095
1926			**1953**			**1980**	15100	645	**2007**	60400	2168

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[75] Activity represents world production of niobium, defined at usgs.gov as "…the niobium content of niobium-bearing ores and mineral concentrates that were produced from mines throughout the world. Data for the years 1964–68 were recorded from the MFP [*Mineral Facts and Problems*]and the MCP [*Mineral Commodity Summaries*], and for the years 1969 to the most recent were recorded from the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[76] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Niobium or Nb or Columbium were used as keywords found in the patent title or abstract by year of publication.

Table A3.64. Correlation Eq.(A1.1) terms calculated from Table A3.63 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
772700	50930	2.22E+10	82904308	1.24E+09	8.637E+09	23952833	3.43E+08	**0.754531**	**56.93172**

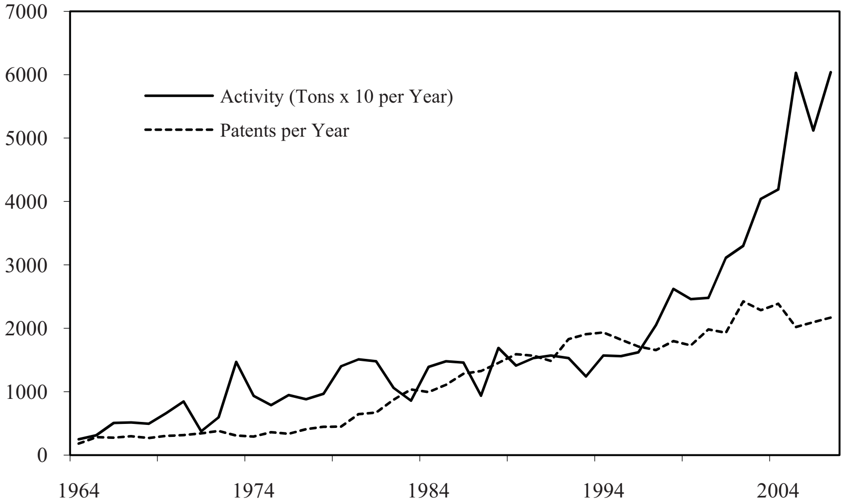

Figure A3.140. Niobium Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

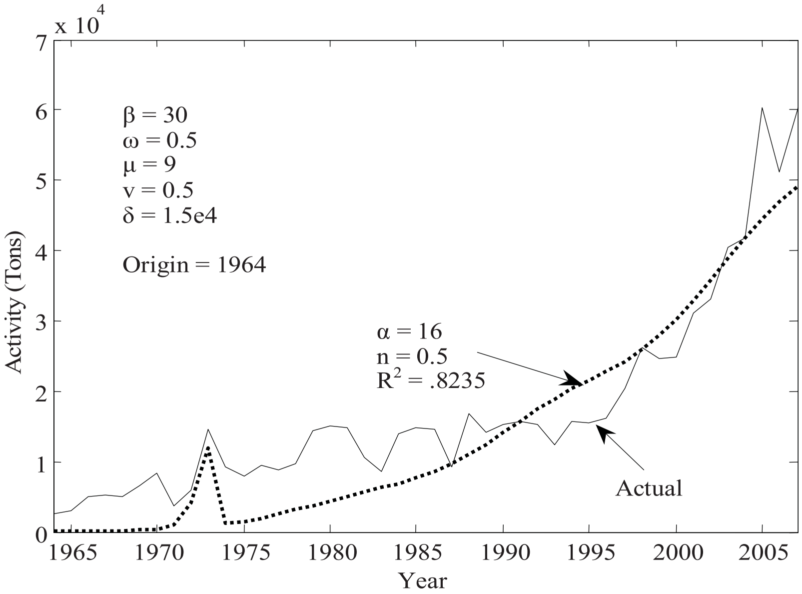

Figure A3.141. **USGS World Niobium Production.** World niobium production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

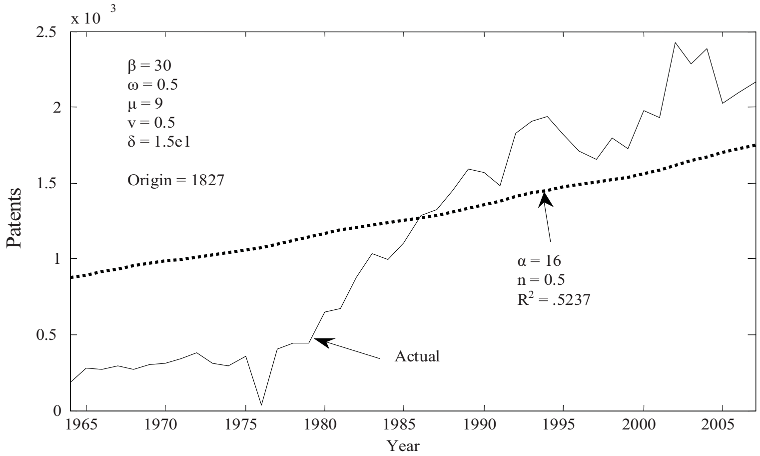

Figure A3.142. EPO Worldwide Patent Search: Niobium, Nb or Columbium in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

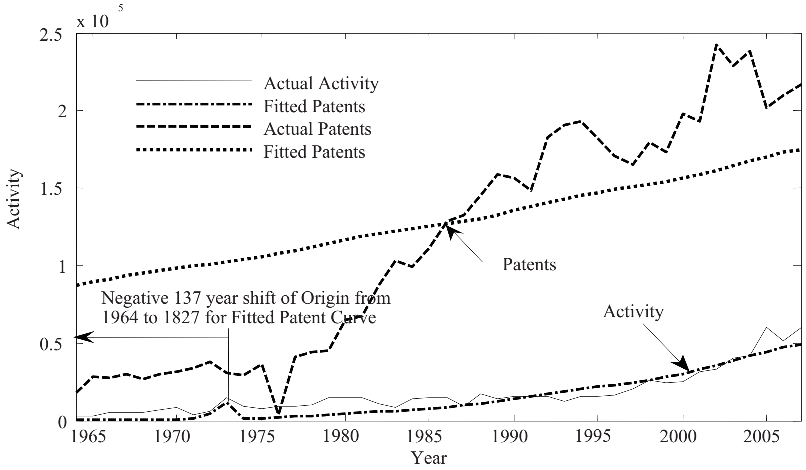

Figure A3.143. Niobium Best-Fit Activity and Patents. Illustrates best-fit origin shift.

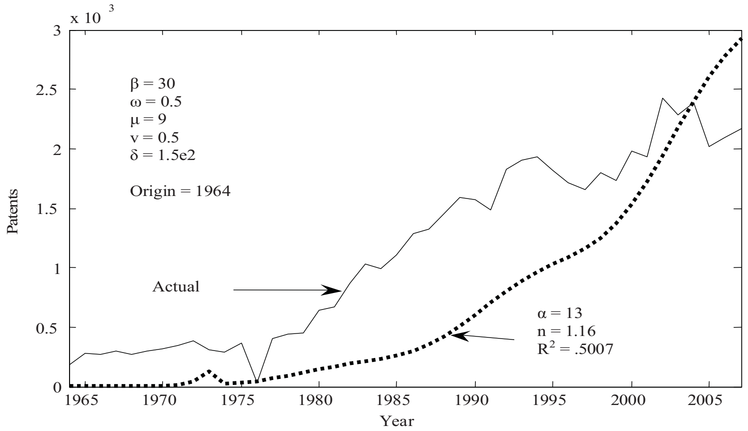

Figure A3.144. Niobium Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.65 Nitrogen Activity[77] and Patents[78]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y
1900			**1927**			**1954**	7300000	387	**1981**	77000000	2601
1901			**1928**			**1955**	8070000	486	**1982**	75900000	2702
1902			**1929**			**1956**	8620000	567	**1983**	80400000	2746
1903			**1930**			**1957**	9270000	668	**1984**	88600000	2868
1904			**1931**			**1958**	10800000	658	**1985**	91000000	3225
1905			**1932**			**1959**	11800000	651	**1986**	91100000	3718
1906			**1933**			**1960**	12900000	920	**1987**	95100000	3892
1907			**1934**			**1961**	14000000	878	**1988**	99300000	4634
1908			**1935**			**1962**	11900000	910	**1989**	99300000	5372
1909			**1936**			**1963**	17100000	968	**1990**	97500000	5299
1910			**1937**			**1964**	19400000	1077	**1991**	93800000	5314
1911			**1938**			**1965**	21800000	1202	**1992**	93400000	6091
1912			**1939**			**1966**	25000000	999	**1993**	91600000	5700
1913			**1940**			**1967**	28700000	1230	**1994**	93800000	6041
1914			**1941**			**1968**	32100000	1163	**1995**	100000000	6039
1915			**1942**			**1969**	35900000	1059	**1996**	105000000	5676
1916			**1943**			**1970**	38800000	1098	**1997**	103000000	5907
1917			**1944**			**1971**	41100000	1023	**1998**	104000000	6945
1918			**1945**			**1972**	43000000	1391	**1999**	107000000	7085
1919			**1946**	2380000	175	**1973**	46700000	1284	**2000**	108000000	8344
1920			**1947**	3330000	245	**1974**	48400000	1170	**2001**	105000000	8452
1921			**1948**	3950000	299	**1975**	49500000	1634	**2002**	109000000	8885
1922			**1949**	4560000	308	**1976**	56900000	1935	**2003**	110000000	8761
1923			**1950**	4810000	208	**1977**	62000000	2111	**2004**	117000000	9024
1924			**1951**	5240000	273	**1978**	67200000	2039	**2005**	123000000	7868
1925			**1952**	5300000	382	**1979**	71100000	1897	**2006**	126000000	7508
1926			**1953**	6450000	324	**1980**	73600000	2442	**2007**	131000000	7844

Table A3.66. Correlation Eq.(A1.1) terms calculated from Table A3.65 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
3.625E+09	192602	3.18E+17	1.09E+09	1.79E+13	1.063E+17	4.89E+08	6.61E+12	**0.916433**	**83.98487**

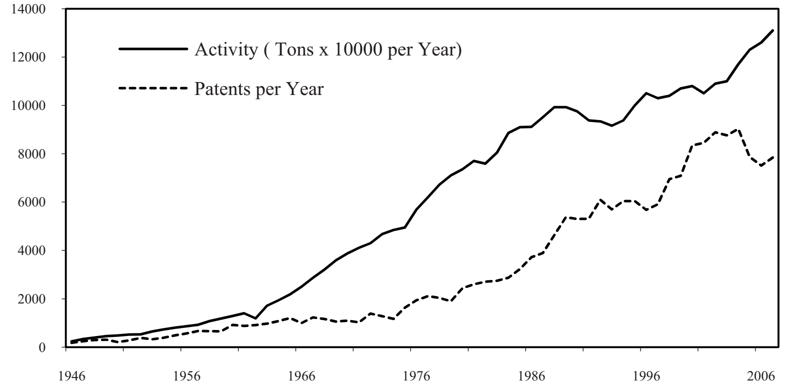

Figure A3.145. Nitrogen Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[77] Activity represents world production of nitrogen, defined at usgs.gov as "… ammonia produced. Data for 1946–57 were for "fertilizer nitrogen compounds," and were reported as fertilizer years (July 1–June 30), not calendar years. Blank cells in the worksheet indicate that data were not available for the years 1943–45. Data were from the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[78] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Nitrogen was used as the keyword found in the patent title or abstract by year of publication.

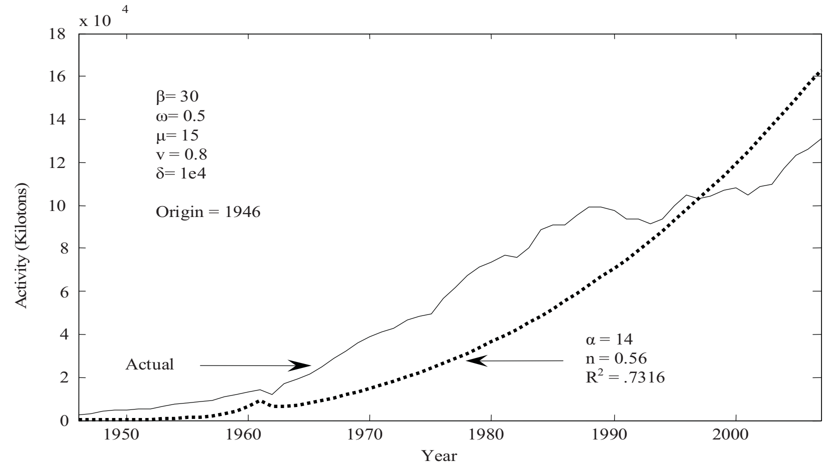

Figure A3.146. USGS World Nitrogen Production. World nitrogen production (activity) scaled in metric kilotons with actual and best-fit curves and common pattern equation parameters. No best-fit for the patent data was obtainable.

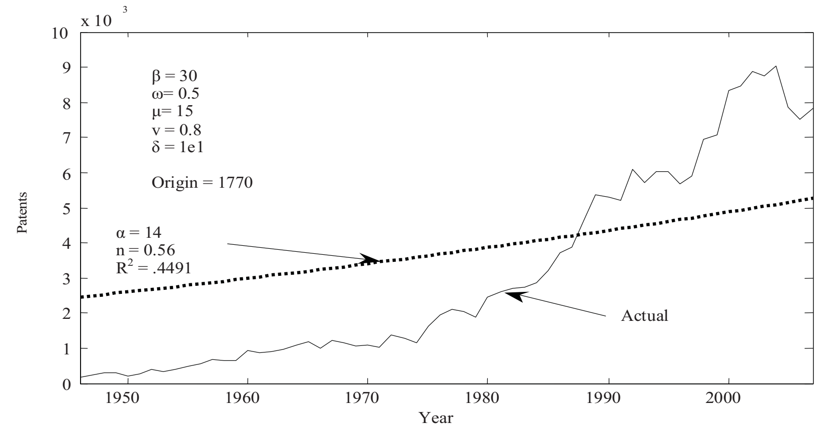

Figure A3.147. EPO Worldwide Patent Search: Nitrogen in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

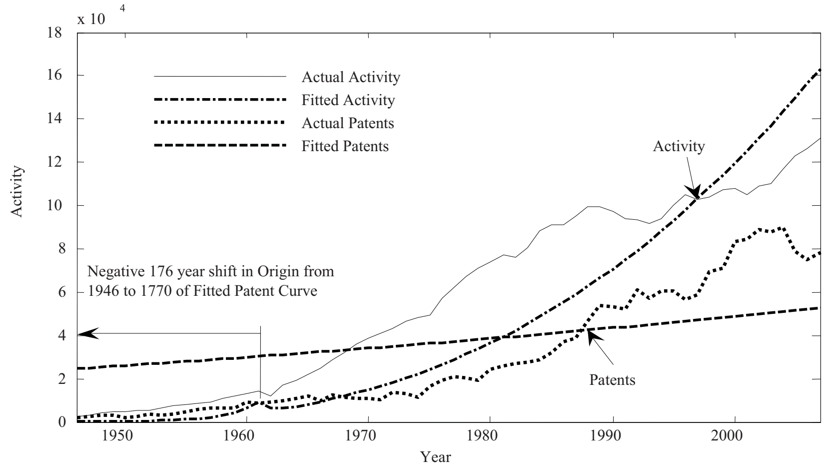

Figure A3.148. Nitrogen Best-Fit Activity and Patents. Illustrates best-fit origin shift.

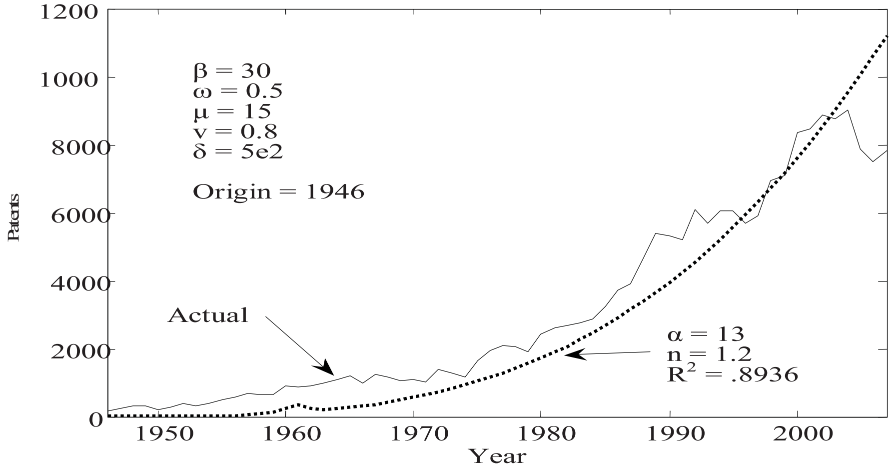

Figure A3.149. Nitrogen Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.67 Phosphate Rock[79] Activity[80] and Patents[81]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (pat)
1900	3150000	16	**1927**	9990000	78	**1954**	30500000	385	**1981**	145000000	1253
1901	3000000	13	**1928**	10100000	136	**1955**	30500000	424	**1982**	129000000	1370
1902	3120000	13	**1929**	10400000	147	**1956**	34200000	420	**1983**	143000000	1376
1903	3450000	19	**1930**	11800000	274	**1957**	33200000	534	**1984**	154000000	1411
1904	3870000	20	**1931**	7860000	318	**1958**	33700000	426	**1985**	151000000	1532
1905	3850000	19	**1932**	7110000	260	**1959**	38400000	531	**1986**	141000000	1639
1906	4190000	17	**1933**	8900000	214	**1960**	41800000	638	**1987**	147000000	1605
1907	4720000	17	**1934**	9510000	203	**1961**	45500000	558	**1988**	166000000	1614
1908	5380000	13	**1935**	10500000	227	**1962**	63300000	570	**1989**	163000000	1878
1909	4950000	24	**1936**	11300000	207	**1963**	54600000	597	**1990**	162000000	1932
1910	5430000	29	**1937**	12900000	219	**1964**	63700000	601	**1991**	150000000	1920
1911	5940000	28	**1938**	12900000	241	**1965**	71400000	701	**1992**	139000000	2170
1912	6730000	21	**1939**	12800000	202	**1966**	84500000	638	**1993**	119000000	1974
1913	7230000	22	**1940**	10300000	146	**1967**	87300000	811	**1994**	127000000	1931
1914	5420000	25	**1941**	10800000	147	**1968**	94100000	683	**1995**	130000000	2087
1915	4120000	21	**1942**	8800000	123	**1969**	92100000	688	**1996**	135000000	2085
1916	4830000	20	**1943**	9250000	114	**1970**	95100000	735	**1997**	143000000	2129
1917	4710000	13	**1944**	9330000	101	**1971**	94000000	765	**1998**	144000000	2565
1918	4190000	18	**1945**	10900000	171	**1972**	101000000	914	**1999**	137000000	2598
1919	4150000	29	**1946**	15300000	178	**1973**	111000000	747	**2000**	132000000	2922
1920	6870000	17	**1947**	18300000	206	**1974**	123000000	689	**2001**	126000000	2860
1921	5430000	54	**1948**	19400000	270	**1975**	109000000	818	**2002**	136000000	3156
1922	5940000	41	**1949**	19700000	232	**1976**	109000000	908	**2003**	138000000	3233
1923	7120000	45	**1950**	23400000	228	**1977**	121000000	960	**2004**	143000000	3386
1924	7780000	35	**1951**	24600000	281	**1978**	127000000	1078	**2005**	150000000	3028
1925	8900000	48	**1952**	26400000	327	**1979**	134000000	929	**2006**	151000000	3138
1926	9380000	68	**1953**	27200000	311	**1980**	147000000	1226	**2007**	156000000	3520

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[79] Phosphates or salts based formally on phosphorous oxoacids [128].

[80] Activity represents world production of phosphate, defined at usgs.gov as "…marketable phosphate rock. Data are from the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[81] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Phosphate was used as the keyword found in the patent title or abstract by year of publication.

Table A3.68. Correlation Eq.(A1.1) terms calculated from Table A3.67 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
6.541E+09	85552	7.7E+17	1.63E+08	1.04E+13	3.738E+17	95356234	5.2E+12	**0.870809**	**75.83086**

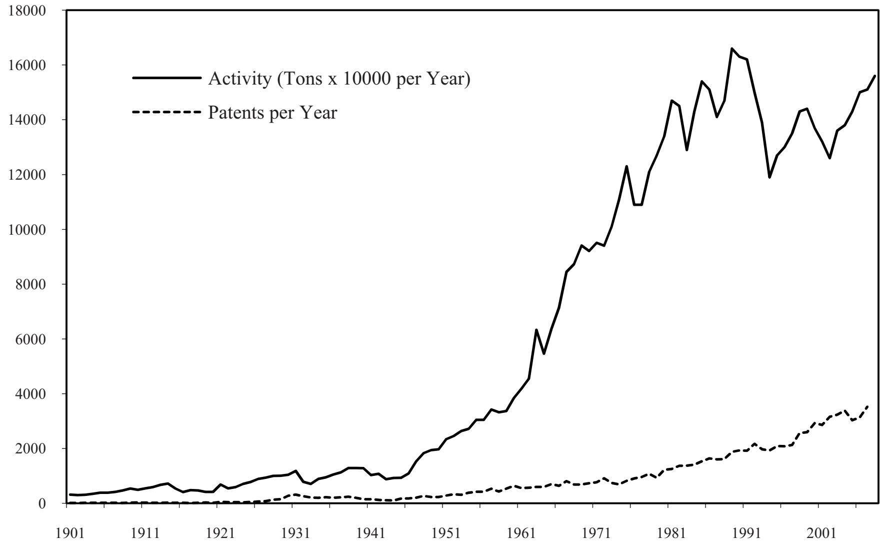

Figure A3.150. Phosphate Rock Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

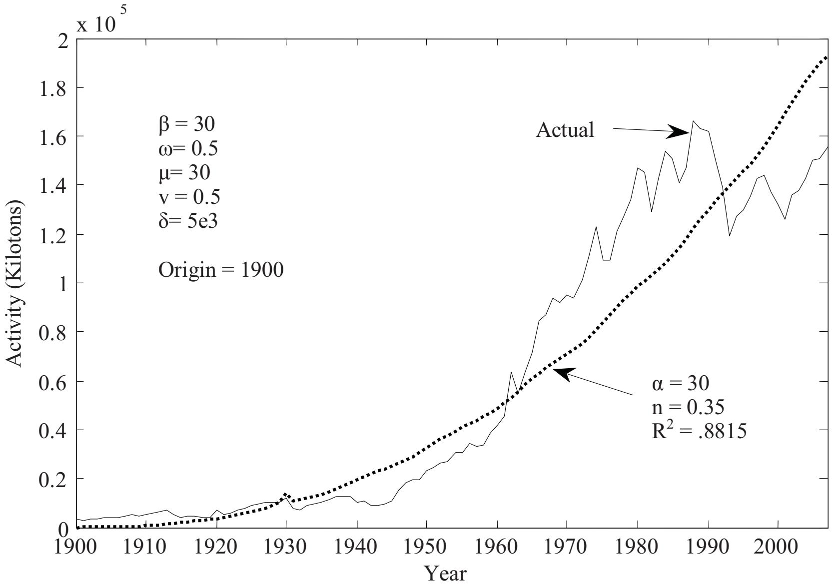

Figure A3.151. USGS World Phosphate Rock Production. World phosphate rock production (activity) scaled in metric kilotons with actual and best-fit curves and common pattern equation parameters.

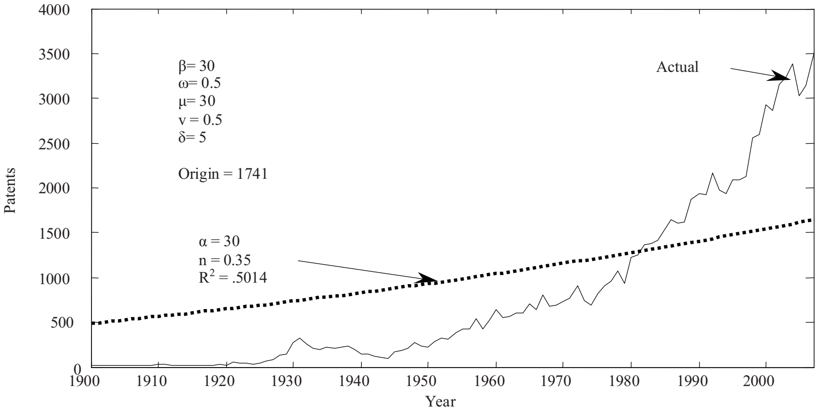

Figure A3.152. EPO Worldwide Patent Search: Phosphate in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

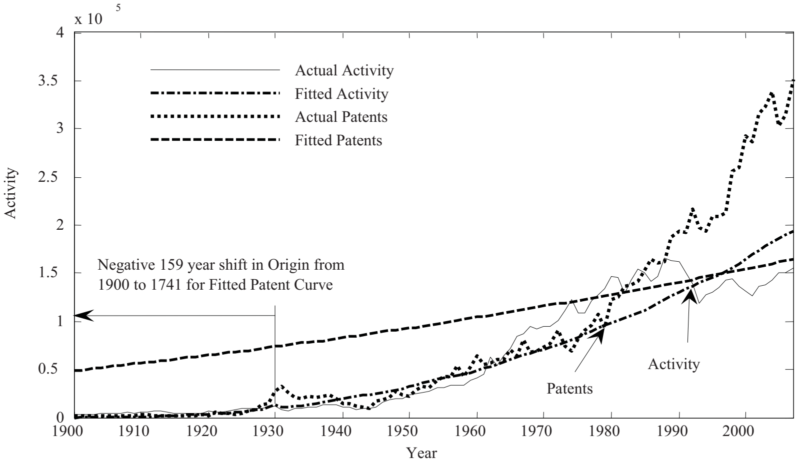

Figure A3.153. Phosphate Rock Best-fit Activity and Patents. Illustrates best-fit origin shift.

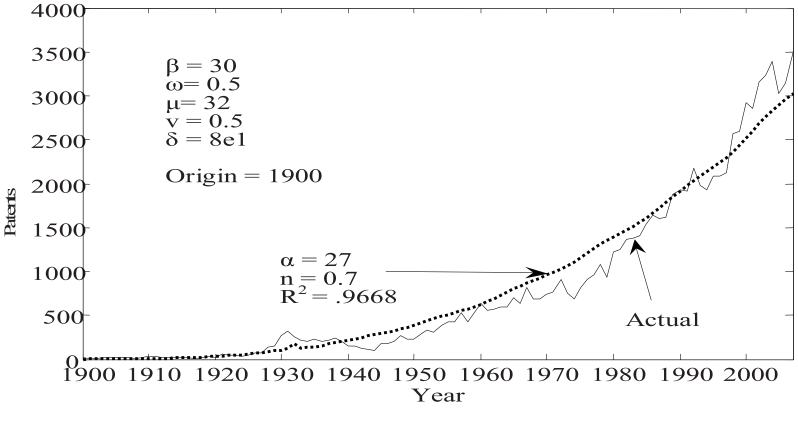

Figure A3.154. Phosphate Rock Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.69 Platinum Activity[82] and Patents[83]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	6.62	57	**1927**	4.64	59	**1954**	29.2	116	**1981**	216	1288
1901	9.85	58	**1928**	4.31	71	**1955**	33.9	177	**1982**	200	1417
1902	9.33	55	**1929**	4.84	75	**1956**	34.5	204	**1983**	203	1525
1903	7.03	53	**1930**	4.75	84	**1957**	41.1	215	**1984**	238	1567
1904	9.03	54	**1931**	8.94	71	**1958**	27.7	288	**1985**	247	1615
1905	6.24	79	**1932**	6.53	66	**1959**	32.8	263	**1986**	260	2088
1906	6.59	64	**1933**	6.77	55	**1960**	39.7	364	**1987**	271	1811
1907	9.65	61	**1934**	12.9	54	**1961**	41.8	312	**1988**	280	1955
1908	8	58	**1935**	12.1	88	**1962**	50.5	293	**1989**	282	2466
1909	8.45	38	**1936**	14.2	83	**1963**	63.4	306	**1990**	291	2727
1910	8.89	46	**1937**	14.8	88	**1964**	79.2	372	**1991**	287	2757
1911	9.74	50	**1938**	16.8	100	**1965**	92.3	422	**1992**	280	3055
1912	9.77	48	**1939**	16.9	81	**1966**	94.5	405	**1993**	276	2687
1913	8.31	58	**1940**	14.5	54	**1967**	98.8	550	**1994**	269	2714
1914	8.11	44	**1941**	14.9	60	**1968**	106	515	**1995**	326	2646
1915	4.45	44	**1942**	16.9	36	**1969**	107	507	**1996**	324	2869
1916	2.8	26	**1943**	19.6	38	**1970**	132	629	**1997**	339	2783
1917	2.59	20	**1944**	16	35	**1971**	127	648	**1998**	354	3092
1918	1.96	17	**1945**	30	31	**1972**	133	758	**1999**	366	3078
1919	2.11	32	**1946**	17.9	58	**1973**	163	688	**2000**	364	3345
1920	2.3	31	**1947**	15.6	69	**1974**	179	604	**2001**	395	3026
1921	1.84	36	**1948**	16.3	105	**1975**	178	664	**2002**	414	3159
1922	2.17	53	**1949**	17.9	81	**1976**	194	740	**2003**	466	3011
1923	2.56	42	**1950**	18.7	81	**1977**	203	710	**2004**	481	2999
1924	3.56	39	**1951**	21	96	**1978**	200	805	**2005**	504	2828
1925	3.23	55	**1952**	21.8	108	**1979**	202	855	**2006**	513	2993
1926	4.42	42	**1953**	24.1	91	**1980**	213	1206	**2007**	509	2925

Table A3.70. Correlation Eq.(A1.1) terms calculated from Table A3.69 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
12404.68	85220	3635945	1.92E+08	25696304	2211166.3	1.25E+08	15908093	**0.956927**	**91.57099**

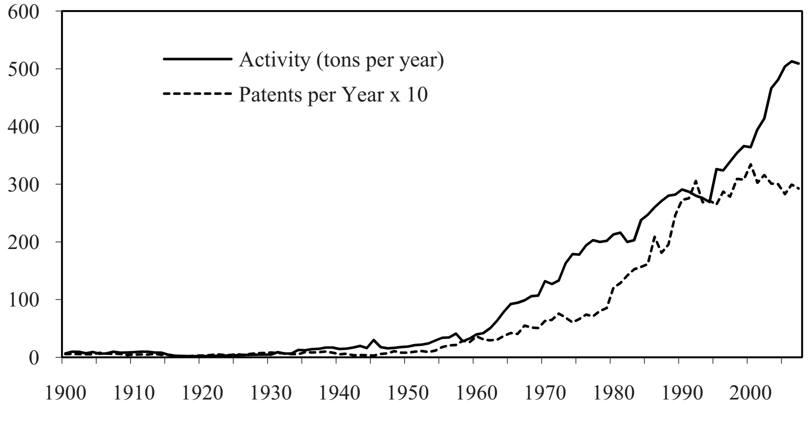

Figure A3.155. Platinum Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[82] Activity represents world production of platinum, defined at usgs.gov as "…recorded from the MR [*Mineral Resources of the United States*] and MYB [*Minerals Yearbook*] for the years 1900 to the most recent." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[83] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Platinum or Pt were used as keywords found in the patent title or abstract by year of publication.

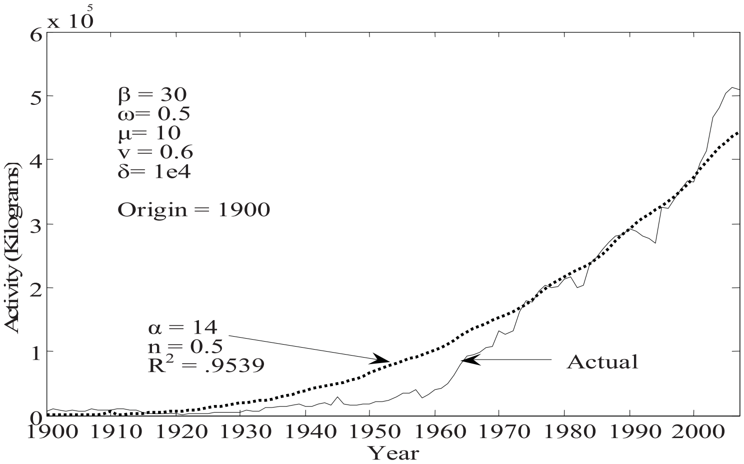

Figure A3.156. USGS World Platinum Production. World platinum production (activity) scaled to kilograms with actual and best-fit curves and common pattern equation parameters.

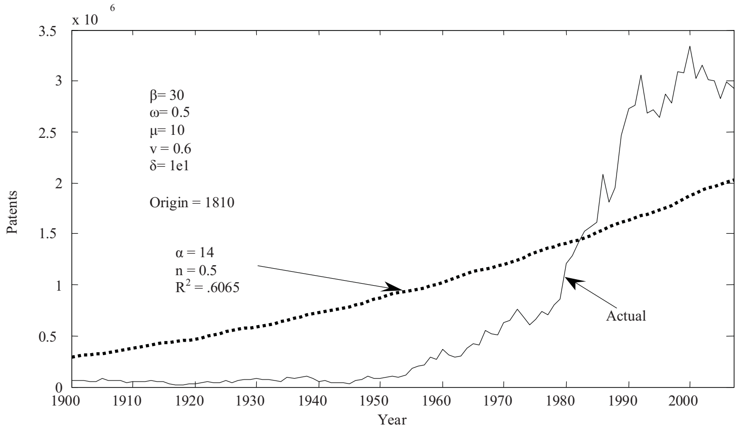

Figure A3.157. EPO Worldwide Patent Search: Platinum or Pt in Title or Abstract by date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

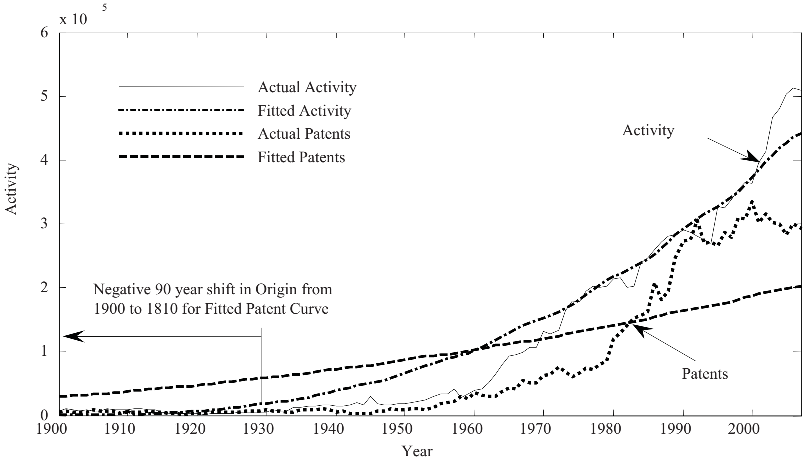

Figure A3.158. Platinum Best-fit Activity and Patents. Illustrates best-fit origin shift.

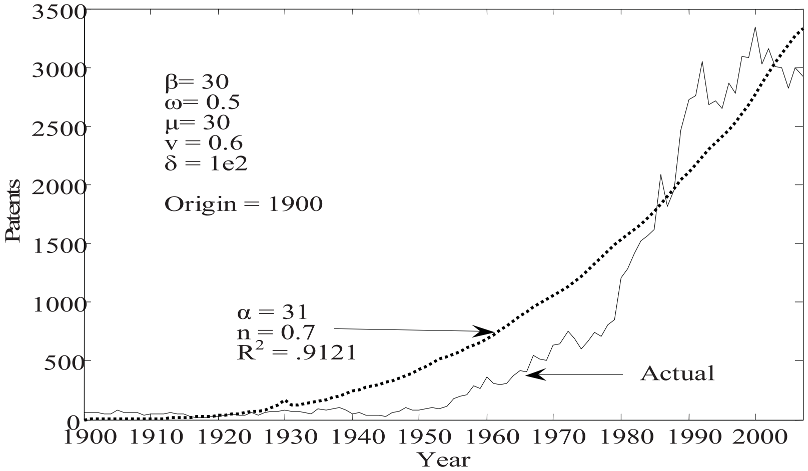

Figure A3.159. Platinum Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.71 Potash[84] Activity[85] and Patents[86]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**	2000000	55	**1954**	6620000	35	**1981**	27100000	37
1901			**1928**	2030000	87	**1955**	7260000	48	**1982**	24500000	56
1902			**1929**	2200000	103	**1956**	7530000	56	**1983**	27400000	54
1903			**1930**	2050000	98	**1957**	7890000	54	**1984**	29300000	43
1904			**1931**	1400000	122	**1958**	7980000	40	**1985**	29200000	45
1905			**1932**	1250000	89	**1959**	8530000	34	**1986**	28800000	69
1906			**1933**	1670000	86	**1960**	9070000	33	**1987**	30500000	42
1907			**1934**	1980000	80	**1961**	9710000	43	**1988**	31800000	32
1908			**1935**	2270000	94	**1962**	9800000	42	**1989**	29300000	22
1909			**1936**	2310000	70	**1963**	11300000	32	**1990**	27500000	27
1910			**1937**	2820000	79	**1964**	12300000	28	**1991**	26100000	44
1911			**1938**	3010000	85	**1965**	13700000	24	**1992**	23900000	40
1912			**1939**	2730000	53	**1966**	14600000	22	**1993**	20400000	32
1913			**1940**	2810000	41	**1967**	15700000	36	**1994**	23100000	25
1914			**1941**	3210000	31	**1968**	16200000	33	**1995**	24700000	33
1915			**1942**	3170000	24	**1969**	17400000	28	**1996**	23900000	40
1916			**1943**	3270000	18	**1970**	18200000	30	**1997**	25500000	32
1917			**1944**	3040000	28	**1971**	19900000	20	**1998**	26000000	59
1918			**1945**	1910000	18	**1972**	20000000	25	**1999**	27200000	41
1919	122000	30	**1946**	2310000	34	**1973**	18900000	19	**2000**	27000000	61
1920	224000	32	**1947**	2620000	36	**1974**	21100000	23	**2001**	26400000	48
1921	994000	53	**1948**	2940000	50	**1975**	24700000	19	**2002**	27100000	43
1922	1400000	52	**1949**	2540000	26	**1976**	24300000	15	**2003**	28600000	66
1923	1250000	31	**1950**	3130000	23	**1977**	25200000	18	**2004**	31100000	67
1924	1100000	30	**1951**	5080000	31	**1978**	26100000	20	**2005**	32500000	84
1925	1590000	70	**1952**	5620000	49	**1979**	25700000	12	**2006**	29100000	88
1926	1710000	45	**1953**	5900000	46	**1980**	27900000	46	**2007**	34600000	113

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[84] Potassium compounds [128].

[85] Activity represents world production of potash, defined at usgs.gov as "…recorded from the MR [*Mineral Resources of the United States*] and MYB [*Minerals Yearbook*] for the years 1900 to the most recent." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[86] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Potash was used as the keyword found in the patent title or abstract by year of publication.

Table A3.72. Correlation Eq.(A1.1) terms calculated from Table A3.71 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
1.254E+09	4077	2.89E+16	237793	5.4E+10	1.127E+16	51029.75	-3.4E+09	**-0.14144**	**2.000428**

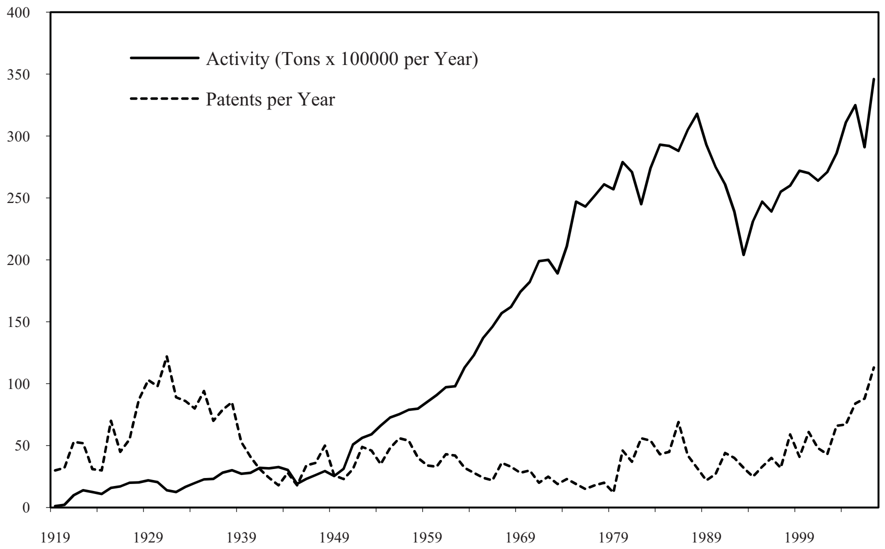

Figure A3.160. Potash Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

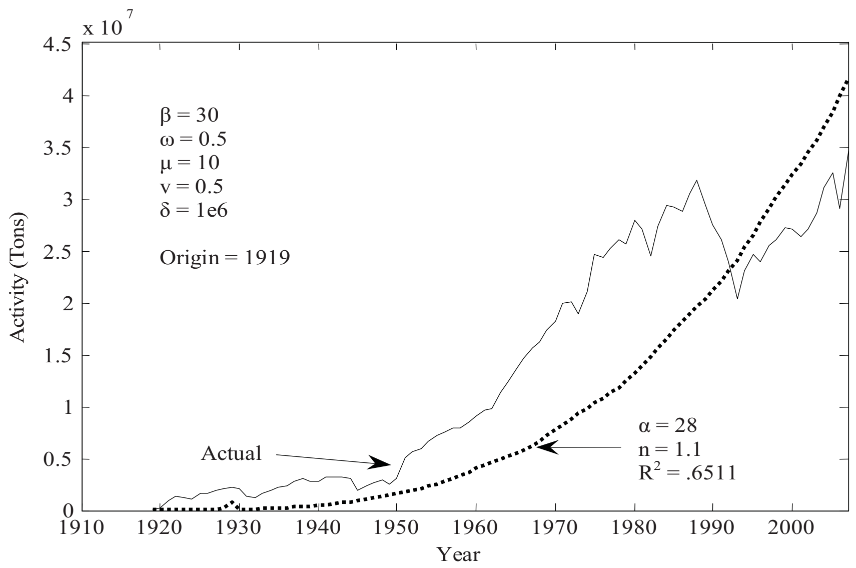

Figure A3.161. USGS World Potash production. World potash production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters. No best-fit for the patent data was obtainable.

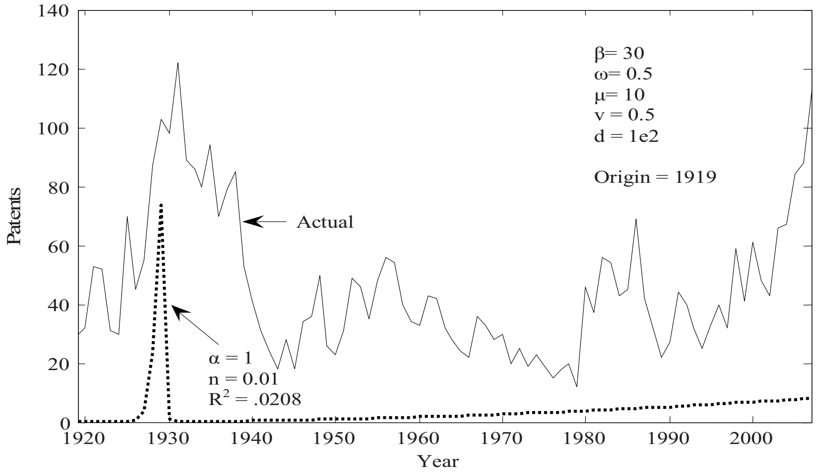

Figure A3.162. Potash Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.73 Rare Earths[87] Activity[88] and Patents[89]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	1040	3	**1927**	352	2	**1954**	7840	3	**1981**	30600	229
1901	1090	1	**1928**	180	4	**1955**	5760	7	**1982**	26600	229
1902	863	2	**1929**	197	3	**1956**	5230	6	**1983**	31400	204
1903	2030	1	**1930**	17	8	**1957**	5980	16	**1984**	41400	212
1904	2860	4	**1931**	50	1	**1958**	8060	8	**1985**	43500	223
1905	2780	0	**1932**	530	3	**1959**	2810	9	**1986**	39900	267
1906	2600	2	**1933**	302	8	**1960**	2270	30	**1987**	46900	328
1907	2580	3	**1934**	564	1	**1961**	3690	23	**1988**	55300	429
1908	2840	2	**1935**	2130	4	**1962**	8020	24	**1989**	60700	762
1909	3690	0	**1936**	1840	4	**1963**	6060	28	**1990**	52900	551
1910	3020	0	**1937**	2150	6	**1964**	3680	27	**1991**	41700	496
1911	2490	0	**1938**	3310	4	**1965**	6960	35	**1992**	50100	506
1912	2500	1	**1939**	2510	2	**1966**	16200	44	**1993**	46700	554
1913	1480	0	**1940**	2370	2	**1967**	16900	56	**1994**	55100	497
1914	992	2	**1941**	2380	2	**1968**	16200	78	**1995**	74300	503
1915	870	1	**1942**	1500	1	**1969**	18100	75	**1996**	79700	482
1916	731	0	**1943**	1900	0	**1970**	15900	89	**1997**	68300	509
1917	1730	0	**1944**	3200	2	**1971**	16400	83	**1998**	77100	566
1918	1470	0	**1945**	1440	2	**1972**	18200	92	**1999**	86600	605
1919	1210	0	**1946**	721	0	**1973**	24000	106	**2000**	90900	714
1920	1590	0	**1947**	1300	7	**1974**	25600	82	**2001**	94500	742
1921	929	1	**1948**	2720	5	**1975**	22100	82	**2002**	98200	811
1922	189	3	**1949**	1290	1	**1976**	19700	100	**2003**	97100	853
1923	138	5	**1950**	470	4	**1977**	24500	113	**2004**	102000	851
1924	348	1	**1951**	1240	3	**1978**	26500	163	**2005**	122000	792
1925	12	2	**1952**	1820	2	**1979**	28800	131	**2006**	137000	822
1926	146	2	**1953**	3960	3	**1980**	27300	196	**2007**	124000	983

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[87] Rare earth oxides [78]. Lanthanide, lanthanoid, yttrium or scandium.

[88] Activity represents world production of the rare earths, defined at usgs.gov as "…REO (Rare Earth Oxides) content of ores produced." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[89] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Lanthanide, lanthanoid, yttrium or scandium were used as keywords found in the patent title or abstract by year of publication.

Table A3.74. Correlation Eq.(A1.1) terms calculated from Table A3.73 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**100r^2**
2339921	16546	1.62E+11	9589606	1.22E+09	1.116E+11	7054698	8.61E+08	**0.96997**	**94.08413**

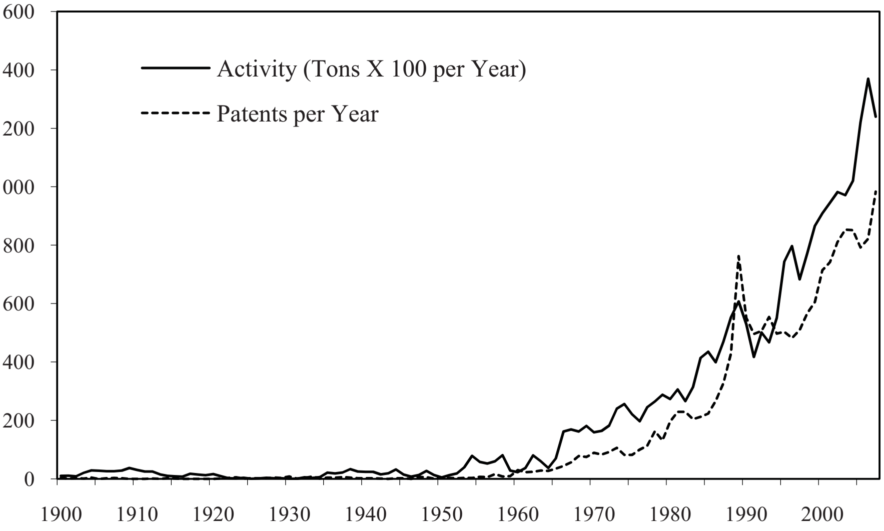

Figure A3.163. Rare Earths Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

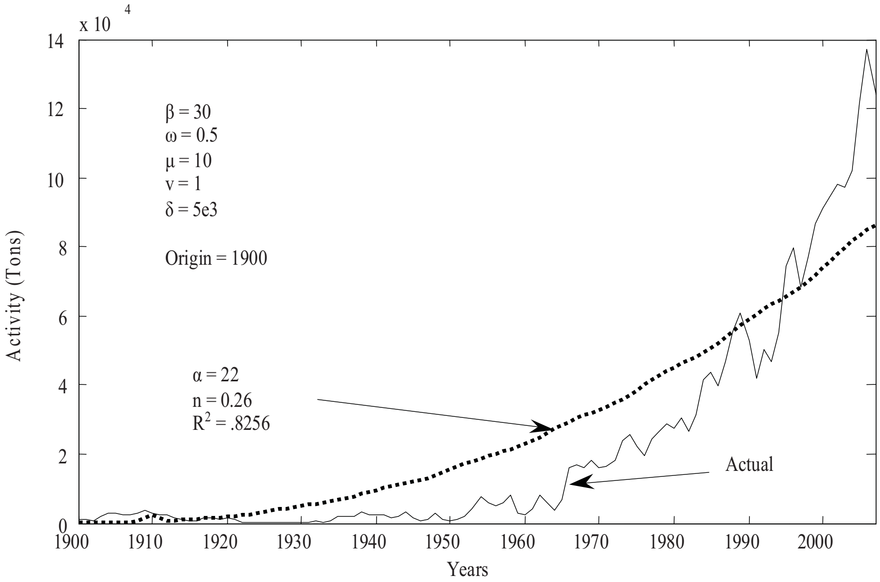

Figure A3.164. **USGS World Rare Earth Production.** World rare earths production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

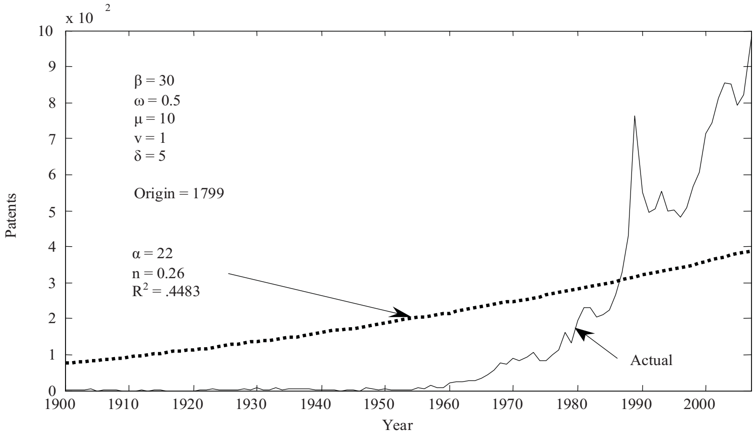

Figure A3.165. EPO Worldwide Patent Search: Lanthanide, Lanthanoid, Yttrium or Scandium in Title or Abstract by date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

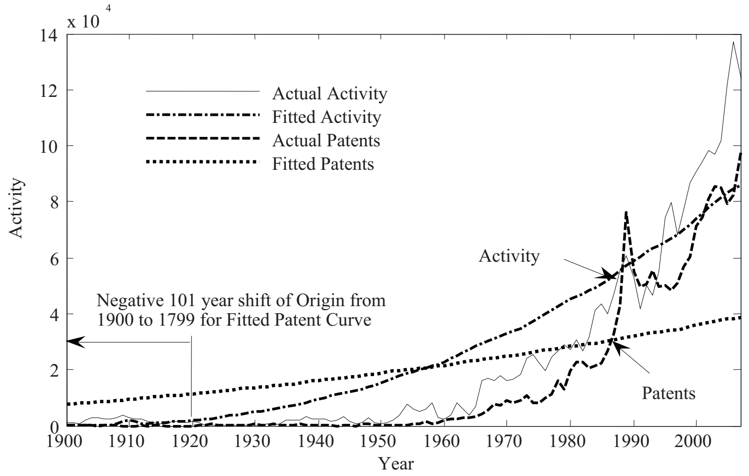

Figure A3.166. Rare Earths Best-Fit Activity and Patents. Illustrates best-fit origin shift.

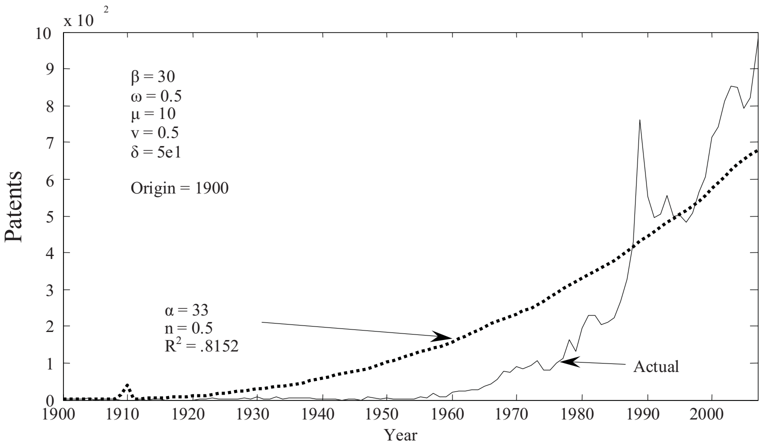

Figure A3.167. **Rare Earths Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.75 Salt Activity[90] and Patents[91]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (pat)	Yr.	x (activity)	y (patent)
1900			**1927**	26100000	291	**1954**	60500000	836	**1981**	171000000	6311
1901			**1928**	27100000	343	**1955**	65000000	997	**1982**	164000000	6632
1902			**1929**	25700000	431	**1956**	68200000	1169	**1983**	159000000	6703
1903			**1930**	28100000	463	**1957**	71900000	1291	**1984**	173000000	7003
1904			**1931**	24400000	560	**1958**	74800000	1100	**1985**	173000000	7234
1905			**1932**	26200000	485	**1959**	79700000	1175	**1986**	175000000	7875
1906			**1933**	28500000	440	**1960**	84800000	1606	**1987**	179000000	7890
1907			**1934**	30200000	492	**1961**	85000000	1411	**1988**	186000000	8081
1908			**1935**	30700000	559	**1962**	91500000	1374	**1989**	192000000	9163
1909			**1936**	31800000	579	**1963**	96100000	1514	**1990**	183000000	9630
1910			**1937**	30200000	579	**1964**	98600000	1692	**1991**	202000000	9151
1911			**1938**	27900000	703	**1965**	109000000	2088	**1992**	185000000	9830
1912			**1939**	32000000	498	**1966**	111000000	1782	**1993**	187000000	9829
1913	17600000	153	**1940**	33200000	435	**1967**	119000000	2420	**1994**	191000000	10815
1914	16900000	140	**1941**	36700000	335	**1968**	126000000	2186	**1995**	199000000	11042
1915	15300000	116	**1942**	38600000	272	**1969**	137000000	1960	**1996**	204000000	10836
1916	17100000	73	**1943**	41200000	261	**1970**	146000000	2442	**1997**	221000000	11252
1917	17600000	65	**1944**	40400000	267	**1971**	144000000	2309	**1998**	200000000	12879
1918	17800000	90	**1945**	36000000	310	**1972**	146000000	3041	**1999**	210000000	12277
1919	19800000	123	**1946**	38300000	350	**1973**	155000000	2607	**2000**	195000000	14103
1920	21900000	127	**1947**	40500000	455	**1974**	166000000	2368	**2001**	199000000	13958
1921	17600000	202	**1948**	44000000	665	**1975**	162000000	2996	**2002**	214000000	15031
1922	23400000	186	**1949**	43000000	571	**1976**	161000000	3609	**2003**	225000000	15927
1923	23300000	168	**1950**	48100000	548	**1977**	157000000	3707	**2004**	236000000	16829
1924	23700000	208	**1951**	55900000	664	**1978**	168000000	3929	**2005**	250000000	16158
1925	25000000	260	**1952**	54200000	812	**1979**	173000000	4069	**2006**	262000000	15119
1926	26200000	247	**1953**	59300000	689	**1980**	169000000	5833	**2007**	257000000	17405

Table A3.76. Correlation Eq.(A1.1) terms calculated from Table A3.76 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
9.879E+09	375689	1.56E+18	3.8E+09	7.08E+13	5.359E+17	2.32E+09	3.17E+13	**0.899574**	**80.92342**

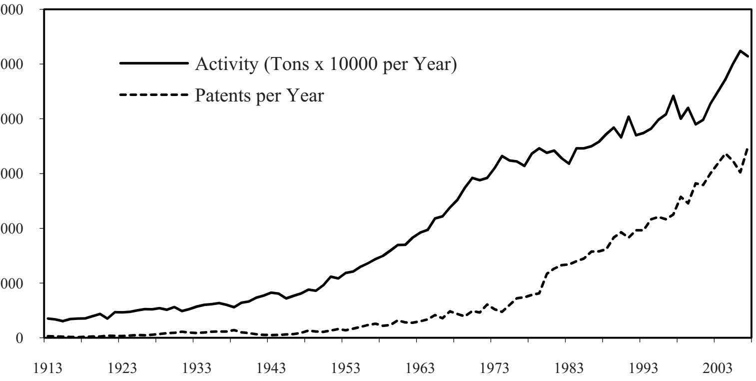

Figure A3.168. Salt Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[90] Activity represents world production of salt, defined at usgs.gov as "…reported in the MR for the years 1900–06. The MR stopped reporting world production for the years 1907–22. The 1923 MR reported world salt production for the years 1913–23 with continued reporting in the MR [*Minerals resources of the United states*] and in the MYB [*Minerals Yearbook*]for the years 1924 to the most recent." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[91] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Salt was used as the keyword found in the patent title or abstract by year of publication.

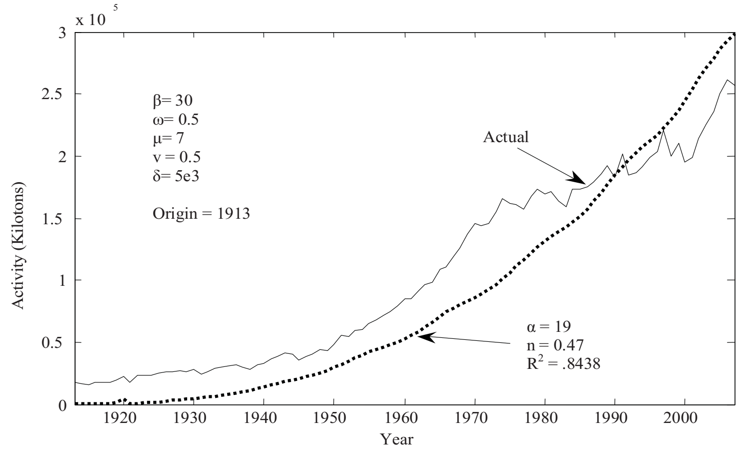

Figure A3.169. **USGS World Salt Production.** World salt production (activity) scaled to metric kilotons with actual and best-fit curves and common pattern equation parameters.

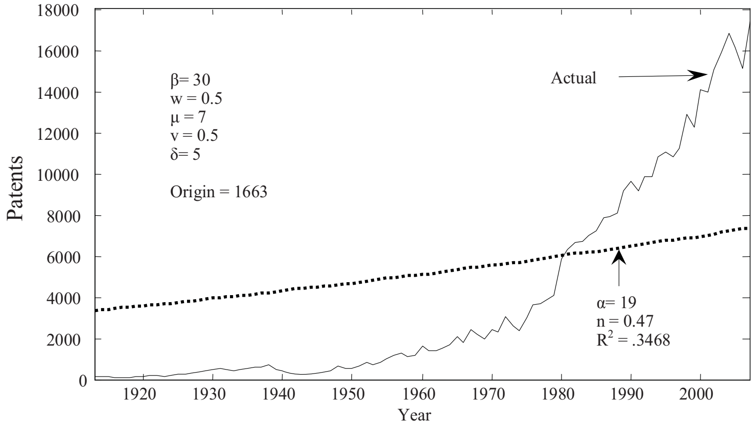

Figure A3.170. EPO Worldwide Patent Search: Salt in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

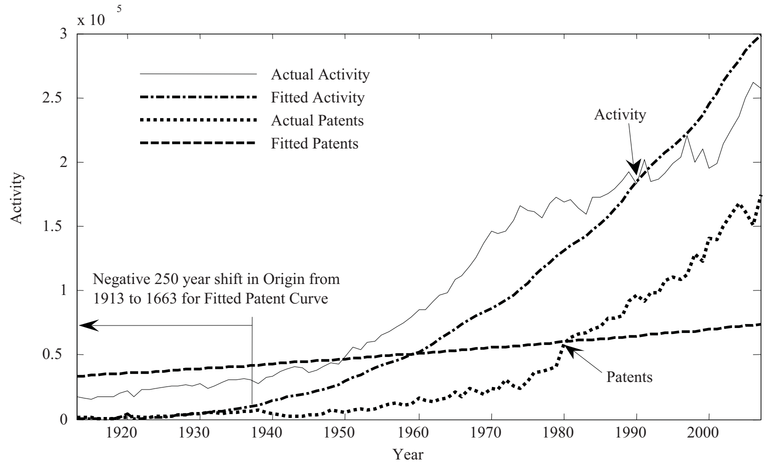

Figure A3.171. Salt Best-Fit Activity and Patents. Illustrates best-fit origin shift.

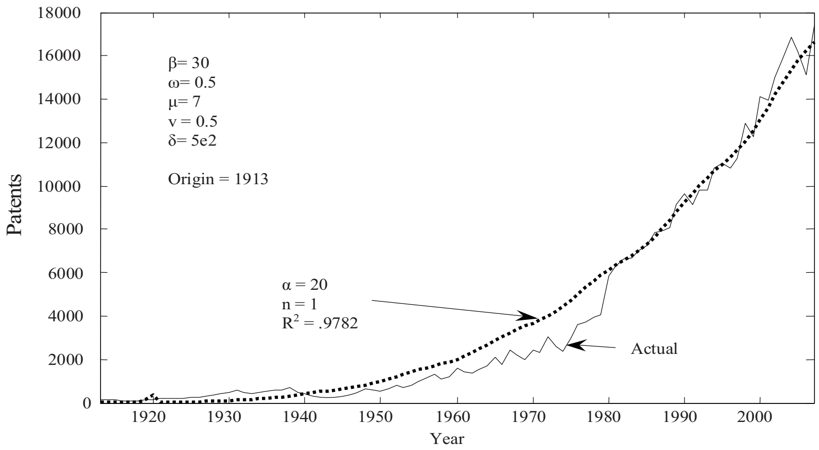

Figure A3.172. Salt Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.77 Selenium Activity[92] and Patents[93]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**	636	77	**1981**	1290	173
1901			**1928**			**1955**	736	72	**1982**	1120	212
1902			**1929**			**1956**	872	90	**1983**	1400	206
1903			**1930**			**1957**	872	86	**1984**	1490	168
1904			**1931**			**1958**	663	92	**1985**	1320	199
1905			**1932**			**1959**	748	83	**1986**	1400	184
1906			**1933**			**1960**	758	102	**1987**	1420	201
1907			**1934**			**1961**	951	92	**1988**	1680	230
1908			**1935**			**1962**	948	107	**1989**	1600	261
1909			**1936**			**1963**	914	97	**1990**	1770	206
1910			**1937**			**1964**	981	113	**1991**	1640	193
1911			**1938**	285	75	**1965**	816	96	**1992**	1770	253
1912			**1939**	194	40	**1966**	895	80	**1993**	1740	220
1913			**1940**	251	43	**1967**	930	104	**1994**	2160	249
1914			**1941**	754	38	**1968**	883	82	**1995**	2070	260
1915			**1942**	645	42	**1969**	1290	77	**1996**	2250	267
1916			**1943**	532	45	**1970**	1310	94	**1997**	1720	317
1917			**1944**	424	55	**1971**	1140	84	**1998**	1470	310
1918			**1945**	387	48	**1972**	1230	102	**1999**	1410	323
1919			**1946**	475	52	**1973**	1220	103	**2000**	1460	304
1920			**1947**	508	77	**1974**	1210	89	**2001**	1470	305
1921			**1948**	471	117	**1975**	1180	106	**2002**	1480	353
1922			**1949**	387	97	**1976**	1110	117	**2003**	1570	400
1923			**1950**	418	66	**1977**	1380	148	**2004**	1440	453
1924			**1951**	488	55	**1978**	1440	157	**2005**	1340	500
1925			**1952**	532	66	**1979**	1620	132	**2006**	1440	385
1926			**1953**	668	60	**1980**	1280	184	**2007**	1470	534

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[92] Activity represents world production of selenium, defined at usgs.gov as "…world refinery production of selenium metal. Data were not available for the years 1900–37. World production estimates for the years 1985–1987 and 1997 to the most recent do not include withheld U.S. production data. Data were recorded from the MR [*Minerals Resources of the United* States] and MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[93] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Selenium was used as the keyword found in the patent title or abstract by year of publication.

Table A3.78. Correlation Eq.(A1.1) terms calculated from Table A3.77 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
77822	11408	1.03E+08	2800784	15380861	16376463	941605.9	2698098	**0.687089**	**47.20916**

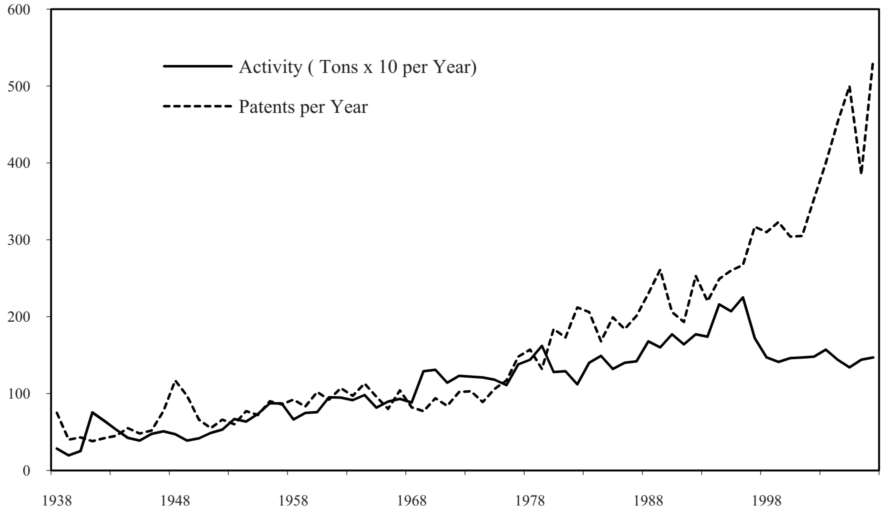

Figure A3.173. Selenium Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

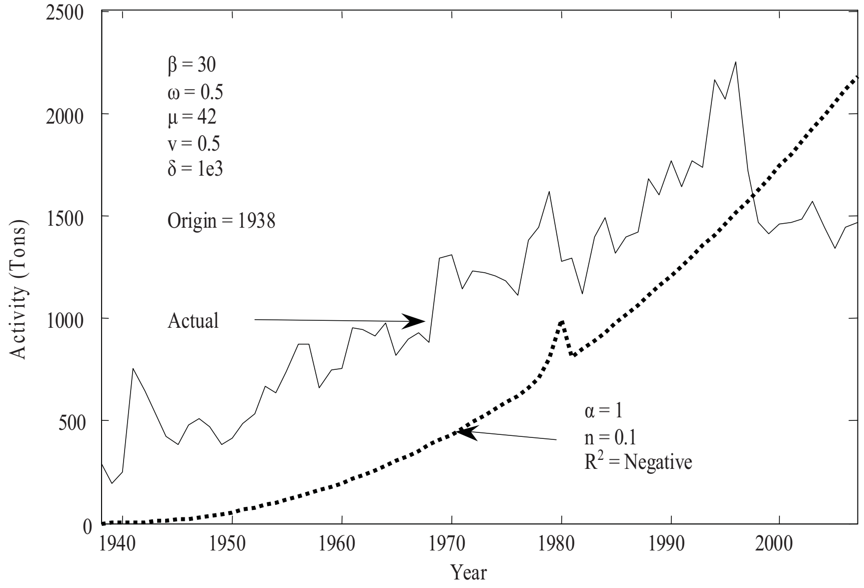

Figure A3.174. USGS World Selenium Production. World selenium production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters. The negative R^2 may indicate a possible Stage IV. No best-fit for the patent data was obtainable.

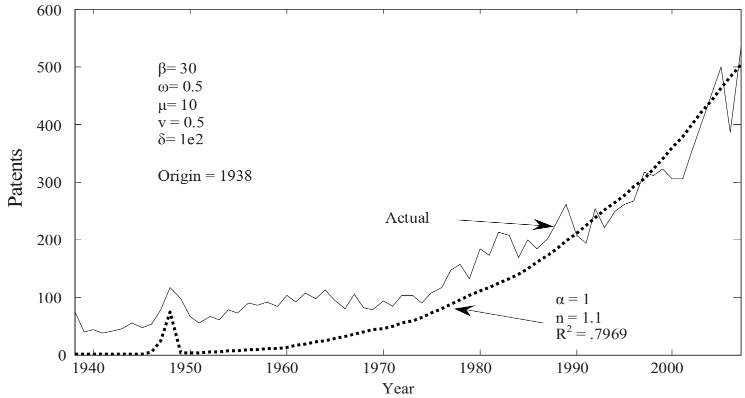

Figure A3.175. Selenium Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.79 Silicon Activity[94] and Patents[95]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**			**1981**	2600000	7028
1901			**1928**			**1955**			**1982**	2410000	8852
1902			**1929**			**1956**			**1983**	2540000	9680
1903			**1930**			**1957**			**1984**	2730000	10189
1904			**1931**			**1958**			**1985**	2830000	11640
1905			**1932**			**1959**			**1986**	2740000	13130
1906			**1933**			**1960**			**1987**	2760000	13268
1907			**1934**			**1961**			**1988**	2990000	13966
1908			**1935**			**1962**			**1989**	3380000	14889
1909			**1936**			**1963**			**1990**	4130000	14900
1910			**1937**			**1964**	1130000	995	**1991**	3950000	14050
1911			**1938**			**1965**	1160000	1225	**1992**	3470000	16106
1912			**1939**			**1966**	1160000	1157	**1993**	3200000	15057
1913			**1940**			**1967**	1490000	1387	**1994**	3170000	15032
1914			**1941**			**1968**	1540000	1345	**1995**	3100000	14428
1915			**1942**			**1969**	1590000	1277	**1996**	3200000	14643
1916			**1943**			**1970**	1640000	1485	**1997**	3400000	14422
1917			**1944**			**1971**	1570000	1510	**1998**	3200000	16633
1918			**1945**			**1972**	1670000	2058	**1999**	3400000	17869
1919			**1946**			**1973**	1780000	1752	**2000**	3500000	22557
1920			**1947**			**1974**	1800000	1516	**2001**	3500000	23289
1921			**1948**			**1975**	2100000	1730	**2002**	3720000	24647
1922			**1949**			**1976**	2320000	2029	**2003**	4500000	22817
1923			**1950**			**1977**	2260000	2698	**2004**	5030000	22574
1924			**1951**			**1978**	2550000	3071	**2005**	5160000	21012
1925			**1952**			**1979**	2840000	4126	**2006**	5400000	21762
1926			**1953**			**1980**	2750000	6338	**2007**	5590000	22494

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[94] Activity represents world production of silicon, defined at usgs.gov as "…for the years 1964–78 were reported in the MFP [*Mineral Facts and Problems*]. World production data for the years 1979 to the most recent were reported in the MCS [*Mineral Commodity Summaries*]. World production data for the years 1964–2005 represent the total silicon content in all ferrosilicon and 3 silicon metal that were produced annually, excluding silicon metal production in China. Starting in 2006, world production data exclude the amount of silicon metal that was produced annually in the United States. Global silicon metal production data were found on a gross-weight basis in the ferroalloys chapter of the MYB [*Minerals Yearbook*]; the typical silicon content of silicon metal is 98% of the gross weight." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[95] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Silicon or Si were used as keywords found in the patent title or abstract by year of publication.

Table A3.80. Correlation Eq.(A1.1) terms calculated from Table A3.79 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
126950000	472633	4.22E+14	7.8E+09	1.71E+12	5.528E+13	2.72E+09	3.45E+11	**0.889319**	**79.08883**

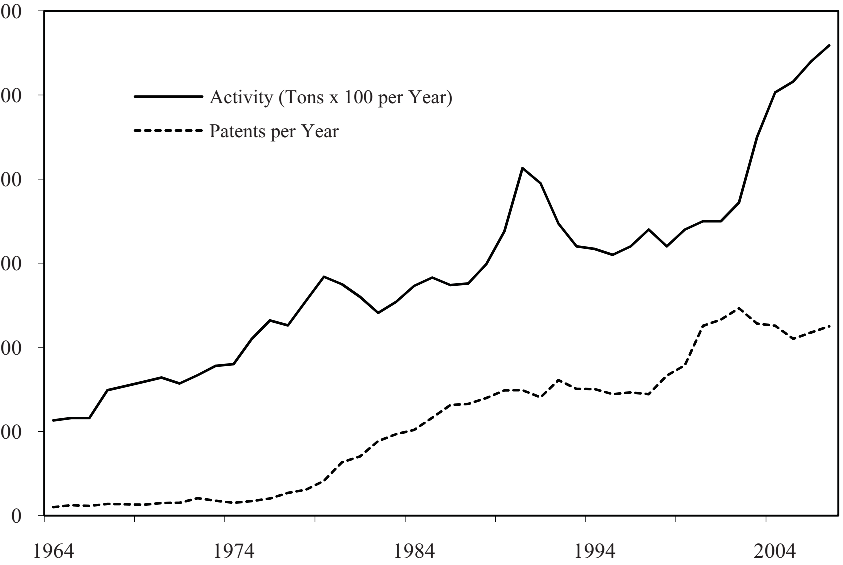

Figure A3.176. Silicon Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

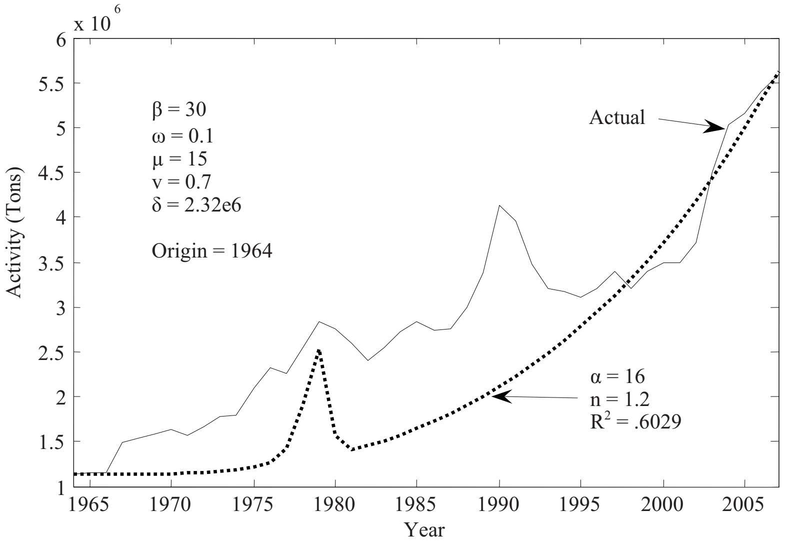

Figure A3.177. **USGS World Silicon production.** World silicon production scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

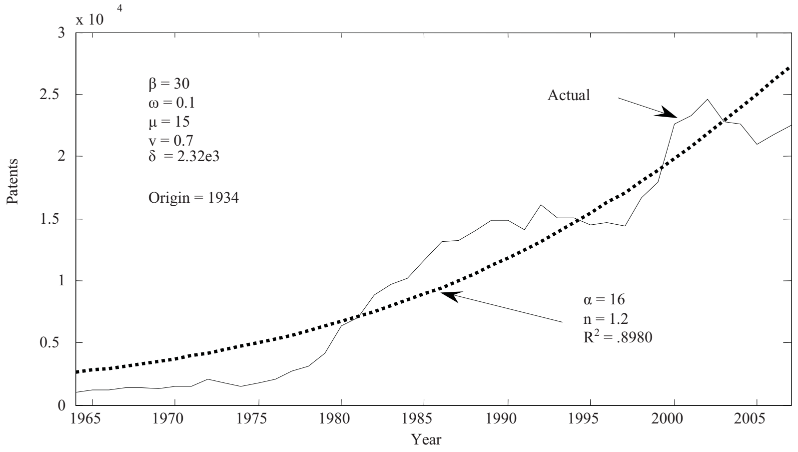

Figure A3.178. EPO Worldwide Patent Search: Silicon or Si in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

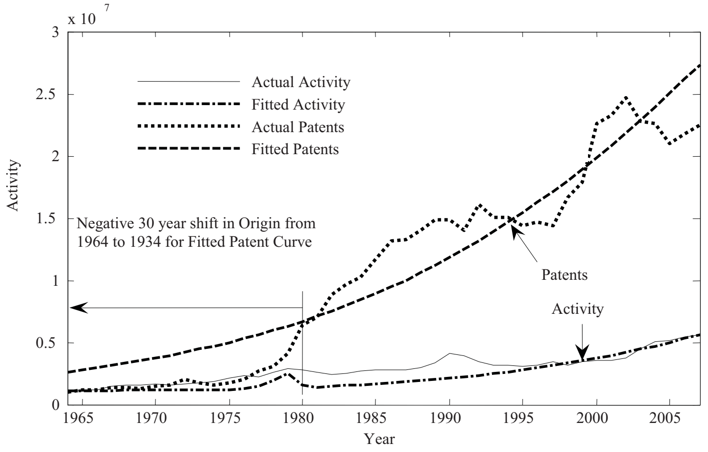

Figure A3.179. Silicon Best-Fit Activity and Patents. Illustrates best-fit origin shift.

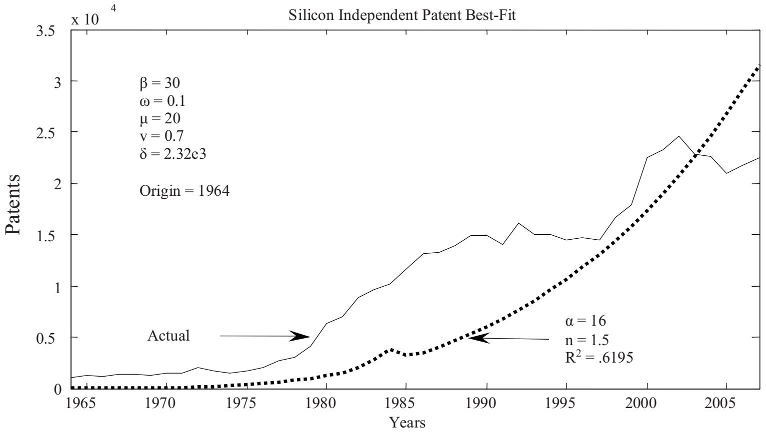

Figure A3.180. **Silicon Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.81 Silver Activity[96] and Patents[97]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	5400	62	**1927**	7900	146	**1954**	6670	422	**1981**	11200	2797
1901	5380	58	**1928**	8020	184	**1955**	7000	464	**1982**	11500	2975
1902	5060	57	**1929**	8120	227	**1956**	7020	475	**1983**	12100	3264
1903	5220	77	**1930**	7740	208	**1957**	7190	555	**1984**	13100	3686
1904	5110	59	**1931**	6080	230	**1958**	7430	577	**1985**	13100	3824
1905	5360	74	**1932**	5130	220	**1959**	6910	654	**1986**	13000	4516
1906	5130	53	**1933**	5340	216	**1960**	7320	718	**1987**	14000	5050
1907	5730	75	**1934**	5990	260	**1961**	7370	818	**1988**	15500	5709
1908	6320	70	**1935**	6890	296	**1962**	7650	867	**1989**	16400	5736
1909	6600	77	**1936**	7920	371	**1963**	7780	898	**1990**	16600	6312
1910	6900	66	**1937**	8640	373	**1964**	7730	1023	**1991**	15600	5726
1911	7040	63	**1938**	8320	261	**1965**	8010	1140	**1992**	14900	5940
1912	6980	71	**1939**	8300	211	**1966**	8300	1207	**1993**	14100	5999
1913	7010	69	**1940**	8570	212	**1967**	8030	1209	**1994**	14000	5831
1914	5240	57	**1941**	8140	212	**1968**	8560	1954	**1995**	14900	5995
1915	5730	43	**1942**	7780	262	**1969**	9200	4102	**1996**	15100	5994
1916	5250	39	**1943**	6380	276	**1970**	9360	5156	**1997**	16500	6264
1917	5420	49	**1944**	7540	310	**1971**	9170	4980	**1998**	17200	5775
1918	6140	44	**1945**	5040	237	**1972**	9380	5256	**1999**	17600	5918
1919	5490	83	**1946**	3970	318	**1973**	9700	5373	**2000**	18100	6139
1920	5390	72	**1947**	5220	254	**1974**	9260	4742	**2001**	18900	6346
1921	5330	73	**1948**	5440	251	**1975**	9430	3269	**2002**	18800	6040
1922	6530	84	**1949**	5570	295	**1976**	9840	2089	**2003**	18800	6119
1923	7650	86	**1950**	6320	292	**1977**	10300	1434	**2004**	19900	5528
1924	7450	93	**1951**	6210	357	**1978**	10700	1953	**2005**	20600	5249
1925	7650	119	**1952**	6700	369	**1979**	10800	2322	**2006**	20200	4230
1926	7890	137	**1953**	6900	427	**1980**	10700	2356	**2007**	20800	2860

Table A3.82 Correlation Eq.(A1.1) terms calculated from Table A3.81 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
1011880	205020	1.15E+10	9.55E+08	2.85E+09	1.998E+09	5.66E+08	9.29E+08	**0.873549**	**76.30875**

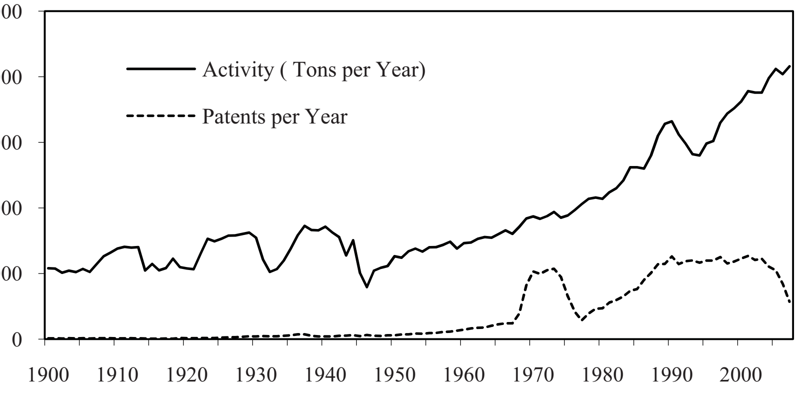

Figure A3.181. Silver Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[96] Activity represents world production of silver, defined at usgs.gov as "…for the years 1900 to the most recent represent the recoverable silver content of precious-metal ores that were extracted from mines throughout the world. World production data were recorded from the MR [*Minerals Resources of the United* States] and MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[97] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Silver or Ag were used as keywords found in the patent title or abstract by year of publication.

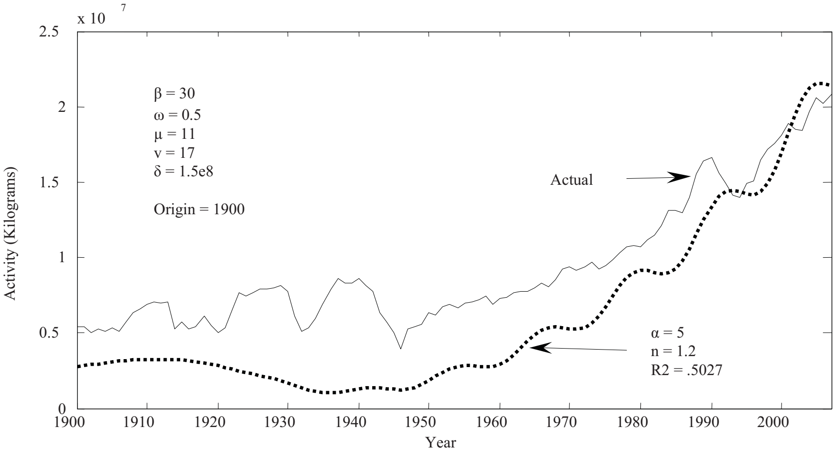

Figure A3.182. **USGS World Silver Production.** World silver production (activity) scaled in kilograms with actual and best-fit curves and common pattern equation parameters.

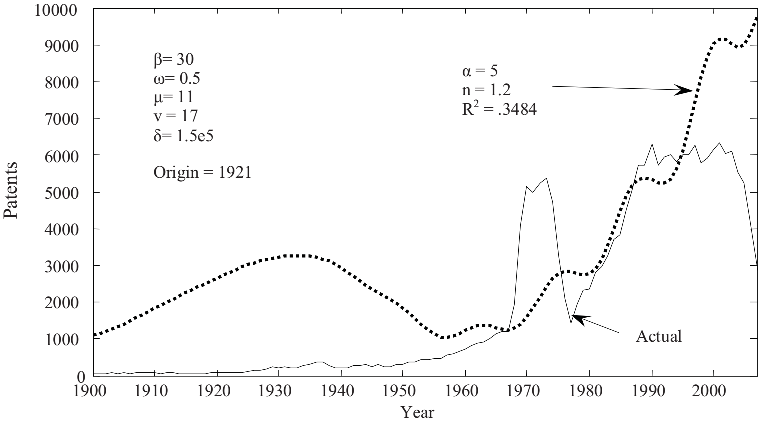

Figure A3.183. EPO Worldwide Patent Search: Silver or Ag in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

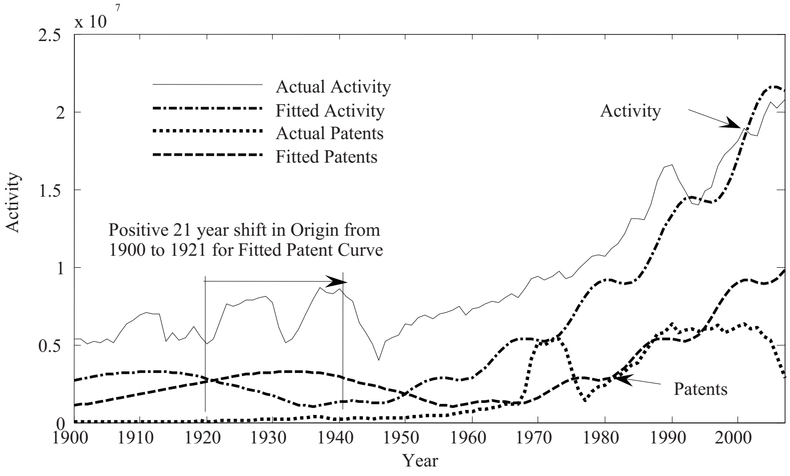

Figure A3.184. Silver Best-Fit Activity and Patents. Illustrates best-fit origin shift.

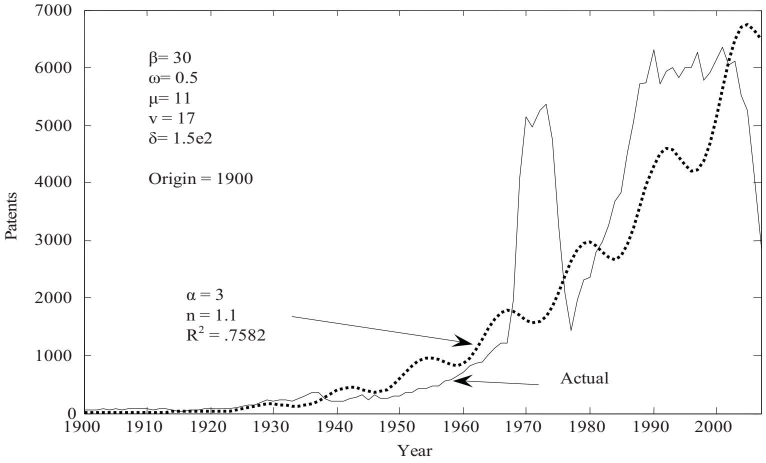

Figure A3.185. Silver Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.83 Sulfur Activity[98] and Patents[99]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	1420000	101	**1927**	5890000	214	**1954**	12800000	474	**1981**	53600000	2229
1901	1420000	80	**1928**	5690000	285	**1955**	15500000	462	**1982**	50600000	2125
1902	4390000	117	**1929**	6200000	334	**1956**	17000000	606	**1983**	49800000	2010
1903	4540000	114	**1930**	6400000	392	**1957**	17000000	613	**1984**	52500000	1970
1904	1320000	70	**1931**	5180000	499	**1958**	16100000	532	**1985**	53800000	2008
1905	1420000	79	**1932**	3760000	408	**1959**	17200000	539	**1986**	53700000	2206
1906	1320000	89	**1933**	4570000	409	**1960**	19600000	675	**1987**	57000000	2284
1907	1320000	83	**1934**	5080000	364	**1961**	20600000	579	**1988**	59200000	2457
1908	1220000	95	**1935**	5690000	392	**1962**	21300000	643	**1989**	58900000	2620
1909	1320000	84	**1936**	5390000	385	**1963**	21900000	689	**1990**	57800000	2654
1910	1420000	110	**1937**	5990000	412	**1964**	23500000	745	**1991**	54600000	2789
1911	1420000	101	**1938**	5590000	440	**1965**	25200000	805	**1992**	50700000	3080
1912	1630000	106	**1939**	7320000	316	**1966**	26500000	741	**1993**	51600000	2896
1913	1830000	97	**1940**	7930000	237	**1967**	28400000	815	**1994**	53400000	3082
1914	1070000	85	**1941**	7520000	201	**1968**	29500000	857	**1995**	54800000	2919
1915	1290000	67	**1942**	8030000	182	**1969**	30700000	743	**1996**	55200000	3000
1916	1440000	37	**1943**	6710000	122	**1970**	41900000	851	**1997**	56900000	3299
1917	1980000	56	**1944**	6600000	148	**1971**	42700000	854	**1998**	57400000	3563
1918	2140000	56	**1945**	6200000	209	**1972**	45500000	1081	**1999**	57400000	3652
1919	1800000	89	**1946**	7320000	260	**1973**	48200000	1075	**2000**	59300000	4182
1920	1590000	108	**1947**	8640000	302	**1974**	51200000	1081	**2001**	59500000	4079
1921	2230000	172	**1948**	9450000	331	**1975**	50700000	1470	**2002**	62000000	4535
1922	2090000	160	**1949**	9960000	328	**1976**	50900000	1745	**2003**	64100000	4410
1923	2380000	151	**1950**	10800000	299	**1977**	52300000	1698	**2004**	66200000	4523
1924	3860000	176	**1951**	11400000	347	**1978**	52100000	1776	**2005**	67000000	4288
1925	4780000	190	**1952**	12100000	433	**1979**	53200000	1687	**2006**	66800000	3766
1926	5490000	195	**1953**	11700000	368	**1980**	55000000	2192	**2007**	68400000	4181

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[98] Activity represents world production of sulfur, defined at usgs.gov as "…all forms of sulfur and are in terms of their sulfur content. Data prior to 1936 include elemental sulfur production from principal producing countries and world pyrite production. Data for the years 1936 to the most recent are world production of all forms of sulfur. Data are from the MR [*Minerals Resources of the United* States] and MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[99] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Sulfur or Sulphur were used as keywords found in the patent title or abstract by year of publication.

Table A3.84 Correlation Eq.(A1.1) terms calculated from Table A3.83 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
2.694E+09	122320	1.27E+17	3.2E+08	6.06E+12	5.937E+16	1.81E+08	3.01E+12	**0.915594**	**83.83128**

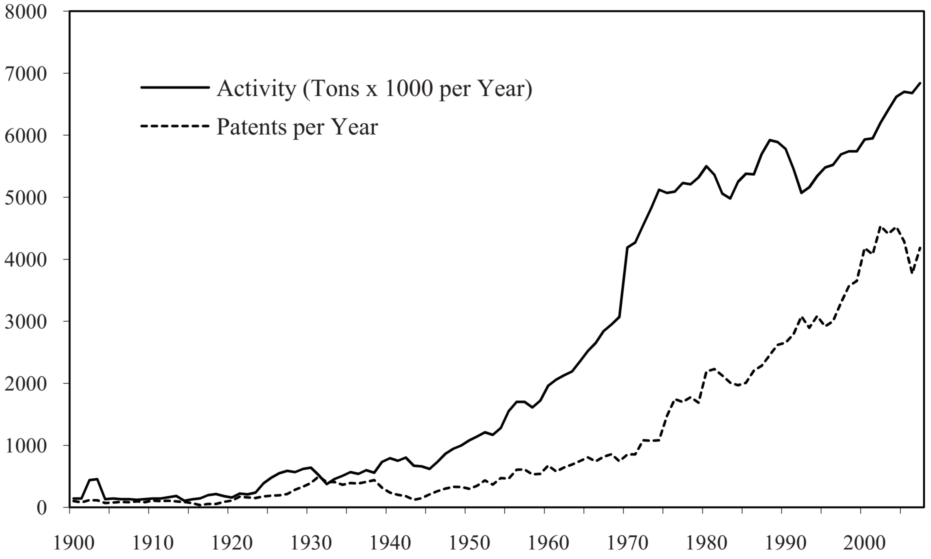

Figure A3.186. Sulfur Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

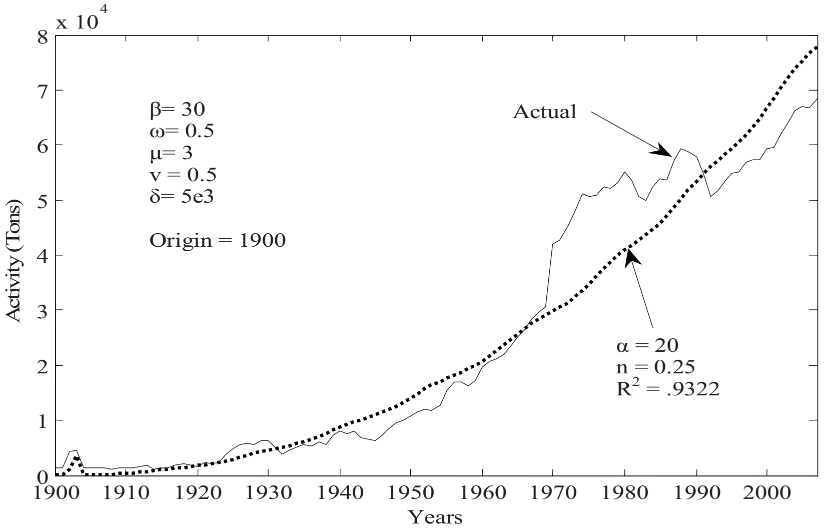

Figure A3.187. **USGS World Sulfur Production.** World sulfur production (activity) scaled in metric kilotons with actual and best-fit curves and common pattern equation parameters.

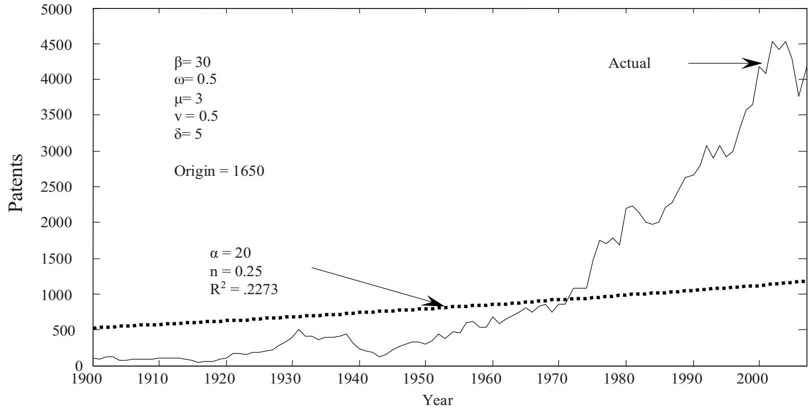

Figure A3.188. EPO Worldwide Patent Search: Sulfur or Sulphur in Title or Abstract by date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

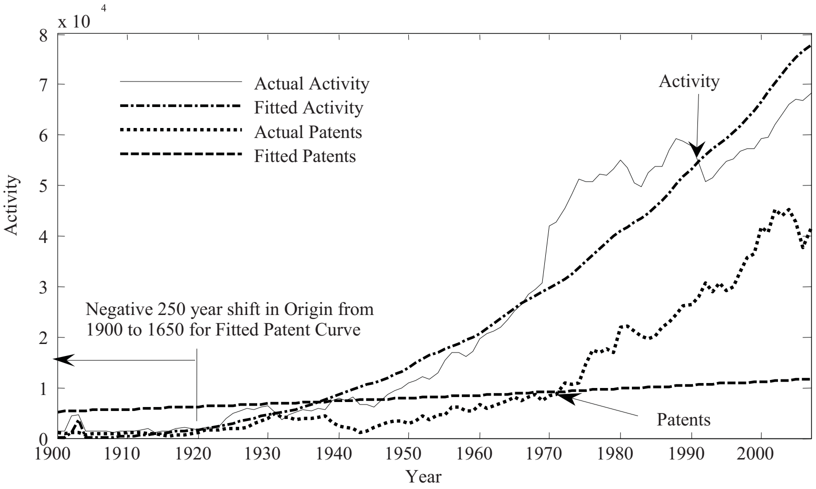

Figure A3.189. Sulfur Best-Fit Activity and Patents. Illustrates best-fit origin shift.

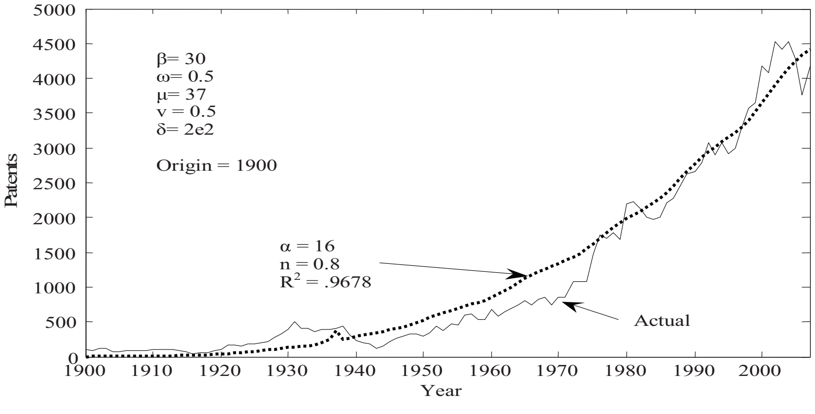

Figure A3.190. Sulfur Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.85 Talc and Pyrophyllite[100] Activity[101] and Patents[102]

Year	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**
1900			**1927**	431000	18	**1954**	1470000	59	**1981**	7270000	198
1901			**1928**	389000	26	**1955**	1620000	88	**1982**	7060000	212
1902			**1929**	421000	24	**1956**	1750000	98	**1983**	7060000	249
1903			**1930**	364000	30	**1957**	2010000	131	**1984**	7570000	246
1904	118000	11	**1931**	384000	40	**1958**	1910000	98	**1985**	7830000	271
1905	124000	9	**1932**	331000	32	**1959**	2350000	159	**1986**	7760000	285
1906	151000	12	**1933**	430000	35	**1960**	2520000	153	**1987**	8470000	264
1907	191000	13	**1934**	399000	36	**1961**	2710000	129	**1988**	8810000	285
1908	160000	16	**1935**	424000	51	**1962**	2670000	110	**1989**	9240000	361
1909	178000	13	**1936**	472000	53	**1963**	2990000	160	**1990**	9370000	315
1910	202000	9	**1937**	515000	45	**1964**	3520000	143	**1991**	9060000	317
1911	208000	11	**1938**	420000	49	**1965**	3570000	167	**1992**	8500000	349
1912	171000	15	**1939**	488000	38	**1966**	3710000	131	**1993**	8420000	340
1913	279000	10	**1940**	664000	33	**1967**	3960000	162	**1994**	8260000	323
1914	213000	11	**1941**	840000	26	**1968**	4350000	119	**1995**	8490000	365
1915	224000	3	**1942**	1170000	20	**1969**	4680000	107	**1996**	9880000	371
1916	257000	5	**1943**	1120000	13	**1970**	4820000	128	**1997**	10400000	379
1917	266000	4	**1944**	1010000	12	**1971**	4740000	138	**1998**	9410000	445
1918	252000	4	**1945**	840000	20	**1972**	4830000	169	**1999**	9470000	424
1919	255000	7	**1946**	950000	28	**1973**	5400000	114	**2000**	8730000	497
1920	322000	10	**1947**	1060000	33	**1974**	5810000	105	**2001**	9060000	401
1921	207000	12	**1948**	1300000	46	**1975**	4900000	120	**2002**	8030000	446
1922	353000	16	**1949**	1280000	39	**1976**	5270000	143	**2003**	7800000	389
1923	336000	14	**1950**	1430000	41	**1977**	6090000	118	**2004**	7840000	393
1924	375000	8	**1951**	1570000	42	**1978**	6400000	141	**2005**	7950000	289
1925	398000	10	**1952**	1410000	54	**1979**	6870000	125	**2006**	7750000	263
1926	344000	17	**1953**	1480000	51	**1980**	7540000	208	**2007**	7620000	338

Table A3.86 Correlation Eq.(A1.1) terms calculated from Table A3.85 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**$100r^2$**
362746000	13713	2.47E+15	3678389	9.23E+10	1.2E+15	1870251	4.45E+10	**0.938294**	**88.03948**

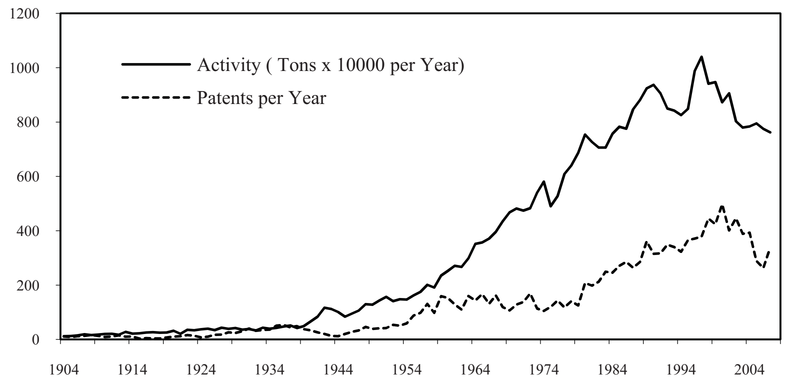

Figure A3.191. Talc and Pyrophyllite Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[100] Magnesium silicate and aluminum silicate hydroxide [78,128].

[101] Activity represents world production of talc, defined at usgs.gov as "…for the years 1904 to the most recent were recorded from the MR [*Minerals Resources of the United* States] and MYB [*Minerals Yearbook*]. World production data for the years 1904–12 represent the summed weights of all talc and soapstone materials that were produced annually throughout the world. World production data for the years 1913 to the most recent represent the summed weights of all talc, pyrophyllite, soapstone, steatite, and other unspecified talc-related materials that were produced annually throughout the world." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[102] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Talc or Pyrophyllite were used as keywords found in the patent title or abstract by year of publication.

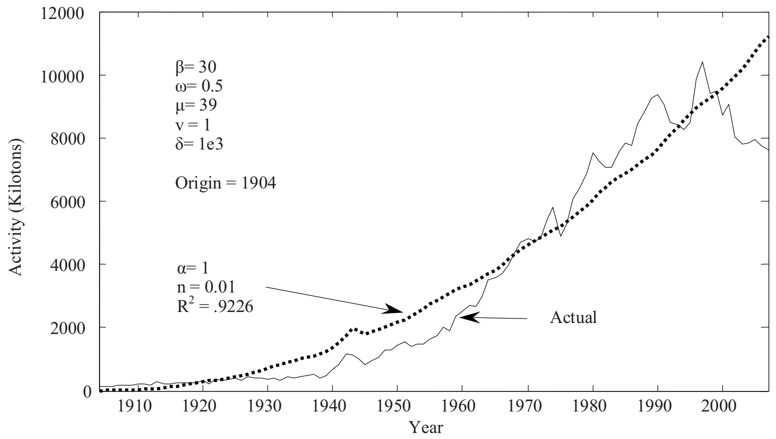

Figure A3.192. USGS World Talc Production. World talc and pyrophyllite production (activity) scaled in metric kilotons with actual and best-fit curves and common pattern equation parameters.

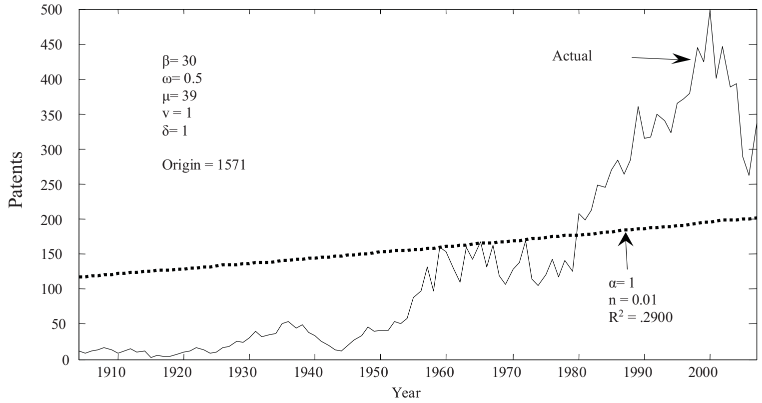

Figure A3.193. EPO Worldwide Patent Search: Talc or Pyrophyllite in Title or Abstract by date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

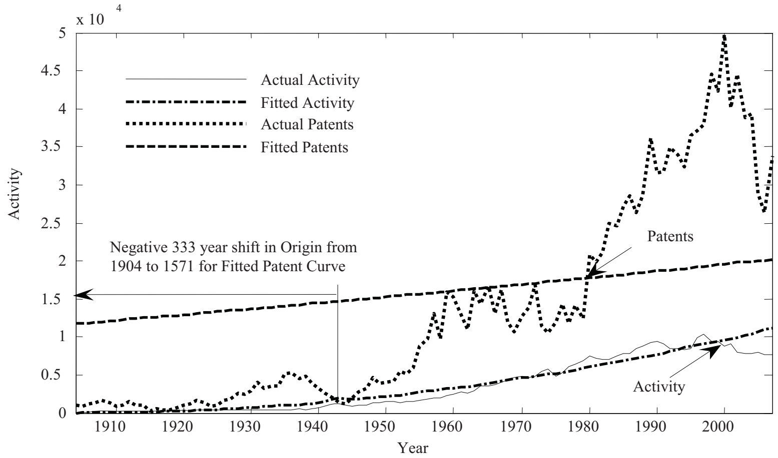

Figure A3.194. Talc and Pyrophyllite Best-Fit Patents and Activity. Illustrates best-fit origin shift.

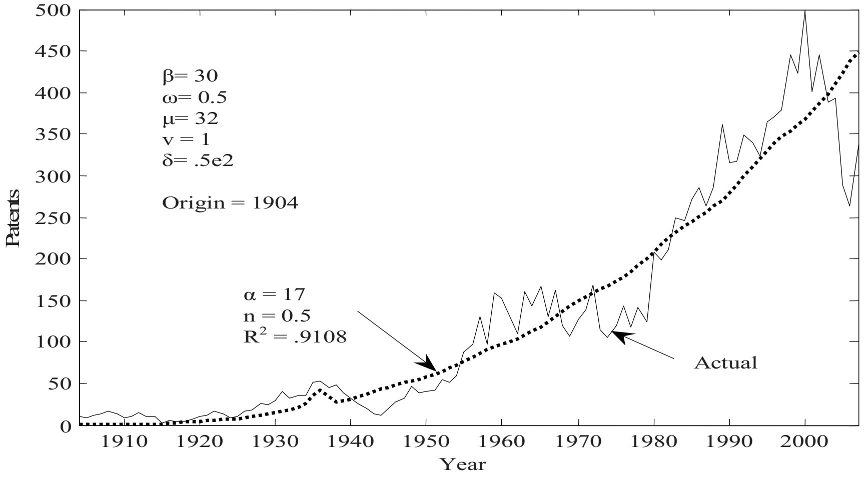

Figure A3.195. Talc and Pyrophyllite Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.87 Tantalum Activity[103] and Patents[104]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**			**1981**	403	614
1901			**1928**			**1955**			**1982**	284	801
1902			**1929**			**1956**			**1983**	313	877
1903			**1930**			**1957**			**1984**	315	883
1904			**1931**			**1958**			**1985**	315	1031
1905			**1932**			**1959**			**1986**	215	1126
1906			**1933**			**1960**			**1987**	275	1187
1907			**1934**			**1961**			**1988**	292	1245
1908			**1935**			**1962**			**1989**	395	1561
1909			**1936**			**1963**			**1990**	396	1491
1910			**1937**			**1964**			**1991**	477	1577
1911			**1938**			**1965**			**1992**	399	1775
1912			**1939**			**1966**			**1993**	292	1557
1913			**1940**			**1967**			**1994**	333	1587
1914			**1941**			**1968**			**1995**	361	1436
1915			**1942**			**1969**	388	319	**1996**	436	1402
1916			**1943**			**1970**	318	360	**1997**	562	1468
1917			**1944**			**1971**	496	368	**1998**	779	1674
1918			**1945**			**1972**	371	412	**1999**	656	1802
1919			**1946**			**1973**	384	357	**2000**	1070	2210
1920			**1947**			**1974**	436	328	**2001**	1180	2304
1921			**1948**			**1975**	411	351	**2002**	1340	2513
1922			**1949**			**1976**	339	381	**2003**	1390	2370
1923			**1950**			**1977**	409	393	**2004**	1520	2241
1924			**1951**			**1978**	362	422	**2005**	1470	2021
1925			**1952**			**1979**	476	410	**2006**	964	2030
1926			**1953**			**1980**	544	584	**2007**	815	2098

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[103] Activity represents world production of talc, defined at usgs.gov as "…data for the years 1964–68 were not available. World production data for the years 1969 to the most recent represent the tantalum content in tantalum-bearing ores and mineral concentrates that were produced from mines throughout the world. World production data for the years 1969 to the most recent were recorded from the MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[104] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Talc or Pyrophyllite were used as keywords found in the patent title or abstract by year of publication.

Table A3.88 Correlation Eq.(A1.1) terms calculated from Table A3.87 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
22181	47566	17723137	76964848	34118459	5107835.4	18951403	7065601	**0.718141**	**51.57272**

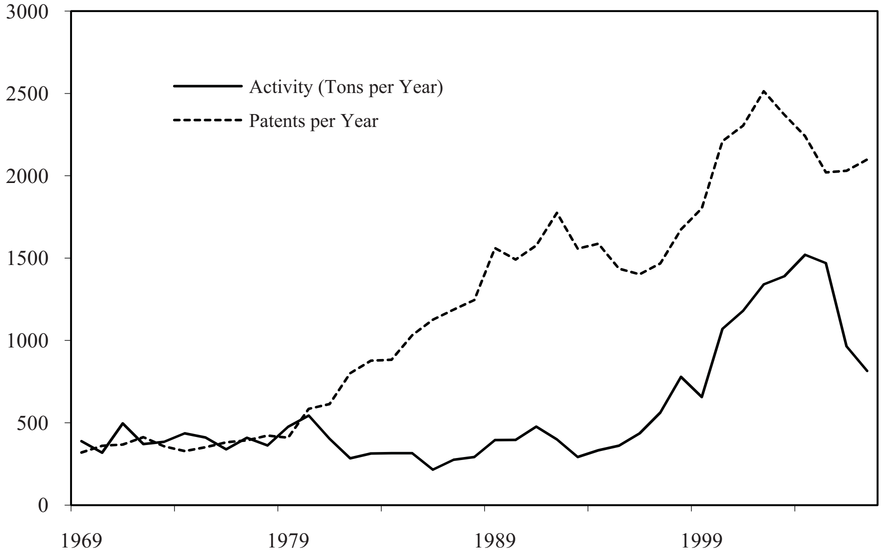

Figure A3.196. Tantalum Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

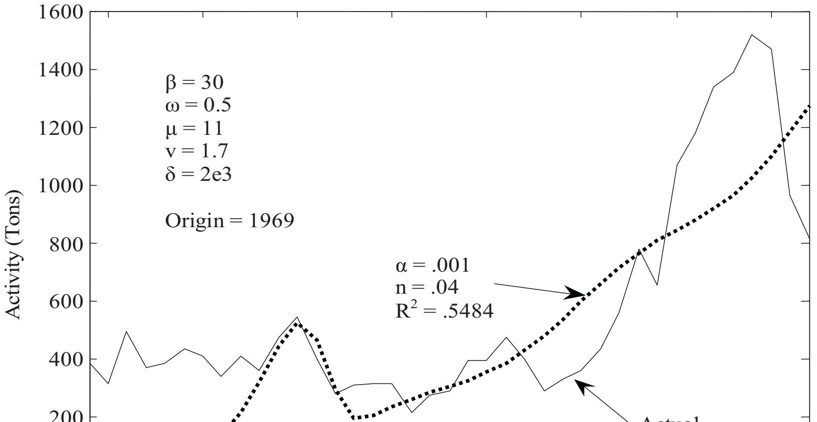

Figure A3.197. **USGS World Tantalum Production**. World tantalum production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters. No best-fit for the patent data was obtainable.

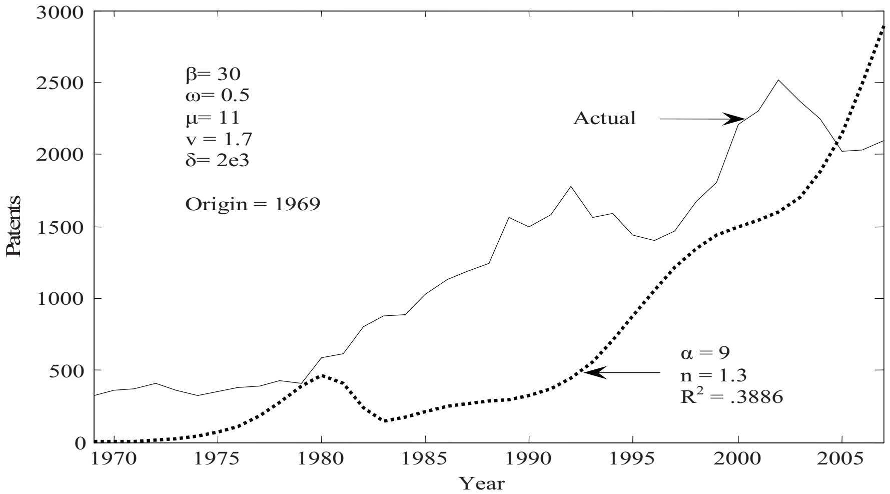

Figure A3.198. Tantalum Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.89 Tin Activity[105] and Patents[106]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**	161000	180	**1954**	192000	255	**1981**	238000	1652
1901			**1928**	180000	183	**1955**	200000	268	**1982**	219000	1873
1902			**1929**	196000	195	**1956**	203000	284	**1983**	197000	2096
1903			**1930**	179000	200	**1957**	204000	303	**1984**	188000	2154
1904			**1931**	149000	198	**1958**	156000	277	**1985**	181000	2345
1905	93600	117	**1932**	96500	210	**1959**	164000	309	**1986**	173000	2583
1906	98400	95	**1933**	90400	187	**1960**	183000	452	**1987**	180000	2742
1907	93800	104	**1934**	122000	159	**1961**	187000	378	**1988**	205000	2803
1908	106000	107	**1935**	137000	209	**1962**	190000	471	**1989**	233000	3165
1909	106000	118	**1936**	182000	223	**1963**	194000	517	**1990**	221000	3097
1910	105000	116	**1937**	213000	207	**1964**	197000	542	**1991**	201000	2965
1911	112000	120	**1938**	166000	200	**1965**	204000	650	**1992**	191000	3382
1912	122000	121	**1939**	180000	181	**1966**	211000	604	**1993**	190000	3078
1913	136000	107	**1940**	240000	168	**1967**	218000	705	**1994**	178000	3149
1914	128000	100	**1941**	244000	154	**1968**	232000	680	**1995**	201000	3009
1915	129000	76	**1942**	124000	108	**1969**	229000	632	**1996**	220000	2987
1916	128000	75	**1943**	146000	100	**1970**	232000	731	**1997**	241000	2929
1917	135000	58	**1944**	102000	75	**1971**	235000	796	**1998**	231000	3259
1918	128000	60	**1945**	88400	99	**1972**	244000	954	**1999**	245000	3459
1919	123000	81	**1946**	89400	126	**1973**	238000	757	**2000**	278000	4068
1920	126000	109	**1947**	115000	151	**1974**	233000	697	**2001**	246000	4031
1921	110000	134	**1948**	156000	197	**1975**	222000	842	**2002**	233000	4173
1922	127000	150	**1949**	164000	170	**1976**	218000	945	**2003**	258000	4010
1923	130000	152	**1950**	172000	132	**1977**	231000	1002	**2004**	298000	3945
1924	142000	150	**1951**	172000	137	**1978**	241000	1069	**2005**	292000	3569
1925	147000	176	**1952**	177000	210	**1979**	245000	1134	**2006**	302000	3760
1926	146000	140	**1953**	193000	176	**1980**	245000	1640	**2007**	320000	3697

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[105] Activity represents world production of talc, defined at usgs.gov as "…tin content of mine and mill production. Data were from the MYB [*Minerals Yearbook*] and MR [*Mineral Resources of the United States*]. Blank cells in the worksheet indicate that data were not available for the years 1900–04." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[106] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Talc or Pyrophyllite were used as keywords found in the patent title or abstract by year of publication.

Table A3.90 Correlation Eq.(A1.1) terms calculated from Table A3.89 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
18814500	108875	3.73E+12	2.89E+08	2.46E+10	2.959E+11	1.74E+08	4.72E+09	**0.657578**	**43.24093**

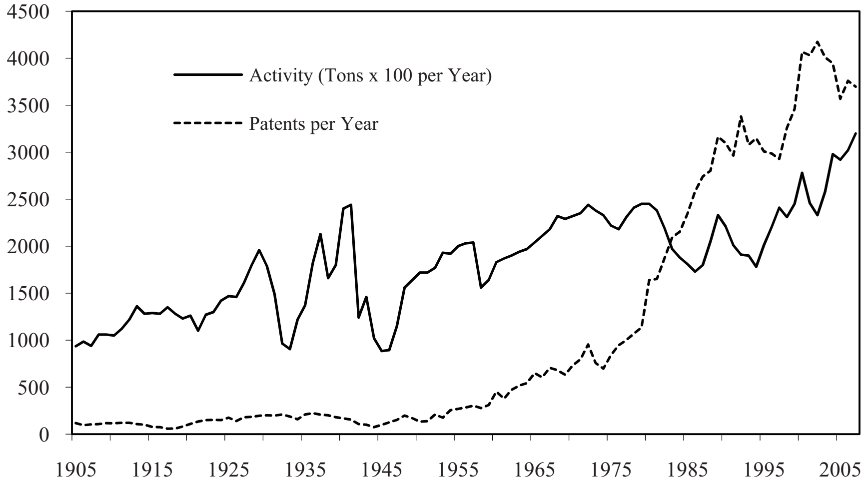

Figure A3.199. Tin Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

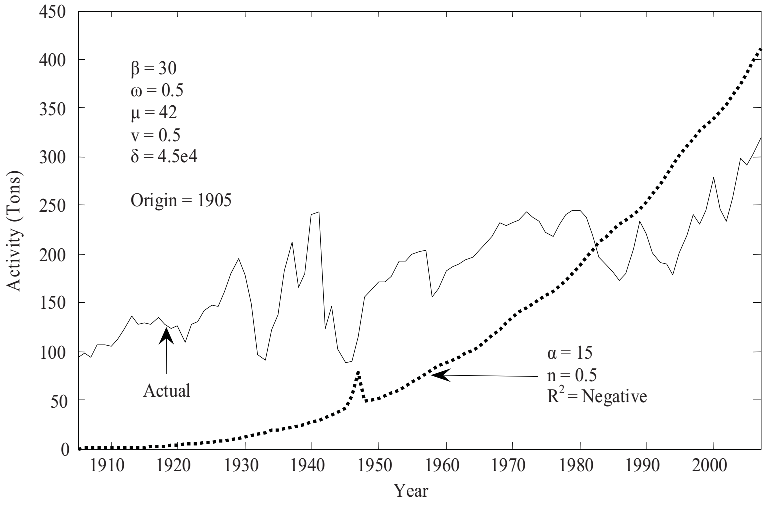

Figure A3.200. **USGS World Tin Production.** World tin production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters. The negative *R^2* may indicate possible Stage IV. No best-fit for the patent data was obtainable.

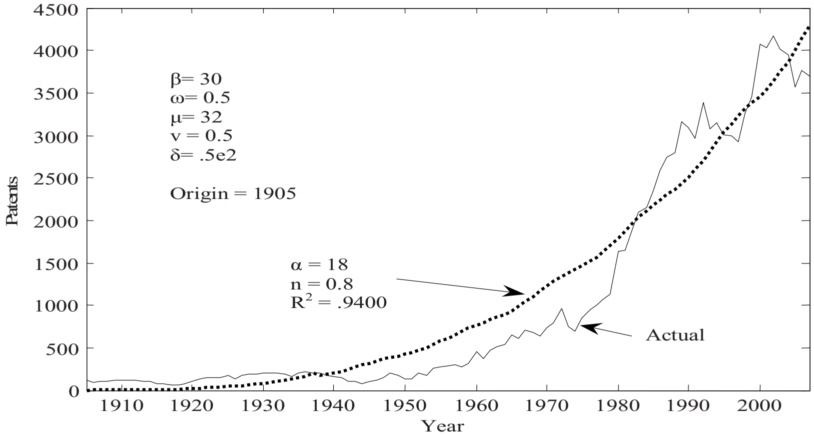

Figure A3.201. Tin Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.91 Titanium Activity[107] and Patents[108]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**	36100	60	**1954**	1180000	317	**1981**	5140000	2623
1901			**1928**	40100	80	**1955**	1340000	450	**1982**	4420000	3105
1902			**1929**	48200	91	**1956**	1750000	493	**1983**	4040000	3283
1903			**1930**	43500	123	**1957**	1930000	569	**1984**	5320000	3469
1904			**1931**	43700	150	**1958**	1650000	650	**1985**	5110000	3869
1905			**1932**	65700	150	**1959**	1830000	707	**1986**	5100000	4333
1906			**1933**	79000	133	**1960**	2100000	984	**1987**	5950000	4676
1907			**1934**	106000	152	**1961**	2230000	836	**1988**	6280000	5038
1908			**1935**	174000	154	**1962**	2100000	835	**1989**	6570000	5696
1909			**1936**	226000	192	**1963**	2190000	856	**1990**	6250000	5769
1910			**1937**	284000	210	**1964**	2540000	828	**1991**	5330000	5868
1911			**1938**	323000	226	**1965**	2680000	971	**1992**	6050000	6557
1912			**1939**	89600	208	**1966**	2870000	786	**1993**	6040000	6116
1913			**1940**	361000	164	**1967**	3020000	1007	**1994**	6030000	6361
1914			**1941**	248000	170	**1968**	3230000	952	**1995**	6240000	6030
1915			**1942**	217000	156	**1969**	3610000	879	**1996**	6210000	6148
1916			**1943**	379000	123	**1970**	4020000	1064	**1997**	6450000	6344
1917			**1944**	483000	109	**1971**	3750000	1084	**1998**	7050000	8456
1918			**1945**	532000	108	**1972**	3610000	1340	**1999**	6550000	8690
1919			**1946**	527000	132	**1973**	3920000	1221	**2000**	7350000	9308
1920			**1947**	704000	146	**1974**	4400000	1056	**2001**	7570000	8650
1921			**1948**	736000	190	**1975**	4030000	1308	**2002**	7730000	8938
1922			**1949**	844000	205	**1976**	4390000	1290	**2003**	8210000	8816
1923			**1950**	884000	186	**1977**	4350000	1519	**2004**	8380000	9298
1924			**1951**	160000	199	**1978**	4760000	1646	**2005**	8450000	8326
1925	14800	49	**1952**	942000	288	**1979**	4660000	1611	**2006**	9740000	8165
1926	21400	47	**1953**	860000	228	**1980**	5380000	2390	**2007**	10000000	8520

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[107] Activity represents world production of titanium, defined at usgs.gov as "…ilmenite and natural rutile, and titanium slag, but does not include ilmenite used to produce titanium slag to avoid double counting. Data are not available prior to 1925. Titanium slag was not produced prior to 1950. Data are from the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]; the typical silicon content of silicon metal is 98% of the gross weight." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[108] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Titanium or Ti were used as keywords found in the patent title or abstract by year of publication.

Table A3.92. Correlation Eq.(A1.1) terms calculated from Table A3.91 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
270552100	204530	1.52E+15	1.25E+09	1.3E+12	6.429E+14	7.47E+08	6.34E+11	**0.915079**	**83.73694**

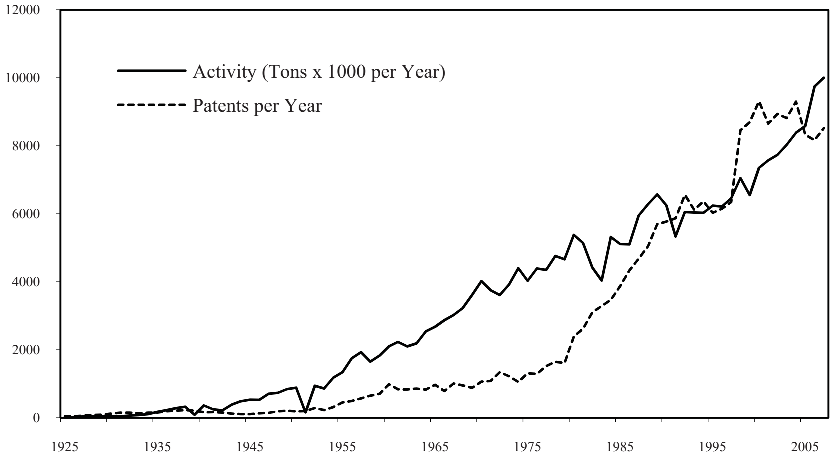

Figure A3.202. Titanium Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

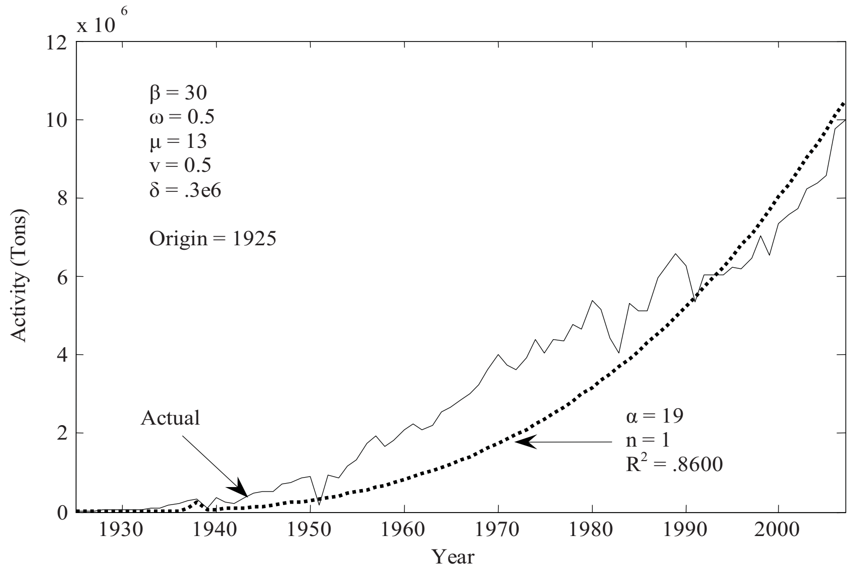

Figure A3.203. USGS World Titanium Production. World titanium production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

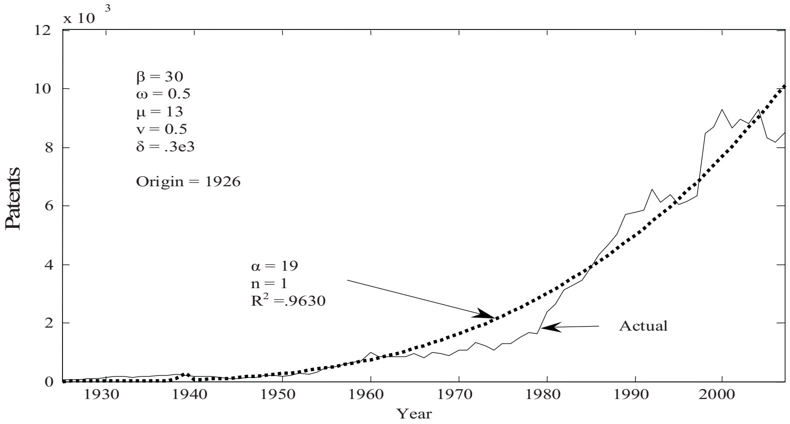

Figure A3.204. EPO Worldwide Patent Search: Titanium or Ti in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

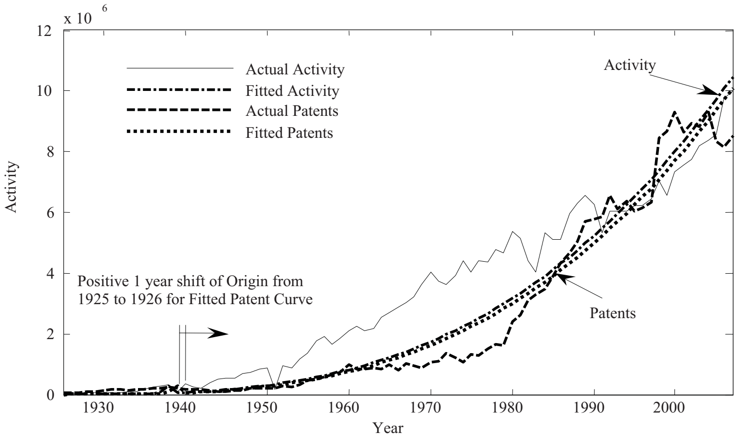

Figure A3.205. Titanium Best-Fit Activity and Patents. Illustrates best-fit origin shift.

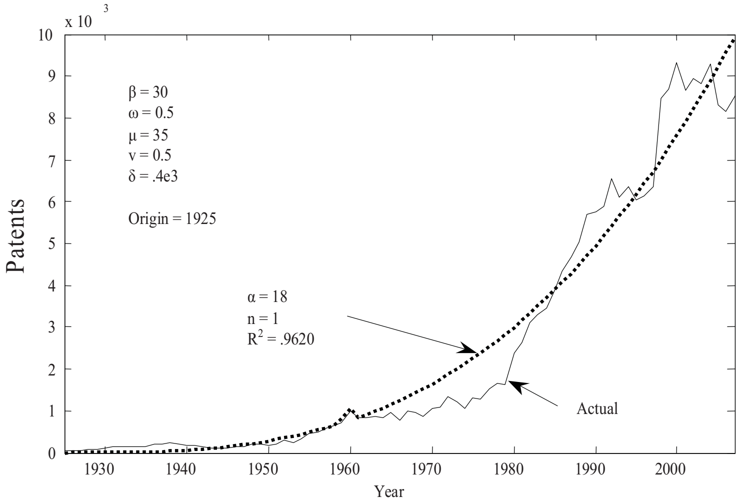

Figure A3.206. Titanium Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.93 Tungsten Activity[109] and Patents[110]

Year	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**
1900			**1927**	4400	100	**1954**	33800	160	**1981**	50300	602
1901			**1928**	5500	144	**1955**	35700	205	**1982**	47000	666
1902			**1929**	7500	145	**1956**	35800	169	**1983**	40900	740
1903			**1930**	7900	190	**1957**	29100	233	**1984**	46200	787
1904			**1931**	6400	244	**1958**	24200	200	**1985**	46600	890
1905	1700	14	**1932**	3200	230	**1959**	26400	195	**1986**	43500	1036
1906	1900	22	**1933**	5900	193	**1960**	31200	293	**1987**	42500	1030
1907	2600	55	**1934**	7800	187	**1961**	33000	260	**1988**	50900	1180
1908	1800	64	**1935**	10700	187	**1962**	31300	240	**1989**	51000	1331
1909	2500	39	**1936**	11800	189	**1963**	27100	289	**1990**	51900	1409
1910	3300	34	**1937**	18500	213	**1964**	28100	327	**1991**	48200	1323
1911	3200	48	**1938**	17800	245	**1965**	27000	341	**1992**	42900	1581
1912	4200	35	**1939**	20100	194	**1966**	28600	297	**1993**	34300	1285
1913	3900	65	**1940**	20700	126	**1967**	28500	380	**1994**	34000	1307
1914	3500	46	**1941**	23900	123	**1968**	31000	398	**1995**	38500	1201
1915	5200	41	**1942**	24100	85	**1969**	32500	380	**1996**	34700	1288
1916	10000	33	**1943**	28600	75	**1970**	32400	398	**1997**	33200	1230
1917	12300	26	**1944**	23400	73	**1971**	35400	417	**1998**	37000	1523
1918	15200	29	**1945**	10900	89	**1972**	38500	511	**1999**	37700	1616
1919	7000	31	**1946**	9040	131	**1973**	37900	501	**2000**	44000	2237
1920	5500	49	**1947**	13700	122	**1974**	37600	429	**2001**	50800	2217
1921	2300	63	**1948**	17800	139	**1975**	38300	419	**2002**	47000	2341
1922	3000	75	**1949**	15800	152	**1976**	38000	441	**2003**	47200	2094
1923	3300	87	**1950**	18300	117	**1977**	41100	411	**2004**	66600	1955
1924	2900	94	**1951**	24800	124	**1978**	46100	424	**2005**	59600	1584
1925	4900	123	**1952**	32700	174	**1979**	48600	415	**2006**	56600	1559
1926	5800	97	**1953**	34400	128	**1980**	52000	559	**2007**	54500	1603

Table A3.94. Correlation Eq.(A1.1) terms calculated from Table A3.93 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**$100r^2$**
2698440	52196	1.01E+11	62604270	2.15E+09	3.05E+10	36153567	7.79E+08	**0.741966**	**55.05131**

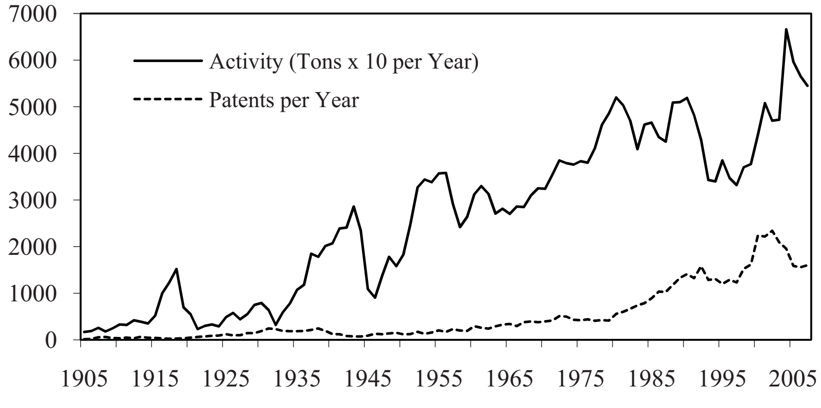

Figure A3.207. Tungsten Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[109] Activity represents world production of tungsten, defined at usgs.gov as "…tungsten content of concentrate. Data for the years 1905–2001 were from the MR [*Mineral Resources of the United States*] and the MYB [*Minerals Yearbook*]; datum for 2002 is a previously unpublished revision; data for 2003 to the most recent year are from the MYB. Blank cells in the worksheet indicate that data were not available for the years 1900–04." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[110] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Tungsten or Wolfram were used as keywords found in the patent title or abstract by year of publication.

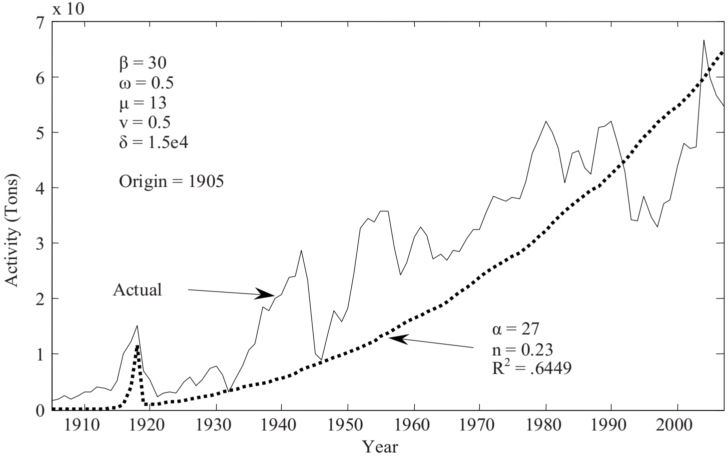

Figure A3.208. USGS World Tungsten Production. World tungsten production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

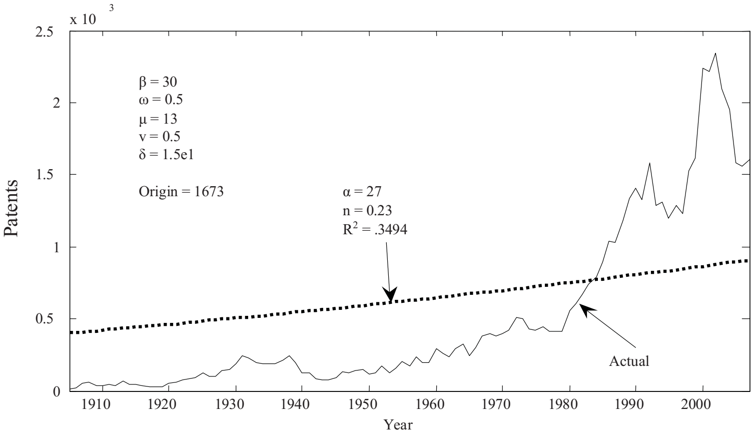

Figure A3.209. EPO Worldwide Patent Search: Tungsten or Wolfram in Title or Abstract by date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

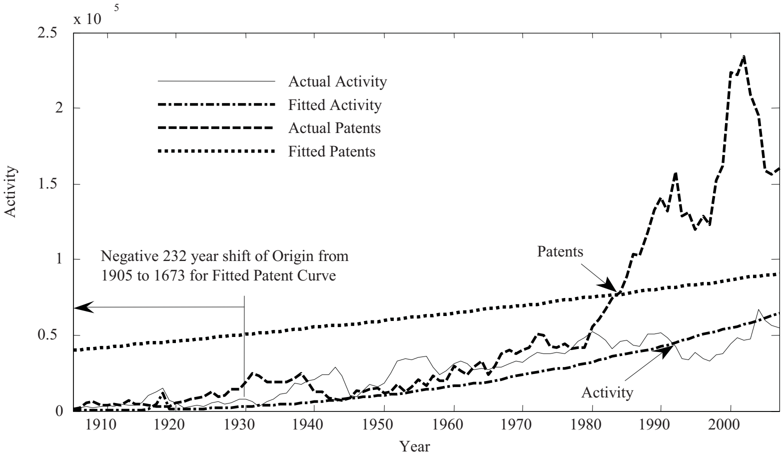

Figure A3.210. Tungsten Best-Fit Activity and Patents. Illustrates best-fit origin shift.

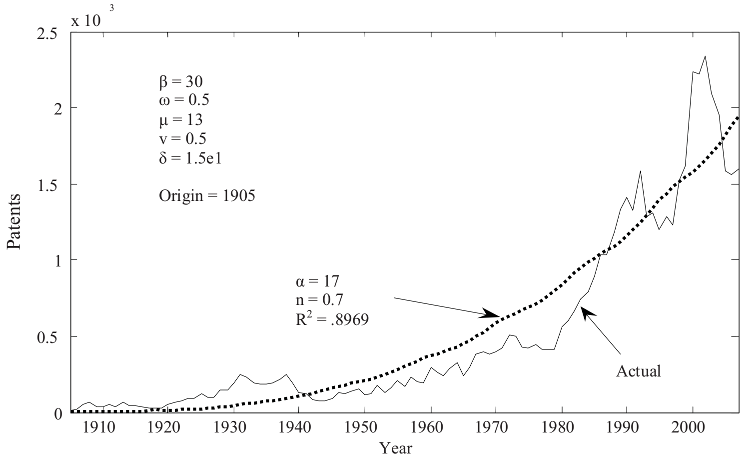

Figure A3.211. Tungsten Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.95 Vanadium Activity[111] and Patents[112]

Year	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**
1900			**1927**			**1954**			**1981**	35300	501
1901			**1928**			**1955**			**1982**	27200	500
1902			**1929**			**1956**			**1983**	27200	447
1903			**1930**			**1957**			**1984**	31100	501
1904			**1931**			**1958**			**1985**	31000	475
1905			**1932**			**1959**			**1986**	32000	415
1906			**1933**			**1960**	5040	196	**1987**	32000	476
1907			**1934**			**1961**	7850	154	**1988**	33000	471
1908			**1935**			**1962**	6080	164	**1989**	33000	510
1909			**1936**			**1963**	6500	160	**1990**	33200	503
1910			**1937**			**1964**	7170	172	**1991**	26400	553
1911			**1938**			**1965**	8300	215	**1992**	26700	624
1912			**1939**			**1966**	8440	173	**1993**	2500	607
1913			**1940**			**1967**	9610	217	**1994**	3200	616
1914			**1941**			**1968**	11400	216	**1995**	3600	542
1915			**1942**			**1969**	10300	172	**1996**	35100	587
1916			**1943**			**1970**	14900	206	**1997**	37100	599
1917			**1944**			**1971**	15800	257	**1998**	42700	736
1918			**1945**			**1972**	15500	250	**1999**	36300	764
1919			**1946**			**1973**	16000	215	**2000**	41000	949
1920			**1947**			**1974**	20400	203	**2001**	41800	877
1921			**1948**			**1975**	21600	292	**2002**	51000	880
1922			**1949**			**1976**	29200	288	**2003**	47900	1017
1923			**1950**			**1977**	29000	326	**2004**	51900	899
1924			**1951**			**1978**	29400	409	**2005**	56400	780
1925			**1952**			**1979**	37700	329	**2006**	56300	840
1926			**1953**			**1980**	35900	454	**2007**	58500	1027

Activity represents world production of Vanadium, defined at usgs.gov as "…mine production of vanadium. Data were from the MR [*Mineral Resources of the United States*] and MYB [*Minerals Yearbook*] for the years 1912–22, 1925, 1927-31, 1934–43, 1945–47, and 1998 to the most recent, the CDS [*Commodity Data Summaries*] for the years 1960–77, and the MCS for the years 1978–84 and 1990–97. Blank cells in the worksheet indicate that data were not available for the years 1900–11, 1923–24, and 1948–59. World production was interpolated to two significant figures for the years 1926, 1932–33, 1944, and 1985–89. World production data for the years 1927–31 and 1997–99 do not contain U.S. production." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[112] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Vanadium was used as the keyword found in the patent title or abstract by year of publication.

Table A3.96. Correlation Eq.(A1.1) terms calculated from Table A3.95 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	100r^2
1279490	22764	4.58E+10	13890388	7.56E+08	1.166E+10	3094561	1.49E+08	**0.783991**	**61.46415**

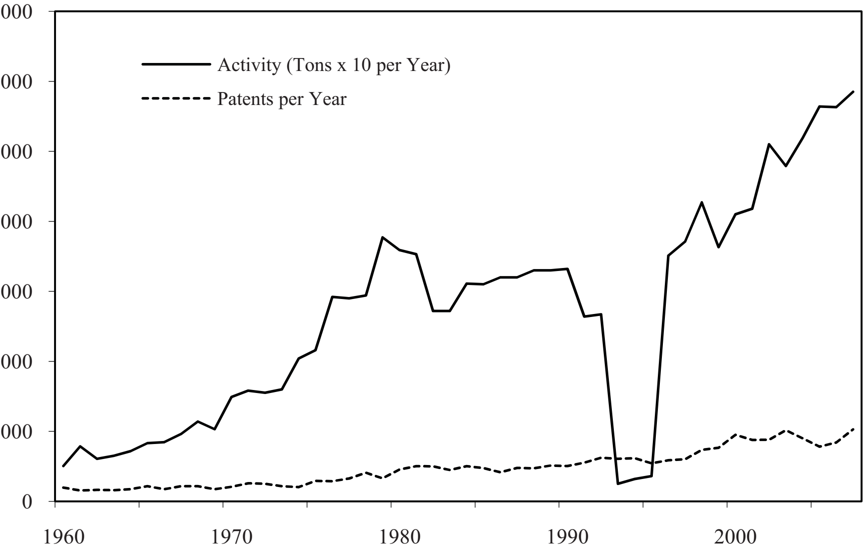

Figure A3.212. Vanadium Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

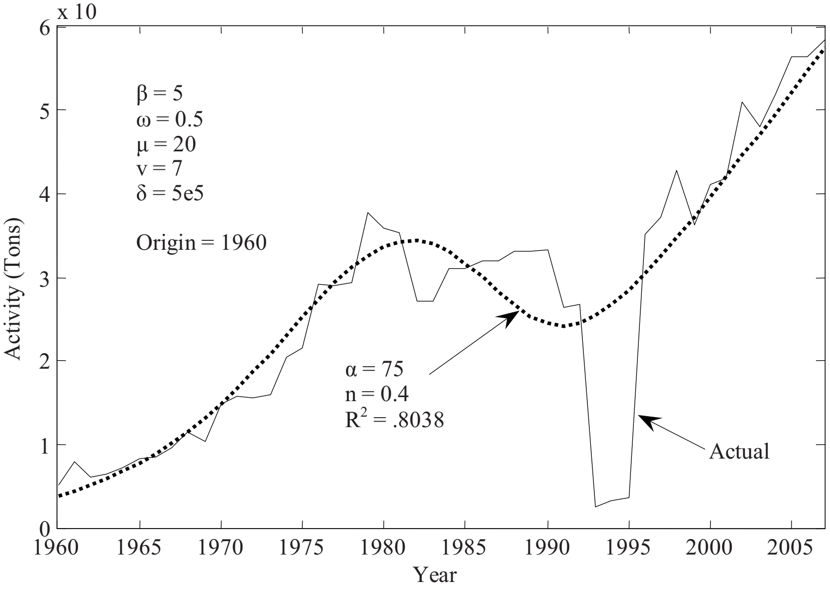

Figure A3.213. **USGS World Vanadium Production.** World vanadium production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

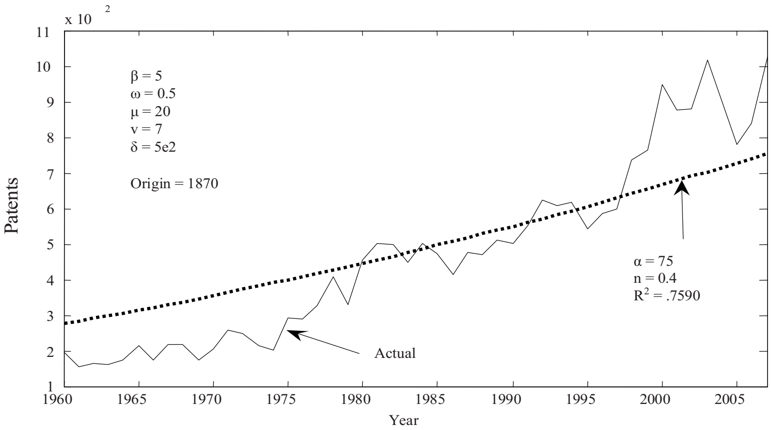

Figure A3.214. EPO Worldwide Patent search: Vanadium in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

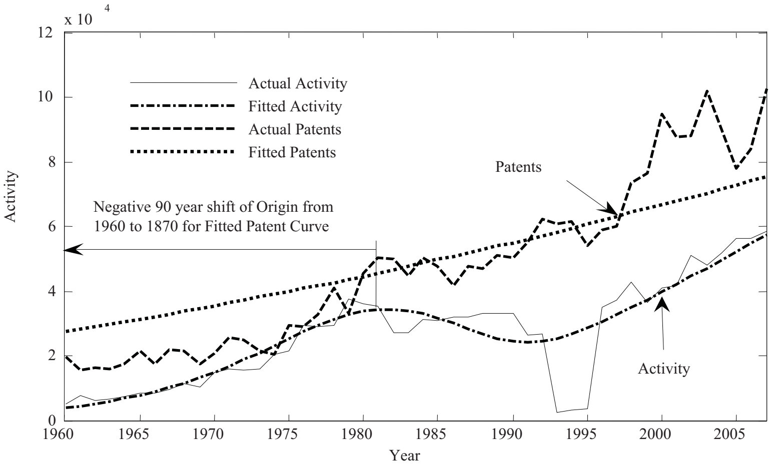

Figure A3.215. Vanadium Best-Fit Activity and Patents. Illustrates best-fit origin shift.

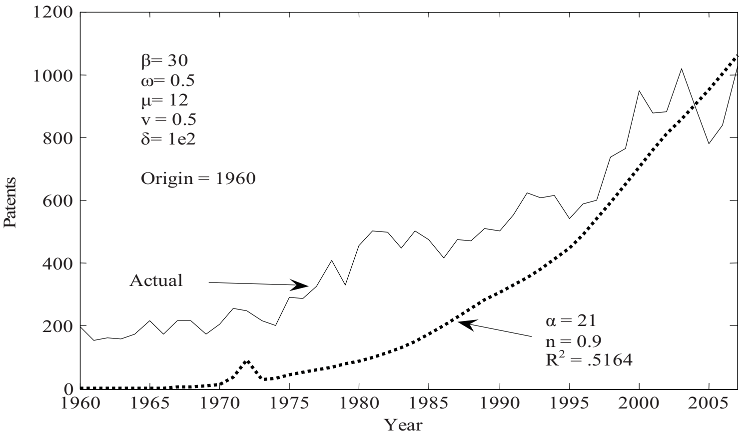

Figure A3.216. Vanadium Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.97 Zinc Activity[113] and Patents[114]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	479000	141	**1927**	1420000	313	**1954**	2660000	647	**1981**	5950000	2788
1901	510000	121	**1928**	1360000	361	**1955**	2900000	699	**1982**	6130000	3144
1902	547000	120	**1929**	1320000	384	**1956**	3110000	796	**1983**	6280000	3144
1903	574000	156	**1930**	1260000	517	**1957**	3150000	781	**1984**	6520000	3247
1904	629000	134	**1931**	904000	556	**1958**	2950000	715	**1985**	6760000	3367
1905	660000	122	**1932**	709000	488	**1959**	3020000	752	**1986**	6840000	3682
1906	704000	135	**1933**	892000	506	**1960**	3090000	1119	**1987**	7190000	3627
1907	738000	146	**1934**	1060000	511	**1961**	3490000	1019	**1988**	6770000	4000
1908	723000	151	**1935**	1210000	549	**1962**	3570000	924	**1989**	6820000	4387
1909	775000	132	**1936**	1330000	542	**1963**	3660000	992	**1990**	7150000	4233
1910	810000	148	**1937**	1470000	496	**1964**	4030000	1022	**1991**	7270000	4395
1911	895000	144	**1938**	1420000	643	**1965**	4310000	1164	**1992**	7250000	4914
1912	971000	154	**1939**	1500000	470	**1966**	4500000	1042	**1993**	6910000	4485
1913	939000	142	**1940**	1470000	357	**1967**	4840000	1291	**1994**	7050000	4561
1914	795000	115	**1941**	1590000	320	**1968**	4970000	1167	**1995**	7280000	4277
1915	760000	101	**1942**	1630000	274	**1969**	5340000	1087	**1996**	7480000	4352
1916	882000	86	**1943**	1830000	225	**1970**	5460000	1231	**1997**	7540000	4157
1917	901000	77	**1944**	1870000	191	**1971**	5520000	1335	**1998**	7570000	4851
1918	849000	74	**1945**	1470000	306	**1972**	5440000	1485	**1999**	7960000	4908
1919	719000	124	**1946**	1440000	327	**1973**	5710000	1339	**2000**	8770000	5522
1920	682000	162	**1947**	1600000	365	**1974**	5780000	1217	**2001**	8910000	5554
1921	464000	234	**1948**	1690000	492	**1975**	5850000	1510	**2002**	8880000	5953
1922	730000	228	**1949**	1730000	468	**1976**	5690000	1610	**2003**	9520000	5954
1923	889000	222	**1950**	2150000	385	**1977**	5920000	1677	**2004**	9590000	5797
1924	986000	225	**1951**	2360000	503	**1978**	5850000	2034	**2005**	9930000	5689
1925	1190000	261	**1952**	2590000	608	**1979**	5990000	2066	**2006**	10000000	5645
1926	1410000	254	**1953**	2670000	482	**1980**	5950000	2698	**2007**	10900000	5884

Table A3.98. Correlation Eq.(A1.1) terms calculated from Table A3.97 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
395126000	171684	2.35E+15	6.34E+08	1.16E+12	9.058E+14	3.61E+08	5.37E+11	**0.938743**	**88.12379**

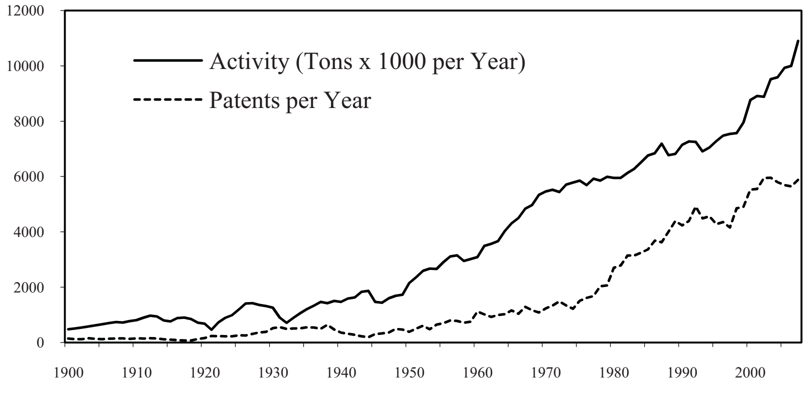

Figure A3.217. Zinc Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

Activity represents world production of Zinc, defined at usgs.gov as "…zinc content of smelter production for the years 1900–12, 1914–17, and 1929–42. World mine production data were used for the years 1913, 1918–28, and 1943 to the most recent. Data were from the MR [*Mineral Resources of the United States*] and MYB [*Minerals Yearbook*]." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[114] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Zinc or Zn were used as keywords found in the patent title or abstract by year of publication.

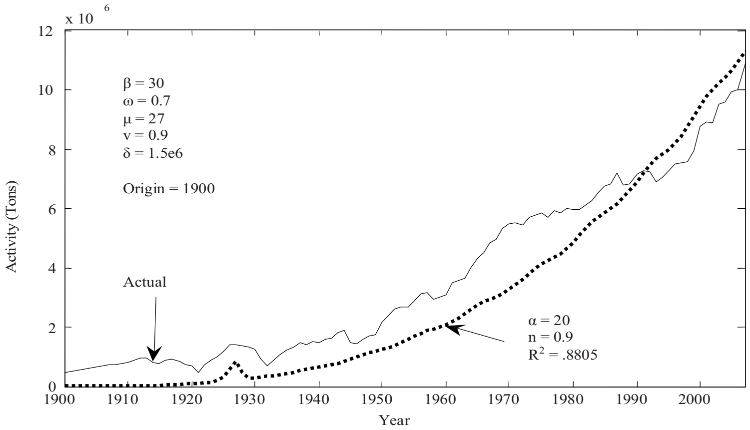

Figure A3.218. USGS World Zinc Production. World zinc production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

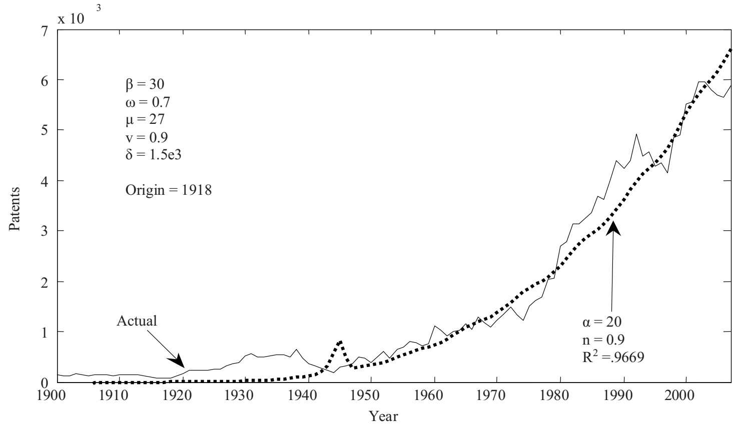

Figure A3.219. EPO Worldwide Patent Search: Zinc or Zn in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

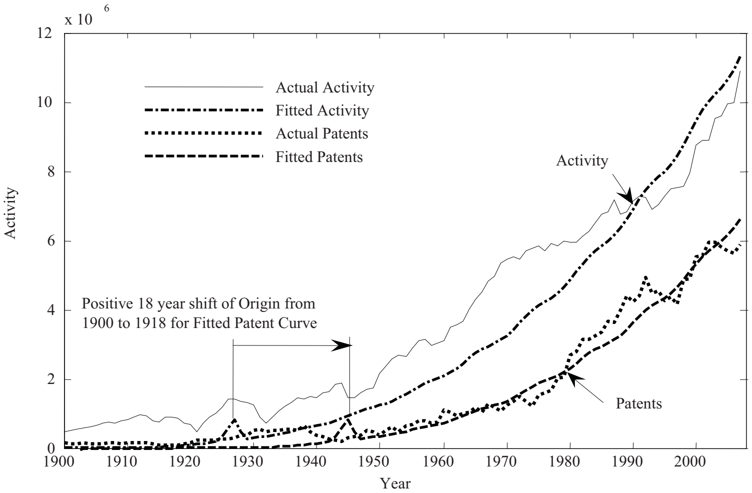

Figure A3.220. Zinc Best-Fit Activity and Patents. Illustrates best-fit origin shift.

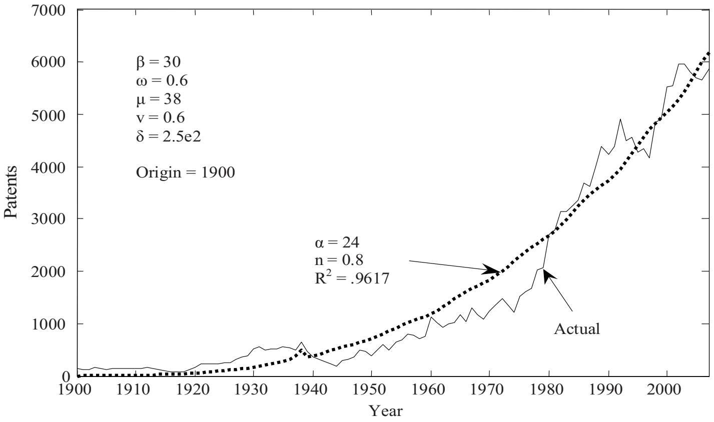

Figure A3.221. **Zinc Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A3.99 Zirconium Activity[115] and Patents[116]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**	63200	109	**1981**	645000	908
1901			**1928**			**1955**	78200	170	**1982**	710000	1030
1902			**1929**			**1956**	118000	186	**1983**	666000	1204
1903			**1930**			**1957**	146000	256	**1984**	736000	1308
1904			**1931**			**1958**	105000	270	**1985**	815000	1419
1905			**1932**			**1959**	103000	272	**1986**	741000	1596
1906			**1933**			**1960**	129000	417	**1987**	753000	1777
1907			**1934**			**1961**	159000	371	**1988**	929000	1941
1908			**1935**			**1962**	149000	387	**1989**	979000	2259
1909			**1936**			**1963**	195000	365	**1990**	852000	2155
1910			**1937**			**1964**	191000	363	**1991**	795000	2173
1911			**1938**			**1965**	235000	408	**1992**	856000	2379
1912			**1939**			**1966**	244000	383	**1993**	796000	2292
1913			**1940**			**1967**	293000	475	**1994**	897000	2257
1914			**1941**			**1968**	309000	476	**1995**	918000	2165
1915			**1942**			**1969**	386000	405	**1996**	894000	2083
1916			**1943**			**1970**	399000	478	**1997**	830000	2004
1917			**1944**	17300	37	**1971**	432000	443	**1998**	732000	2419
1918			**1945**	19700	48	**1972**	369000	557	**1999**	673000	2503
1919			**1946**	24700	51	**1973**	379000	497	**2000**	731000	2711
1920			**1947**	25900	53	**1974**	397000	445	**2001**	750000	2604
1921			**1948**	26600	77	**1975**	418000	535	**2002**	973000	2960
1922			**1949**	24100	88	**1976**	448000	503	**2003**	1030000	2841
1923			**1950**	25200	73	**1977**	505000	562	**2004**	1090000	3106
1924			**1951**	46200	126	**1978**	525000	658	**2005**	1100000	2694
1925			**1952**	33900	114	**1979**	629000	623	**2006**	1250000	2879
1926			**1953**	53300	80	**1980**	680000	867	**2007**	1470000	3082

Activity represents world production of Zirconium, defined at usgs.gov as "…zirconium mineral concentrates. Data were from the MR [*Mineral Resources of the United States*] and MYB [*Minerals Yearbook*]. Blank cells in the worksheet indicate that data were not available for the years 1900–43. Production data for the United States were not included for the years 1944–52, 1959–87, and 1993 to the most recent." Data is in metric tons as reported by the United States Geologic Survey (USGS) at minerals.usgs.gov.

[116] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Zirconium or Zr were used as keywords found in the patent title or abstract by year of publication.

Table A3.100. Correlation Eq.(A1.1) terms calculated from Table A3.99 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
31992300	70977	2.48E+13	1.43E+08	5.75E+10	8.797E+12	64722075	2.2E+10	**0.923869**	**85.35335**

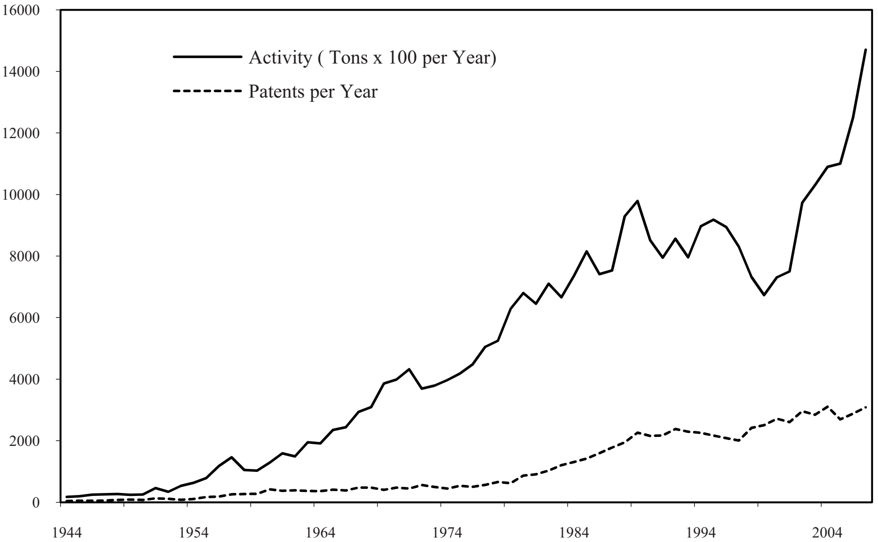

Figure A3.222. Zirconium Activity and Patents. data illustrates correlation. Activity scaled to fit plot.

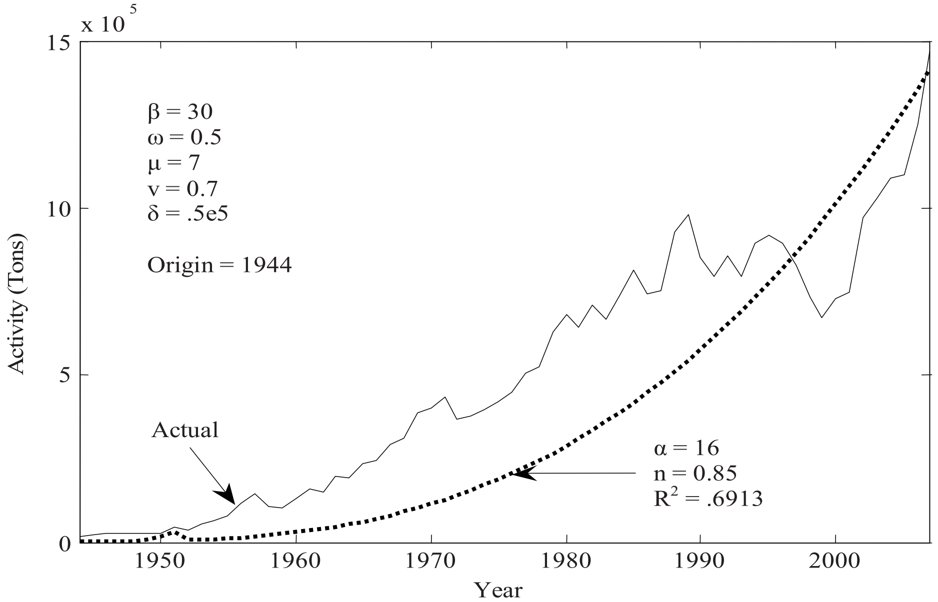

Figure A3.223. **USGS World Zirconium Production.** World zirconium production (activity) scaled in metric tons with actual and best-fit curves and common pattern equation parameters.

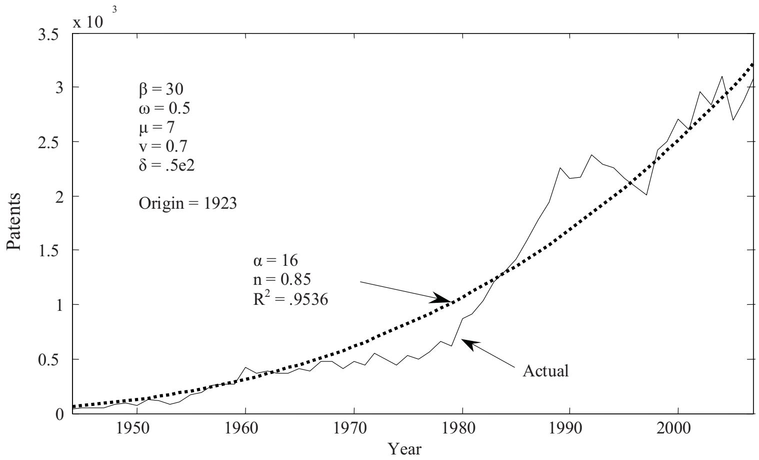

Figure A3.224. EPO Worldwide patent Search: Zirconium or Zr in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

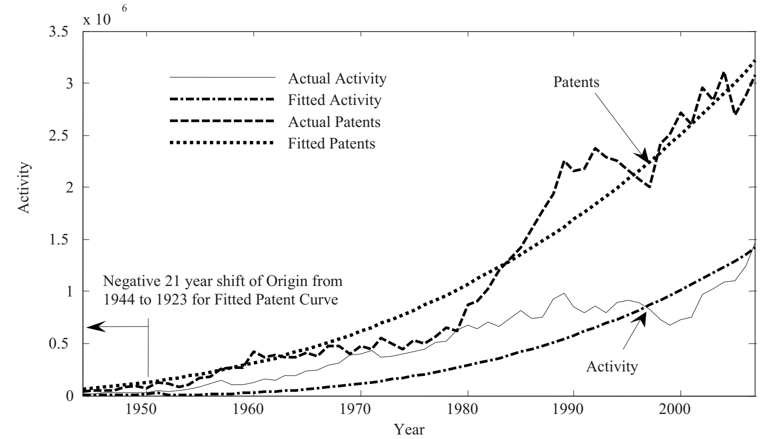

Figure A3.225. Zirconium Best-Fit Activity and Patents. Illustrates best-fit origin shift.

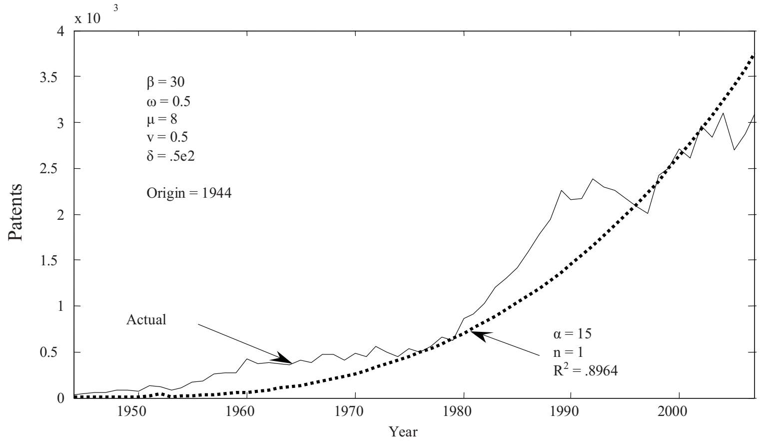

Figure A3.226. Zirconium Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Appendix 4: Energy Sources Data

Table A4.1 U.S. Biofuel Energy Activity[117] and Patents[118]

Year	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**
1900			**1927**			**1954**			**1981**	13043.9	1
1901			**1928**			**1955**			**1982**	35281.53	1
1902			**1929**			**1956**			**1983**	64754.16	0
1903			**1930**			**1957**			**1984**	79274.4	1
1904			**1931**			**1958**			**1985**	95527.26	2
1905			**1932**			**1959**			**1986**	109831.4	0
1906			**1933**			**1960**			**1987**	125855.1	0
1907			**1934**			**1961**			**1988**	127221.9	0
1908			**1935**			**1962**			**1989**	128575.7	0
1909			**1936**			**1963**			**1990**	113694.6	1
1910			**1937**			**1964**			**1991**	131265.1	2
1911			**1938**			**1965**			**1992**	148704.8	0
1912			**1939**			**1966**			**1993**	173374.6	1
1913			**1940**			**1967**			**1994**	193197.2	8
1914			**1941**			**1968**			**1995**	204894.4	5
1915			**1942**			**1969**			**1996**	146431.5	5
1916			**1943**			**1970**			**1997**	188311.9	8
1917			**1944**			**1971**			**1998**	206162.7	10
1918			**1945**			**1972**			**1999**	214298.2	16
1919			**1946**			**1973**			**2000**	241725.6	12
1920			**1947**			**1974**			**2001**	259057.8	13
1921			**1948**			**1975**			**2002**	311003.3	15
1922			**1949**			**1976**			**2003**	415283.1	33
1923			**1950**			**1977**			**2004**	515133.9	62
1924			**1951**			**1978**			**2005**	596543.9	119
1925			**1952**			**1979**			**2006**	798629.3	167
1926			**1953**			**1980**			**2007**	1029982	426
									2008	1420147	638

Table A4.2 Correlation Eq.(A1.1) terms calculated from Table A4.1 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**$100r^2$**
8087206.9	1546	5.07E+12	636588	1.61E+09	2.733E+12	551226.7	1.16E+09	**0.946938**	**89.66916**

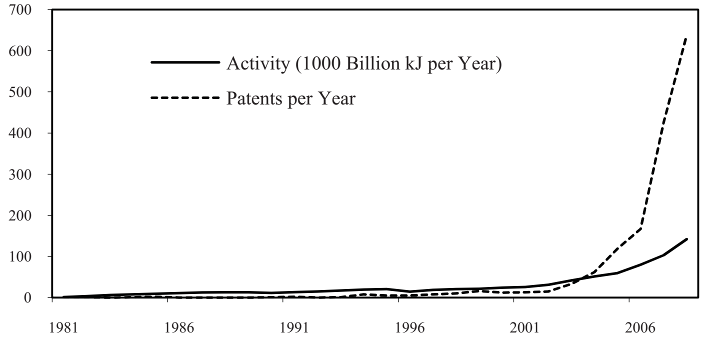

Figure A4.1. U.S. Biofuel Energy Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[117] Activity represents United States production of biofuel energy, defined at eia.doe.gov as energy from " total biomass inputs to the production of fuel ethanol and biodiesel." Data is in billion Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ.

[118] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Biofuel or biofuels or biodiesel were used as keywords found in the patent title or abstract by year of publication.

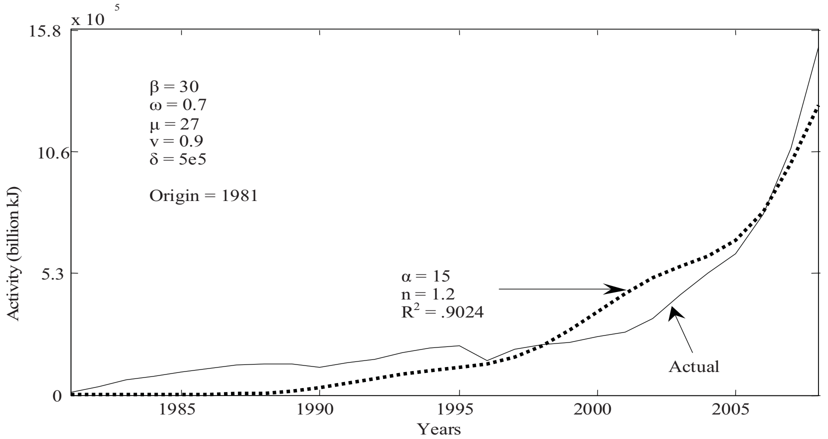

Figure A4.2. **EIA U.S. Biofuel Energy Production.** U.S. biofuel power production (activity) scaled in billion kJ with actual and best-fit curves and common pattern equation parameters.

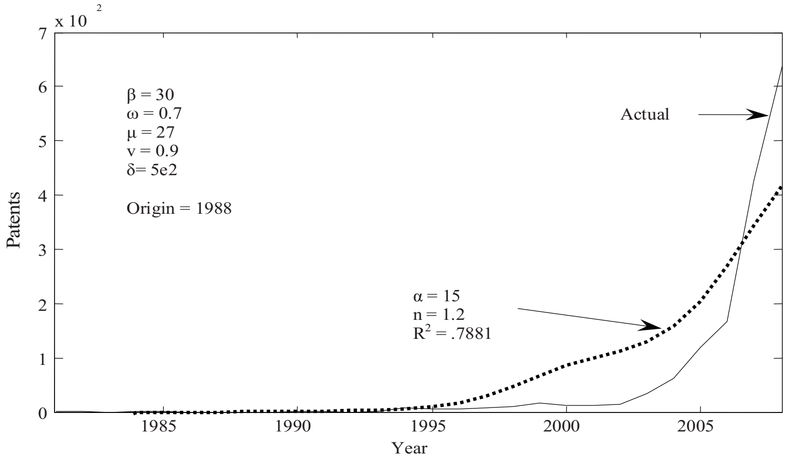

Figure A4.3. EPO Worldwide Patent Search: Biofuel or Biofuels or Biodiesel in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

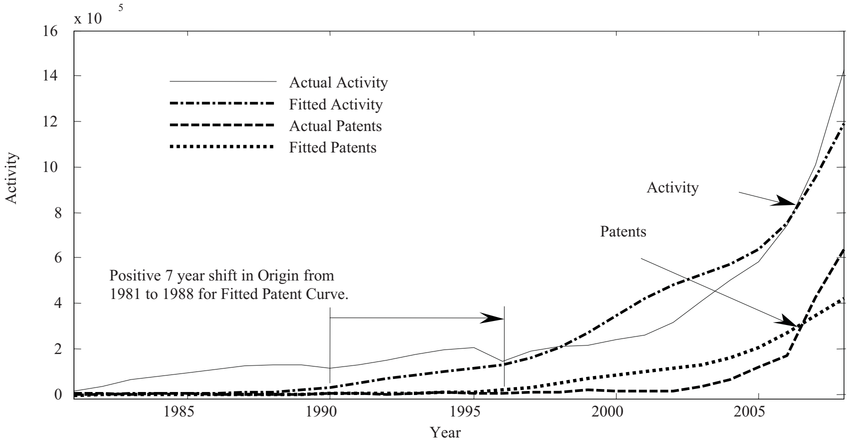

Figure A4.4. U.S. Biofuel Energy best-Fit Activity and Patents. Illustrates best-fit origin shift.

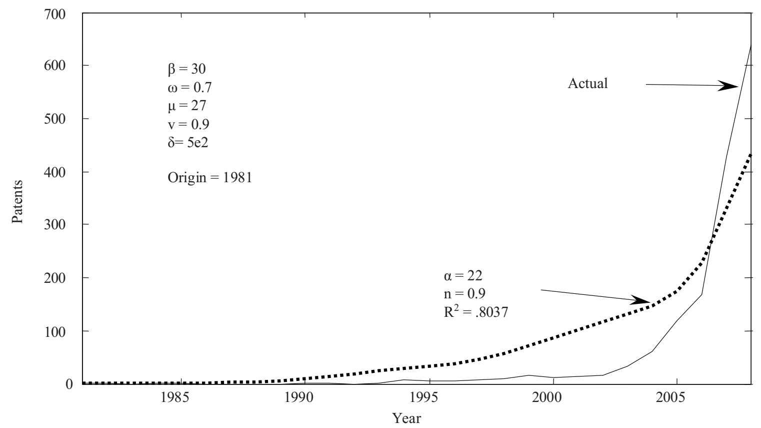

Figure A4.5. U.S. Biofuel Energy Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.3 U.S. Biomass Energy Activity[119] and Patents[120]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**	1471015	0	**1981**	2739352	55
1901			**1928**			**1955**	1502471	0	**1982**	2810682	91
1902			**1929**			**1956**	1493744	0	**1983**	3065517	106
1903			**1930**			**1957**	1406928	0	**1984**	3136195	126
1904			**1931**			**1958**	1395895	0	**1985**	3184131	136
1905			**1932**			**1959**	1427282	0	**1986**	3095665	123
1906			**1933**			**1960**	1392463	0	**1987**	3035644	143
1907			**1934**			**1961**	1365974	0	**1988**	3184602	112
1908			**1935**			**1962**	1371755	0	**1989**	3335821	157
1909			**1936**			**1963**	1396098	0	**1990**	2887927	157
1910			**1937**			**1964**	1410326	0	**1991**	2937553	137
1911			**1938**			**1965**	1408173	0	**1992**	3096042	167
1912			**1939**			**1966**	1444279	0	**1993**	3072057	164
1913			**1940**			**1967**	1413963	0	**1994**	3198106	175
1914			**1941**			**1968**	1497567	0	**1995**	3273789	211
1915			**1942**			**1969**	1519714	0	**1996**	3331884	199
1916			**1943**			**1970**	1509665	0	**1997**	3282854	224
1917			**1944**			**1971**	1511101	0	**1998**	3094379	373
1918			**1945**			**1972**	1585734	7	**1999**	3132753	554
1919			**1946**			**1973**	1613167	7	**2000**	3175992	491
1920			**1947**			**1974**	1624338	1	**2001**	2773944	728
1921			**1948**			**1975**	1581164	10	**2002**	2860810	677
1922			**1949**	1634471	0	**1976**	1807609	13	**2003**	2969689	1912
1923			**1950**	1648234	0	**1977**	1939440	18	**2004**	3176138	1728
1924			**1951**	1619076	0	**1978**	2149673	41	**2005**	3291750	3179
1925			**1952**	1555459	0	**1979**	2270261	47	**2006**	3491022	1183
1926			**1953**	1496624	0	**1980**	2611653	52	**2007**	3780533	1503
									2008	4114410	2304

Activity represents U.S. production of biomass energy, defined at usgs.gov as energy from "Wood and wood derived fuels, biomass waste, fuel ethanol and biodiesel." Data is in billion Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ..

[120] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Biomass was used as the keyword found in the patent title or abstract by year of publication.

Table A4.4. Correlation Eq.(A1.1) terms calculated from Table A4.3 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	100r^2
139604559	17311	3.66E+14	27790219	5.75E+10	4.132E+13	22795707	1.73E+10	**0.562375**	**31.62656**

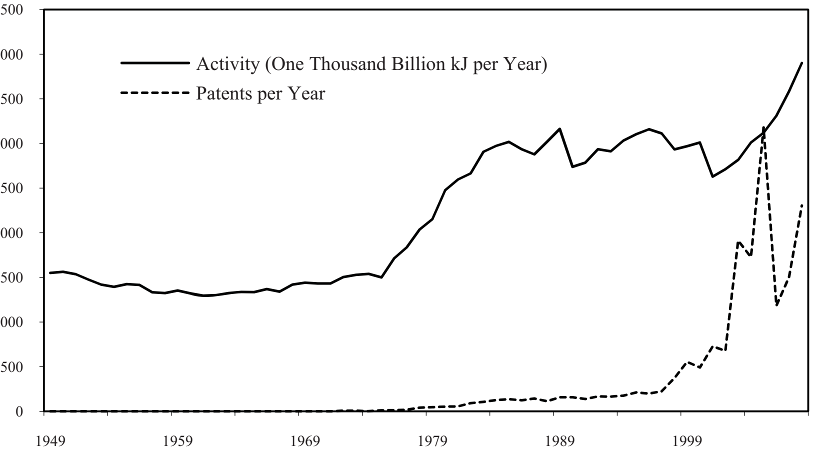

Figure A4.6. U.S. Biomass Energy Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

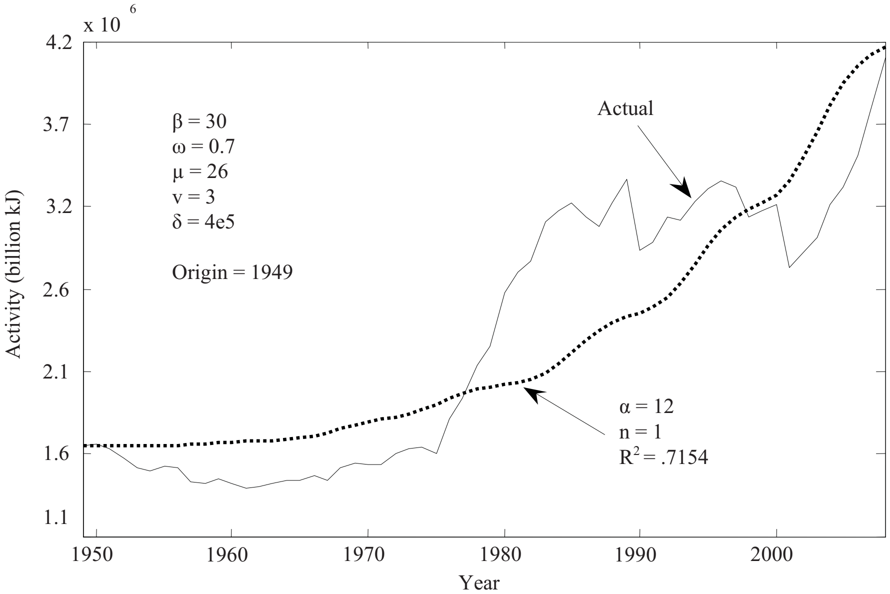

Figure A4.7. EIA U.S. Biomass Energy Production. U.S. biomass energy production (activity) scaled in billion kJ with actual and best-fit curves and common pattern equation parameters.

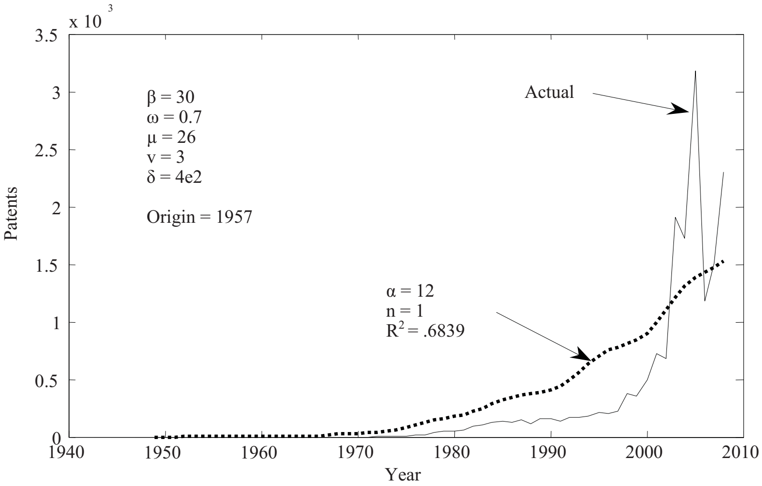

Figure A4.8. EPO Worldwide Patent Search: Biomass in title or abstract by date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

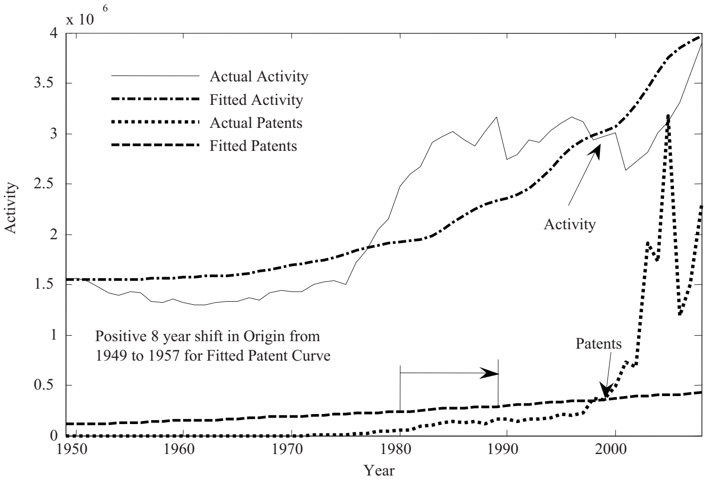

Figure A4.9. U.S. Biomass Energy Best-Fit Activity and Patents. Illustrates best-fit origin shift.

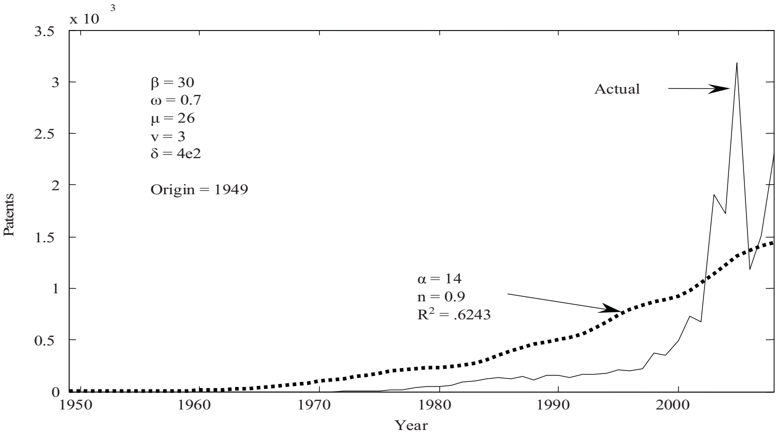

Figure A4.10. U.S. Biomass Energy Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.5 U.S. Coal Energy Activity[121] and Patents[122]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (pat.)
1900			**1927**			**1954**	11122283	267	**1981**	19387496	2289
1901			**1928**			**1955**	13049936	279	**1982**	19663906	2539
1902			**1929**			**1956**	14038182	312	**1983**	18195238	2675
1903			**1930**			**1957**	13779770	301	**1984**	20803773	2442
1904			**1931**			**1958**	11376158	232	**1985**	20388050	2266
1905			**1932**			**1959**	11370773	217	**1986**	20582487	2209
1906			**1933**			**1960**	11412355	285	**1987**	21248865	2200
1907			**1934**			**1961**	11021681	288	**1988**	21878209	1981
1908			**1935**			**1962**	11500091	262	**1989**	22534988	2022
1909			**1936**			**1963**	12500937	262	**1990**	23724363	1676
1910			**1937**			**1964**	13212694	270	**1991**	22826427	1842
1911			**1938**			**1965**	13773326	318	**1992**	22887309	1857
1912			**1939**			**1966**	14208401	281	**1993**	21454115	1556
1913			**1940**			**1967**	14585889	343	**1994**	23423198	1613
1914			**1941**			**1968**	14357155	327	**1995**	23346675	1561
1915			**1942**			**1969**	14625830	266	**1996**	24043606	1510
1916			**1943**			**1970**	15410453	297	**1997**	24591643	1596
1917			**1944**			**1971**	13910727	333	**1998**	25367685	1722
1918			**1945**			**1972**	14866728	373	**1999**	24576314	1781
1919			**1946**			**1973**	14761693	340	**2000**	23985929	1676
1920			**1947**			**1974**	14848546	356	**2001**	24842169	1660
1921			**1948**			**1975**	15813727	435	**2002**	23982510	1733
1922			**1949**	12632446	214	**1976**	16514640	648	**2003**	23308803	1843
1923			**1950**	14833442	162	**1977**	16621252	921	**2004**	24108964	2012
1924			**1951**	15212388	195	**1978**	15729848	1262	**2005**	24460374	2144
1925			**1952**	13434700	301	**1979**	18504260	1378	**2006**	25097933	3000
1926			**1953**	12953022	221	**1980**	19620601	1725	**2007**	24784843	4032
									2008	25167991	4778

Table A4.6 Correlation Eq.(A1.1) terms calculated from Table A4.5 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
1092767796	73886	2.13E+16	1.54E+08	1.59E+12	1.382E+15	63499265	2.44E+11	**0.823513**	**67.81735**

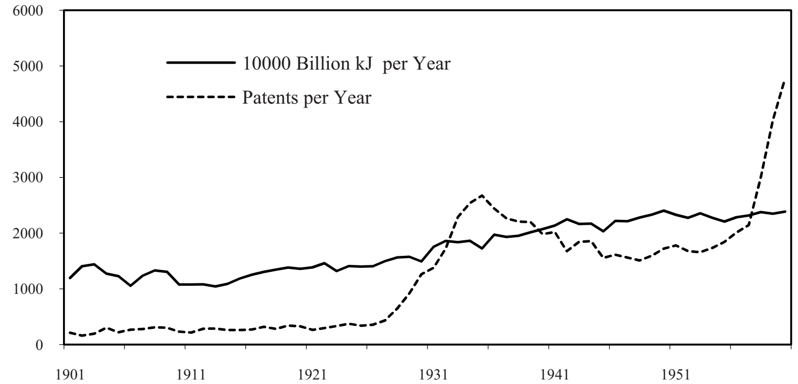

Figure A4.11. U.S. Coal Energy Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[121] Activity represents United States production of coal energy, defined at eia.doe.gov as primary energy production from coal and in 1989 waste coal and 2001 refuse recovery. Data is in billions of Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ..

[122] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Coal was used as the keyword found in the patent title or abstract by year of publication.

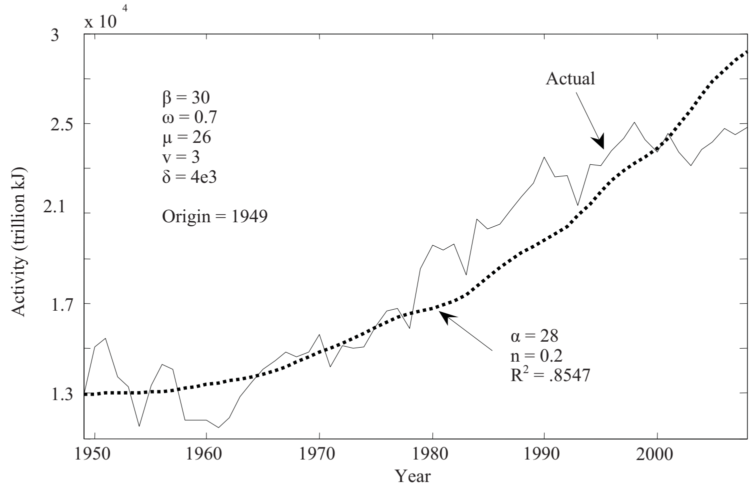

Figure A4.12. **EIA U.S. Coal Energy Production.** U.S. coal production (activity) scaled in trillions of kJ's with actual and best-fit curves and common pattern equation parameters.

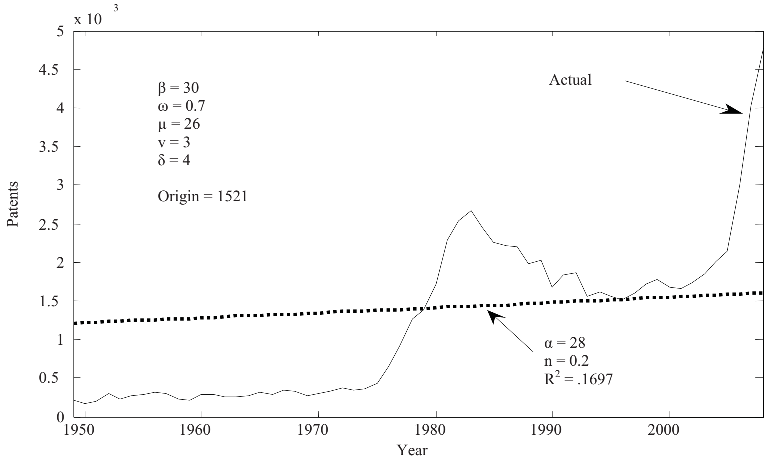

Figure A4.13. EPO Worldwide Patent Search: Coal in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

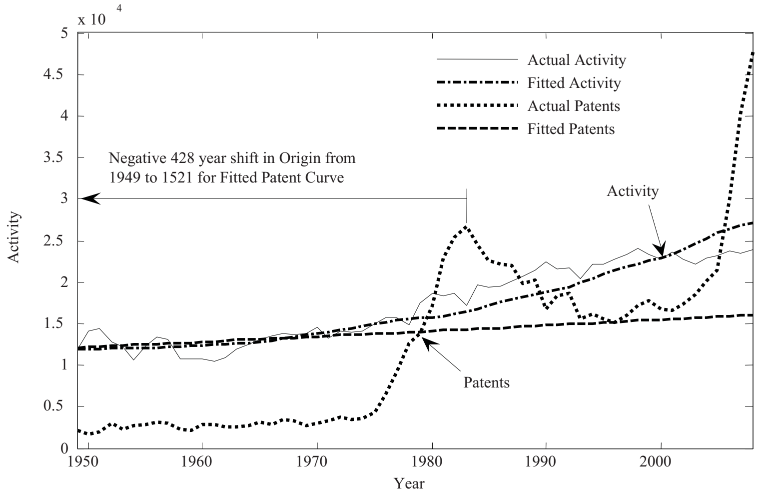

Figure A4.14. U.S. Coal Energy Best-Fit Activity and Patents. Illustrates best-fit origin shift.

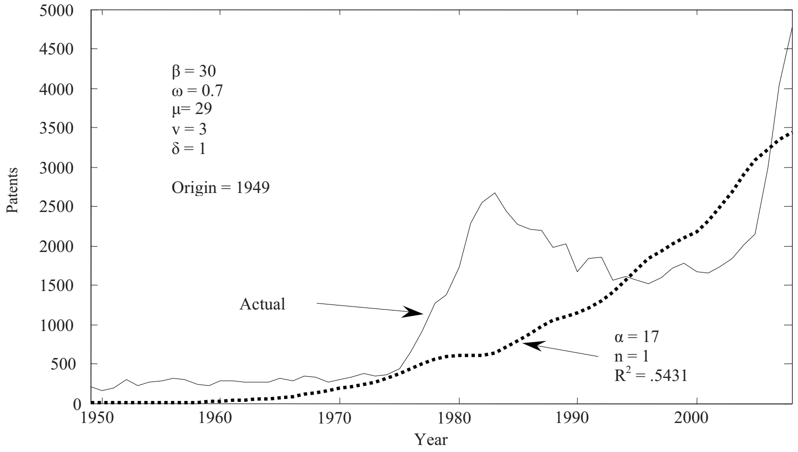

Figure A4.15. U.S. Coal Energy Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.7 U.S. Fossil Fuel Energy Activity[123] and Patents[124]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (pat)
1900			**1927**			**1954**	35621368	820	**1981**	61748438	3838
1901			**1928**			**1955**	39418682	847	**1982**	60617996	4154
1902			**1929**			**1956**	41958882	1026	**1983**	57408839	4460
1903			**1930**			**1957**	42340826	1160	**1984**	62085860	4236
1904			**1931**			**1958**	39263220	1075	**1985**	60703354	4115
1905			**1932**			**1959**	41192703	1005	**1986**	59686869	4114
1906			**1933**			**1960**	42061918	1312	**1987**	60310921	4077
1907			**1934**			**1961**	42524028	1222	**1988**	61058103	3810
1908			**1935**			**1962**	44027139	1114	**1989**	60644226	4078
1909			**1936**			**1963**	46459226	1072	**1990**	61780380	3869
1910			**1937**			**1964**	48307343	1088	**1991**	61054672	3829
1911			**1938**			**1965**	49832822	1252	**1992**	60826087	4207
1912			**1939**			**1966**	52787312	1129	**1993**	58892299	3596
1913			**1940**			**1967**	55489974	1321	**1994**	61236037	3769
1914			**1941**			**1968**	57293027	1269	**1995**	60704840	3782
1915			**1942**			**1969**	59381275	1105	**1996**	61598522	3599
1916			**1943**			**1970**	62441305	1193	**1997**	62093750	3763
1917			**1944**			**1971**	61233846	1240	**1998**	62576342	4590
1918			**1945**			**1972**	62179489	1528	**1999**	60783280	4706
1919			**1946**			**1973**	61444773	1318	**2000**	60521144	5067
1920			**1947**			**1974**	59428950	1267	**2001**	61761121	4458
1921			**1948**			**1975**	57743603	1486	**2002**	60022709	5321
1922			**1949**	30329326	572	**1976**	57732655	1786	**2003**	59245148	5552
1923			**1950**	34353614	454	**1977**	58131325	2188	**2004**	58989213	6039
1924			**1951**	37760719	596	**1978**	58103194	2464	**2005**	58083775	6038
1925			**1952**	36900452	860	**1979**	61195917	2410	**2006**	59046401	7237
1926			**1953**	37293549	673	**1980**	62253306	3210	**2007**	59339357	9154
									2008	61126974	10376

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[123] Activity represents United States production of fossil fuel energy, defined at eia.doe.gov as primary energy from coal, natural gas (dry), crude oil, and natural gas plant liquids."Data is in billion Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ.

[124] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Coal, petroleum and natural gas were used as keywords found in the patent title or abstract by year of publication.

Table A4.8 Correlation Eq.(A1.1) terms calculated from Table A4.7 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**$100r^2$**
3270432426	176896	1.83E+17	7.95E+08	1.04E+13	5.185E+15	2.74E+08	7.1E+11	**0.595587**	**35.47237**

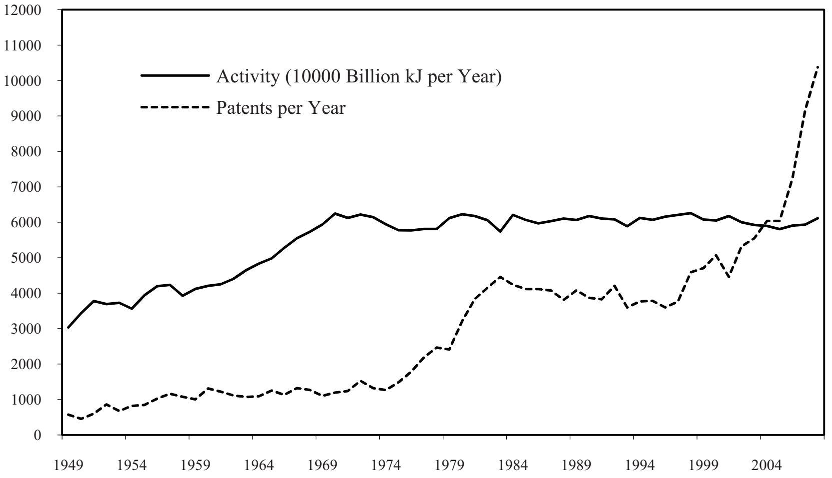

Figure A4.16. U.S. Fossil Fuel Energy Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

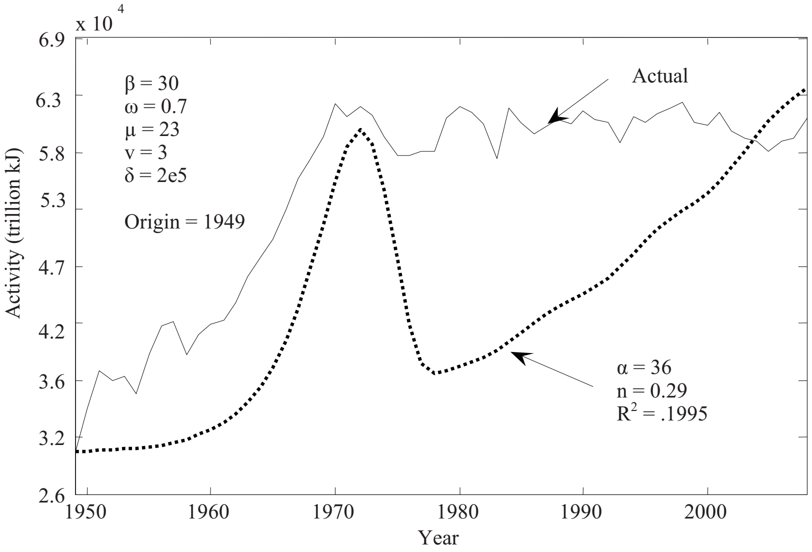

Figure A4.17. **EIA U.S. Fossil Fuel Energy Production.** U.S. fossil fuel power production (activity) scaled in trillion kJ with actual and best-fit curves and common pattern equation parameters.

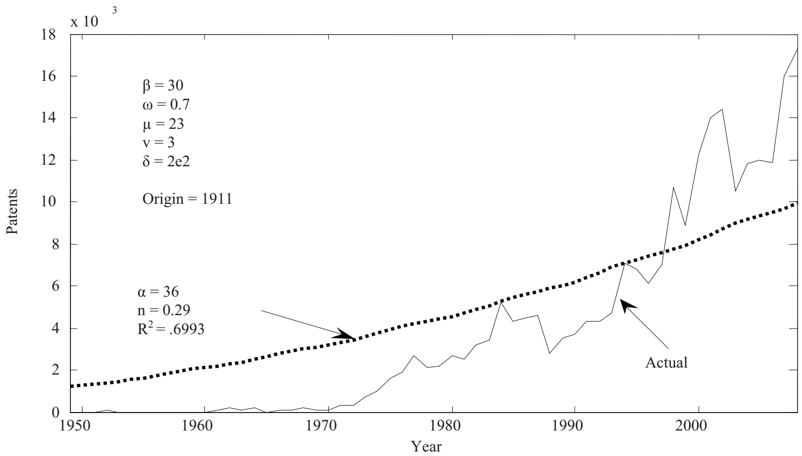

Figure A4.18. EPO Worldwide Patent Search: Fossil Fuel or Natural Gas or Coal in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

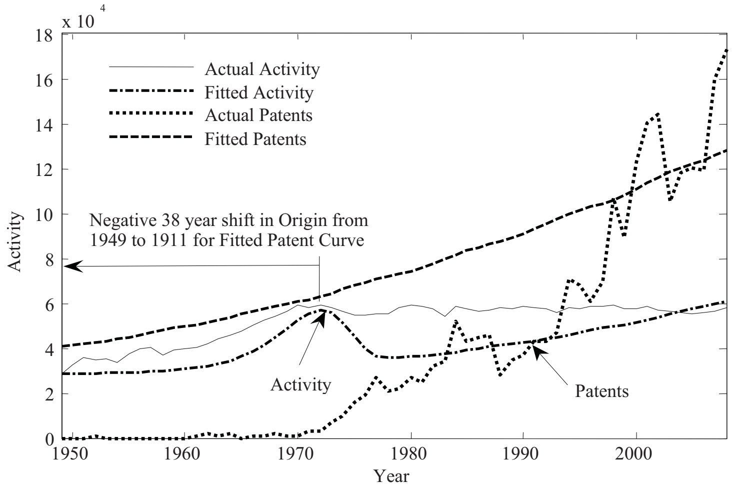

Figure A4.19. U.S. Fossil Fuel Power Best-fit Activity and Patents. Illustrates best-fit origin shift.

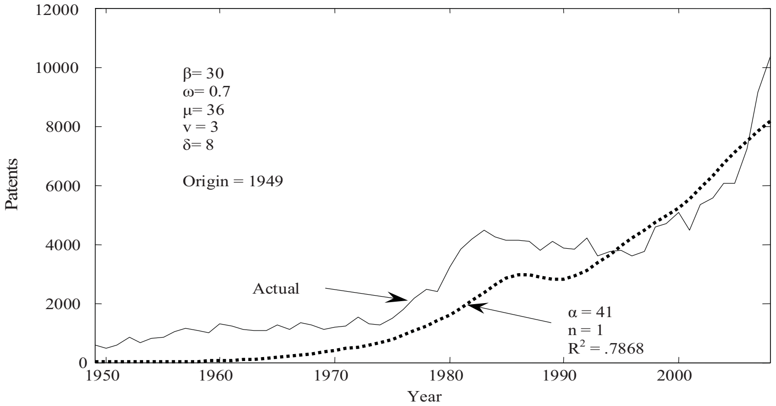

Figure A4.20. U.S. Fossil Fuel Energy Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.9 U.S. Geothermal Energy Activity[125] and Patents[126]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**			**1981**	129810.4	30
1901			**1928**			**1955**			**1982**	110507	52
1902			**1929**			**1956**			**1983**	136452.6	46
1903			**1930**			**1957**			**1984**	173965.3	41
1904			**1931**			**1958**			**1985**	209187.5	48
1905			**1932**			**1959**			**1986**	231232.8	38
1906			**1933**			**1960**	816.57	0	**1987**	241720.5	34
1907			**1934**			**1961**	2300.955	0	**1988**	229241	31
1908			**1935**			**1962**	2459.205	0	**1989**	334607	27
1909			**1936**			**1963**	3930.93	0	**1990**	354270.1	27
1910			**1937**			**1964**	4768.6	1	**1991**	365290.6	24
1911			**1938**			**1965**	4427.835	0	**1992**	368521	22
1912			**1939**			**1966**	4399.35	0	**1993**	383720.4	13
1913			**1940**			**1967**	7264.73	1	**1994**	356703.9	20
1914			**1941**			**1968**	9933.88	0	**1995**	310057.1	26
1915			**1942**			**1969**	14011.46	0	**1996**	332883.1	36
1916			**1943**			**1970**	11971.09	0	**1997**	342831.7	45
1917			**1944**			**1971**	12514.41	1	**1998**	346359.7	36
1918			**1945**			**1972**	33210.35	4	**1999**	349119.5	37
1919			**1946**			**1973**	44948.28	3	**2000**	334219.8	40
1920			**1947**			**1974**	56081.69	11	**2001**	328383.5	53
1921			**1948**			**1975**	74011.42	13	**2002**	346364.9	54
1922			**1949**			**1976**	82452.47	29	**2003**	348734.5	56
1923			**1950**			**1977**	81675.99	28	**2004**	359841.5	66
1924			**1951**			**1978**	67889.25	32	**2005**	361417.7	54
1925			**1952**			**1979**	88396.34	31	**2006**	361734.2	85
1926			**1953**			**1980**	115813.7	35	**2007**	367910.2	116
									2008	378214.3	139

Table A4.10. Correlation Eq.(A1.1) terms calculated from Table A4.9 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
9216580.2	1485	2.82E+12	85903	4.19E+08	1.082E+12	40898.41	1.4E+08	**0.665995**	**44.35495**

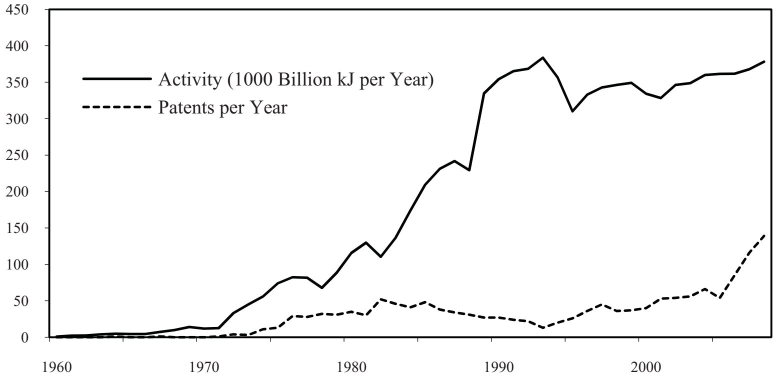

Figure A4.21. U.S. Geothermal Energy Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

Activity represents U.S. production of geothermal energy, defined at usgs.gov as "…electricity generation (converted to Btu using the geothermal energy plants heat rate), and geothermal heat pump and direct energy use energy." Data is in billion Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ.

[126] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Geothermal and (power or energy) were used as keywords found in the patent title or abstract by year of publication.

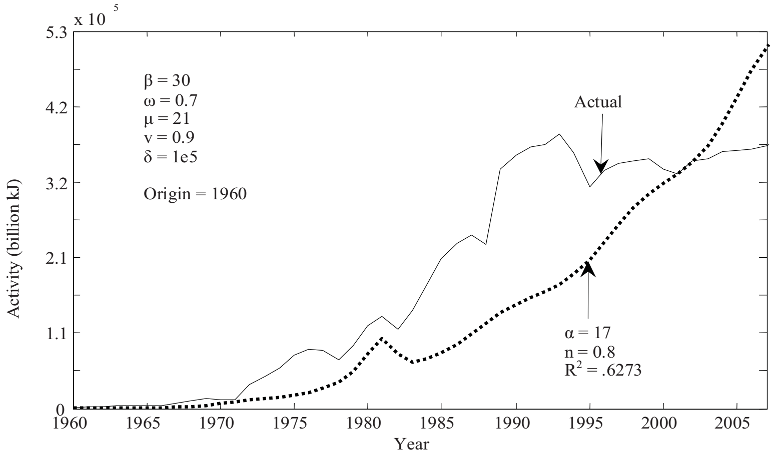

Figure A4.22. EIA U.S. Geothermal Energy Production. U.S. geothermal energy production (activity) scaled in billion kJ with actual and best-fit curves and common pattern equation parameters.

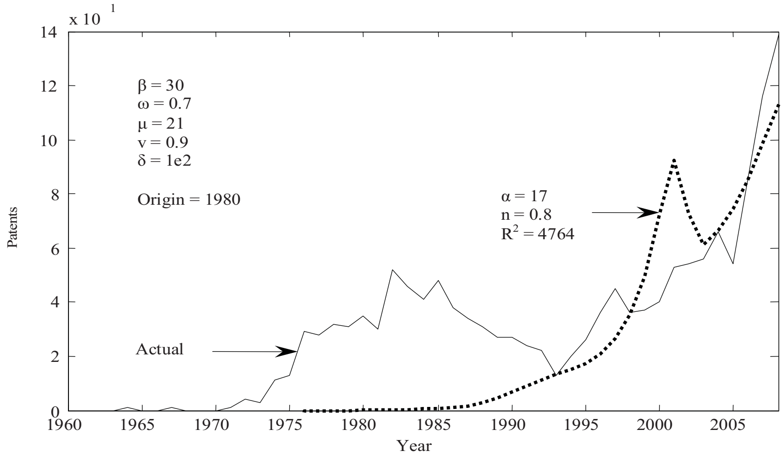

Figure A4.23. EPO Worldwide Patent Search: Geothermal and (Energy or Power) in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

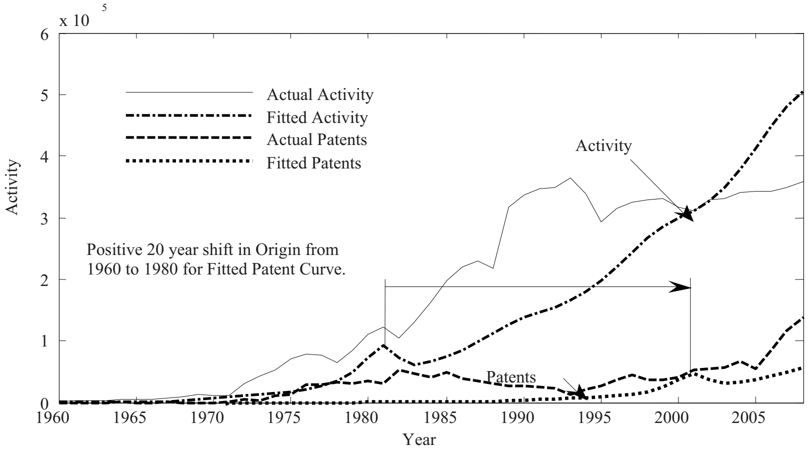

Figure A4.24. U.S. Geothermal Energy Best-Fit Activity and Patents. Illustrates best-fit origin shift.

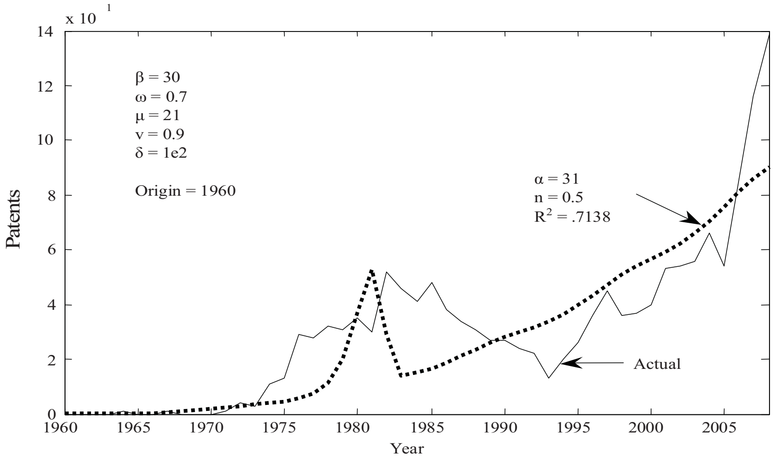

Figure A4.25. U.S. Geothermal Energy Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.11 U.S. Hydroelectric Energy Activity[127] and Patents[128]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**	1366571	0	**1981**	2771758	36
1901			**1928**			**1955**	1366643	2	**1982**	3281886	55
1902			**1929**			**1956**	1441885	3	**1983**	3544896	25
1903			**1930**			**1957**	1523191	1	**1984**	3402740	32
1904			**1931**			**1958**	1599927	2	**1985**	2985043	35
1905			**1932**			**1959**	1556207	1	**1986**	3086535	24
1906			**1933**			**1960**	1616015	1	**1987**	2647681	39
1907			**1934**			**1961**	1664745	1	**1988**	2345936	40
1908			**1935**			**1962**	1825222	0	**1989**	2851449	30
1909			**1936**			**1963**	1780212	0	**1990**	3061623	43
1910			**1937**			**1964**	1895746	1	**1991**	3031023	40
1911			**1938**			**1965**	2069372	6	**1992**	2630523	55
1912			**1939**			**1966**	2071827	4	**1993**	2906071	44
1913			**1940**			**1967**	2358397	0	**1994**	2696874	64
1914			**1941**			**1968**	2360372	2	**1995**	3221334	41
1915			**1942**			**1969**	2661223	2	**1996**	3607604	46
1916			**1943**			**1970**	2646715	6	**1997**	3658660	65
1917			**1944**			**1971**	2838272	4	**1998**	3313539	40
1918			**1945**			**1972**	2878184	2	**1999**	3283913	69
1919			**1946**			**1973**	2875755	4	**2000**	2825172	66
1920			**1947**			**1974**	3192463	3	**2001**	2253067	68
1921			**1948**			**1975**	3170380	1	**2002**	2702462	79
1922			**1949**	1431846	0	**1976**	2991146	2	**2003**	2838656	105
1923			**1950**	1422488	2	**1977**	2344918	6	**2004**	2703528	90
1924			**1951**	1430914	2	**1978**	2951668	12	**2005**	2716457	105
1925			**1952**	1473141	1	**1979**	2945339	15	**2006**	2883380	113
1926			**1953**	1419923	0	**1980**	2914645	20	**2007**	2458621	157
									2008	2464333	206

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[127] Activity represents United States production of hydroelectric energy, defined at eia.doe.gov as "Conventional hydroelectricity net generation…" Data is in billion Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ.

[128] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Hydroelectric was used as the keyword found in the patent title or abstract by year of publication.

Table A4.12 Correlation Eq.(A1.1) terms calculated from Table A4.11 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
150260117	1918	4.03E+14	164888	5.4E+09	2.653E+13	103575.9	6E+08	**0.361657**	**13.07958**

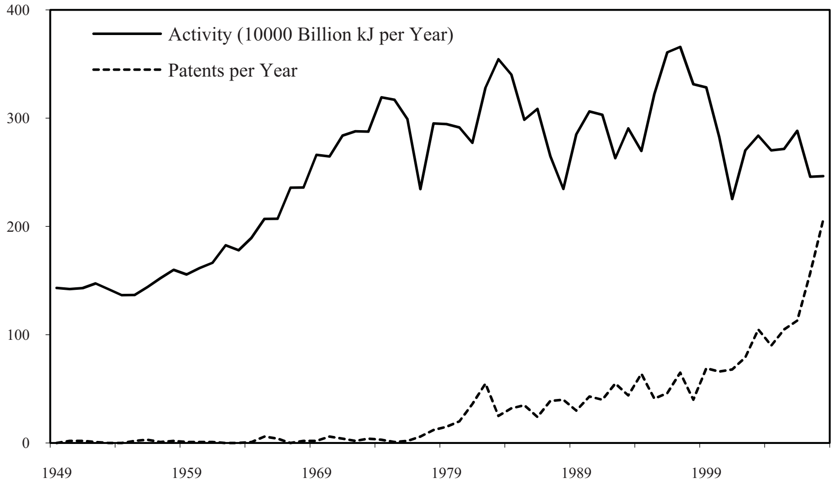

Figure A4.26. U.S. Hydroelectric Power Activity and Patent. Data illustrates correlation. Activity scaled to fit plot.

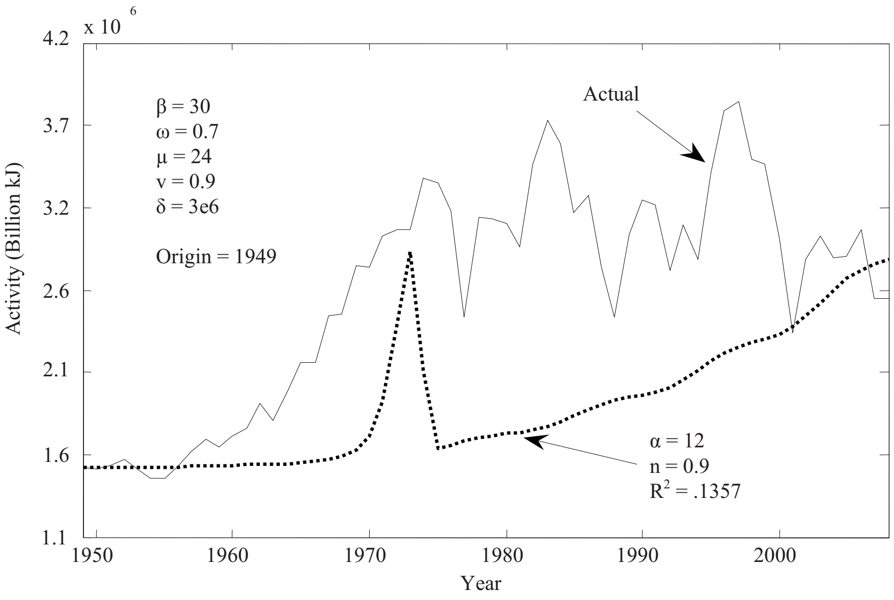

Figure A4.27. **EIA U.S. Hydroelectric Energy Production.** U.S. hydroelectric energy (activity) production scaled in billion kJ with actual and best-fit curves and common pattern equation parameters. No best-fit for the patent data or origin shift was obtained suggesting Stage IV.

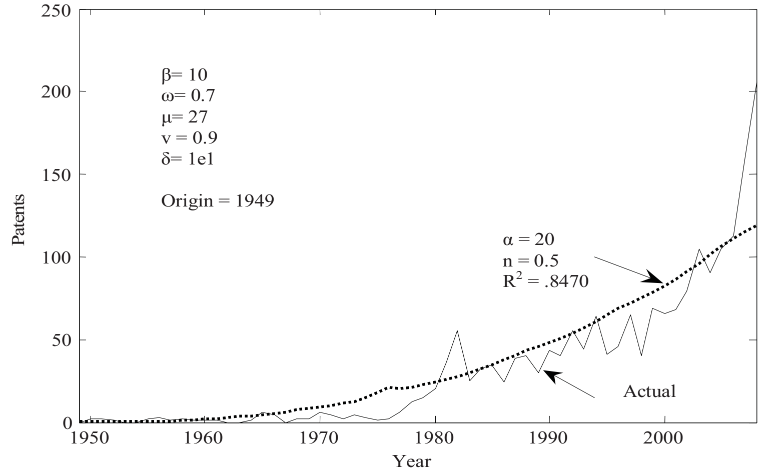

Figure A4.28. U.S. Hydroelectric Power Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.13 U.S. Natural Gas Energy Activity[129] and Patents[130]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (pat.)
1900			**1927**			**1954**	10333674	58	**1981**	23216892	284
1901			**1928**			**1955**	11166530	56	**1982**	21638152	309
1902			**1929**			**1956**	11905545	42	**1983**	19810258	310
1903			**1930**			**1957**	12548239	63	**1984**	21397197	334
1904			**1931**			**1958**	12901710	57	**1985**	20278314	373
1905			**1932**			**1959**	14068012	76	**1986**	19717848	328
1906			**1933**			**1960**	14893548	111	**1987**	20415151	352
1907			**1934**			**1961**	15459810	89	**1988**	20950640	361
1908			**1935**			**1962**	16151448	74	**1989**	21105926	422
1909			**1936**			**1963**	17114378	90	**1990**	21628417	473
1910			**1937**			**1964**	18042085	93	**1991**	21663872	462
1911			**1938**			**1965**	18629439	115	**1992**	21878654	560
1912			**1939**			**1966**	20052029	91	**1993**	22146601	525
1913			**1940**			**1967**	21226961	140	**1994**	22934638	559
1914			**1941**			**1968**	22565464	152	**1995**	22707639	637
1915			**1942**			**1969**	24123701	98	**1996**	23077258	627
1916			**1943**			**1970**	25507577	148	**1997**	23092897	656
1917			**1944**			**1971**	26188618	141	**1998**	23245595	884
1918			**1945**			**1972**	26169364	209	**1999**	23071112	952
1919			**1946**			**1973**	26117715	200	**2000**	23497418	1144
1920			**1947**			**1974**	24983786	164	**2001**	23961903	1118
1921			**1948**			**1975**	23225445	191	**2002**	23207896	1206
1922			**1949**	6426049	43	**1976**	23006770	181	**2003**	23248886	1269
1923			**1950**	7443872	21	**1977**	23096381	245	**2004**	22744423	1369
1924			**1951**	8794588	30	**1978**	22925843	217	**2005**	22057842	1340
1925			**1952**	9454245	58	**1979**	23592362	203	**2006**	22553307	1347
1926			**1953**	9917543	48	**1980**	23380098	309	**2007**	23243847	1699
									2008	24860924	1827

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[129] Activity represents United States production of natural gas energy, defined at eia.doe.gov as primary energy produced from dry natural gas and natural gas plant liquids. Data is in billions of Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ..

[130] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Natural and gas or methane or ethane were used as keywords found in the patent title or abstract by year of publication.

Table A4.14 Correlation Eq.(A1.1) terms calculated from Table A4.13 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
1.195E+09	25540	2.54E+16	23262650	5.75E+11	1.577E+15	12391123	6.61E+10	**0.472812**	**22.35514**

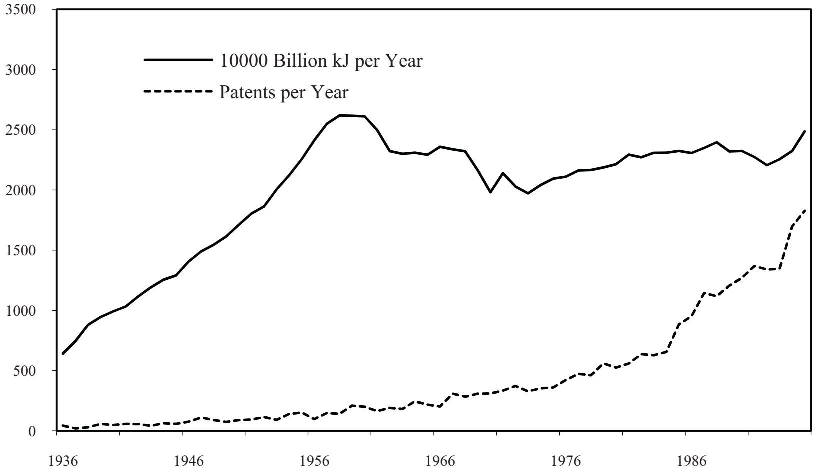

Figure A4.29. U.S. Natural Gas Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

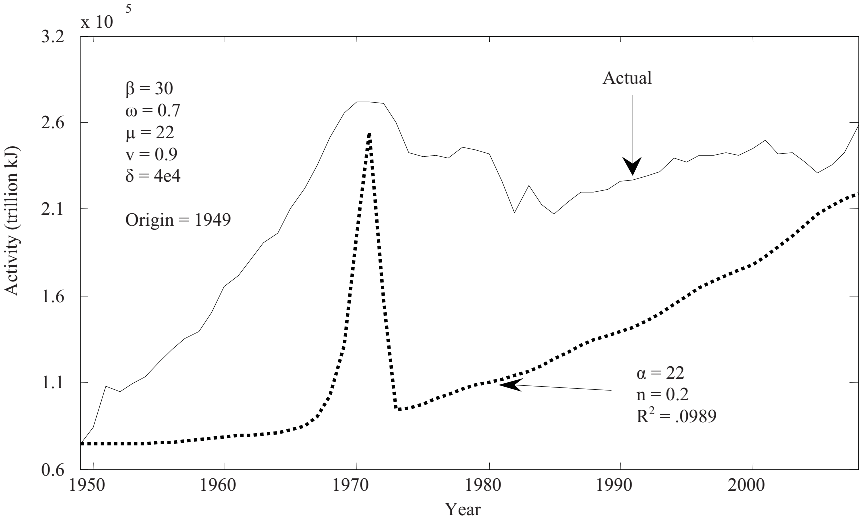

Figure A4.30. EIA U.S. Natural Gas Energy Production. U.S. natural gas energy production (activity) scaled in billion kJ with actual and best-fit curves and common pattern equation parameters.

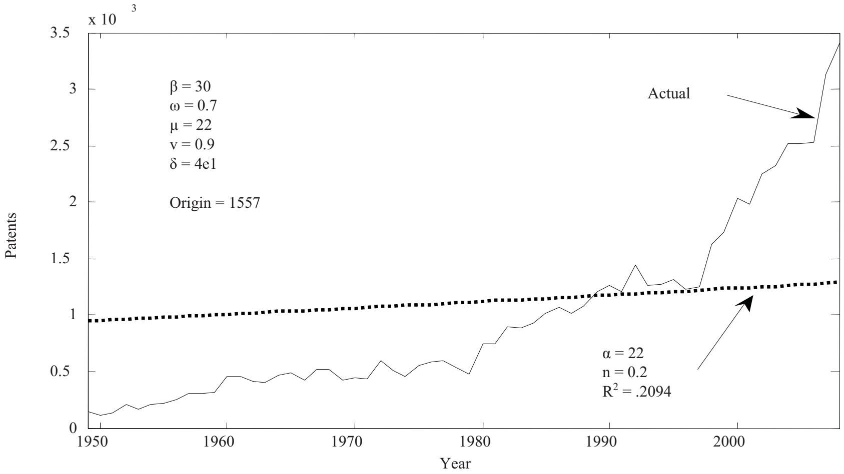

Figure A4.31. EPO Worldwide Patent Search: Natural Gas or Methane or Ethane in Title or Abstract by Date of Production. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

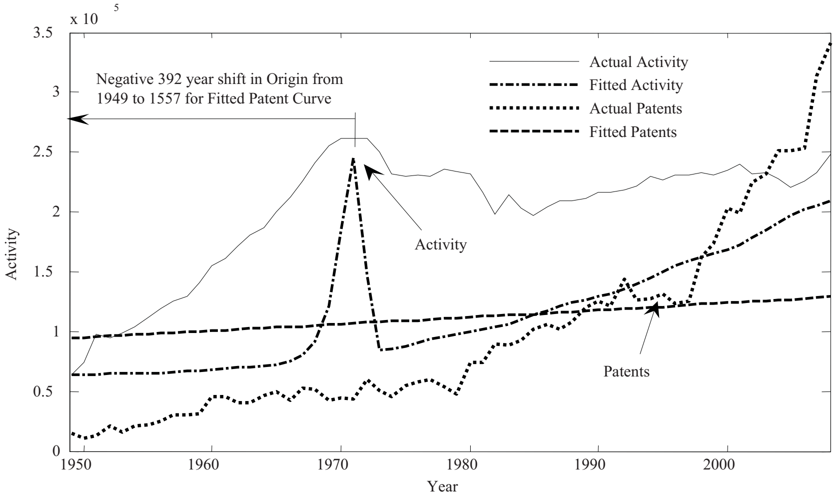

Figure A4.32. U.S. Natural Gas Energy Best-Fit Activity and Patents. Illustrates best-fit origin shift.

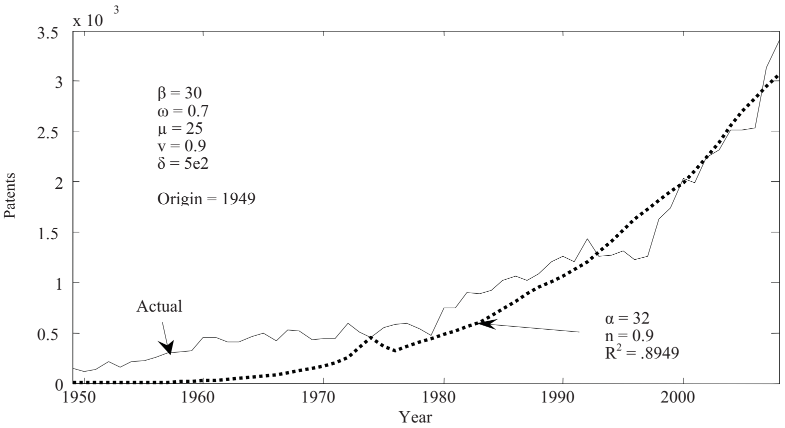

Figure A4.33. U.S. Natural Gas Energy Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.15 U.S. Nuclear Energy Activity[131] and Patents[132]

Year	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**
1900			**1927**			**1954**			**1981**	3173006	1995
1901			**1928**			**1955**			**1982**	3303361	1957
1902			**1929**			**1956**			**1983**	3378689	1684
1903			**1930**			**1957**	118.16	246	**1984**	3747920	1745
1904			**1931**			**1958**	2020.325	402	**1985**	4299719	2424
1905			**1932**			**1959**	2307.285	490	**1986**	4621015	2572
1906			**1933**			**1960**	6357.43	852	**1987**	5015399	2715
1907			**1934**			**1961**	20760.29	844	**1988**	5894251	2202
1908			**1935**			**1962**	27845.67	855	**1989**	5910280	2300
1909			**1936**			**1963**	40245.09	911	**1990**	6440089	2106
1910			**1937**			**1964**	42009.05	886	**1991**	6775349	1983
1911			**1938**			**1965**	45538.02	871	**1992**	6835562	1993
1912			**1939**			**1966**	67686.69	871	**1993**	6763076	1781
1913			**1940**			**1967**	93321.08	907	**1994**	7062040	1826
1914			**1941**			**1968**	149318.4	941	**1995**	7464585	1619
1915			**1942**			**1969**	162176.7	758	**1996**	7476441	1632
1916			**1943**			**1970**	252511.1	766	**1997**	6959827	1729
1917			**1944**			**1971**	435650.6	821	**1998**	7456538	1896
1918			**1945**			**1972**	615858.4	828	**1999**	8028820	1912
1919			**1946**			**1973**	960236.7	752	**2000**	8294778	1959
1920			**1947**			**1974**	1342048	718	**2001**	8474495	1977
1921			**1948**			**1975**	2004287	693	**2002**	8590959	2245
1922			**1949**			**1976**	2227233	877	**2003**	8396595	2327
1923			**1950**			**1977**	2850359	1169	**2004**	8674194	2307
1924			**1951**			**1978**	3190453	1190	**2005**	8608830	2242
1925			**1952**			**1979**	2928497	1337	**2006**	8665600	2130
1926			**1953**			**1980**	2889823	1558	**2007**	8922961	2297
									2008	8920274	2461

Table A4.16 Correlation Eq.(A1.1) terms calculated from Table A4.15 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**$100r^2$**
208511317	78559	1.41E+15	1.42E+08	4.13E+11	5.71E+14	23119498	9.81E+10	**0.854099**	**72.94843**

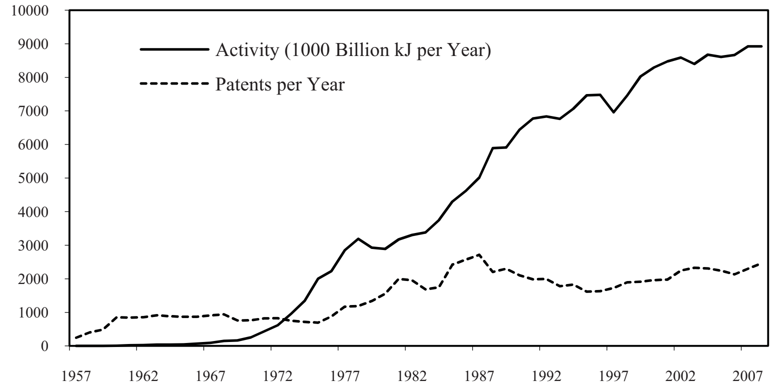

Figure A4.34. U.S. Nuclear Energy Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[131] Activity represents United States production of nuclear electric power. Data is in billion Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ.

[132] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Nuclear or uranium were used as keywords found in the patent title or abstract by year of publication.

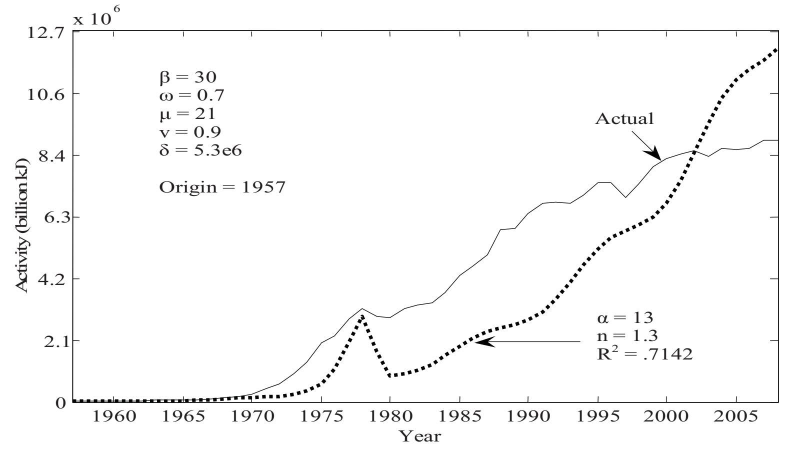

Figure A4.35. **EIA U.S. Nuclear Energy Production.** U.S. nuclear energy production (activity) scaled in billion kJ with actual and best-fit curves and common pattern equation parameters.

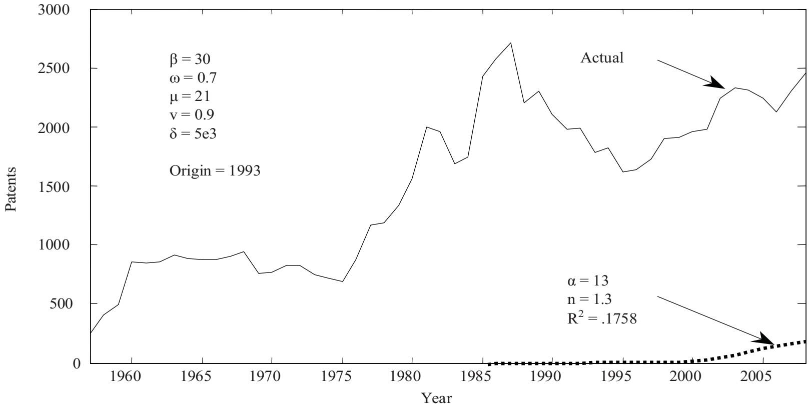

Figure A4.36. EPO Worldwide Patent Search: Nuclear or Uranium in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

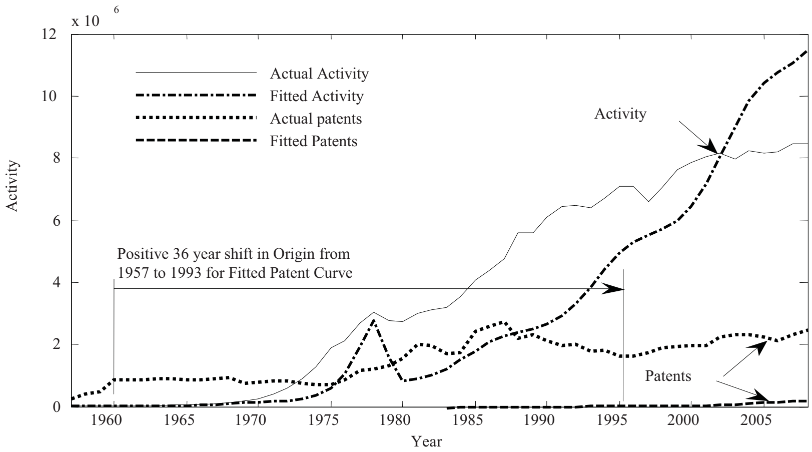

Figure A4.37. U.S. Nuclear Energy Best-Fit Activity and Patents. Illustrates best-fit origin shift.

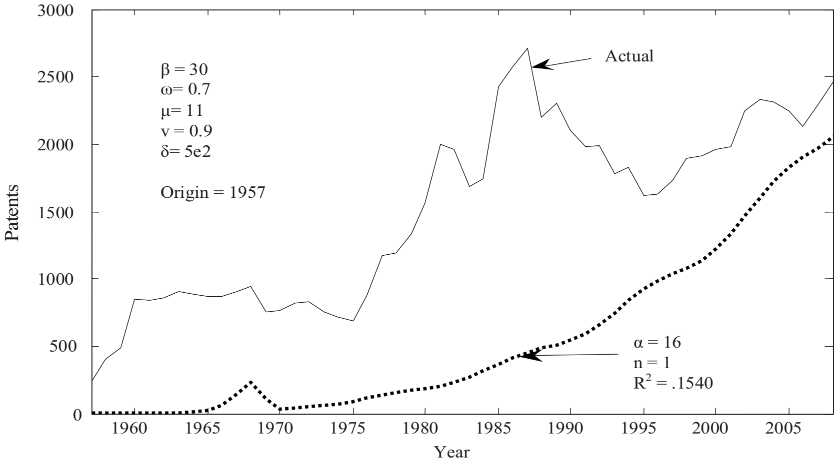

Figure A4.38. U.S. Nuclear Energy Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.17 U.S. Oil Energy Activity[133] and Patents[134]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (pat.)
1900			**1927**			**1954**	14165411	343	**1981**	19144050	807
1901			**1928**			**1955**	15202215	345	**1982**	19315939	873
1902			**1929**			**1956**	16015154	460	**1983**	19403343	895
1903			**1930**			**1957**	16012817	558	**1984**	19884890	870
1904			**1931**			**1958**	14985352	537	**1985**	20036989	834
1905			**1932**			**1959**	15753916	471	**1986**	19386534	841
1906			**1933**			**1960**	15756015	575	**1987**	18646906	860
1907			**1934**			**1961**	16042537	482	**1988**	18229253	749
1908			**1935**			**1962**	16375600	400	**1989**	17003312	852
1909			**1936**			**1963**	16843912	405	**1990**	16427600	936
1910			**1937**			**1964**	17052564	355	**1991**	16564371	978
1911			**1938**			**1965**	17430057	441	**1992**	16060124	920
1912			**1939**			**1966**	18526881	424	**1993**	15291583	787
1913			**1940**			**1967**	19677126	454	**1994**	14878202	883
1914			**1941**			**1968**	20370408	426	**1995**	14650525	911
1915			**1942**			**1969**	20631745	411	**1996**	14477658	859
1916			**1943**			**1970**	21523277	450	**1997**	14409211	913
1917			**1944**			**1971**	21134500	470	**1998**	13963062	1241
1918			**1945**			**1972**	21143396	561	**1999**	13135854	1189
1919			**1946**			**1973**	20565365	470	**2000**	13037797	1357
1920			**1947**			**1974**	19596618	455	**2001**	12957050	1312
1921			**1948**			**1975**	18704430	503	**2002**	12832302	1342
1922			**1949**	11270831	214	**1976**	18211245	557	**2003**	12687458	1367
1923			**1950**	12076299	180	**1977**	18413693	673	**2004**	12135825	1514
1924			**1951**	13753744	270	**1978**	19447504	667	**2005**	11565559	1379
1925			**1952**	14011507	346	**1979**	19099296	609	**2006**	11395163	1704
1926			**1953**	14422985	289	**1980**	19252607	741	**2007**	11310668	1989
									2008	11098059	2190

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[133] Activity represents United States production of oil energy, defined at eia.doe.gov as primary energy production of crude oil and lease condensate. Data is in thousand barrels as reported by the Energy Information Administration (EIA) at eia.doe.gov.

[134] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Petroleum was used as the keyword found in the patent title or abstract by year of publication.

Table A4.18 Correlation Eq.(A1.1) terms calculated from Table A4.17 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
983398293	45894	1.66E+16	46031010	7.15E+11	5.274E+14	10926689	-3.7E+10	**-0.48622**	**23.64057**

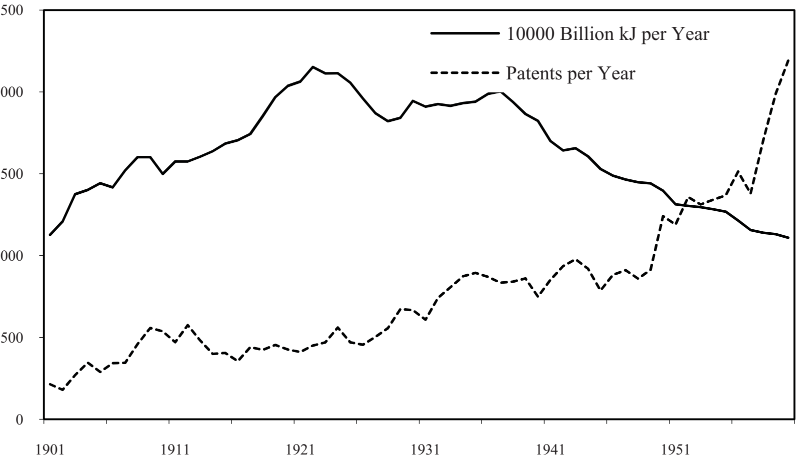

Figure A4.39. U.S. Oil Energy Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

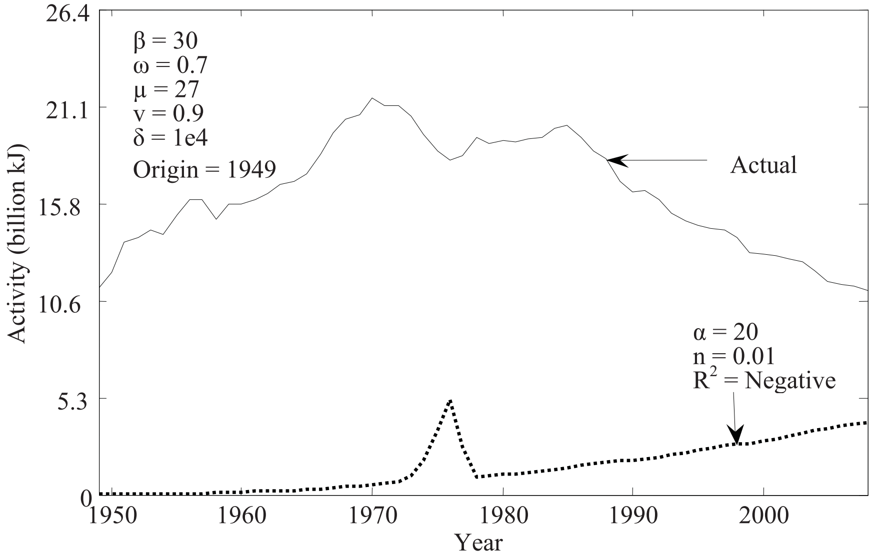

Figure A4.40. EIA U.S. Oil Energy Production. U.S. oil energy production (activity) scaled billion kJ with actual and best-fit curves and common pattern equation parameters. No best-fit for the patent data was obtainable.

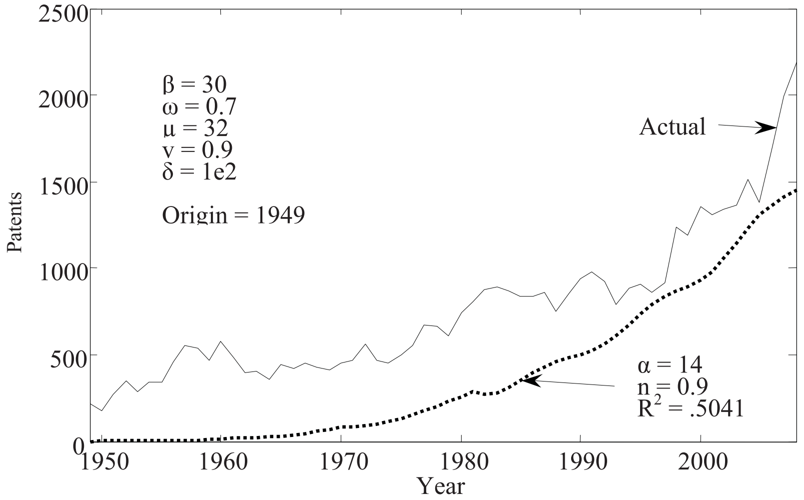

Figure A4.41. U.S. Oil Energy Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.19 U.S. Renewable Energy Activity[135] and Patents[136]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (pat.)
1900			**1927**			**1954**	290.55744	0	**1981**	577.88195	1
1901			**1928**			**1955**	293.71063	0	**1982**	636.63542	4
1902			**1929**			**1956**	300.7364	0	**1983**	692.32582	1
1903			**1930**			**1957**	300.58997	0	**1984**	688.23199	2
1904			**1931**			**1958**	307.542	0	**1985**	652.70529	1
1905			**1932**			**1959**	306.09126	0	**1986**	656.71925	2
1906			**1933**			**1960**	308.9693	0	**1987**	605.69249	5
1907			**1934**			**1961**	311.58433	0	**1988**	587.66011	8
1908			**1935**			**1962**	329.02433	0	**1989**	674.53187	4
1909			**1936**			**1963**	326.88078	0	**1990**	654.9746	7
1910			**1937**			**1964**	340.5157	0	**1991**	658.32897	3
1911			**1938**			**1965**	358.4928	0	**1992**	632.48632	3
1912			**1939**			**1966**	362.35811	0	**1993**	660.92332	13
1913			**1940**			**1967**	389.69579	0	**1994**	649.5692	13
1914			**1941**			**1968**	398.53058	0	**1995**	707.35693	11
1915			**1942**			**1969**	432.73473	0	**1996**	756.18634	8
1916			**1943**			**1970**	430.00291	0	**1997**	757.58959	9
1917			**1944**			**1971**	450.30934	0	**1998**	702.53062	14
1918			**1945**			**1972**	464.03215	0	**1999**	705.01599	10
1919			**1946**			**1973**	467.69427	0	**2000**	660.61726	9
1920			**1947**			**1974**	503.17117	0	**2001**	560.99878	16
1921			**1948**			**1975**	498.32862	0	**2002**	622.31475	38
1922			**1949**	3137553	0	**1976**	503.00206	1	**2003**	648.62972	45
1923			**1950**	3141492	0	**1977**	448.26971	1	**2004**	659.16041	46
1924			**1951**	3121180	0	**1978**	531.60796	0	**2005**	676.24223	75
1925			**1952**	3101891	0	**1979**	545.05298	0	**2006**	723.40263	88
1926			**1953**	2987190	0	**1980**	578.71181	2	**2007**	717.40095	201
									2008	771.80751	313

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[135] Activity represents United States production of renewable energy, defined at eia.doe.gov as "…hydroelectric, geothermal, solar, wind and biomass power." Data is in billion Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ.

[136] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Renewable and energy were used as the keywords found in the patent title or abstract by year of publication.

Table A4.20 Correlation Eq.(A1.1) terms calculated from Table A4.19 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
310250481	954	1.76E+15	158766	6.81E+09	1.51E+14	143597.4	1.88E+09	**0.403048**	**16.24474**

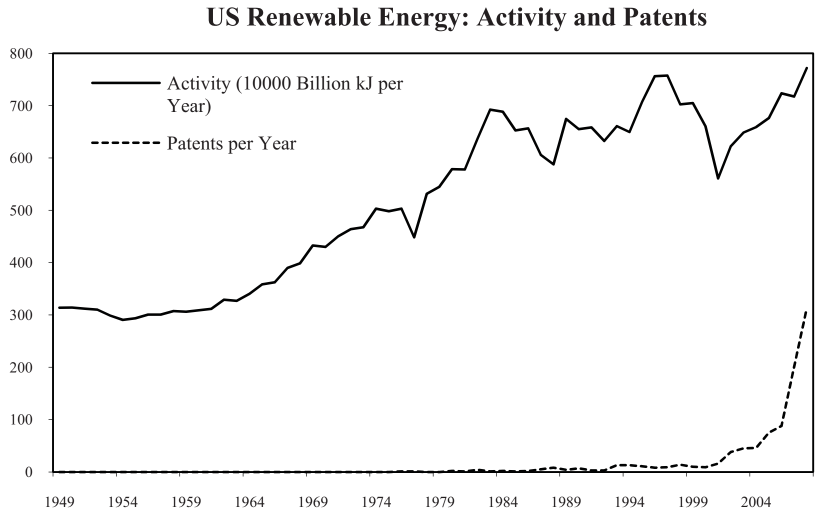

Figure A4.42. U.S. Renewable Energy Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

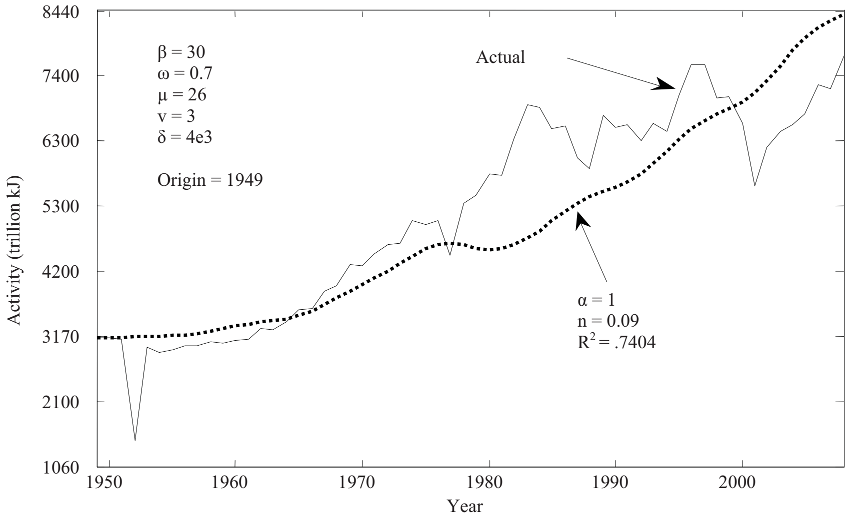

Figure A4.43. EIA U.S. Renewable Energy Production. U.S. renewable energy production (activity) scaled trillion kJ with actual and best-fit curves and common pattern equation parameters.

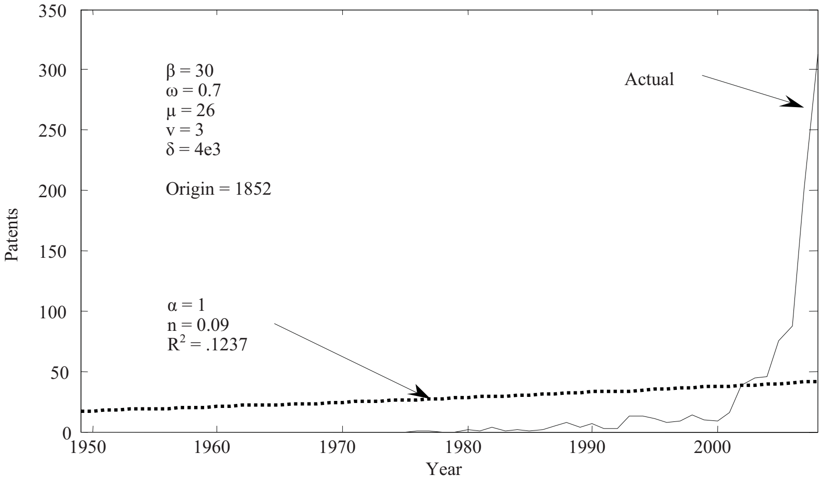

Figure A4.44. EPO Worldwide Patent Search: Renewable and Energy in Title or Abstract by date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

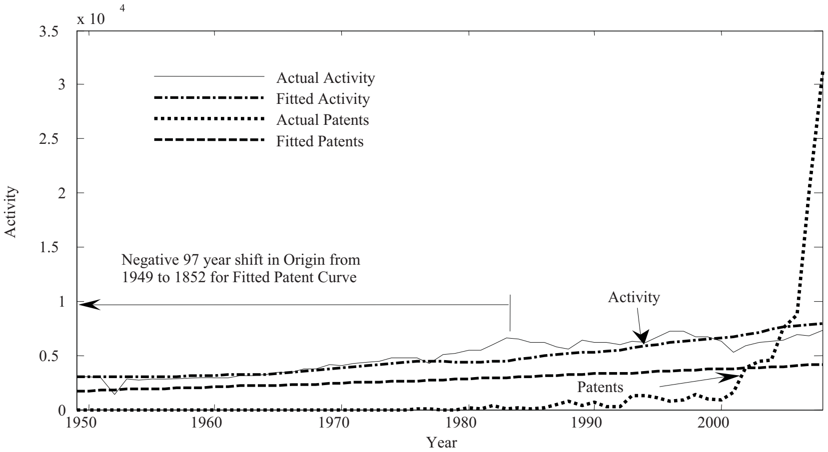

Figure A4.45. U.S. Renewable Energy Best-Fit Activity and Patents. Illustrates best-fit origin shift.

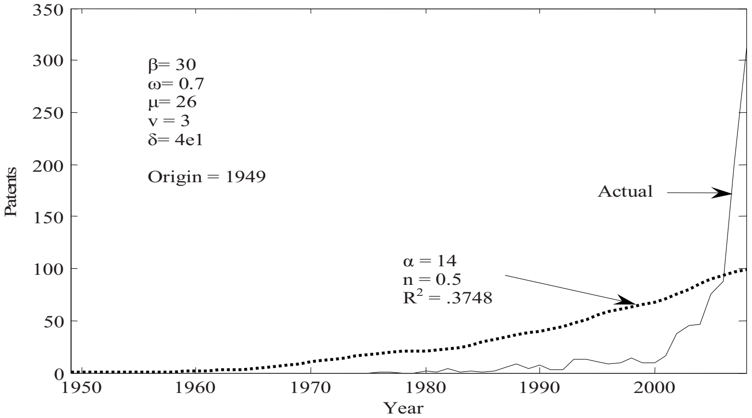

Figure A4.46. U.S. Renewable Energy Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.21 U.S. Solar Energy Activity[137] and Patents[138]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**			**1981**		
1901			**1928**			**1955**			**1982**		
1902			**1929**			**1956**			**1983**		
1903			**1930**			**1957**			**1984**	58.025	2323
1904			**1931**			**1958**			**1985**	117.105	2155
1905			**1932**			**1959**			**1986**	155.085	1928
1906			**1933**			**1960**			**1987**	114.995	1656
1907			**1934**			**1961**			**1988**	99.17	1415
1908			**1935**			**1962**			**1989**	58332.01	1507
1909			**1936**			**1963**			**1990**	63002.49	1457
1910			**1937**			**1964**			**1991**	66135.84	1445
1911			**1938**			**1965**			**1992**	67399.73	1740
1912			**1939**			**1966**			**1993**	70113.19	1718
1913			**1940**			**1967**			**1994**	72318.14	1939
1914			**1941**			**1968**			**1995**	73699.14	1990
1915			**1942**			**1969**			**1996**	74728.82	2043
1916			**1943**			**1970**			**1997**	74100.04	2186
1917			**1944**			**1971**			**1998**	73625.29	2597
1918			**1945**			**1972**			**1999**	72576.62	3025
1919			**1946**			**1973**			**2000**	70039.34	3534
1920			**1947**			**1974**			**2001**	69053.97	3761
1921			**1948**			**1975**			**2002**	67932.51	4105
1922			**1949**			**1976**			**2003**	67119.1	4252
1923			**1950**			**1977**			**2004**	68047.5	4378
1924			**1951**			**1978**			**2005**	69767.15	5016
1925			**1952**			**1979**			**2006**	76194.21	5605
1926			**1953**			**1980**			**2007**	85394.87	7327
									2008	96008.17	9165

Table A4.22. Correlation Eq.(A1.1) terms calculated from Table A4.21 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
1436132.5	78267	1.04E+11	3.39E+08	5.18E+09	2.174E+10	93491639	6.82E+08	**0.478581**	**22.90399**

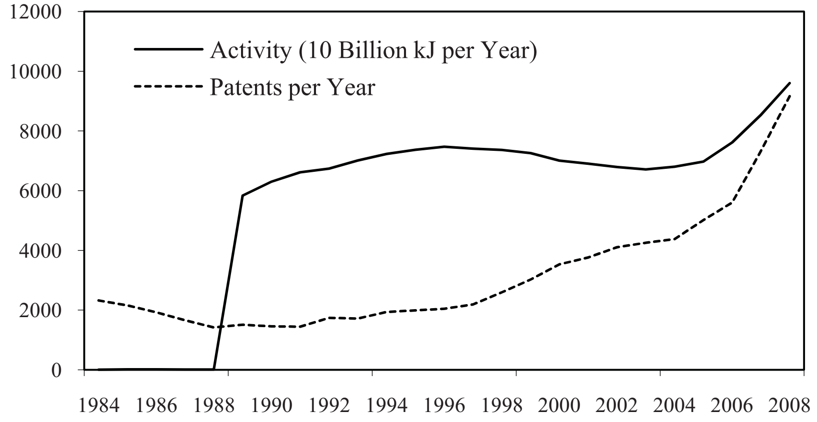

Figure A4.47. U.S. Solar Energy Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

Activity represents U.S. production of solar energy, defined at usgs.gov as "…solar thermal and photovoltaic electricity net generation (converted to Btu using the fossil-fueled plants heat rate, and solar thermal direct use energy." Data is in billion Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ.

[138] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Solar was used as the keyword found in the patent title or abstract by year of publication.

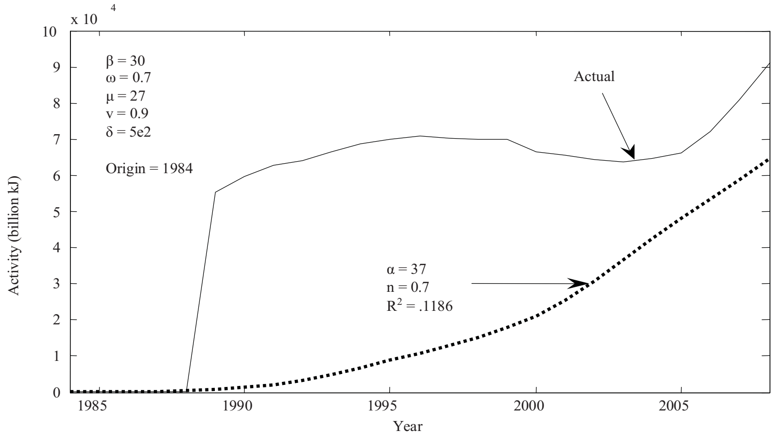

Figure A4.48. EIA U.S. Solar Energy Production. U.S. solar energy (activity) production scaled in billion kJ with actual and best-fit curves and common pattern equation parameters.

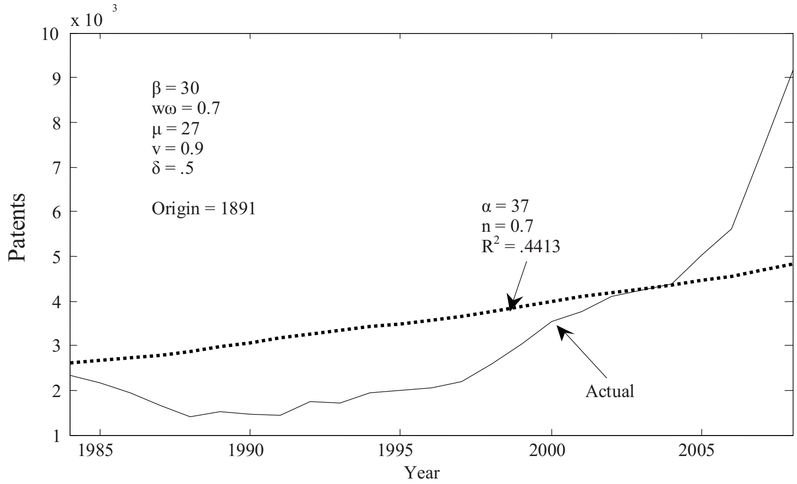

Figure A4.49. EPO Worldwide Patent Search: Solar in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

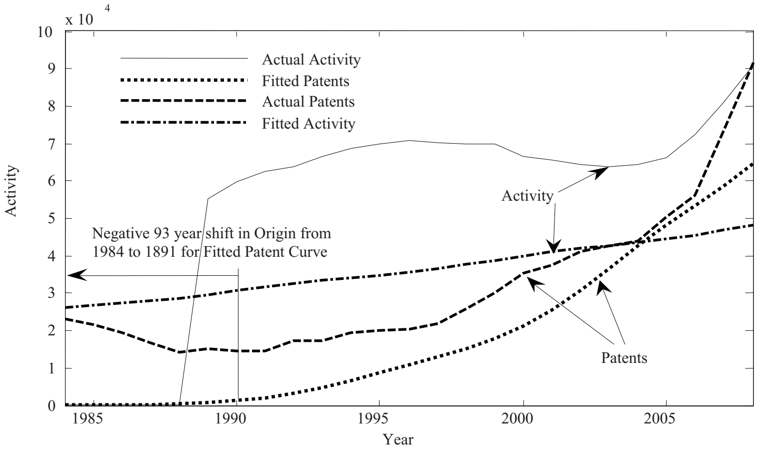

Figure A4.50. U.S. Solar Energy Best-Fit Activity and Patents. Illustrates best-fit origin shift.

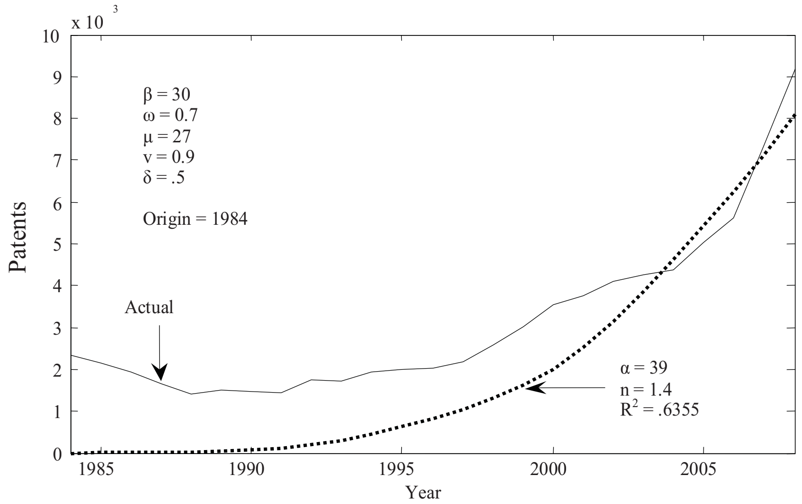

Figure A4.51. U.S. Solar Energy Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.23 U.S. Total Energy Activity[139] and Patents[140]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (pat)
1900			**1927**			**1954**	38526944	820	**1981**	70700263	4395
1901			**1928**			**1955**	42355789	847	**1982**	70287711	4725
1902			**1929**			**1956**	44966245	1026	**1983**	67710786	5015
1903			**1930**			**1957**	45346843	1310	**1984**	72716099	4775
1904			**1931**			**1958**	42340660	1345	**1985**	71530126	4704
1905			**1932**			**1959**	44255923	1324	**1986**	70875075	4733
1906			**1933**			**1960**	45157969	1781	**1987**	71383246	4702
1907			**1934**			**1961**	45660632	1652	**1988**	72828956	4372
1908			**1935**			**1962**	47345229	1515	**1989**	73299825	4754
1909			**1936**			**1963**	49768279	1437	**1990**	74770215	4467
1910			**1937**			**1964**	51754508	1457	**1991**	74413311	4373
1911			**1938**			**1965**	53463287	1573	**1992**	73986513	4765
1912			**1939**			**1966**	56478580	1438	**1993**	72264608	4033
1913			**1940**			**1967**	59480253	1662	**1994**	74793769	4247
1914			**1941**			**1968**	61427650	1641	**1995**	75242995	4237
1915			**1942**			**1969**	63870798	1377	**1996**	76636826	4008
1916			**1943**			**1970**	66993845	1510	**1997**	76629473	4233
1917			**1944**			**1971**	66172590	1552	**1998**	77058186	5169
1918			**1945**			**1972**	67435669	1827	**1999**	75862260	5330
1919			**1946**			**1973**	67081951	1529	**2000**	75422096	5638
1920			**1947**			**1974**	65802709	1528	**2001**	75845604	5014
1921			**1948**			**1975**	64731176	1754	**2002**	74836815	6001
1922			**1949**	33466879	572	**1976**	64989908	2126	**2003**	74128040	6213
1923			**1950**	37495105	454	**1977**	65464382	2626	**2004**	74255012	6740
1924			**1951**	40881899	596	**1978**	66609727	2843	**2005**	73455026	6707
1925			**1952**	40002343	860	**1979**	69574945	2815	**2006**	74946029	7885
1926			**1953**	40280740	673	**1980**	70930247	3658	**2007**	75436328	10029
									2008	77765323	11429

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[139] Activity represents United States production of total energy, defined at eia.doe.gov as "…fossil, nuclear and renewable power." Data is in billion Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ.

[140] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Fossil fuel, nuclear and renewables were used as the keywords found in the patent title or abstract by year of publication.

Table A4.24 Correlation Eq.(A1.1) terms calculated from Table A4.23 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**$100r^2$**
3.789E+09	201821	2.49E+17	1.01E+09	1.42E+13	9.363E+15	3.28E+08	1.41E+12	**0.806353**	**65.02049**

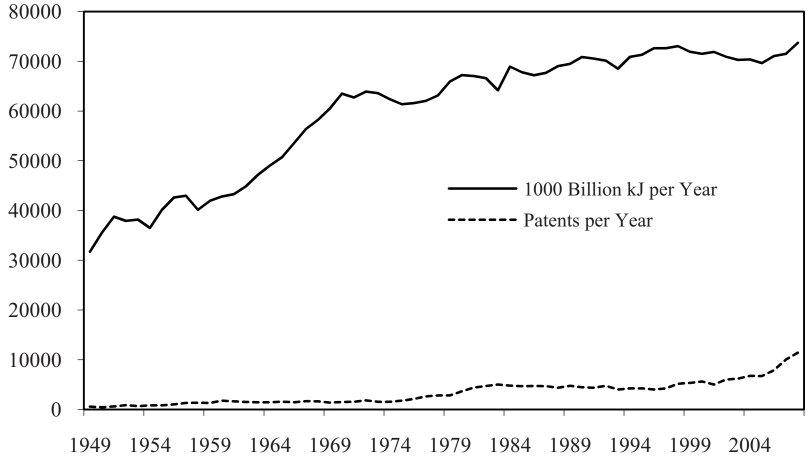

Figure A4.52. U.S. Total Energy Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

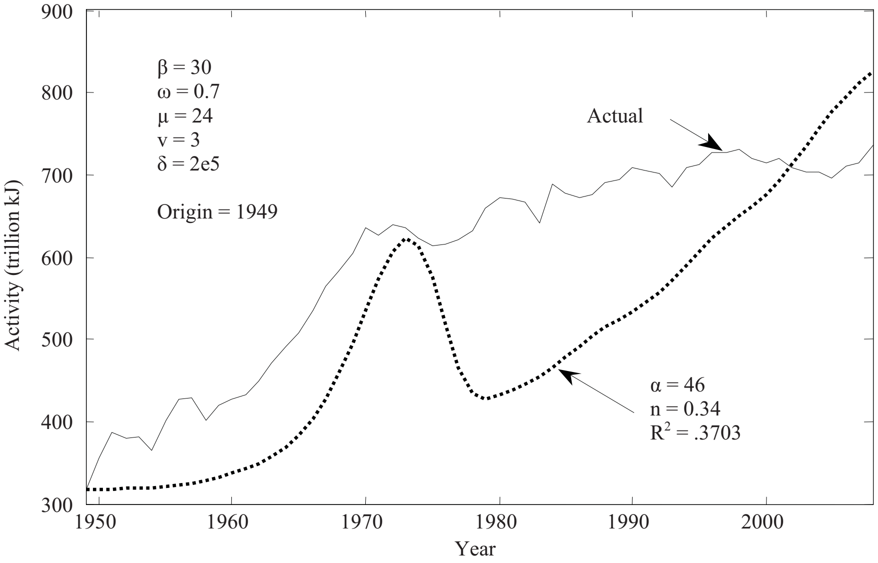

Figure A4.53. EIA U.S. Total Energy Production. U.S. total power production (activity) scaled in trillion kJ with actual and best-fit curves and common pattern equation parameters.

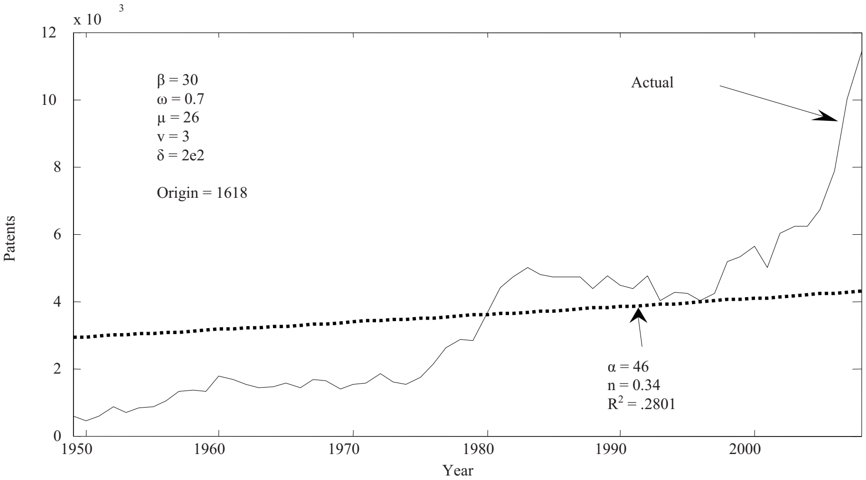

Figure A4.54. EPO Worldwide Patent Search: Fossil Fuel, Nuclear or Renewables in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

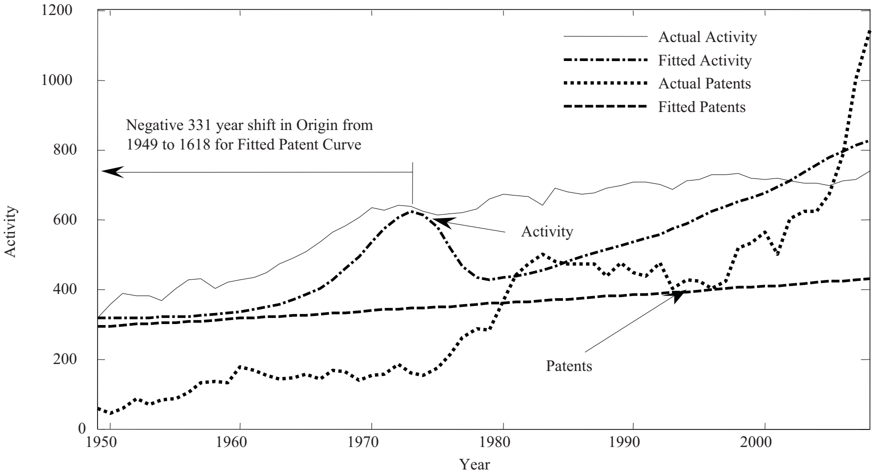

Figure A4.55. U.S. Total Energy Best-Fit Activity and Patents. Illustrates best-fit origin shift.

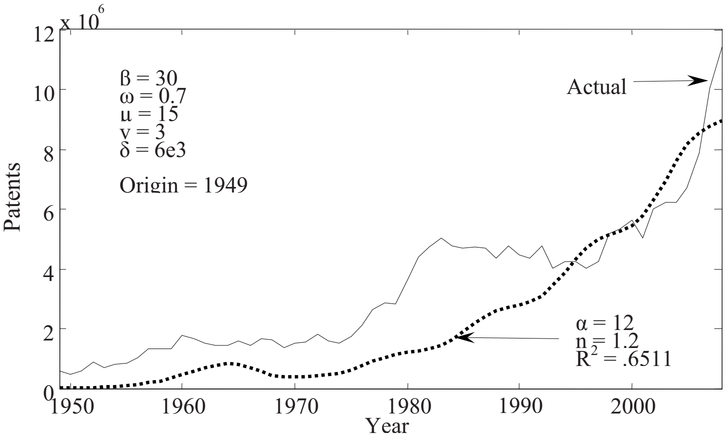

Figure A4.56. U.S. Total Energy Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.27 U.S. Wind Power Activity[141] and Patents[142]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**			**1981**		
1901			**1928**			**1955**			**1982**		
1902			**1929**			**1956**			**1983**	29.54	364
1903			**1930**			**1957**			**1984**	71.74	296
1904			**1931**			**1958**			**1985**	63.3	339
1905			**1932**			**1959**			**1986**	46.42	329
1906			**1933**			**1960**			**1987**	39.035	280
1907			**1934**			**1961**			**1988**	9.495	258
1908			**1935**			**1962**			**1989**	23244.82	310
1909			**1936**			**1963**			**1990**	30602.39	325
1910			**1937**			**1964**			**1991**	32489.78	301
1911			**1938**			**1965**			**1992**	31505.47	388
1912			**1939**			**1966**			**1993**	32691.29	376
1913			**1940**			**1967**			**1994**	37515.8	527
1914			**1941**			**1968**			**1995**	34424.65	543
1915			**1942**			**1969**			**1996**	35279.2	541
1916			**1943**			**1970**			**1997**	35427.96	601
1917			**1944**			**1971**			**1998**	32549.92	660
1918			**1945**			**1972**			**1999**	48418.17	913
1919			**1946**			**1973**			**2000**	60195.14	1002
1920			**1947**			**1974**			**2001**	73445.94	1161
1921			**1948**			**1975**			**2002**	111127.4	1420
1922			**1949**			**1976**			**2003**	120872.4	1773
1923			**1950**			**1977**			**2004**	149545.2	1912
1924			**1951**			**1978**			**2005**	187882.8	2053
1925			**1952**			**1979**			**2006**	278243.6	2357
1926			**1953**			**1980**			**2007**	359230.7	3182
									2008	542506.3	3805

Table A4.28. Correlation Eq.(A1.1) terms calculated from Table A4.27 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
2257458.4	26016	6.08E+11	49209118	5.25E+09	4.115E+11	23177108	2.99E+09	**0.968074**	**93.71671**

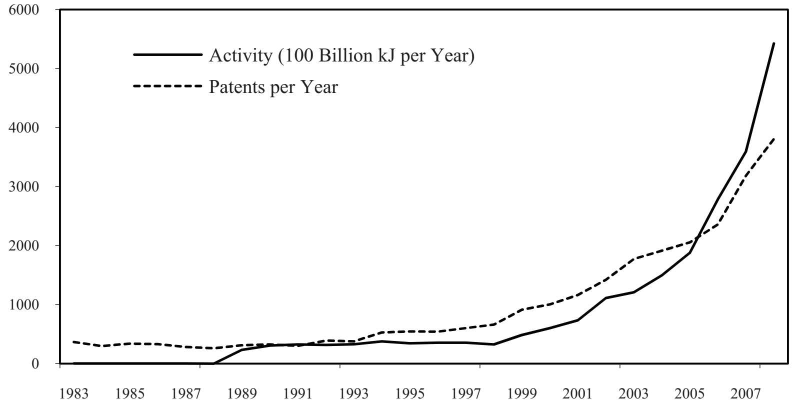

Figure A4.57. U.S. Wind Energy Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

Activity represents U.S. production of wind energy, defined at usgs.gov as "wind electricity net generation (converted to Btu using the fossil-fueled plants heat rate)." Data is in billion Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ.

[142] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Wind and (energy or power) were used as keywords found in the patent title or abstract by year of publication.

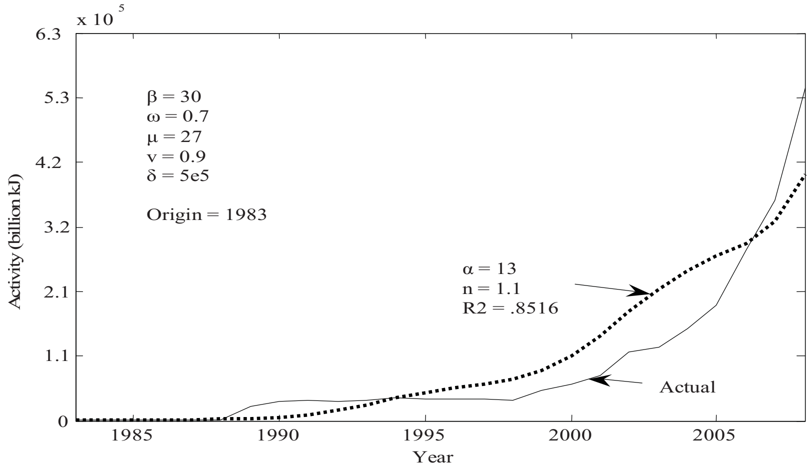

Figure A4.58. EIA U.S. Wind Energy Production. U.S. wind energy production (activity) scaled in billion kJ with actual and best-fit curves and common pattern equation parameters.

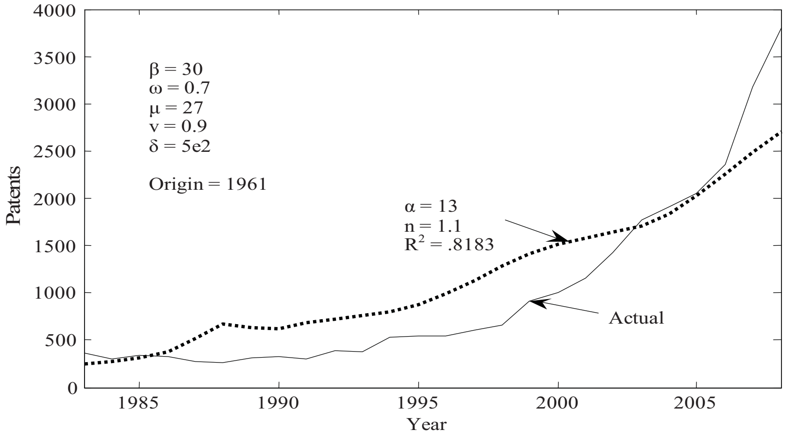

Figure A4.59. EPO Worldwide Patent Search: Wind and (Power or Energy) in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

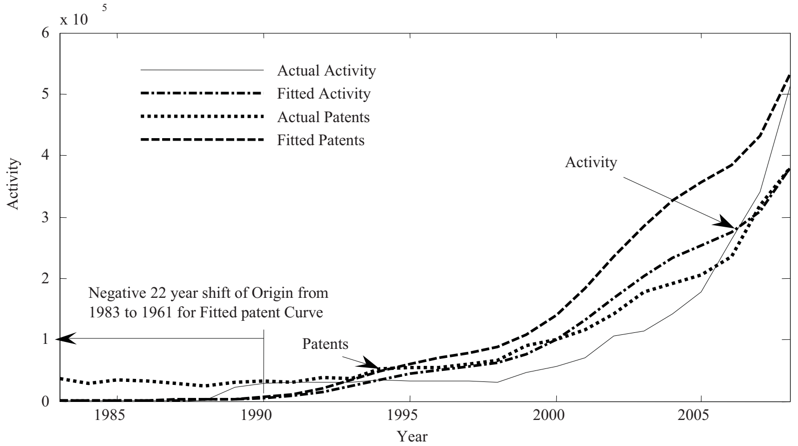

Figure A4.60. U.S. Wind Energy Best-Fit Activity and Patents. Illustrates best-fit origin shift.

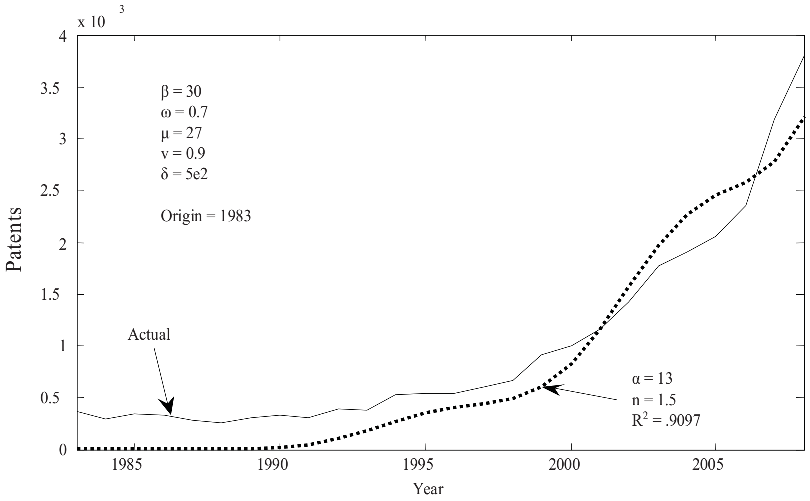

Figure A4.61. **U.S. Wind Energy Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A4.29 U.S. Wood Energy Activity[143] and Patents[144]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (pat)
1900			**1927**			**1954**	1471015	5	**1981**	2632819	70
1901			**1928**			**1955**	1502471	5	**1982**	2648101	80
1902			**1929**			**1956**	1493744	2	**1983**	2831906	79
1903			**1930**			**1957**	1406928	3	**1984**	2833537	88
1904			**1931**			**1958**	1395895	4	**1985**	2834537	77
1905			**1932**			**1959**	1427282	2	**1986**	2703051	70
1906			**1933**			**1960**	1392463	2	**1987**	2598633	55
1907			**1934**			**1961**	1365974	1	**1988**	2718379	44
1908			**1935**			**1962**	1371755	4	**1989**	2827002	45
1909			**1936**			**1963**	1396098	1	**1990**	2338054	52
1910			**1937**			**1964**	1410326	2	**1991**	2335858	51
1911			**1938**			**1965**	1408173	3	**1992**	2440712	48
1912			**1939**			**1966**	1444279	1	**1993**	2384062	49
1913			**1940**			**1967**	1413963	6	**1994**	2451630	60
1914			**1941**			**1968**	1497567	9	**1995**	2500212	57
1915			**1942**			**1969**	1519714	4	**1996**	2571063	60
1916			**1943**			**1970**	1507225	3	**1997**	2501396	52
1917			**1944**			**1971**	1508892	4	**1998**	2304289	66
1918			**1945**			**1972**	1583547	10	**1999**	2335946	81
1919			**1946**			**1973**	1610998	8	**2000**	2386109	86
1920			**1947**			**1974**	1622332	8	**2001**	2116154	93
1921			**1948**			**1975**	1579259	7	**2002**	2105024	68
1922			**1949**	1634471	4	**1976**	1805616	12	**2003**	2112152	75
1923			**1950**	1648234	2	**1977**	1937533	14	**2004**	2237920	86
1924			**1951**	1619076	6	**1978**	2148138	16	**2005**	2253850	82
1925			**1952**	1555459	6	**1979**	2268096	30	**2006**	2270076	85
1926			**1953**	1496624	4	**1980**	2609923	59	**2007**	2260250	88
									2008	2152850	120

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[143] Activity represents United States production of wood power, defined at eia.doe.gov as energy from "Wood and wood-derived fuels." Data is in billion Btu's as reported by the Energy Information Administration (EIA) at eia.doe.gov converted to kJ.

[144] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Wood and combustion were used as keywords found in the patent title or abstract by year of publication.

Table A4.30 Correlation Eq.(A1.1) terms calculated from Table A4.29 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
119738640	2214	2.54E+14	152602	5.27E+09	1.491E+13	70905.4	8.5E+08	**0.827053**	**68.40168**

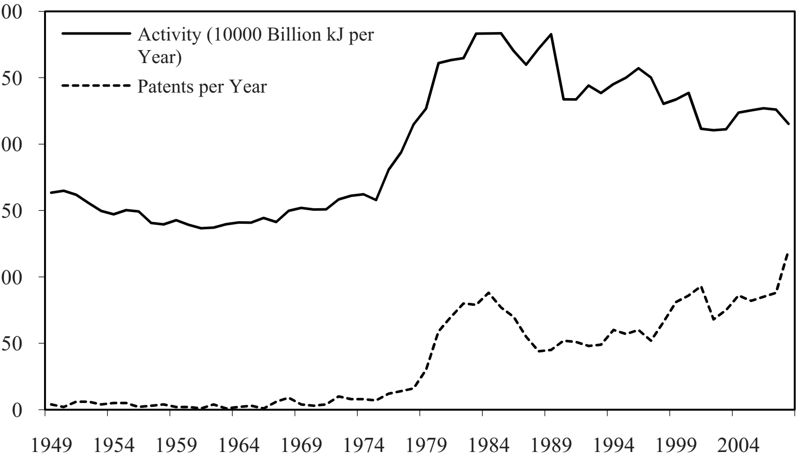

Figure A4.66. U.S. Wood Energy Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

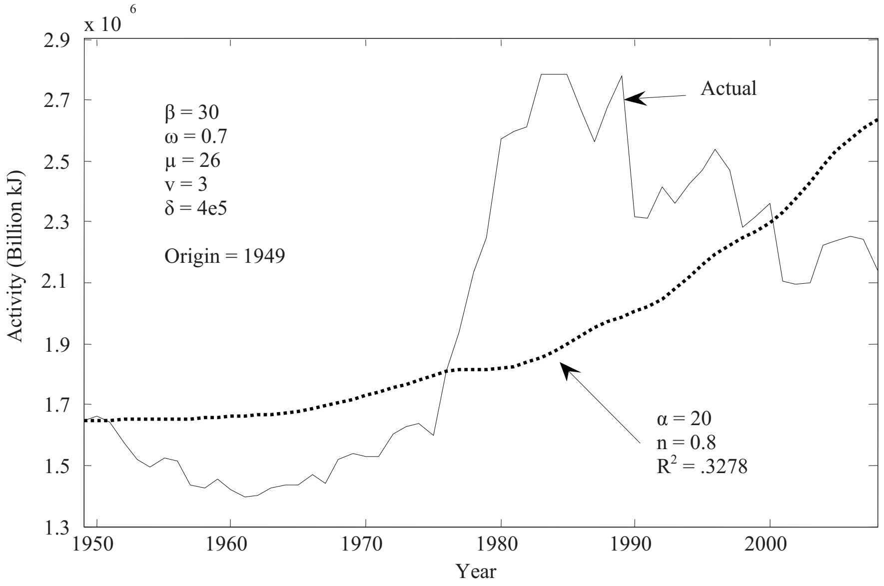

Figure A4.67. EIA U.S. Wood Energy Production. U.S. wood power (activity) production scaled in billion kJ with actual and best-fit curves and common pattern equation parameters. No best-fit for the patent data was obtainable.

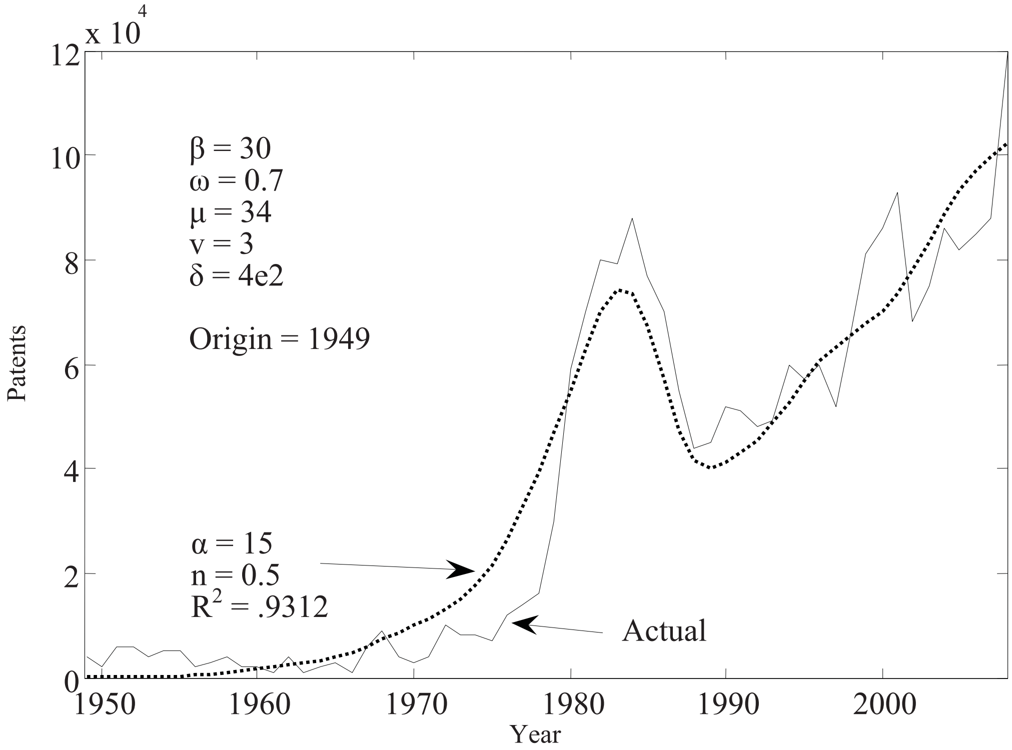

Figure A4.68. U.S. Wood Energy Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Appendix 5: Energy Materials Data

Table A5.1 U.S. Coal Activity[145] and Patents[146]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900	268	125	**1927**	597	378	**1954**	421	267	**1981**	824	2289
1901	292	120	**1928**	575	440	**1955**	492	279	**1982**	838	2539
1902	300	138	**1929**	608	453	**1956**	532	312	**1983**	782	2675
1903	356	209	**1930**	536	513	**1957**	520	301	**1984**	896	2442
1904	350	210	**1931**	441	514	**1958**	433	232	**1985**	884	2266
1905	391	160	**1932**	359	382	**1959**	435	217	**1986**	890	2209
1906	412	163	**1933**	383	323	**1960**	436	285	**1987**	919	2200
1907	478	166	**1934**	417	373	**1961**	423	288	**1988**	946	1981
1908	414	165	**1935**	424	355	**1962**	441	262	**1989**	981	2022
1909	459	141	**1936**	493	343	**1963**	479	262	**1990**	1,029	1676
1910	500	202	**1937**	497	268	**1964**	506	270	**1991**	996	1842
1911	495	202	**1938**	394	312	**1965**	521	318	**1992**	998	1857
1912	533	176	**1939**	446	258	**1966**	549	281	**1993**	945	1556
1913	568	147	**1940**	512	189	**1967**	567	343	**1994**	1,034	1613
1914	511	142	**1941**	570	135	**1968**	559	327	**1995**	1,033	1561
1915	530	143	**1942**	643	117	**1969**	573	266	**1996**	1,064	1510
1916	589	98	**1943**	651	95	**1970**	615	297	**1997**	1,090	1596
1917	650	110	**1944**	683	113	**1971**	563	333	**1998**	1,118	1722
1918	677	140	**1945**	632	122	**1972**	603	373	**1999**	1,100	1781
1919	553	146	**1946**	594	123	**1973**	599	340	**2000**	1,074	1676
1920	657	230	**1947**	682	140	**1974**	610	356	**2001**	1,127.7	1660
1921	505	304	**1948**	657	182	**1975**	654	435	**2002**	1,094.3	1733
1922	476	364	**1949**	481	214	**1976**	685	648	**2003**	1,071.8	1843
1923	657	298	**1950**	560	162	**1977**	697	921	**2004**	1,112.1	2012
1924	571	319	**1951**	576	195	**1978**	670	1262	**2005**	1,131.5	2144
1925	581	361	**1952**	507	301	**1979**	778	1378	**2006**	1,162.7	3000
1926	657	306	**1953**	488	221	**1980**	830	1725	**2007**	1,146.6	4032
									2008	1,171.5	4778

Table A5.2. Correlation Eq.(A1.1) terms calculated from Table A5.1 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
71,481	85299	53066191	1.58E+08	75803600	6190218.4	91036847	19865741	**0.836841**	**70.03036**

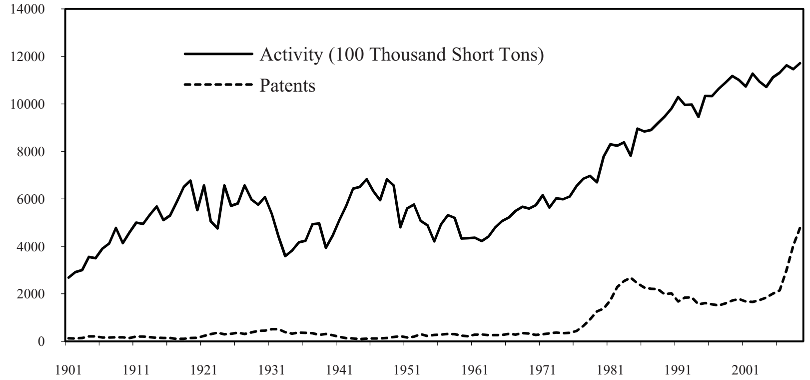

Figure A5.1. U.S. Coal Activity and Patents. data illustrates correlation. Activity scaled to fit plot.

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[145] Activity represents United States production of coal, defined at eia.doe.gov as "Beginning in 2001, includes a small amount of refuse recovery" Data is in thousand of ktons as reported by the Energy Information Administration (EIA) at eia.doe.gov.

[146] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Coal was used as the keyword found in the patent title or abstract by year of publication.

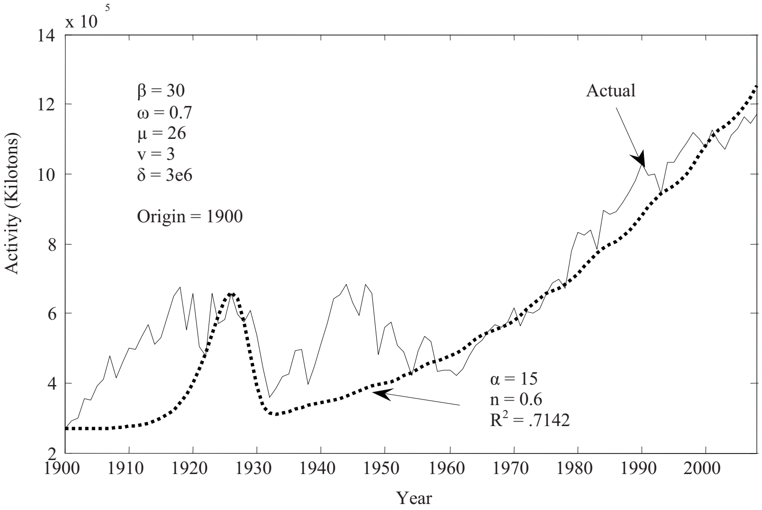

Figure A5.2. EIA U.S. Coal Production. U.S. coal production (activity) scaled in kilotons with actual and best-fit curves and common pattern equation parameters. No best-fit for the patent data was obtainable.

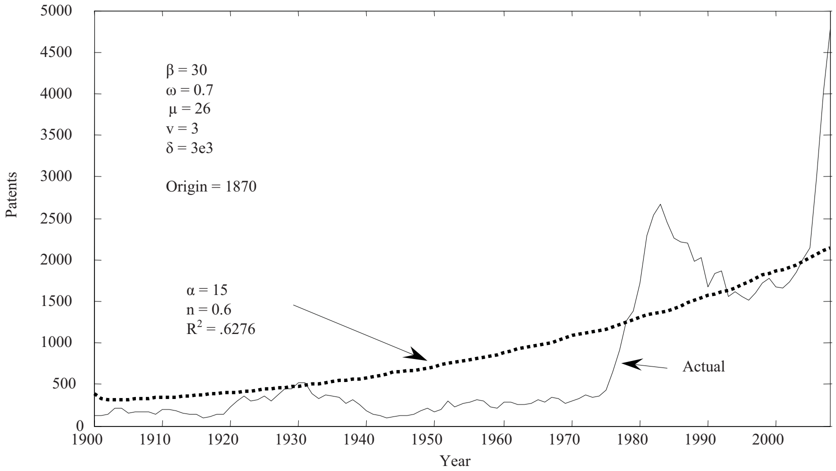

Figure A5.3. EPO Worldwide Patent Search: Coal in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

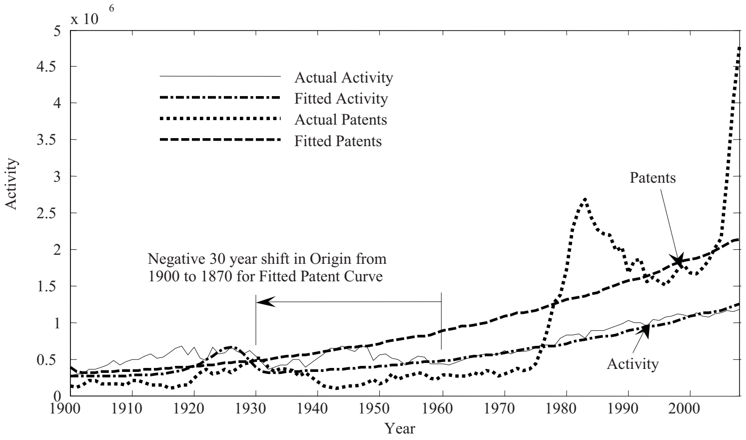

Figure A5.4. U.S. Coal Best-Fit Activity and Patents. Illustrates best-fit origin shift.

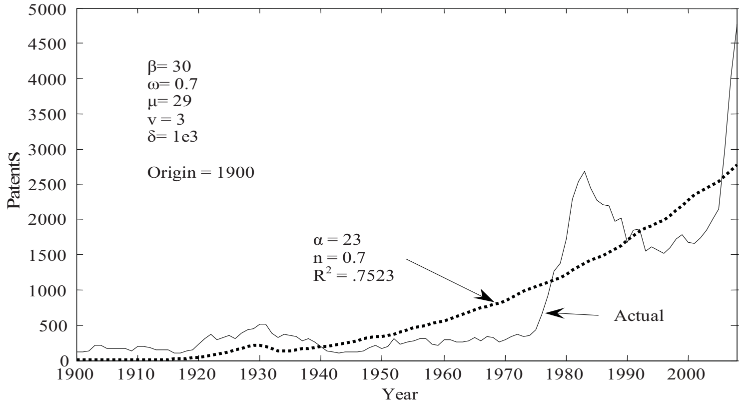

Figure A5.5. **U.S. Coal Independent Patent Best-Fit.** Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A5.3. U.S. Natural Gas Activity[147] and Patents[148]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**	10984850	210	**1981**	21587453	742
1901			**1928**			**1955**	11719794	223	**1982**	20272254	898
1902			**1929**			**1956**	12372905	254	**1983**	18659046	890
1903			**1930**			**1957**	12906669	301	**1984**	20266522	924
1904			**1931**			**1958**	13146635	306	**1985**	19606699	1015
1905			**1932**			**1959**	14229272	317	**1986**	19130711	1064
1906			**1933**			**1960**	15087911	452	**1987**	20140200	1017
1907			**1934**			**1961**	15460312	452	**1988**	20999255	1080
1908			**1935**			**1962**	16038973	408	**1989**	21074425	1204
1909			**1936**	2691512	120	**1963**	16973368	405	**1990**	21522622	1257
1910			**1937**	3084567	95	**1964**	17535553	463	**1991**	21750108	1209
1911			**1938**	3108858	119	**1965**	17963100	493	**1992**	22132249	1439
1912			**1939**	3387095	86	**1966**	19033839	424	**1993**	22725642	1263
1913			**1940**	3752702	65	**1967**	20251776	524	**1994**	23580706	1273
1914			**1941**	4168116	57	**1968**	21325000	516	**1995**	23743628	1310
1915			**1942**	4525095	51	**1969**	22679195	428	**1996**	24113536	1230
1916			**1943**	5024449	34	**1970**	23786453	446	**1997**	24212677	1254
1917			**1944**	5708288	45	**1971**	24088031	437	**1998**	24108128	1627
1918			**1945**	6000161	58	**1972**	24016109	594	**1999**	23822711	1736
1919			**1946**	6293037	88	**1973**	24067202	508	**2000**	24173875	2034
1920			**1947**	6733230	111	**1974**	22849793	456	**2001**	24500779	1986
1921			**1948**	7178777	127	**1975**	21103530	548	**2002**	23941279	2246
1922			**1949**	7546825	144	**1976**	20943778	581	**2003**	24118978	2322
1923			**1950**	8479650	112	**1977**	21097071	594	**2004**	23969678	2513
1924			**1951**	9689372	131	**1978**	21308815	535	**2005**	23456822	2515
1925			**1952**	10272566	213	**1979**	21883353	473	**2006**	23535018	2533
1926			**1953**	10645798	163	**1980**	21869692	744	**2007**	24590602	3133
									2008	26032337	3408

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[147] Activity represents United States production of natural gas, defined at eia.doe.gov as "Natural gas gross withdrawals." Data is in million cubic feet as reported by the Energy Information Administration (EIA) at eia.doe.gov.

[148] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Natural and gas were used as keywords found in the patent title or abstract by year of publication.

Table A5.4. Correlation Eq.(A1.1) terms calculated from Table A5. 3 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**100r^2**
1.245E+09	59033	2.5E+16	92636613	1.29E+12	3.794E+15	44898324	2.88E+11	**0.698263**	**48.75718**

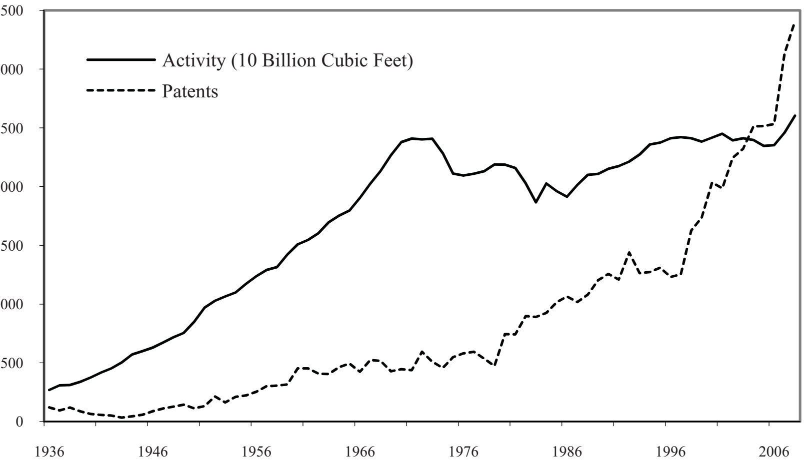

Figure A5.6. U.S. Natural Gas Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

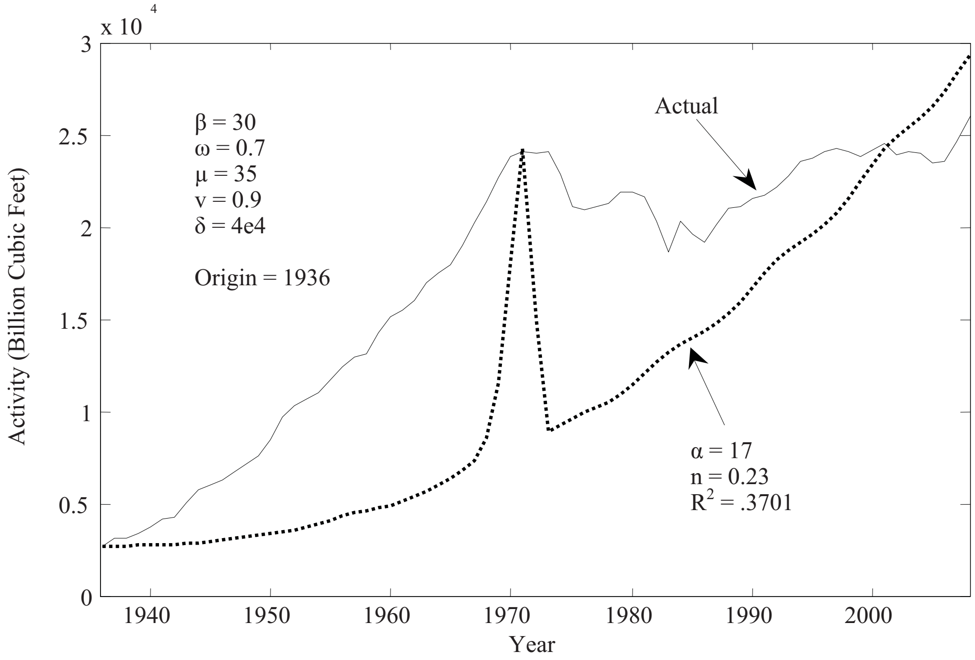

Figure A5.7. EIA U.S. Natural Gas Production. U.S. natural gas production (activity) scaled in billion cubic feet with actual and best-fit curves and common pattern equation parameters.

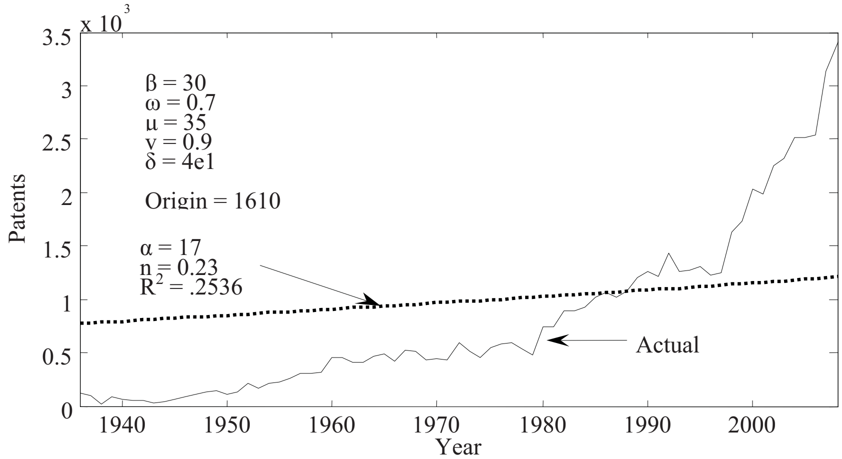

Figure A5.8. EPO Worldwide Patent Search: Natural Gas in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

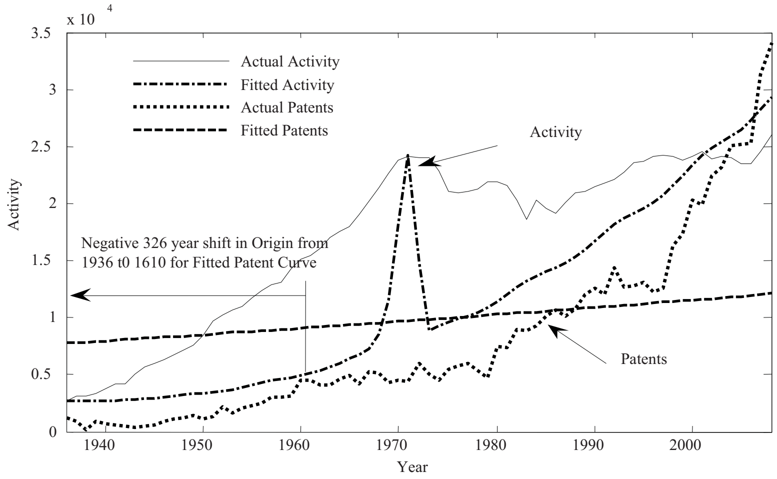

Figure A5.9. U.S. Natural Gas Best-Fit Activity and Patents. Illustrates best-fit origin shift.

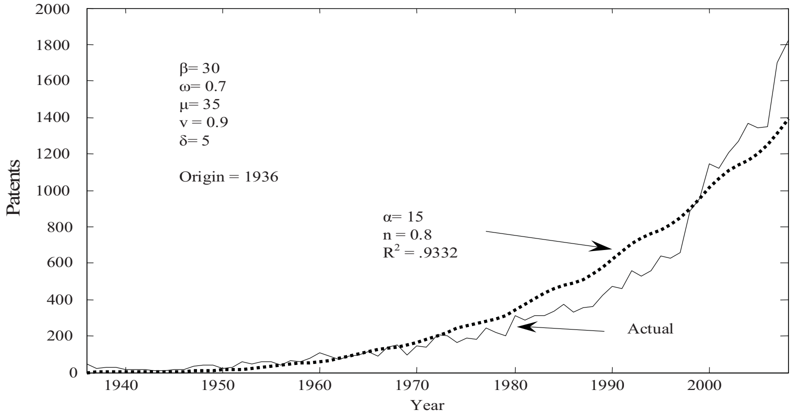

Figure A5.10. U.S. Natural Gas Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A5.5. U.S. Oil Activity[149] and Patents[150]

Year	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**	**Year**	**x (activity)**	**y (patent)**
1900	63621	55	**1927**	901129	109	**1954**	2314988	343	**1981**	3128624	807
1901	69389	60	**1928**	901474	146	**1955**	2484428	345	**1982**	3156715	873
1902	88767	56	**1929**	1007323	159	**1956**	2617283	460	**1983**	3170999	895
1903	100461	65	**1930**	898011	236	**1957**	2616901	558	**1984**	3249696	870
1904	117081	74	**1931**	851081	248	**1958**	2448987	537	**1985**	3274553	834
1905	134717	73	**1932**	785159	220	**1959**	2574590	471	**1986**	3168252	841
1906	126494	49	**1933**	905656	210	**1960**	2574933	575	**1987**	3047378	860
1907	166095	60	**1934**	908065	209	**1961**	2621758	482	**1988**	2979123	749
1908	178527	57	**1935**	993942	231	**1962**	2676189	400	**1989**	2778773	852
1909	183171	50	**1936**	1098513	248	**1963**	2752723	405	**1990**	2684687	936
1910	209557	47	**1937**	1277653	188	**1964**	2786822	355	**1991**	2707039	978
1911	220449	45	**1938**	1213254	222	**1965**	2848514	441	**1992**	2624632	920
1912	222935	51	**1939**	1264256	207	**1966**	3027763	424	**1993**	2499033	787
1913	248446	61	**1940**	1503176	179	**1967**	3215742	454	**1994**	2431476	883
1914	265763	55	**1941**	1404182	210	**1968**	3329042	426	**1995**	2394268	911
1915	281104	45	**1942**	1385479	149	**1969**	3371751	411	**1996**	2366017	859
1916	300767	26	**1943**	1505613	139	**1970**	3517450	450	**1997**	2354831	913
1917	335316	21	**1944**	1677904	153	**1971**	3453914	470	**1998**	2281919	1241
1918	355928	22	**1945**	1713655	147	**1972**	3455368	561	**1999**	2146732	1189
1919	378367	52	**1946**	1733424	154	**1973**	3360903	470	**2000**	2130707	1357
1920	442929	61	**1947**	1856987	195	**1974**	3202585	455	**2001**	2117511	1312
1921	472183	75	**1948**	2020185	232	**1975**	3056779	503	**2002**	2097124	1342
1922	557531	109	**1949**	1841940	214	**1976**	2976180	557	**2003**	2073453	1367
1923	732407	83	**1950**	1973574	180	**1977**	3009265	673	**2004**	1983302	1514
1924	713940	86	**1951**	2247711	270	**1978**	3178216	667	**2005**	1890106	1379
1925	620373	103	**1952**	2289836	346	**1979**	3121310	609	**2006**	1862259	1704
1926	770874	128	**1953**	2357082	289	**1980**	3146365	741	**2007**	1848450	1989
									2008	1811817	2190

Table A5.6. Correlation Eq.(A1.1) terms calculated from Table A5.5 data.

Sum x	**Sum y**	**Sum x^2**	**Sum y^2**	**Sum xy**	**Sxx**	**Syy**	**Sxy**	**r**	**$100r^2$**
196873681	51754	4.86E+14	46982414	1.23E+11	1.307E+14	22409235	2.92E+10	**0.540152**	**29.17646**

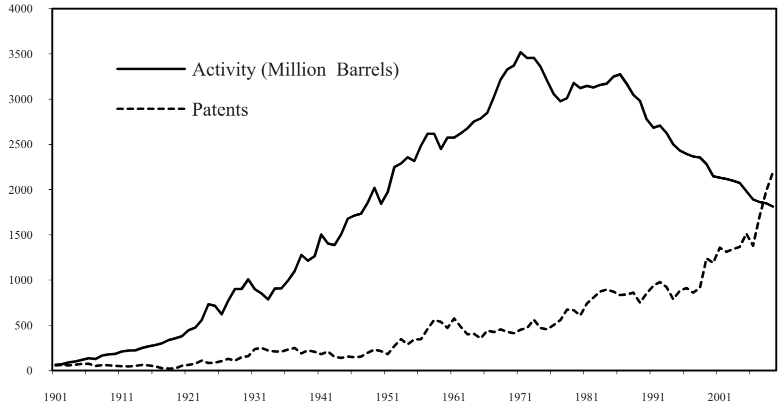

Figure A5.11. U.S. Oil Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

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[149] Activity represents United States production of oil, defined at eia.doe.gov as "Field production of crude oil." Data is in thousand barrels as reported by the Energy Information Administration (EIA) at eia.doe.gov.

[150] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Petroleum was used as the keyword found in the patent title or abstract by year of publication.

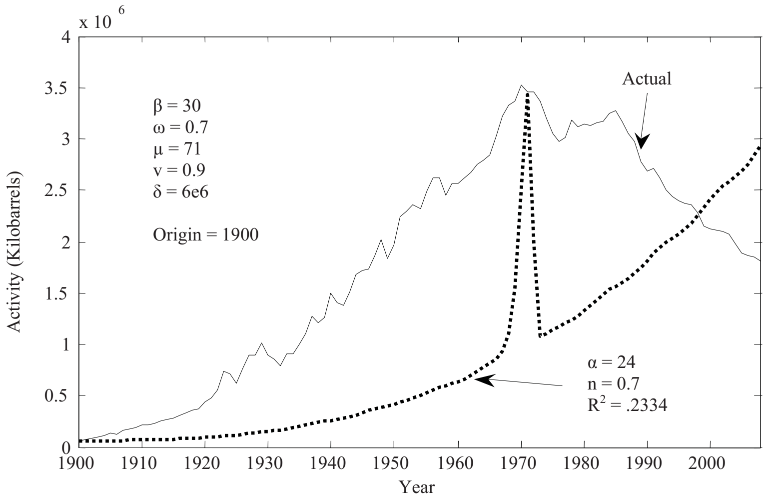

Figure 5.12. EIA U.S. Oil Production. U.S. oil production (activity) scaled in kilo barrels with actual and best-fit curves and common pattern equation parameters. No best-fit for the patent data was obtainable.

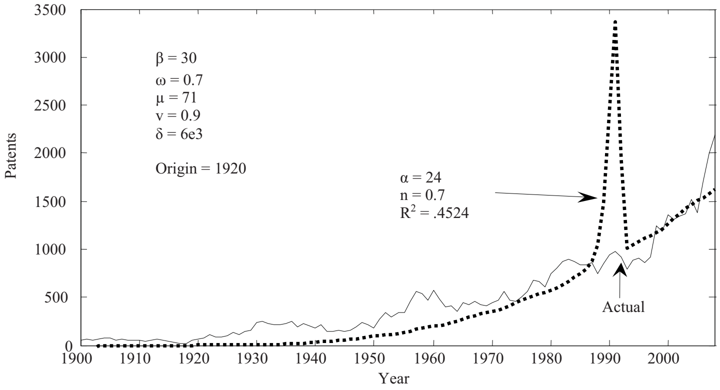

Figure A5.13. EPO Worldwide Patent Search: Petroleum in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

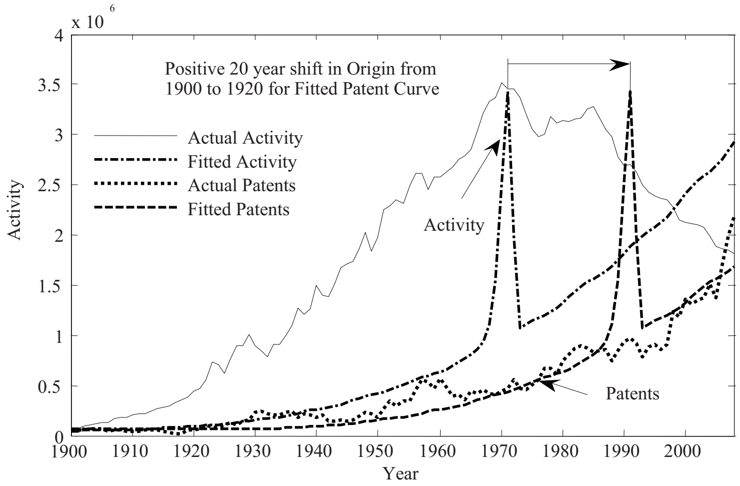

Figure A5.14. U.S. Oil best-Fit Activity and Patents. Illustrates best-fit origin shift.

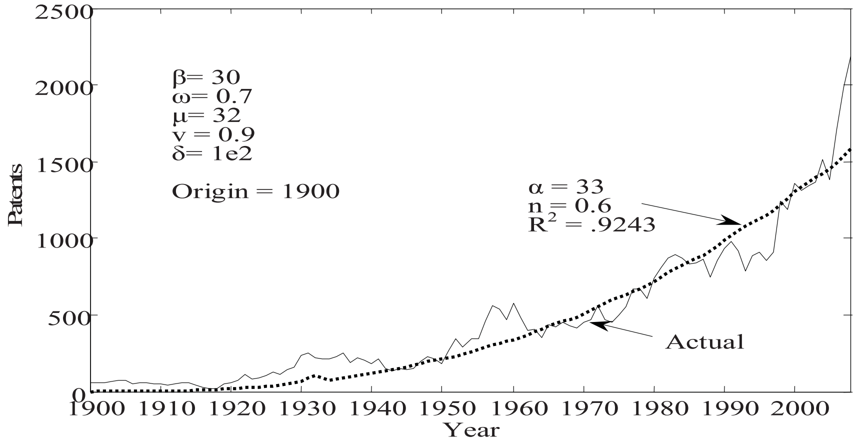

Figure A5.15. U.S. Oil Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Table A5.7. U.S. Uranium Usage Activity[151] and Patents[152]

Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)	Year	x (activity)	y (patent)
1900			**1927**			**1954**	4.95	43	**1981**	20.335	341
1901			**1928**			**1955**	6.58	43	**1982**	18.885	313
1902			**1929**			**1956**	12.21	79	**1983**	13.03	321
1903			**1930**			**1957**	17.03	131	**1984**	12.59	239
1904			**1931**			**1958**	28.59	236	**1985**	8.855	213
1905			**1932**			**1959**	34.39	271	**1986**	12.705	219
1906			**1933**			**1960**	35.64	306	**1987**	13.545	210
1907			**1934**			**1961**	31.85	234	**1988**	12.815	177
1908			**1935**			**1962**	29.11	196	**1989**	12.42	210
1909			**1936**			**1963**	25.42	199	**1990**	15.295	169
1910			**1937**			**1964**	17.9	200	**1991**	10.375	171
1911			**1938**			**1965**	14.44	182	**1992**	13.075	180
1912			**1939**			**1966**	12.49	184	**1993**	10.53	121
1913			**1940**			**1967**	10.55	184	**1994**	11.125	137
1914			**1941**			**1968**	11.57	134	**1995**	18.77	158
1915			**1942**			**1969**	11.11	107	**1996**	20.11	122
1916			**1943**			**1970**	10.805	125	**1997**	15.82	144
1917			**1944**			**1971**	17.075	135	**1998**	16.655	169
1918			**1945**			**1972**	12.8	130	**1999**	21.855	203
1919			**1946**			**1973**	12.635	140	**2000**	17.63	192
1920			**1947**			**1974**	10.03	137	**2001**	18.82	147
1921			**1948**			**1975**	11.8	135	**2002**	19.82	165
1922			**1949**	2.33	19	**1976**	13.945	172	**2003**	20.9	139
1923			**1950**	3.21	22	**1977**	15.74	229	**2004**	27.59	185
1924			**1951**	3.82	28	**1978**	17.685	213	**2005**	23.845	162
1925			**1952**	3.72	26	**1979**	17.135	233	**2006**	25.105	150
1926			**1953**	3.06	31	**1980**	20.75	271	**2007**	22.215	145
									2008	21.9	143

Activity represents U.S. uranium usage, defined at usgs.gov as domestic concentrate production and imports minus exports. Data is in thousands of tons as reported by the Energy Information Administration (EIA) at eia.doe.gov.

[152] Patents are total patents by a worldwide data base patent search on the European Patent Office (EPO) search engine esp@cenet. Uranium was used as the keyword found in the patent title or abstract by year of publication.

Table A5.8. Correlation Eq.(A1.1) terms calculated from Table A5.7 data.

Sum x	Sum y	Sum x^2	Sum y^2	Sum xy	Sxx	Syy	Sxy	r	$100r^2$
956.985	10020	18620.23	1989320	180220.5	3356.5606	315980	20404.03	**0.626526**	**39.25345**

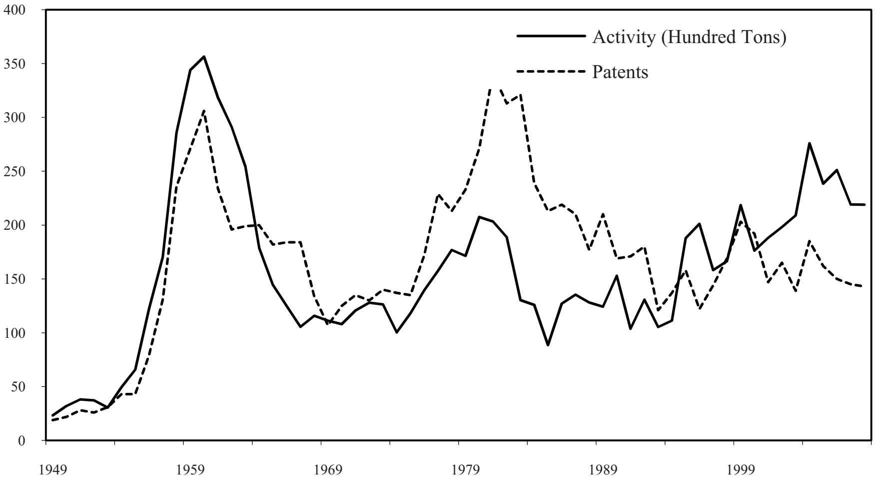

Figure A5.16. U.S. Uranium Usage Activity and Patents. Data illustrates correlation. Activity scaled to fit plot.

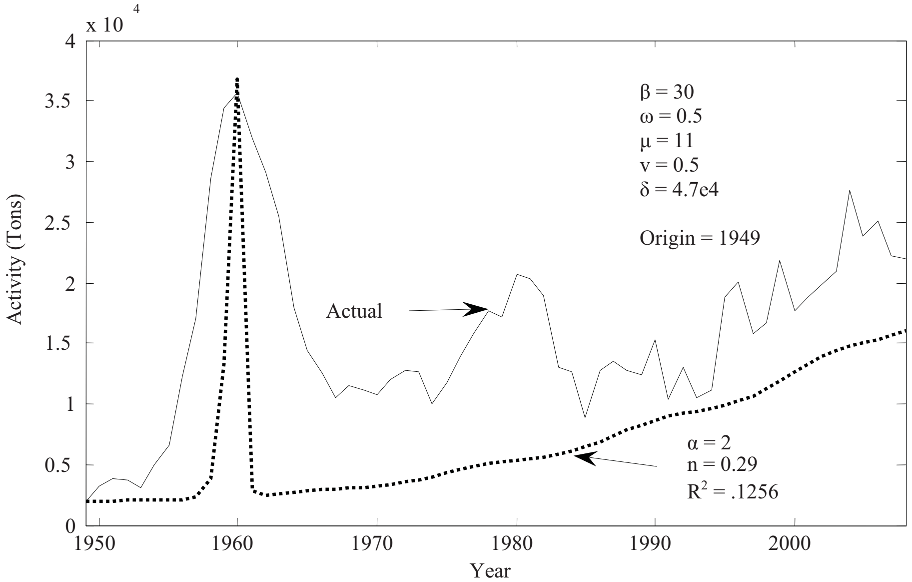

Figure A5.17. EIA Uranium Usage (Production and Imports minus Exports). U.S. uranium usage (activity) scaled in tons with actual and best-fit curves and common pattern equation parameters.

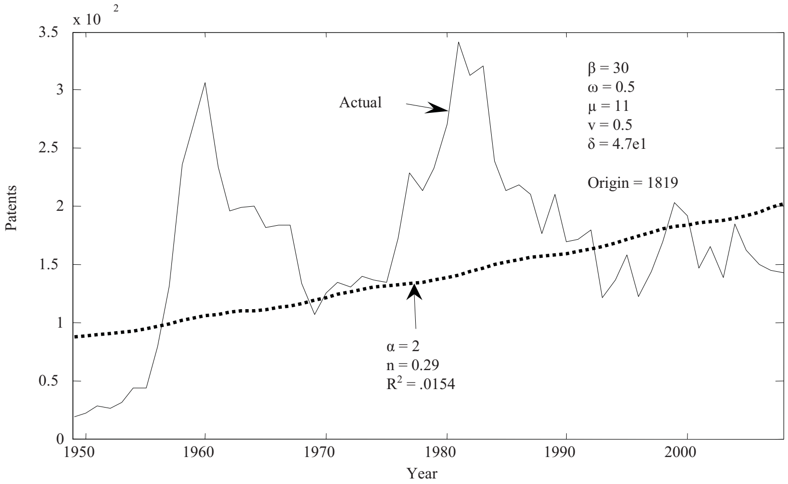

Figure A5.18. EPO Worldwide Patent Search: Uranium in Title or Abstract by Date of Publication. Best-fit generated using patent data in the production best-fit equation with production parameters. Only origin is changed.

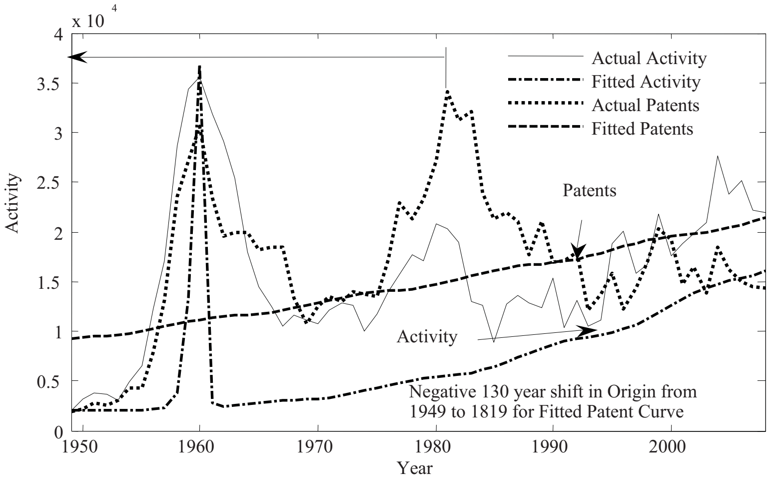

Figure A5.19. U.S. Uranium Best-Fit Activity and Patents. Illustrates best-fit origin shift.

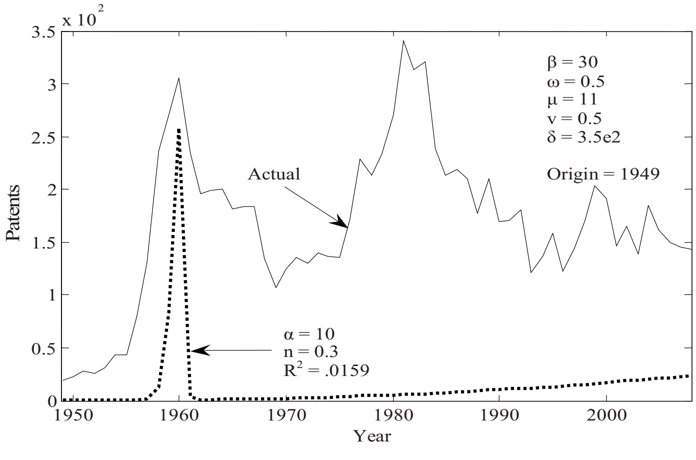

Figure A5.20. U.S. Uranium Independent Patent Best-Fit. Best-fit evaluation using patent data and pattern equation with unique patent equation parameters.

Appendix 6: Patent Search Keywords

Table A6.1. Engineering materials, energy sources and energy materials with the patent search keyword terms used for the patent search for each per year on the European Patent Office (EPO) Search Engine. Keywords were to be searched for in the title or abstract of the patents.

Engineering Material	Patent Search Keywords
Aluminum	Al, aluminum or aluminium
Antimony	antimony or stibium
Arsenic	arsenic
Asbestos	asbestos
Barite	barite, baryte or (barium and sulfate)
Bauxite/Alumina	bauxite or alumina
Beryllium	beryllium
Bismuth	bismuth
Boron	boron
Cadmium	cadmium or Cd
Chromium	cobalt
Cobalt	chromium, chrome or Cr
Copper	copper or Cu
Feldspar	feldspar
Fluorspar	fluorspar or fluorite
Gold	gold
Graphite	graphite
Gypsum	gypsum
Helium	helium
Hydraulic Cement	hydraulic and cement
Iodine	iodine
Iron	iron or Fe
Kyanite	kyanite or (aluminum and silicate)
Lead	lead or Pb
Lithium	lithium or Li
Magnesite	magnesium and carbonate
Magnesium	magnesium or Mg
Manganese	manganese or Mn
Mercury	mercury or Hg
Molybdenum	molybdenum or Mo
Nickel	nickel or Ni
Niobium	niobium, Nb or columbium
Nitrogen	nitrogen
Phosphate Rock	phosphate
Platinum	platinum or Pt
Potash	potash
Rare Earths	lanthanide, lanthanoid, yttrium or scandium
Salt	salt
Selenium	selenium
Silicon	silicon or Si
Silver	silver or Ag
Sulfur	sulfur or sulphur

Talc	talc or pyrophyllite
Tantalum	tantalum or Ta
Tin	tin or Sn
Titanium	titanium or Ti
Tungsten	tungsten or wolfram
Vanadium	vanadium or V
Zinc	zinc or Zn
Zirconium	zirconium or Zr
Energy Sources	**Patent Search Keywords**
U.S. Biofuel Energy	biofuel or biofuels or biodiesel
U.S. Biomass Energy	biomass
U.S. Coal Energy	coal
U.S. Fossil Fuel Energy	coal + (natural and gas) or methane or ethane + petroleum
U.S. Geothermal Energy	geothermal and (power or energy)
U.S. Hydroelectric Energy	hydroelectric
U.S. Natural Gas Energy	(natural and gas) or methane or ethane
U.S. Nuclear Energy	(nuclear and(power or energy)) or uranium
U.S. Oil Energy	petroleum
U.S. Renewable Energy	renewable and energy
U.S. Solar Energy	solar
U.S. Total Energy	coal + (natural and gas) or methane or ethane + petroleum + renewable and energy + (nuclear and(power or energy)) or uranium
U.S. Wind Energy	wind and (energy or power)
U.S. Wood Energy	wood and combustion
Energy Materials	**Patent Search Keywords**
Coal	coal
Natural Gas	natural and gas
Oil	petroleum
Uranium	uranium

Appendix 7: Scaling

In general, the production data is entered in the best-fit production equation as thousands of tons. For many materials this leads to a high R^2 value and also to an eventual shift in origin. In other cases the production must be scaled differently to achieve a high R^2 value and an origin shift. Scaling is sought to achieve the least differential between the scale of the production and patent data. A material with production numbers much larger than its patent numbers may need to be scaled up and entered as thousands of kilotons or megatons. When patent data counts are much greater than production, the production is entered as thousands of kilograms. This procedure allows for a more accurate evaluation of the best-fit of both production and patent data by resulting in R^2 values generally closer to one and resulting origin in shifts, but also is representative of the same amount of production only in a different scale.

Table A7.1 lists the materials which were tested with their production in tons and scaled in kilotons, megatons or kilograms. Listed also are three energy sources that were evaluated in billion kJ and scaled in trillion kJ. Some patterns may be revealed. In many cases R^2 values are closer to one for the scaled production best-fits meaning the fit is better in these cases. When the R^2 value is less for the scaled data it is still near the original R^2. When a material or source is scaled up the numbers entered into the Matlab program are smaller by units of a thousand (kiloton, megaton, trillion kJ) depending on the new scale. For example, one million tons would be entered in the program as 1000. But when scaled in kilotons it is entered as one. The resulting y-axis data would be less by a degree of 1000 as would the δ parameter (e.g. 4e6 goes to 4e3) which is the peak amplitude of the Stage II hump given in tons. In all cases δ decreased by the same multiple that the entered scaled data was subjected to.

Similarly when a material or source is scaled down the numbers entered into the Matlab program are larger by units of a thousand (kilogram) depending on the new scale. For example, one ton would be entered in the program as .001. But when scaled in kilograms it is entered as one. The resulting y-axis data would be more by a degree of 1000 as would the δ parameter (e.g. 4e3 to 4e6) which is the peak amplitude of the Stage II hump given in tons. In the only case of scaling down presented here, δ decreased by the same multiple that the entered scaled data was subjected to. Platinum had no original parameters to compare because definite ones are not produced with a negative R^2.

Table A7.1. Materials and energy sources that had scaled production data to achieve a modified patent data origin shift. Production is scaled up or down to better match the scale of the patent data. Platinum had no α, n, μ or δ for material in tons since with the case of a negative R^2 these best value of these parameters cannot be precisely determined. Best-fit parameters not listed (β, ω and v) did not change when materials or sources were scaled. δ may not have change exactly the by the same multiple as the scaling, but this is due to the original in tons not being at the optimal amount.

Engineering Material in Tons	α	n	δ	μ	R^2	**Units Scaled to**	α	n	δ	μ	R^2
Barite	14	1	1e6	11	.5876	Ktons	14	.017	1e3	11	.7803
Bauxite/Alumina	22	1.25	8e6	43	.9776	Ktons	59	0.3	4e4	43	.9521
Feldspar	13	1	1e6	19	.8925	Ktons	11	.01	1e3	19	.7833
Fluorspar	18	0.9	0.6e6	30	.6347	Ktons	1	.003	.6e3	30	.5703
Gypsum	29	1.29	4e7	39	.7524	Ktons	28	0.4	4e4	6	.8740
Hydraulic Cem.	16	1.8	1e8	16	.9224	Mtons	15	.05	1e4	16	.9743
Iron	18	1.6	1.3e8	25	.7549	Ktons	13	0.7	1.3e5	25	.8599
Magnesite	22	1	1e6	30	.6706	Ktons	35	.08	1e3	30	.8231
Nitrogen	14	1.58	1e7	15	.5337	Ktons	14	.56	1e4	15	.7316
Phosphate	33	1.2	5e6	30	.7896	Ktons	30	.35	5e3	30	.8815
Platinum	-	-	-	-	Neg.	Kilograms	14	0.5	1e4	10	.9539
Salt	19	1.4	5e6	7	.6760	Ktons	19	.47	5e3	7	.8438
Silver	4	0.1	1.5e5	11	.6964	Kilograms	5	1.2	1.5e8	11	.5027
Sulfur	16	1.2	5e6	3	.8399	Ktons	20	.25	5e3	3	.9322
Talc	11	1	1e6	39	.8551	Ktons	1	.01	1e3	39	.9226
Energy Sources in Billion kJ	α	n	δ	μ	R^2	**Units Scaled to**	α	n	δ	μ	R^2
Coal	18	0.6	4.2e6	26	.2633	Trillion kJ	28	0.2	4e3	26	.8547
Fossil Fuel	24	1.2	8.4e7	26	.0153	Trillion kJ	36	0.29	2e5	23	.1995
Total Energy	20	1.3	4.2e5	26	.0258	Trillion kJ	46	0.34	2e5	24	.3703

It is possible that the relative changes from year to year in the production data create the features in the plots that determine the stage of the material rather than the scale of the data. A material would be in the same stage whether its data is in tens, hundreds or thousands because the relative changes between data points would be the same from year to year resulting in identical plots of the actual production data with different y-axis scales. As shown in Figs. A7.1 and A7.2 there is a change in the fitted curve when the production is scaled to kilotons. This change would be caused by the differing best-fit parameters used in either case.

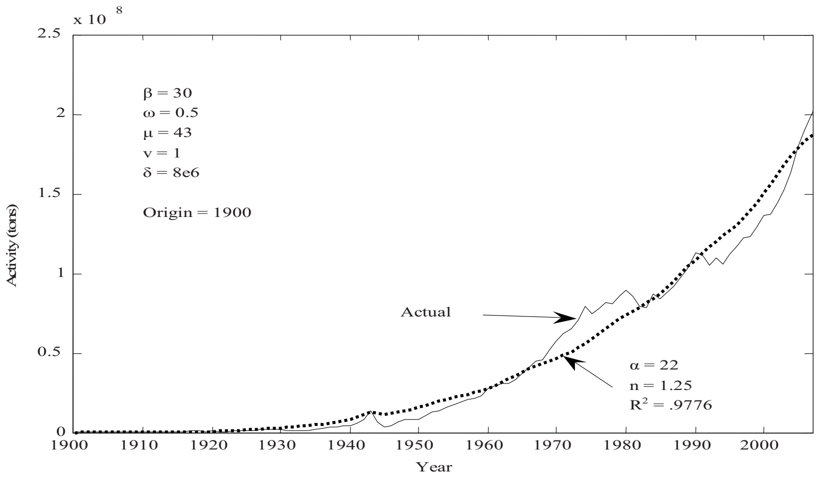

Figure A7.1. Bauxite production best-fit with production in tons.

For example, best-fit parameters were determined for bauxite as shown by Fig. A7.1 using tons as the unit for production activity producing a strong R^2 of 0.9776. However the numbers entered for the production data were in the tens of thousands to the hundreds of Millions while the entered patent data ranged from the tens to the thousands. The δ peak, which is measured in tons, produced by the production was to large to allow the patent data to run with the production equation. The δ peak was larger than the patent data itself. By scaling up to kilotons the entered production data was in the range of tens to hundreds of thousands with the patent data remaining the same. This scaling factor was mirrored by the δ value and peak in Fig. A7.2 that resulted in a scale that could be handled by the patent data. The scale also matches more accurately the scale of the production data in the y-axis. The shift in the production data of a certain multiple of 1000 is matched by the δ being scaled by the same amount allowing the data set and equation to use the same y_0 as the un-scaled one, leaving α dimensionless and rendering such scaling permissible. The same procedures were performed for all of the scaled engineering materials of energy sources.

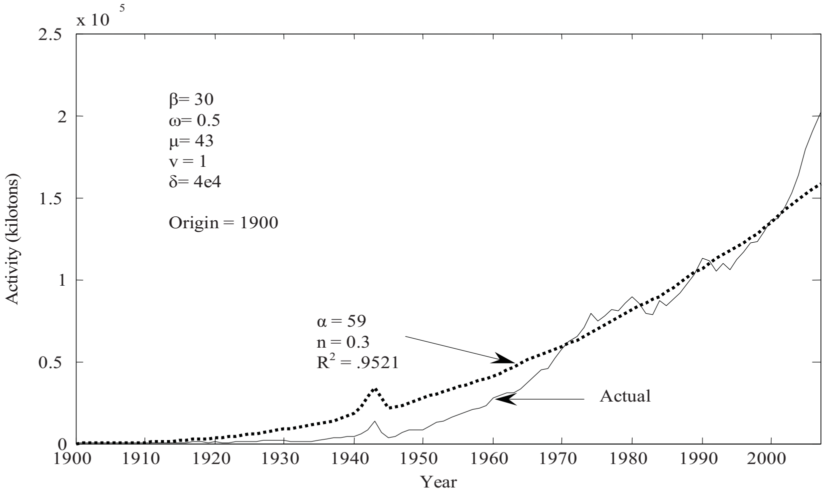

Figure A7.2. Bauxite production best-fit plot with production scaled in metric kilotons. The actual patent data curve is identical in shape to the curve in Fig. A6.1. Note the fitted curve is different due to different parameters.

While the δ parameter used for the calculation of the modified best-fit was identical to the δ used to obtain the production best-fit, the δ presented on all of the modified and independent patent best-fit figures was scaled down by a factor of one thousand. If the δ was 1e6 for production it was recorded on the figure as 1e3 since this better reflects the scale of the entered patent data. The patent data was not entered as one thousands as was the production data, but was still processed by an equation that treated the data as one thousands. The resulting δ values would describe a Stage II hump that was greater than the scale of the data itself. Scaling back δ solved this discrepancy with no change in results and only in the scale of the Stage II hump to reflect it more accurately.

Appendix 8: Executive Summary

1) Long-term life cycles can be used to describe the patterns that exist in the overall lifetime of a product, system or even living organism [2,84-89]. Such cycles exist in nature and in the business, manufacturing and engineering worlds. Life cycles may display the changes in the production of an item or the physical growth of a system or organism over a period of years. Four common stages have been identified in the past within the life cycle allowing for an evaluation of the trends that are present in the item and giving an indication of where the item is positioned in reference to its life cycle.

   a) Stage I: This stage is called the Initial Stage and is a developmental stage that begins with the discovery and invention of a process or product and ends when the development of the technology is great enough to start low-scale industrial production [2].

   b) Stage II: Stage II is known as the Lift Off and Decay Stage and begins with the rise of in the activity, or production, of a material and ends at the low point, or "valley of death" of the activity. Invention driven activity occurs in Stages I and II [2]

   c) Stage III: Stage III, or Revival and Rapid Growth starts at the "valley of death" and continues through the material's full growth potential with the take-off in activity typically being at a high rate [2].

   d) Stage IV: This stage is called the Survival or Low Growth Stage and is where the material has reached maturity and the activity has leveled off or has begun to die. Innovation is dominant in Stages III and IV [2]

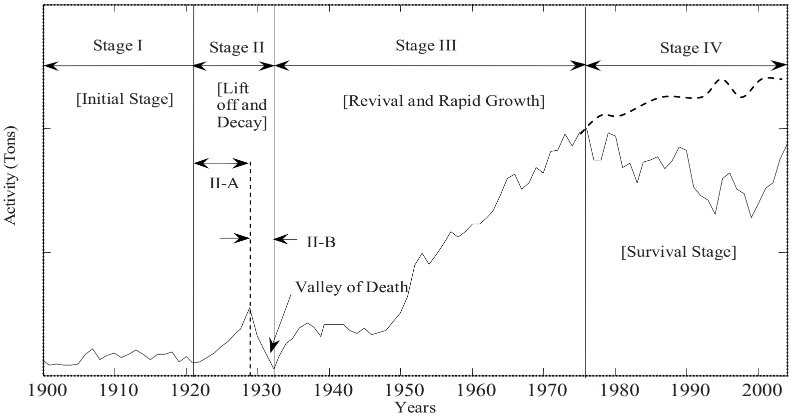

Figure A8.1. Illustration of a Typical Long-term Life Cycle for a Material. The plot indicates the division of the life cycle into four stages that is common to metals and non-metals. Common stage features are displayed.

2) The features common to the various life cycle stages are presented in Fig. A8.1. These features may be obvious from the raw data, but at times the stage of a material or system in not obvious. A model was needed that would mathematically capture the features of the stages of the life cycle and present a fitted curve that would represent the life cycle of a material in a form more suitable for evaluation.

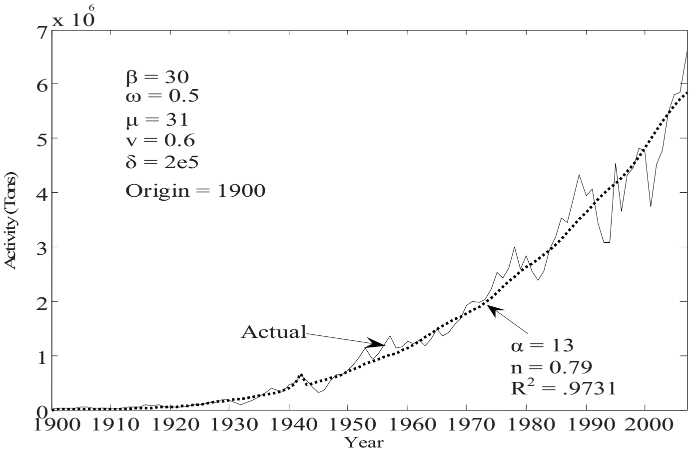

Figure A8.2. USGS World Chromium Production. Typical fitted production activity curve with best-fit parameters and R^2 value and origin. Shown in the figure are both the actual data curve and a best-fit curve.

a) A life cycle model for metals was proposed by Yeramilli in 2006. An equation, $y = x^n [\alpha x^2 + \beta x \sin(\omega x)] + (\exp[(x - \mu) / v] \exp[-\exp[(x - \mu) / v]] \delta / v)$, was developed that revealed that metals could be modeled successfully and that they displayed four-stage life cycles [2]. Such a model is shown in Fig. A8.2.

b) This equation was modified by Connelly in 2008 by raising the α and β parameters to the power of n leading to more consistent and reliable results [1].

c) Here, the equation is further modified by the normalizing of n by dividing it by n_0 which is equal to one, thereby making n dimensionless.

d) Also modified here to account for early years of production data which are far above zero and, as such, are much greater than the corresponding fitted curves resulting in low R^2 values. A constant, called $C1$, equal to the first year of the production data is added to the equation leading to $y = C1 + x^n [\alpha^n x^2 + \beta^n x \sin(\omega x)] + (\exp[(x - \mu) / v] \exp[-\exp[(x - \mu) / v]] \delta / v)$ (2). Employed only with iodine, lead and silicon where more reasonable R^2 resulted.

e) The first part of the equation, $x^n [\alpha^n x^2 + \beta^n x \sin(\omega x)]$, is responsible for the shape of Stage III (and Stage IV if a parabolic Alpha is used) in the fitted curve while the second part, $+ (\exp[(x - \mu) / v] \exp[-\exp[(x - \mu) / v]] \delta / v)$, controls the shape of Stages I-II in the fitted curve.

   i) Therefore, the second part of the equation is concerned with invention and the first part of the equation is concerned with innovation.

ii) Alpha and n are found only in the first part of the equation and only affect the innovative portion of the life cycle (Stage III). If alpha is small, the inventive stages are stretched out, are longer, and dominate the fitted curve. Conversely, if alpha is large, then the inventive stages are shorter and the innovative stage is longer and dominates.

    (1) Large alphas could indicate that a material is more mature and is farther into Stage III, or the innovative portion of its life cycle. Small alphas may indicate that a material is just entering Stage III and less advanced in its overall life cycle.

    (2) Alpha may be a measure of initial invention, measuring the period of time that was needed to develop the material inventively.

    (3) Since alpha, beta and x are all raised to the power n, n may be a measure of the importance of an invention. Materials such as talc with small n values (0.01), might then be of low technical importance and approaching Stage IV along Path A in Fig. A8.5.

3) This modified equation was applied to obtain a best-fit for the production, in tons per year, for over fifty engineering materials (metals and non-metals) and also for their associated patents.

    a) The production data and patent data were evaluated separately to reveal fitted curves modeling life cycle stages I-III. Linear alphas were used in the common pattern equation to reveal Stage III behavior. (Parabolic alphas model and reveal Stage IV, but were not employed here since only Stage III materials were sought.)

b) The result of each production and patent data best-fit evaluation was a fitted curve and an R^2 value indicating the extent of the fit of the generated curves. An R^2 value near one for the fitted curve for the production of a material was considered as an indication that the material was in Stage III of its production life cycle. Likewise, an R^2 value near one for the fitted curve for the patent data of a material was considered as evidence that the material was in Stage III in its patent data life cycle.

c) Correlation theory was applied to the production and the patent data to explore if any relationships exist between the two data sets for each material. It was found that the production data and patent data for materials were correlated to some degree in most cases across their entire life cycles. This implies that changes in the production data set can be attributed to changes in the patent data set or vice versa. If strong correlation exists, Stage III is assumed to be present. Stage IV or V (Stage V being a newly introduced stage beyond Stage IV where production is in a very steep decline with little evidence of future recovery), is assumed if correlation is very weak or is not indicated.

4) The point at which a material leaves Stage III and enters Stage IV is an important concept that, as of yet, has no clear answer. This transition from Stages III to IV could take place over a span of several years. The transition could occur due to resource depletion, environmental concerns or low impact of new patents. A parabolic alpha, when employed in the equation presented here, may be useful in describing a Stage IV material. Conversely, Stage III may be indicated when a constant, or linear alpha, produces a fitted curve with a good R^2 value. Further best-fit analysis presented here may offer a possible dividing line between Stage III and Stage IV.

a) The patent data was manipulated to reveal a new best-fit curve with a new origin that can be either earlier or later than the original.

  i) The patent data was entered into the equation used to determine the best-fit for the production data. The data set was merged by using dimensions of the corresponding data set. All parameters were kept the same except for the data set and the data origin.

  ii) The origin was move backward or forward to obtain the R^2 value nearest to one. This change in origin became a positive (forward) or negative (backward) origin shift.

  iii) The value of R^2 is sensitive to the movement of the origin leading to an optimal R^2 value. A change in the year away from the origin shift that produces the R^2 nearest one results in a typical steep drop-off away from the optimal R^2. Figure A8.3 shows that for biofuel energy the R^2 nearest one was obtained with an origin shift of seven years from 1981 to 1988. The R^2 values drop steeply away from this value as the origin shift moves away from the origin shift of seven years in both directions. A best value of R^2 is thereby assured in all cases.

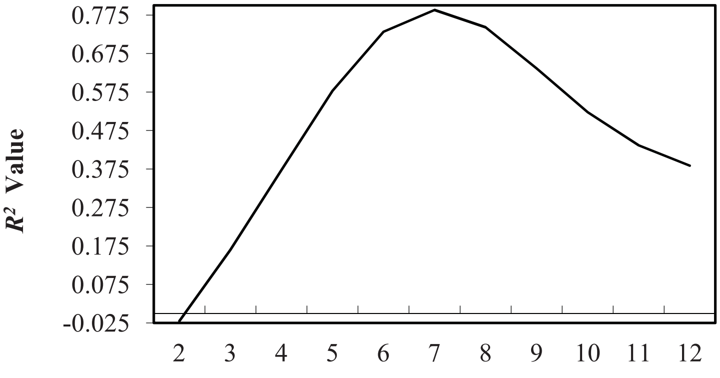

Figure A8.3. Biofuel Energy Sensitivity Curve: R^2 Values by Number of Years Shifted From Origin. Origin at 1981, R^2 closest to 1 at 1988. Illustrates steep drop-off of R2 after best R2 was attained at a positive seven year shift in origin. Such drops are typical for all origin shift evaluations.

b) This new curve can be superimposed upon the original to graphically reveal a shift in origin. A typical origin shift is shown for Zinc in Fig. A8.4.

   i) Shifts may be seen by examining the Stage II humps if they are prominent. They often are not obvious. Shifts may can be seen in both the actual and fitted curves and are the same for both.

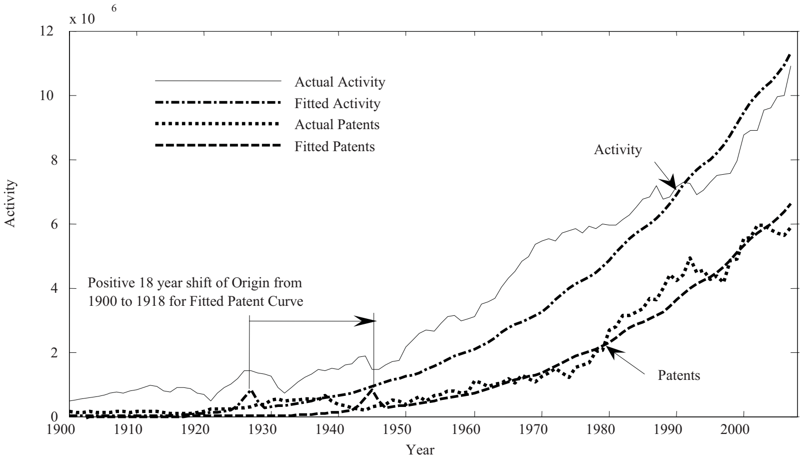

Figure A8.4. Zinc Best-Fit Activity and Patents. Plot depicting the origin shift of patent and activity best-fit curves for zinc. The shift is positive, indicating patent activity occurring after production activity and thus possibly being driven by the production. All parameters for the pattern equation are identical for the patent and production activity curves except for the origins (the matching results in the positive origin shift).

   ii) A positive shift occurs where the production data of the material reached a point in its life cycle previous to the patent data reaching the same point in its life cycle. In a positive shift, the production occurs first and drives the patenting.

iii) A negative shift is present where the production reached a point in its life cycle after the patent data reached the same point in its life cycle. Where a negative shift exists, the production is being driven by the patenting.

c) Positive shifts may indicate innovation being driven by production and the destructive side of the innovative process while negative shifts may represent innovation driving production and the constructive side of the innovative process as proposed by Schumpeter [55]. These shifts in origin are considered as strong evidence of Stage III which verify indications of Stage III provided by strong correlation and R^2 values near one for engineering materials.

d) A graphical representation, such as Fig. A8.5, of the relative scale, or distance, of the origin shift can be made, using a ratio of the shift and the origin, x_0, of the production data, indicating an absolute amount that the patent or activity driving force has on the other. This ratio, called the Origin Ratio, composes the x-axis of Fig. A8.5 and is defined as $(x_0 + OS)/x_0$, where x_0 equals the production data origin and OS is the shift in origin of the modified best-fit patent data. The y-axis of Fig. 4 is the drive ratio of the material and is expressed as $(\alpha^n)_a/(\alpha^n)_p$, where $(\alpha^n)_a$ equals the activity best-fit variable alpha to the n power and $(\alpha^n)_p$ is equal to the patent best-fit variable alpha raised to the power n, in both cases n, being best-fit variables. Such a curve with the origin ratio on the x-axis and the drive ratio on the y-axis, both being non-dimensional (origin ratio is years over years and drive ratio results from $(\alpha^n)_a/(\alpha^n)_p$ which both result from equations with units of patents which cancel each other), may effectively represent innovative behavior.

i) In Figure A8.5 the materials are divided into two groups. Group 1 materials all have drive ratios below one and origin ratios below one. Group 2 materials each have drive ratios of one or above and origin ratios of one or above.

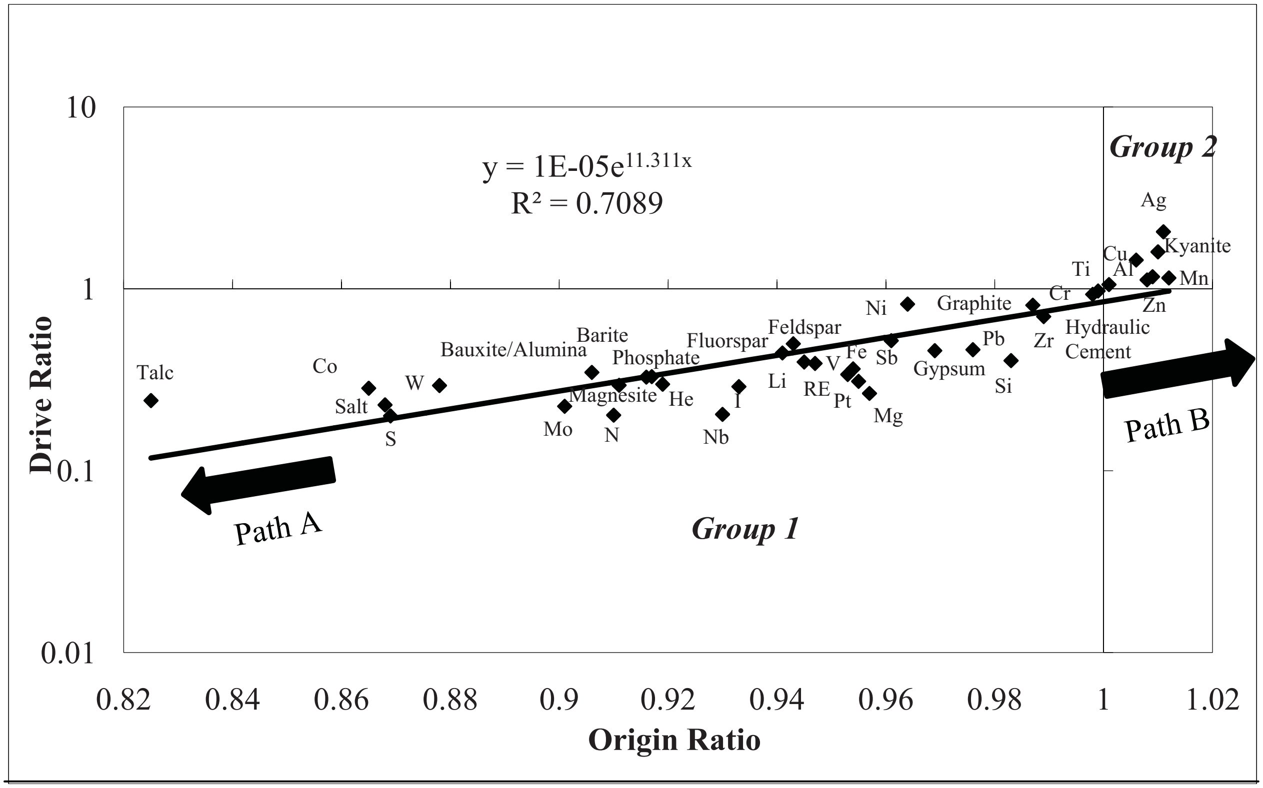

Figure A8.5. Engineering Materials Origin vs. Drive Ratio. Origin Ratio vs. Drive Ratio displaying relative strength of driving force of either patents or production activity. Note also that the cross over point occurs at 1 (y-axis). The origin shift is the shift described in section 3 between the best-fit activity and best-fit patent evaluations for each material using the common pattern equation (1). Also depicts possible paths to Stage IV.

ii) Group 1 materials have negative origin shifts with patents driving production while Group 2 materials have positive origin shifts indicating patents are being driven by production. This may mean that Group 1 materials are in the constructive mode of innovation since patents, which are a measure of innovation, are driving the production of these materials. Group 2 may be in the destructive mode of the innovative process because patents, representing innovation, are being driven by production.

    iii) A point, n_0, equal to one, near where the trend line of the data points cross the y-axis at the point where the x-axis equals one, may delineate the dividing line between the constructive and destructive modes of the innovative process.

    iv) Such a figure may also provide an answer concerning when Stage IV is reached.

  e) Materials such as talc, in Fig. A8.5, may leave Stage III and enter Stage IV as their origin ratios and drive ratios become farther below one as represented by the Path A arrow in Fig. 4. As both the ratios become progressively lower, patenting is strong but there is less production to drive and a point may be reached where the ratios become so small that patenting, or innovation, is no longer correlated to production and Stage IV will thus be reached. The Path B arrow in Fig. A8.5 represents materials such as silver whose origin and drive ratios are growing greater than one. In such an example, production is driving fewer and fewer patents to a point where there is little innovative activity to correlate to production. Stage IV is entered and the material becomes a commodity.

5) All of the preceding analyses were then applied to energy sources. It was discovered that energy sources behaved in a similar manner to engineering materials in regards to correlation, best-fit and origin shift.

  a) Energy sources displayed correlation between production (in kJ) and patents per year.

  b) Similar life cycle and best-fit results were exhibited R^2 values were lower for production best-fit. This may be due newer energy sources, such as wind, solar and renewables, still may only be in Stage I or II of their life cycles. The best-fit analysis and equation may be reading aspects of Stage I or II as Stage III resulting in lower R^2 values. With mature energy sources, such as oil or coal energy which have been used for many decades, the available data sets may be only displaying Stage III production leading to a lower R^2 values as well.

c) Figure A8.6 depicts a comparison of drive ratio and origin ratio done in the same manner as Fig. A8.5 for engineering materials. The same patterns emerge as for engineering materials.

    i) Drive and origin ratios below one exist for Group 1 energy sources which indicate patents driving production inferring constructive innovative behavior.

    ii) Group 2 is composed of energy sources with drive and origin ratios of one or greater indicating patents being driven by production and the negative mode of the innovative process.

    iii) The dividing line between the modes of the innovative process, n_0, appears also to be one as was the case for engineering materials.

    iv) As with engineering materials Stage IV may be entered from either Path A from the constructive mode of innovation or via Path B from the destructive side of the innovative process becoming a commodity.

    v) The dashed line in Fig. A8.6 represents a possible trend line for the remaining energy source data points when coal and total energy are removed or move into Stage IV.

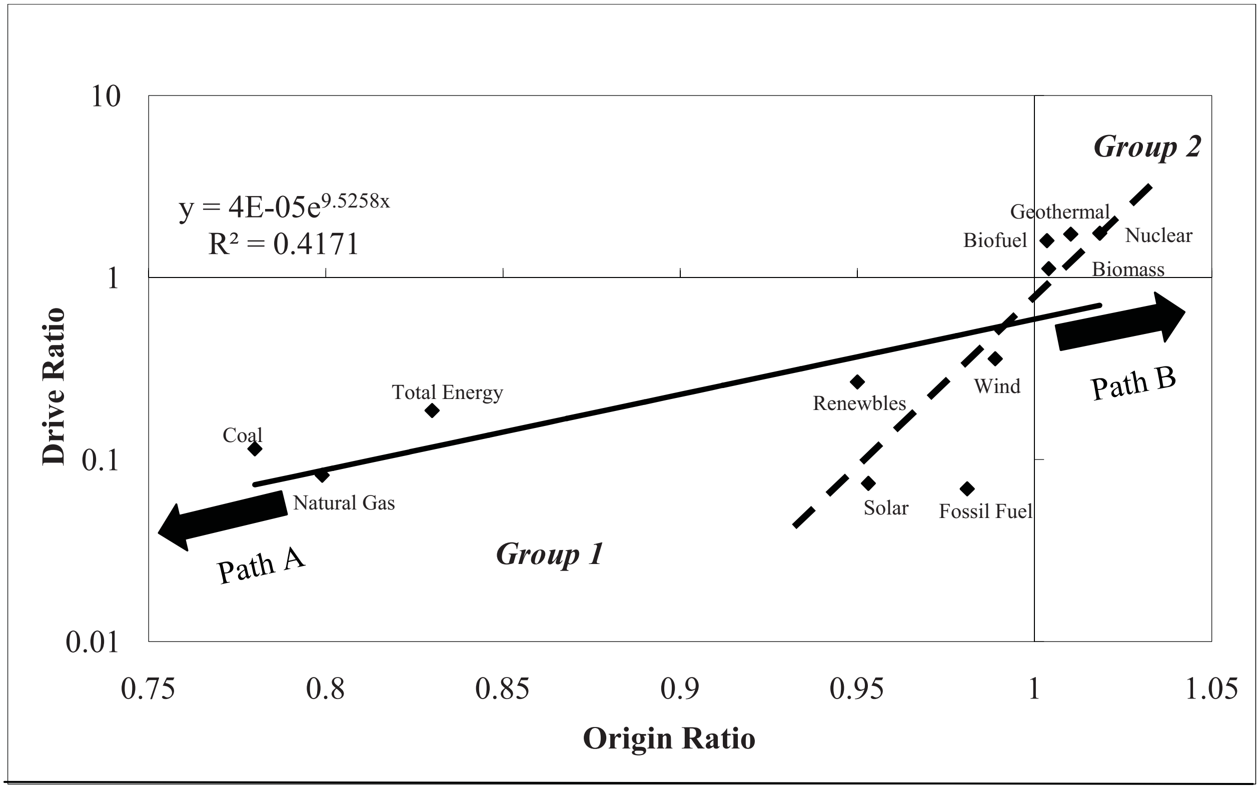

Figure A8.6. Energy Source Origin Ratio vs. Drive Origin. Displays relative strength of driving force of either patents or production activity. Possible paths A and B into Stage IV depicted by Arrows. Predicted trend line of energy source data without coal, natural gas and total energy illustrated by dashed line. R^2 for the dashed line is .6632 with an equation of y = 1E-19e$^{43.483x}$.

6) After evaluation of both engineering materials and energy sources it was realized that Stage III energy sources often employ or are enable by engineering and energy materials that are also in Stage III.

    a) Table A8.1 lists Stage III energy sources and the Stage III engineering materials with their related uses in reference to the energy source.

    b) Table A8.2 lists Stage III energy sources with the Stage III materials that are related to them. In most cases the origin shift is in the same direction and the ratios are higher or lower than one for the material as they are for the energy source. The size of the shift or ratio may not be the same but Table A8.1 is evidence of a relationship between innovatively active energy sources being innovated by or helping to innovate Stage III materials.

Table A8.1. Examples of energy sources and the engineering materials that are innovatively active possibly due to their usage in the related energy source.

Energy source	Related Material	Usage
Solar Energy	Vanadium	Vanadium Redox Batteries (large power storage)
"	Silicon, Selenium	Solar Cells
Wind Energy	Vanadium	Vanadium Redox Batteries (large power storage)
Nuclear Energy	Fluorspar	Nuclear Fuel Additive
"	Uranium	Fuel
Renewable Energy	Graphite	Fuel Cells, Batteries
"	Nickel, Rare Earths, Cobalt	Rechargeable Batteries
"	Lithium, Cadmium, Lead	Batteries
"	Manganese	Dry Cell Batteries
"	Silver	Battery Electrodes
Coal Energy	Coal	Fuel
Natural Gas Energy	Natural Gas	Fuel

Table A8.2 Comparison of origin shifts, origin ratios and drive ratios of energy sources and the engineering and energy materials that are related to them. **Energy sources** are in kJ/year.

	Origin Shift	Origin Ratio	Drive Ratio
Solar Energy	**-93 years**	**0.953**	**0.074**
Vanadium	-90 years	0.954	0.363
Silicon	-30 years	0.985	0.435
Wind Energy	**-22 years**	**0.989**	**0.36**
Vanadium	-90 years	0.954	0.363
Nuclear energy	**+36 years**	**1.018**	**1.75**
Uranium	-130 years	0.94	0.61
Fluorspar	-113 years	0.941	0.444
Coal Energy	**-428 years**	**0.780**	**0.115**
Coal	-30 years	0.984	0.57
Natural Gas Energy	**-392 years**	**0.799**	**0.082**
Natural Gas	-326 years	0.832	0.22
Renewable Energy	**-97 years**	**0.950**	**0.267**
Graphite	-24 years	0.987	0.813
Nickel	-69 years	0.964	0.824
Rare Earths	-101 years	0.947	0.389
Cobalt	-256 years	0.865	0.284
Lithium	-106 years	0.945	0.396
Lead	-41 years	0.978	0.434
Manganese	+23 years	1.012	1.418
Silver	+21 years	1.011	2.060

7) This dissertation expands upon previous research relating to long-term life cycles in materials and extends such research into energy sources. Four-stage life cycles, which were found to

exist for the production of metals were discovered to exist in an expanded list of metals and also were shown to be present in non-metals as well as energy sources and materials. The equation used to model the life cycles of metals was modified here to render it more reliable and consistent. Similar behavior was noted for energy sources as was exhibited by engineering materials. Patterns relating to correlation, best-fit, life cycles and origin shifting were the same for both engineering materials and energy source. Shifts in the origin of the data for a modified patent best-fit revealed a possible point at which Stage III may transition into Stage IV for both materials and energy sources and verify various indicators that point towards the existence of Stage III.

The driving or driven behavior of patents, represented by an origin shift, may indicate the dual nature of innovation by identifying the constructive and destructive modes of the innovative process. A universal constant, n_0, which is equal to one, may represent the dividing point between the two modes of the innovative process and were seen in relation to both engineering materials and energy sources.

Stage III energy sources were often found to be supported by Stage III materials that are innovatively active and seem to be contributing to the innovation of the energy source while possibly being innovated themselves at the same time. Due to lower R^2 values generated from best-fit analyses for energy sources, it is suggested here that mature energy sources such as coal and oil energy may only have production data that is in Stage III with earlier Stage I-II data being unavailable. In contrast, relatively newer energy sources, such as wind and solar energy, may still be in Stage I or II. Since the position in a life cycle can change over the years only the passage of time will reveal the exact position of these newer energy sources in their life cycles.

Advancements in the study of life cycles are presented here which may further the understanding of the innovative process in general and for engineering materials and energy sources in particular. New and original contributions are made concerning the dual nature of the innovative process and the transition from Stage III to Stage IV in long-term life cycles. It is strongly believed that the processes described here could successfully be applied to a variety of materials and systems in the future and not confined solely to the evaluation of engineering materials and energy systems.

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