Modelling Trends and Volatility in Ecological Patents in the USA

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Abstract: Ecological patent registrations have been increasing in the USA steadily over time. The paper analyses trends and volatility in US ecological patents in the USA from 1975 to 1997. Germany contributed more than 10% of the total number of US ecological patents, and has been by far the strongest foreign performer. The time-varying nature of the volatility of the ecological patent share, namely the ratio of US ecological patents to total US patents, is examined using monthly data from January 1975 to December 1997. As negative and positive movements in the patent share may have differential impacts on innovative activity, and hence on volatility, both symmetric and asymmetric models of volatility are estimated. The asymmetric AR(1)-GJR(1,1) model is found to be suitable for modelling the ecological patent share in the USA.

***Keywords*:** Ecological patents, patent share, innovation, trends, volatility, GARCH, GJR, asymmetry, shocks.

1. INTRODUCTION

Ecological problems such as global warming, ozone layer depletion, land erosion, depletion of natural resources and acid rain have drawn the attention of politicians and researchers globally to the challenge of ecologically sustainable development. Since the United Nations Conference on the Environment and Development in Rio de Janeiro in 1992, the business community has established the International Business Council for Sustainable Development to promote technologies that are less harmful to the environment. The voluntary environmental standards ISO 14000 have been developed to establish continually improving processes for environmentally responsible behaviour. There has also been a higher level of research and development (R&D) investment channelled into research that is related to the ecological environment.

The patent system is a firmly entrenched component of the economic and industrial environment in which technologies and trade links are developed. Since the mid-1970s, patenting has become a powerful tool for protecting industrial intellectual property. Patents are also conducive to economic growth, and patent data represent technological knowledge development by countries, companies and individuals, including potential technological strengths (Marinova and McAleer, 2002).

Patenting may be regarded as essential for co-ordinating market forces (see, for example, Arup, 1993, Furman et al., 2002, and Smith, 2001). Consequently, it might be expected that the efforts of the international business community to deal with environmental problems will result in more ecological innovations being patented. Several studies have confirmed that patenting activities cause immediate and subsequent market changes (see, for example, Soete, 1987, Griliches et al., 1991, and Ernst, 1995, 1997). International patenting has also been found to be a significant determinant in productivity performance (Fagerberg, 1987). Thus, the greater the number of ecological patents, the more likely will the market economies be to adopt a course of sustainability.

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With its large and technologically advanced markets, the US economy has always been highly favourable to companies and individuals interested in protecting their intellectual property rights. The USA has also been very attractive to foreign residents who have been willing to establish their innovation priority. There was an unprecedented surge in patenting activities in the USA by foreign countries from the mid-1980s onward (Kortum and Lerner, 1999; Arundel and Kabla, 1998). In absolute numbers, the US Patent and Trademark Office (PTO) receives by far the largest number of foreign applications (Archibugi, 1992), and overall is the largest source of information on technological developments. Amendola et al. (1998) claim that patents granted in the USA are particularly suited for the investigation of the impact of technological change on trade performance at the sectoral level. Of interest for this paper are technologies related to the ecological environment.

This paper analyses trends and volatility in the development of more ecologically-friendly technologies, or technologies which assist in abating existing ecological problems. Monthly data from the US PTO for the period 1975 to 1997 are used to analyse whether there are signs of a technological paradigm shift in relation to the ecology.

The plan of the paper is as follows. Section 2 describes the ecological patent data used in the empirical analysis. General trends in ecological patenting are discussed in Section 3. Section 4 discusses the economic and financial motivation for examining the GARCH and GJR volatility models to be estimated for the ecological patent share, which is followed by an empirical analysis of volatility in the ecological patent share in Section 5. Some concluding remarks are given in Section 6.

2. DATA DESCRIPTION

Empirical information on patent data is available from the US PTO through its on-line search engine (http://164.195.100.11/netahtml/search-adv.htm). The time series data used, which were extracted on 6 April 2001, consist of monthly observations on the number of ecological patents with application dates between 1975 and 1997. It was decided to use the time series of patents according to application date to avoid artificial distortion of the data caused by organisational delays in the process of granting patents[1].

The current US patent classification system does not provide special categories which cover ecological patents. There is also no well-accepted convention in the literature as to what constitutes an ecological (alternatively, environmental, green, clean, or cleaner) technology. Most studies use working definitions, such as: technology which offers considerable environmental benefits (e.g. Journal of Cleaner Production), or minimises the ecological impact of economic production (e.g. Shrivastava, 1995)[2]. The United Nations Environmental Program uses the term "environmentally sound technologies" which "encompass technologies that have the potential for significantly improved environmental performance relative to other technologies" (UNEP, 2002). Such technologies use fewer resources, are less polluting, protect and/or rehabilitate the natural environment, recycle materials and waste, and conserve energy and water. Major parts of any patent are the description of the technical background and the summary of the invention. As a rule, the new technology is judged against the existing technological solutions, with the expectation that it will perform at a higher standard. When the

[1] During this period, there have not been any significant changes in the US legal framework governing patent applications and issuing procedures which might be relevant to this study. The 1997 General Agreement on Trades and Tariffs (GATT) change refers to patent length, and does not affect the application and issuing procedures.

[2] Another working definition would be "the intent of the technology is to reduce overall environmental impact and/or the advantages/benefits of the technology include a significant reduction in environmental impacts." (Marinova and Altham, 2000, p.253).

technology is described in terms of its superior environmental performance, such an invention can be considered to be an ecological patent[3].

The following approach was used to identify ecological patents: a patent is considered to be related to the ecological environment if its abstract or full text contains words such as "ecology", "ecological", "ecologically" (or any other word beginning with "eco-"[4]) or "environmentally". Owing to the limitation in the number of simultaneous search terms in the search engine, selectivity was essential in the choice of keywords[5]. For example, words such as “global warming” and “greenhouse effect” were not included separately as keywords in the definition of ecological patents because of possible ambiguity (e.g. “greenhouse effect” can refer to an actual greenhouse). Random checks confirmed that patents which contain “global warming” and/or “greenhouse effect” used in relation to the environment, also contain in their abstract or full text some of the selected keywords for describing ecological patents. For example, the novelty of the system for the in situ destruction of compressible refrigerant (US patent 5,997,825), and the compositions of 1-bromopropane and an organic solvent (US patent 6,103,684), is described against the background of the use of CFCs contributing to global warming. The same patents also contain the word “environmentally”, which would have been selected by the search engine for the patents to be regarded as ecological. Similarly, new methods for removing sulphur oxides, nitrogen oxides and particulates from the products of combusted carbonaceous fuels (US patent 4,540,554), and for chemically reducing metals in waste compositions (US patent 5,324,341), refer to the adverse greenhouse effect, and also contain the keyword “ecological”.

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[3] Although terms such as ‘ecological’, ‘environmental’, ‘green’, ‘cleaner’, and so on, are considered to be synonymous when applied to patented technologies, for reasons of consistency we have opted to use the term ‘ecological patent’.

[4] The word "eco" was excluded because it generated only patents referring to the so-called Eco enzyme, which is outside the area of this study. The terms related to economics, economic, economical, economically, etc. were not included in the search.

[5] Multiple searches with different keywords would have resulted in double counting of patents.

It is not feasible to incorporate in the definition of ecological patents a keyword search using "environment" or "environmental" because of their widespread use outside the area of the ecological environment, such as in the digital, physical or economic environments. Individual reading and checking of each of the many thousands of US patents containing "environment" or "environmental" would have been an insurmountable exercise. It was decided that the number of patents related to ecologically sustainable technology, which would not include one or more of the various definitions given above, would be very limited[6]. In addition, the same approach was used consistently across the time series, which makes it possible for trends and volatilities in the data to be detected and analysed.

3. GENERAL TRENDS IN ECOLOGICAL PATENTING

Figure 1 shows the trends in ecological patenting in the USA, based on monthly data from January 1975 to December 1997. It is clear that the trend is upward sloping, in general, with the 1990s being a period of intensive patenting of technologies which are related positively to the ecological environment. During this period, the largest annual number of awarded ecological patents came from applications lodged in 1995 (see Figures 1 and 3), with June 1995 being a period of extreme patenting activity. As the monthly patent data show some seasonality for both US ecological and total US patents (see Figures 1 and 2, respectively), the use of patent shares (see Figure 4) mitigates this problem.

Figure 1 and all consequent figures show the trends in issued patents by date of application, which is a more accurate measure of patent activity than the date of issue (as it is not influenced

[6] For example, between 1975 and 1998, the numbers of patents containing “greenhouse effect” or “global warming” in their abstract or full text description were only 1348. If we assume that all of them do not contain any of the used keywords, the omission error would be 3.8%.

by administrative delays in the US Patent and Trademark Office related to the processing of the applications[7]). Figure 1 presents the monthly US ecological patents, with an apparent extreme observation in 1995. A similar comment applies to monthly total US patents in Figure 2. The annual total US patents and US ecological patents in Figure 3 have eliminated the apparent extreme observation in 1995. Moreover, as can be seen from the monthly ecological patent shares in Figure 4, patent shares do not exhibit any extreme observations or outliers.

Figure 3 presents the annual total US patents and annual US ecological patents for 1975-1997. Total annual patents registered in the USA have also been increasing steadily, reaching a peak of close to 170,000 approved patents from the applications lodged in 1997. In addition, the figure shows the annual trend in approved ecological patents, which reached a peak of 3,565 in 1995, and a slightly lower peak of 3,300 in 1997.

A comparison of the two trends in Figure 3 shows that US ecological patents have been growing at a faster rate than total US patents, which is a positive development with regard to ecological considerations. This changing relationship reflects fluctuations in the world economy as technological innovators respond to community concerns regarding the impact of technologies on the ecological environment.

Though increasing, the monthly patent share, which addresses ecological issues and their implications, remains very small (see Figure 4). Since 1993 the ecological patent share has only been around 2% of the total patents lodged in the USA, and also seems to have settled at this level. This may be a warning of a lack of commitment by industry and individuals internationally to improving the ecological patent share in the long run.

[7] It takes an average of two years for a patent application to be approved. However, in some cases it can take much longer, and delays of 7-8 years are not unknown. It is likely that the number of approved applications in more recent

In Figure 5, the observed volatility of the monthly ecological patent share is presented. The time-varying models of volatility in Section 4 will be used to explain the volatility in the patent share, as given in Figure 5.

Figure 6 shows the total ecological patents lodged in the USA by residents and companies of foreign countries, with application dates between 1975 and 2000. The overall major contributor during this period has been Germany with 3,785 patents, which accounts for more than 10% of the total number (including domestic) of US ecological patents.[8] The share of ecological patents in total patents lodged by German residents in the USA has also been increasing steadily, to around 4% in the late 1990s. Both Canada and Japan, which are second and third (see Figure 6), respectively, have less than one-third of the US ecological patents lodged by Germany.

With 215 patents and around 0.6% of total US ecological patents, Australia ranks eleventh, which is perhaps understandable given the small size of the economy. However, a number of countries with smaller populations, such as Sweden, Switzerland and the Netherlands, have demonstrated a greater commitment than Australia to registering ecological patents.

4. ALTERNATIVE MODELS OF VOLATILITY: AR(1)-GARCH(1,1) AND AR(1)-GJR(1,1)

As volatility in ecological patent registrations and patent shares have not yet been analysed in the literature, the primary purpose of this section is to model the volatility in the ecological patent share in the USA. However, a new approach based on Engle's (1982) path-breaking idea of

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years will have increased.

[8] The observations for Germany include a miniscule 7 patents from the former German Democratic Republic.

capturing time-varying volatility using the autoregressive conditional heteroskedasticity (ARCH) model can be applied to analyse ecological patent shares. Subsequent developments have formed the ARCH family of models (see, for example, the useful surveys of Bollerslev, Chou and Kroner, 1992, Bollerslev, Engle and Nelson, 1994; Li, Ling and McAleer, 2002). Of these models, the most popular has been the generalised ARCH (GARCH) model of Bollerslev (1986), especially for the analysis of financial data. In order to accommodate asymmetric behaviour between negative and positive shocks (or movements in the time series), Glosten, Jagannathan and Runkle (1992) proposed the GJR model. Some further developments have been suggested by Wong and Li (1997), He and Teräsvirta (1999), and Ling and McAleer (2002a, b, c).

The reasons for analysing the volatility in ecological patents and patent shares can be quite different from the use of GARCH models in the area of finance and financial economics, in which the main interest is in pricing financial products. Volatility is an inherent characteristic of financial markets, which relates to their established nature and modes of operation. Ecological patents, on the other hand are a relatively new phenomenon, which is expected to have a considerable impact on international economies, with increasing concerns about the ecological environment. For example, under the 1997 Kyoto protocol, the industrialised countries agreed to reduce greenhouse gas emissions by an average of 5.2% between 2008 and 2012. Although this protocol has not (yet) been ratified by the USA (or by Australia), all events leading to the Kyoto meeting and the expectations thereafter are likely to have a significant impact on R&D expenditure. Consequently, there should be a greater number of ecological patents registered in the USA. A reasonable implication from is that the patenting of ecological technologies might not demonstrate substantial volatility. From a policy perspective, for an ecologically sustainable development, the registration of new technologies which reduce the human impact on the ecological environment should not be a volatile process. Therefore, it would be instructive to examine the volatility in the ecological patent share between 1975 and 1997.

From an economic and financial perspective, futures contracts and options, and other derivatives, are used widely to hedge against price risk in commodity markets. Sensible strategies for hedging, and for pricing options and other derivatives, require knowledge of the volatility of the underlying series. As volatility is generally unknown, it must be estimated. These estimated volatilities are fundamental to risk management in financial models that describe the risk-return trade-off. In practice, estimated volatilities are used widely in portfolio selection, asset management, pricing of primary and secondary derivatives, valuation of warrants and options, designing optima hedging strategies, modelling the premium in futures and forward prices, evaluating risk spillovers across markets, and examining asymmetries and leverage effects. For further details regarding the modelling and pricing of risk associated with patents, see McAleer et al. (2002).

Where markets for such commodities do not yet exist, such as options and futures on ecological innovation and intellectual property, the estimation of volatilities associated with ecological patent shares would seem to be a useful first step in this direction. Hence, if the volatility in ecological patent shares were to continue, and to be estimated and forecasted, this would enable a more informed decision making process in both the private and public sectors.

In addition to the ecological patenting trends already described, this paper analyses the volatility in the ecological patent shares in the USA by estimating the AR(1)-GARCH(1,1) and AR(1)-GJR(1,1) models, in which the conditional mean of the patent share follows an AR(1) process.

Consider the stationary AR(1)-GARCH(1,1) model for the patent share, y_t:

$$y_t = \phi_1 + \phi_2 y_{t-1} + \varepsilon_t, \qquad |\phi_2| < 1 \qquad (1)$$

for t=1,…,n, where the shocks (or movements in the patent share) are given by:

$$\varepsilon_t = \eta_t \sqrt{h_t}, \qquad \eta_t \sim ii\delta(0,1) \qquad (2)$$

$$h_t = \omega + \alpha\varepsilon^2_{t-1} + \beta h_{t-1}$$

and $\omega > 0$, $\alpha \geq 0$, $\beta \geq 0$ are sufficient conditions to ensure that the conditional variance $h_t > 0$. The ARCH (or α) effect indicates the short run persistence of shocks, while the GARCH (or β) effect indicates the contribution of shocks to long run persistence (namely, $\alpha+\beta$). The stationary AR(1)-GARCH(1,1) model can be modified to incorporate a non-stationary ARMA(p,q) conditional mean and a stationary GARCH(r,s) conditional variance, as in Ling and McAleer (2002d).

In equations (1) and (2), the parameters are typically estimated by the maximum likelihood method to obtain Quasi-Maximum Likelihood Estimators (QMLE) in the absence of normality of η_t. When η_t is normal, the QMLE are maximum likelihood estimators. The conditional log-likelihood function is given as follows:

$$\sum_{t=1}^{n} l_t = - 1/2\sum_{t=1}^{n} (\log h_t + \varepsilon^2_t/h_t).$$

Using results from Ling and Li (1997) and Ling and McAleer (2002a, b) (see also Bollerslev, 1986; Nelson, 1990; He and Teräsvirta, 1999), the necessary and sufficient condition for the existence of the second moment of ε_t, that is, $E(\varepsilon^2_t) < \infty$, for GARCH(1,1) is $\alpha+\beta < 1$ and, under normality of η_t, the necessary and sufficient condition for the existence of the fourth moment, that is, $E(\varepsilon^4_t) < \infty$, is $(\alpha+\beta)^2+2\alpha^2 < 1$. According to Ling and Li (1997), the GARCH(p,q) model is stationary and ergodic if the second moment is finite, and the local QMLE is asymptotically normal if the fourth moment is finite. Ling and McAleer (2002c) showed that the QMLE for GARCH(p,q) is consistent if the second moment is finite and the global QMLE is asymptotically normal if the sixth moment is finite, that is, $E(\varepsilon^6_t) < \infty$.

A weaker sufficient (log-moment) condition for consistency of the QMLE for the GARCH(p,q) model was established by Elie and Jeantheau (1995) and Jeantheau (1998) (see Lee and Hansen (1994) for the proof in the case of GARCH(1,1)). Boussama (2000) showed that the log-moment condition was sufficient for asymptotic normality of the QMLE for the GARCH(p,q) model. In the case of GARCH(1,1), the log-moment condition is given by

$$E\,[\log(\alpha\eta_t^2 + \beta)] < 0.$$

The log-moment condition is not entirely straightforward to check as it involves the expectation of a function of a random variable and unknown parameters. Although the second and fourth moment conditions are stronger than the log-moment condition, the former are more straightforward to check in practice.

The effects of positive shocks (or upward movements in the patent share) on the conditional variance are assumed to be the same as the effects of negative shocks (or downward movements in the patent share) in the symmetric GARCH model. In order to accommodate asymmetric behaviour, Glosten, Jagannathan and Runkle (1992) proposed the GJR model, which is defined as follows:

$$h_t = \omega + (\alpha + \gamma I(\eta_{t-1}))\varepsilon^2_{t-1} + \beta h_{t-1} \qquad (3)$$

where $\omega > 0$, $\alpha \geq 0$, $\alpha+\gamma \geq 0$, $\beta \geq 0$ are sufficient conditions for $h_t > 0$, and $I(\eta_t)$ is an indicator variable defined by:

$$I(\eta_t) = \begin{cases} 1, & \varepsilon_t < 0 \\ 0, & \varepsilon_t \geq 0 \end{cases}$$

in which η_t has the same sign as ε_t. The indicator variable differentiates between positive and negative shocks, so that asymmetric effects in the data are captured by the coefficient γ, with $\gamma \geq 0$, in general. The asymmetric effect, γ, measures the contribution of negative shocks to both short run persistence, $\alpha+\gamma/2$, and to long run persistence, $\alpha+\beta+\gamma/2$.

For GJR(1,1), Ling and McAleer (2001a) showed that the regularity condition for the existence of the second moment under symmetry of η_t is $\alpha+\beta+\gamma/2 < 1$, and the condition for the existence of the fourth moment under normality of η_t is

$$\beta^2 + 2\alpha\beta + 3\alpha^2 + \beta\gamma + 3\alpha\gamma + 3\gamma^2/2 < 1.$$

McAleer et al. (2002) derived the log-moment condition for the GJR(1,1) model as

$$E\,(\log[(\alpha + \gamma I(\eta_t))\eta_t^2 + \beta]) < 0$$

and showed that the QMLE are consistent and asymptotically normal when the condition is satisfied. As in the case of the GARCH(1,1) model, the log-moment condition is the expectation of a function of a random variable and unknown parameters. Just as the condition $\alpha\eta_t^2+\beta > 0$ may not be satisfied for all observations in the sample for GARCH(1,1), it is possible that

$(\alpha+\gamma I(\eta_t))\eta_t^2+\beta > 0$ may not be satisfied for all observations for GJR(1,1). For this reason, McAleer et al. (2002) suggest that the stronger but computationally more straightforward second and fourth moment conditions be evaluated as useful diagnostic checks in practice. As the log-moment condition is weaker than the second and fourth moment condition, the latter two need not be examined if the log-moment condition is satisfied.

5. EMPIRICAL RESULTS

The remainder of the paper models the volatility in the patent share, namely the number of ecological patents registered in the USA relative to the total number of US patents. As defined in (1)-(2) and (1)-(3), respectively, the AR(1)-GARCH(1,1) and AR(1)-GJR(1,1) models are estimated by the EViews 4.0 econometric software package using 276 monthly observations from January 1975 to December 1997. The estimates based on QMLE are presented in Figures 7 and 8. Furthermore, these models are estimated using 77 rolling windows of size 200 for the patent share, with the first rolling sample from January 1975 to August 1991, and the last from May 1981 to December 1997. The impact of each observation on the estimates and on the log-moment and second and fourth moment conditions can be investigated by examining the respective dynamic paths of the estimate using the rolling samples. A balance was struck at a window size of 200 between having a small window size and a large number of rolling samples versus a large window size and a small number of rolling samples. Moreover, the rolling samples also act as a diagnostic check to analyse whether particular observations have an appreciable effect on the estimates.

In Figure 7, the $\hat{\alpha}$ estimates for the GARCH(1,1) model exhibit some interesting movements. Two dramatic increases occur in January 1976 and October 1976, followed by a 16% decline in November 1978, then remaining low for the rest of the rolling samples. Although the movements of the $\hat{\alpha}$ estimates seem dramatic, the standard deviation of $\hat{\alpha}$ is 0.0076 with a mean 0.0785, which means that short run persistence of shocks is relatively low for the ecological patent share in the USA.

Movements in the $\hat{\beta}$ estimates for the GARCH(1,1) model are different from those of the $\hat{\alpha}$ estimates. There is an upward trend, with $\hat{\beta}$ increasing from 0.825 to 0.857, then decreasing slightly and remaining at around 0.85 for the last 20 rolling samples. Furthermore, there are two dramatic declines occurring in April 1977 and June 1978. These two declines correspond to the increases in the $\hat{\alpha}$ estimates for the same rolling samples. However, the changes in the $\hat{\alpha}$ estimates for these two rolling samples are not as noticeable as the changes in the $\hat{\beta}$ estimates, which have a mean of 0.843 and a standard deviation of 0.0092.

All the rolling samples satisfy the log-moment and second moment conditions, but there are 38 rolling samples which fail to satisfy the fourth moment condition. As the log-moment condition is satisfied, the second and fourth moment conditions are redundant, and the QMLE are consistent and asymptotically normal. The patterns of the log-moment and second moment conditions are similar, but their dimensions differ. It is interesting to note that both the second and fourth moment conditions start at a relatively low value (less than 1), but then increase dramatically in November 1975, and remain high until early 1979, with the fourth moment being generally greater than 1. The means of the second and fourth moment conditions are 0.923 and 1.007, respectively.

Interestingly, there appears to be a downward trend in the $\hat{\alpha}$ estimates for the GJR(1,1) model in Figure 8, but there is no visible trend for the $\hat{\beta}$ estimates. However, there is a dramatic increase in the $\hat{\beta}$ estimates in April 1978, which is followed by an even greater increase in November 1978. These increases correspond to the reduction in the $\hat{\alpha}$ estimates for the same rolling samples. The movements in the $\hat{\gamma}$ estimates are also interesting, starting at around 0.0353 and increasing steadily until June 1977. This is followed by a 16.5% decline in July 1977, but increases dramatically in the following month and stays high at around 0.23 until January 1979. There is a dramatic 45% decrease in January 1979, followed by a steady decline until October 1979, and remaining low at around 0.075 for the rest of the rolling samples. The evident lack of outliers and extreme observations indicates that such changes in the estimates occur toward the end of an abrupt transition period in the late 1970s. It is also worth noting that the $\hat{\gamma}$ estimates are highly volatile, so that the asymmetric behaviour in upward and downward movements in the patent share is important for modelling the ecological patent share in the USA.

The mean estimates of $\hat{\alpha}$, $\hat{\beta}$ and $\hat{\gamma}$ are 0.061, 0.839 and 0.107, respectively. Note that the $\hat{\alpha}$ and $\hat{\beta}$ estimates for the GJR(1,1) model are lower on average than their GARCH(1,1) counterparts. Furthermore, as with the GARCH(1,1) model, all the rolling samples satisfy the log-moment and second moment condition, and only 11 rolling samples fail to satisfy the fourth moment condition. As in the case of the GARCH(1,1) model, the log-moment condition being satisfied renders the second and fourth moments redundant for the QMLE to be consistent and asymptotically normal. The results also suggest that the GJR(1,1) model may be more appropriate than its symmetric counterpart, GARCH(1,1), for modelling the ecological patent share in the USA as positive and negative changes in the patent share are observed to have different impacts on innovative activity.

6. CONCLUDING REMARKS

The paper analysed trends and volatility in the ecological patent share in the USA from 1975 to 1997. Using monthly data, the time-varying nature of the volatility of the ecological patent share in the USA was examined. The volatile and asymmetric nature of the estimates, which distinguish positive from negative movements in the time series, indicated the importance of accommodating asymmetric behaviour in modelling the ecological patent share in the USA. For this reason, the asymmetric AR(1)-GJR(1,1) model was found to be most suitable empirically.

The approach in this paper has treated all ecological patents as being of equal importance. However, the economic value of a patent can vary significantly, from negligibly small to a major breakthrough (Geroski, 1995). Assigned patents are considered to have a higher probability of being profitably commercialised (Firestone, 1971), and could therefore be studied separately or given a larger weight. Ecological patents also originate across all sectors and industries, such as motor vehicles and chemical industries, where patenting is very important as a means of protecting intellectual property, to textiles and telecommunications, where patenting is of far lesser importance. An industry-based analysis may reveal markedly different trends and volatilities than those analysed in this paper. These topics are areas for further research.

From a policy perspective, the understanding of volatility in ecological patenting can enable governments to anticipate industry policy in relation to this new class of emerging technologies. A pro-active approach can include government procurement and use of only ecological technologies, removal of financial barriers to commercialisation of ecological patents, and various forms of assistance to innovating companies and individuals. Such decisions would involve a switch from a free-market stance to one in which a sustainability-oriented culture is fostered.

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Figure 1: Monthly US Ecological Patents by Date of Application, 1975(1) – 1997(12)

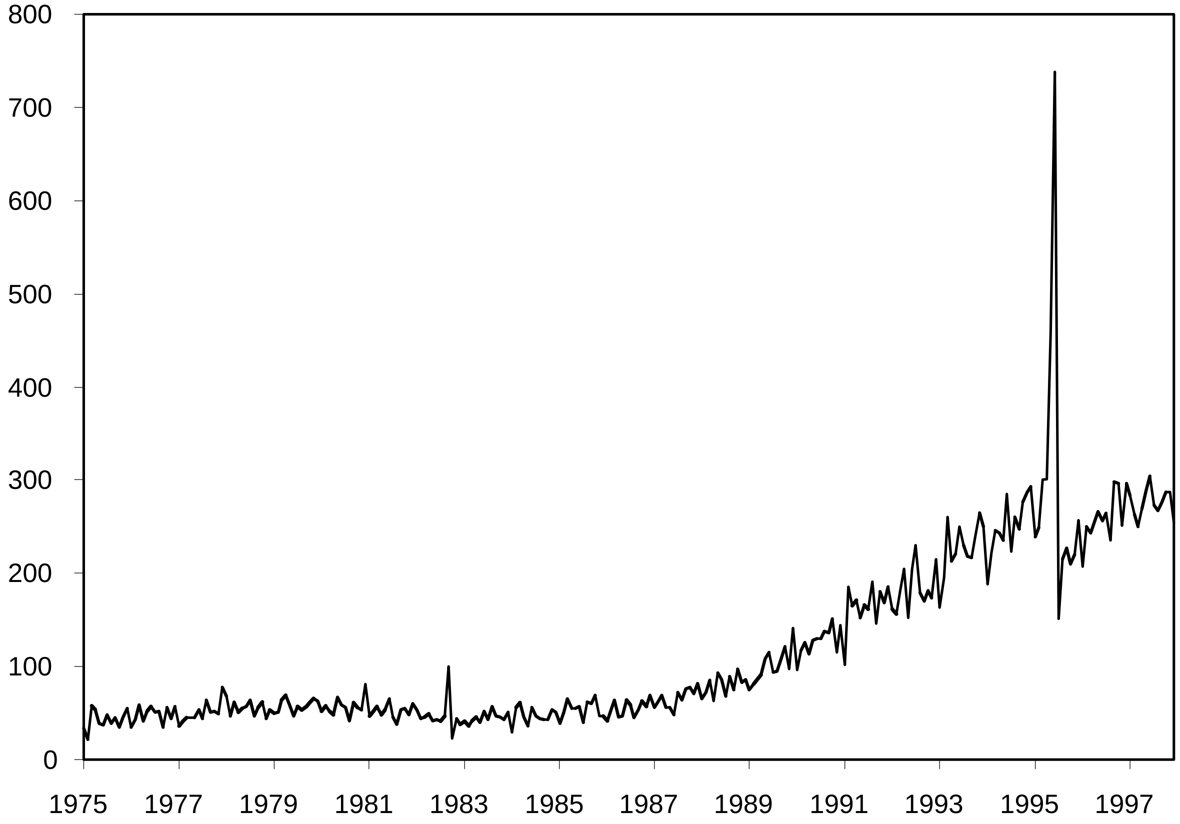


Figure 2: Monthly Total US Patents by Date of Application, 1975(1) – 1997(12)

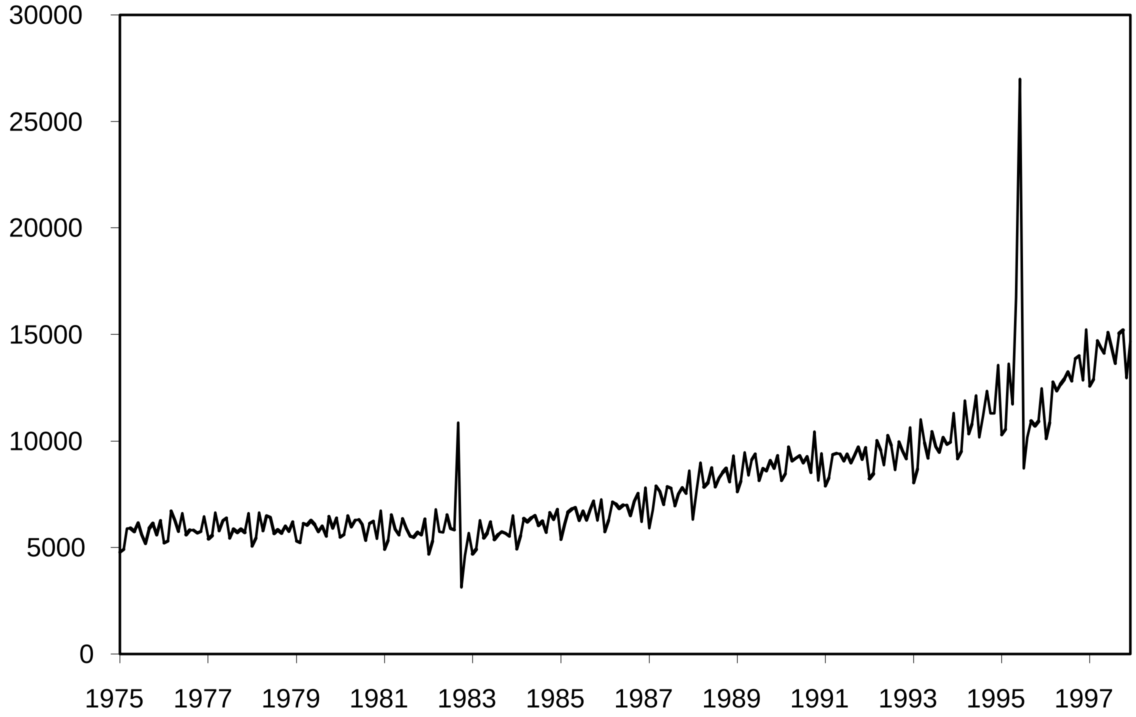


Figure 3: Annual Total US Patents and US Ecological Patents by Date of Application, 1975 – 1997

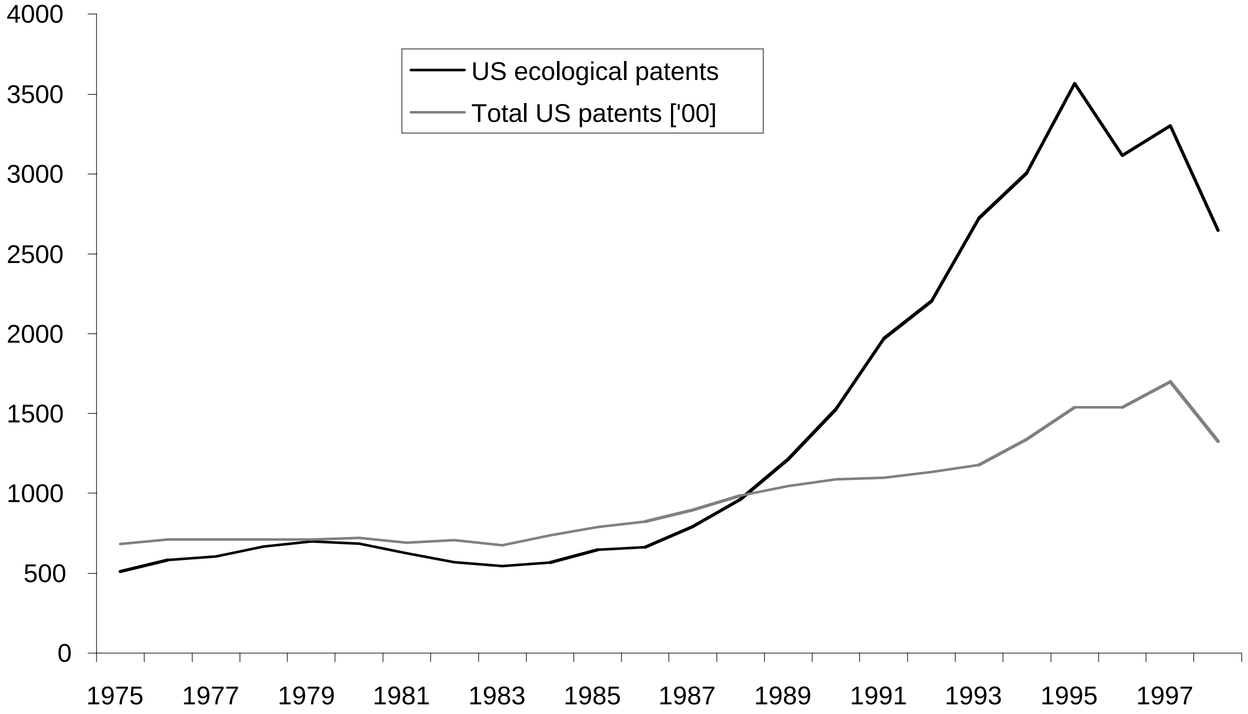


Figure 4: Monthly Ecological Patent Share by Date of Application, 1975 – 1997

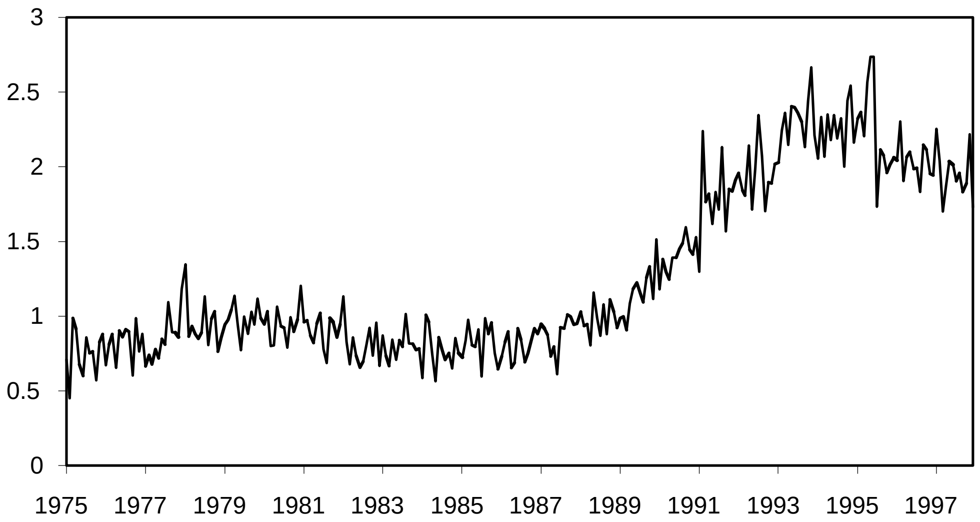


Figure 5: Volatility of the Monthly Ecological Patent Share by Date of Application, 1975 – 1997

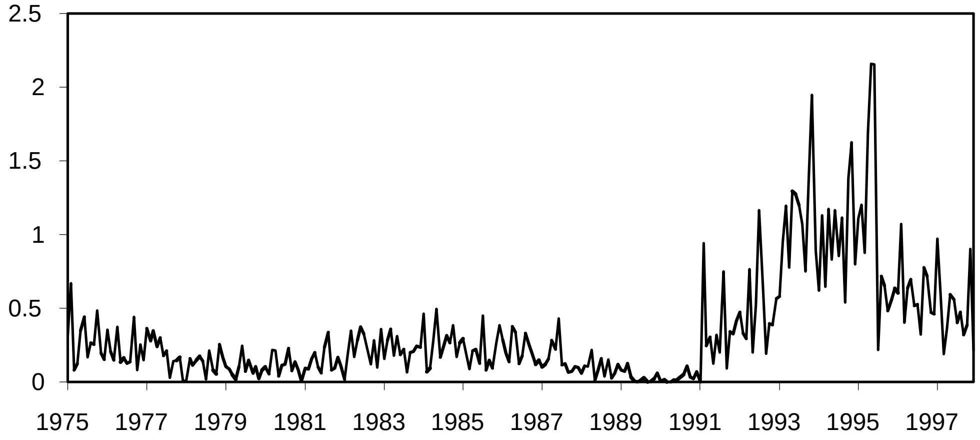


Figure 6: Total Ecological Patents in the USA by Selected Countries, 1975 – 2000

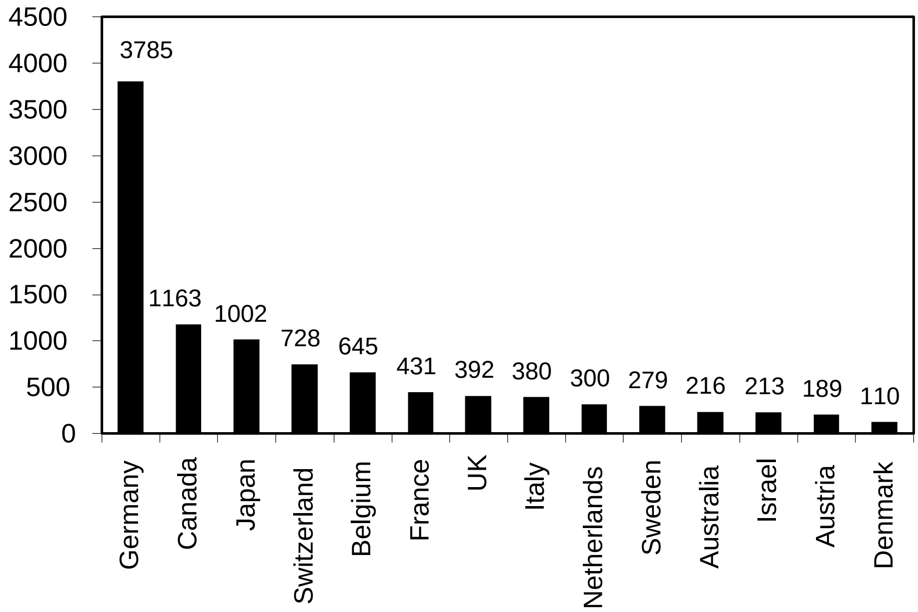
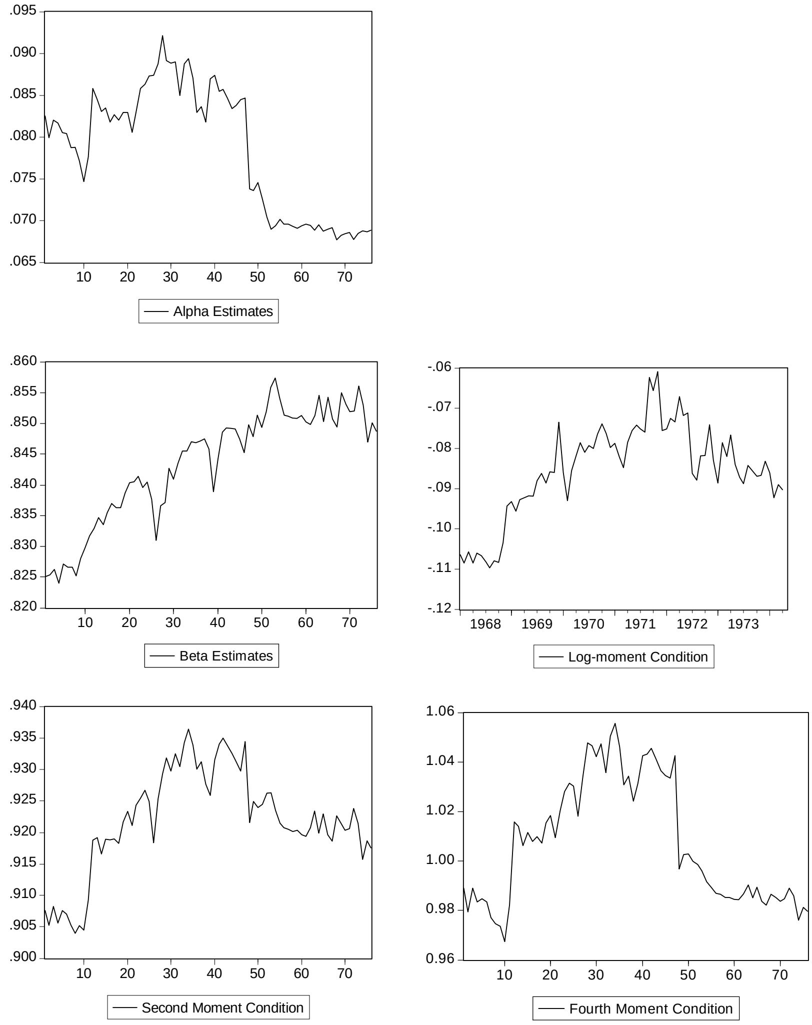
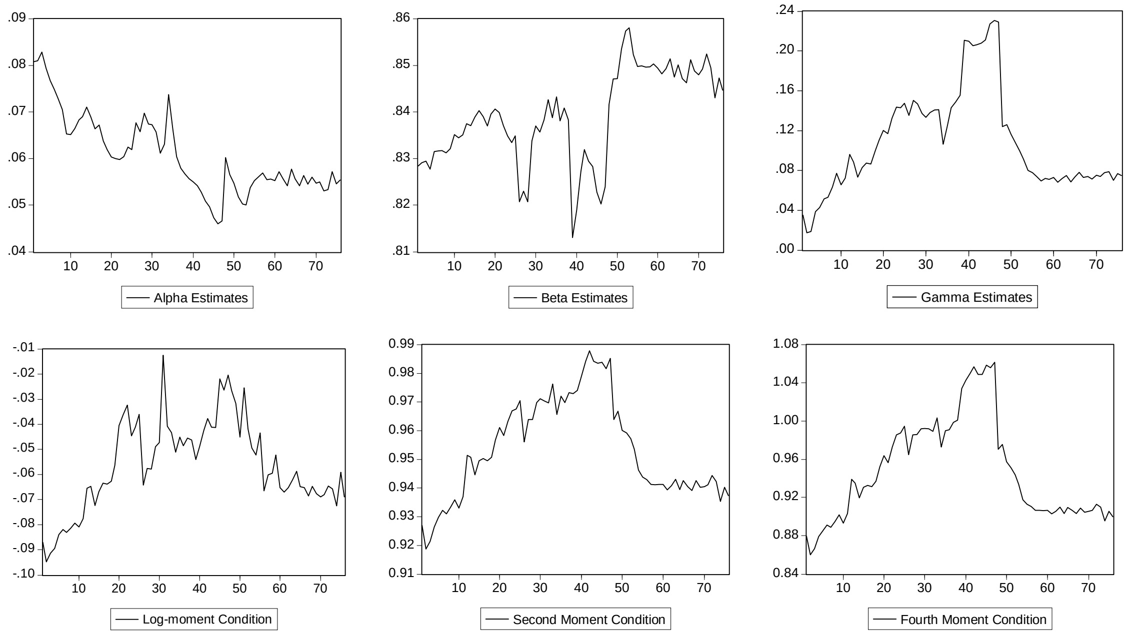


Figure 7: AR(1)-GARCH(1,1) Estimates of Parameters and Moments, 1975(1) – 1997(12)



Note: The horizontal axis indicates the number of the rolling sample.

Figure 8: AR(1)-GJR(1,1) Estimates of Parameters and Moments, 1975(1) – 1997(12)



Note: The horizontal axis indicates the number of the rolling sample.

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