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STAR-GARCH Models of Ecological Patents in the USA

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Abstract: Ecological patents have been increasing steadily over time. The paper analyses trends and volatility in ecological patents in the USA from 1975 to 1997. Germany contributed more than 10% of the total number of US ecological patents, and is by far the strongest foreign performer. The time-varying nature of the volatility of the patents ratio, namely the ratio of US ecological patents to total US patents, is examined using monthly data from January 1975 to December 1997. The regime-switching LSTAR-GARCH model is found to be optimal for modelling the ecological patents ratio.

Keywords: Ecological patents, Trends, Volatility, GARCH, STAR-GARCH.

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 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. They have also developed the voluntary environmental standards ISO 14000 to establish continually improving processes for ecologically 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 patents 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 intellectual property. Patents are also conducive to economic growth. If patents are essential to protect intellectual property, the efforts of the international business community to deal with ecological problems should result in more ecological innovations being patented. A number of studies have confirmed that patenting activities cause immediate and subsequent market changes [see, for example, Soete, 1987; Griliches et al., 1991; 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 market economies adopt a course of sustainability.

With its large and technologically advanced markets, the US economy has always been highly favourable to companies and individuals interested in protecting their intellectual 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 office 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 to this paper are technologies related to the ecological environment.

This paper analyses trends in the development of more ecological-friendly technologies, or technologies which assist in abating existing ecological problems. Monthly data from the US Patent and Trademark Office (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 data used in the analysis. General trends in ecological patenting are discussed in Section 3. Section 4 briefly discusses the GARCH, LSTAR-

GARCH and ESTAR-GARCH models. This is followed by an empirical analysis of volatility in the ecological patents ratio in Section 5. Some concluding remarks are given in Section 6.

2. DATA DESCRIPTION

Empirical information on patents data is collected from the US PTO, through its on-line search engine (http://164.195.100.11/netahtml/search-adv.htm). The time series data used consist of monthly observations for the number of ecological patents with application dates between 1975 and 1997. The data were extracted in April 2001. 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.

The current US patent classification system does not provide special categories which cover ecological patents. Consequently, the following approach was used to identify such 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"[1]) or "environmentally". It was impossible to incorporate in this definition of ecological patents a keyword search using "environment" or "environmental" because of their widespread use outside the area of ecological environment, such as in the digital, physical or economic environments. Individual reading and checking of each of the thousands of American patents containing "environment" or "environmental" would have been an excessively time- and labour-intensive exercise. It is highly unlikely that a patent related to ecologically sustainable technology would not include one or more of the various definitional words given above. In addition, the same approach was used consistently across the time series, which makes it possible for trends and patterns in the data to be analysed.

3. GENERAL TRENDS IN ECOLOGICAL PATENTING

Figure 1 shows the trends in ecological patents 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 1990's being a period of intensive patenting of technologies which are related positively to the ecological environment.
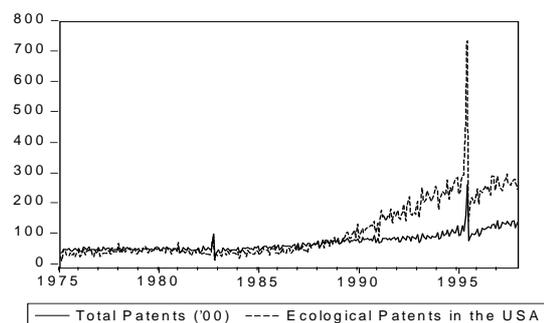
The total number of patents registered in the USA during the same period has also been increasing steadily (see Figure 2), reaching a peak of close to 170,000 approved patents from applications lodged in 1997. Figure 2 shows the trends in issued patents by date of application, which is a more accurate measure of patent activity than the date of issue (as it is not influenced by administrative delays in the US Patent and Trademark Office related to the processing of applications[2]). In addition, the figure shows trends in approved ecological patents, which reached 3,300 in 1997.
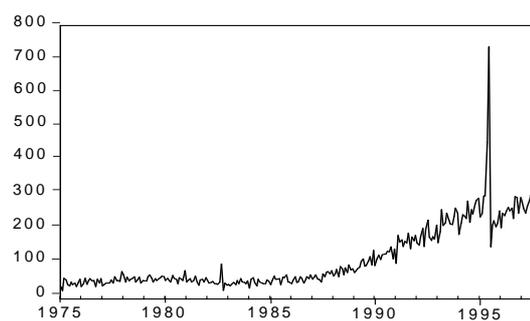
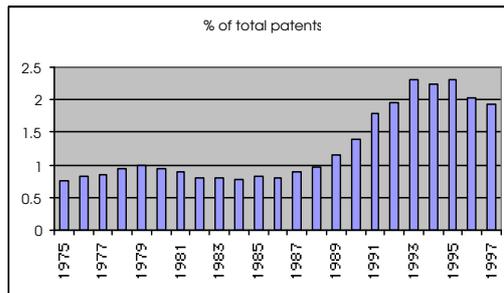**Figure 1**: US Ecological Patents by Date of Application, 1975(1) – 1997(12)

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

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

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[1] The word "eco" was excluded because it generated only patents referring to the so-called Eco enzyme, which is somewhat outside the area of this study.

[2] 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 years will have increased.

Though increasing, the patents share, which addresses ecological issues and their implications, remains very small (see Figure 3). Since 1993 the patents share has only been around 2% of the total number of US patents, and seems to have settled at this level. This may be a warning sign of a lack of commitment by industry and individuals to improving the ecological patents share in the long run.

Figure 3: Percentage Shares of Ecological Patents to Total US Patents by Date of Application, 1975(1) – 1997(12)

Figure 4 shows the total number of ecological patents lodged in the USA by foreign residents, 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[3]. The percentage share of ecological patents to the overall number of 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, respectively (see Figure 4), has less than one-third of the US ecological patents lodged by Germany.
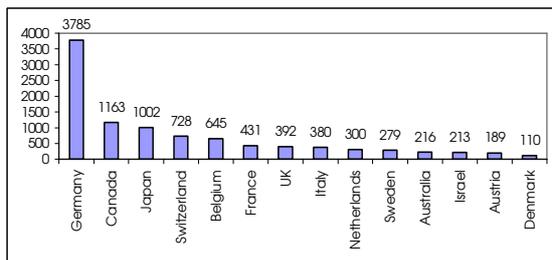
Figure 4: Ecological Patents in the USA by Selected Countries, 1975(1)-2000(12)

With 216 patents and around 0.6% of the total number of US ecological patents, Australia ranks eleventh,

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[3] The observations for Germany include data for both the former Federal and Democratic Republics.

which is perhaps understandable taking into account the small size of the economy. However, a number of countries with smaller populations, such as Sweden, Switzerland, Belgium and The Netherlands, have demonstrated a greater commitment than Australia to registering ecological patents.

4. GARCH AND STAR-GARCH

The primary purpose of this section is to model the volatility of the ratio of the number of US ecological patents to the total number of US patents (henceforth, the "patents ratio"). This approach is based on Engle's [1982] path-breaking idea of capturing time-varying volatility (or uncertainty) using the autoregressive conditional heteroskedasticity (ARCH) model, and subsequent developments forming the ARCH family of models (see, for example, the surveys of Bollerslev, Chou and Kroner [1992], Bollerslev, Engle and Nelson [1994] and, 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. Some further developments have been suggested by Wong and Li [1997], He and Teräsvirta [1999], and Ling and McAleer [2002a, b, c].

Consider the AR(1)-GARCH(1,1) model for the patents ratio, y_t:

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

(1)

where the shocks (or movements in the patents ratio) are given by:

$$\varepsilon_t = \eta_t \sqrt{h_t},$$
$$h_t = \omega + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1},$$

(2)

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, $\alpha + \beta$).

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. The conditional log-likelihood function is given as follows:

$$\sum_t l_t = -\frac{1}{2} \sum_t \left(\log h_t + \frac{\varepsilon_t^2}{h_t} \right).$$

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

A simple first-order STAR model with two regimes is defined as follows:

$$y_t = (\phi_{10} + \phi_{11} y_{t-1})(1 - G(s_t; \gamma, c)) + (\phi_{20} + \phi_{21} y_{t-1})G(s_t; \gamma, c) + \varepsilon_t \tag{3}$$

where $G(s_t; \gamma, c)$ is the transition function, assumed to be twice differentiable and bounded between 0 and 1, γ is the transition rate, and c is the threshold value. Clearly, when $G(s_t; \gamma, c) = 0$, $y_t = \phi_{10} + \phi_{11} y_{t-1}$ (the first regime), and when $G(s_t; \gamma, c) = 1$, $y_t = \phi_{20} + \phi_{21} y_{t-1}$ (the second regime). Therefore, the transition function can be viewed as the weight given to the two regimes. Although there are few theoretical results regarding the stationarity of the STAR model, a sufficient condition is $\phi_{i1} < 1 \ \forall i = 1, 2$ (see van Dijk et al. [2002] for further discussion). Furthermore, in this paper the transition variable, s_t is determined to be time, t, in order to examine the existence of different regimes in the period pre-1990s from more recent periods.

Regarding the selection of the transition function, two of the most popular choices of $G(s_t; \gamma, c)$ are the first-order logistic function,

$$L(s_t; \gamma, c) = \frac{1}{1 + \exp(-\gamma(s_t - c))}, \tag{4}$$

and the first-order exponential function,

$$E(s_t; \gamma, c) = 1 - \exp(-\gamma(s_t - c)^2). \tag{5}$$

The STAR model was proposed by Terasvirta [1994] as an extension of Tong [1978]. Lundbergh and Terasvista [2000] extended the STAR model by specifying the error term to follow a GARCH(p,q) process, as defined in equation (2). The structural and statistical properties of the STAR-GARCH were established in Chan and McAleer [2002].

5. EMPIRICAL RESULTS

The primary purpose of this section is to model the volatility of the ecological patents ratio. As defined in the previous section, the AR(1)-GARCH(1,1), LSTAR-GARCH(1,1) and ESTAR-GARCH(1,1) models are estimated using monthly data from January 1975 to December 1997 (the estimates are available on request). Furthermore, these models are estimated using a rolling window of size 200. The impact of each observation on the estimates and on the second and fourth moment conditions can be investigated by examining their dynamic paths.

The $\hat{\alpha}$ estimates for the GARCH 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 in the $\hat{\alpha}$ estimates seem dramatic, the mean of $\hat{\alpha}$ is 0.0785 with a standard deviation of 0.0076, which suggests that short-run persistence is relatively low for the number of ecological patents registered in the USA.

Movements in the $\hat{\beta}$ estimates for the GARCH model are completely different to 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, corresponding 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.

Although all the rolling samples satisfy the second moment condition, there are 38 rolling samples which fail to satisfy the fourth moment condition. 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. Therefore, the validity of

inferences arising from the GARCH model for these rolling samples may be problematic.

Introducing non-linearity in the conditional mean has a significant impact on the estimates of the conditional variance. For LSTAR-GARCH, the mean $\hat{\alpha}$ estimate is 0.230, which is substantially larger than the mean estimate of $\hat{\alpha}$ in the AR(1)-GARCH(1,1) model. The most noticeable movements is a period of steady growth from October 1978 to January 1979, during which the $\hat{\alpha}$ estimates increase from 0.1662 to 0.326, indicating an increasing level of short-run persistence. Another noticeable movement is the dramatic decrease from 0.394 to 0.079 in January 1981, but the $\hat{\alpha}$ estimates do not remain low, as in the case of AR(1)-GARCH(1,1). In fact, the $\hat{\alpha}$ estimates increase to 0.388 in May 1981.

The $\hat{\beta}$ estimates are relatively low for LSTAR-GARCH for most of the rolling samples, with the mean estimate being 0.285. This is contrary to the $\hat{\beta}$ estimates from AR(1)-GARCH(1,1). In the early rolling samples, namely, January 1975 to December 1975, the $\hat{\beta}$ estimates are highly unstable, fluctuating between 0.4 and 0.8. In January 1976, the $\hat{\beta}$ estimates decrease to 0.288 from 0.850, and remain low until December 1980. This suggests that the long-run persistence is low for most of the rolling samples. In fact, all rolling samples satisfy the second moment condition, with a mean of 0.515. Furthermore, all rolling samples satisfy the fourth moment condition, with one exception in September 1975. This suggests that the sufficient conditions for consistency and asymptotic normality are satisfied, and that valid inferences can be obtained for these rolling samples. Overall, the mean fourth moment is 0.436 for LSTAR-GARCH.

Movements in the $\hat{\alpha}$ estimates for the ESTAR-GARCH model show substantial fluctuations throughout all the rolling samples, with a mean of 0.335. This suggests that the $\hat{\alpha}$ estimates are highly unstable and very sensitive to the rolling samples. This is particularly the case after December 1979, when the $\hat{\alpha}$ estimates fluctuate between 0 and 0.4 continuously until the end of the sample. One explanation for such instability is possible model misspecification, which can cause convergence problems (see Chan and McAleer [2002] for further details). Another explanation concerns estimation of the threshold value. This problem can arise when there are insufficient observations in one of the two regimes, which subsequently affects the estimation of the remaining parameters (see Terasvista [1994] and Chan and McAleer [2002]).

Movements in the $\hat{\beta}$ estimates for the ESTAR-GARCH model also show great fluctuations, especially towards the end of the rolling samples. It is interesting to note that the $\hat{\beta}$ estimates often move in the opposite direction to the $\hat{\alpha}$ estimates, so that when $\hat{\beta}$ increases (decreases), $\hat{\alpha}$ decreases (increases). This is particularly the case when the movements are large. The mean estimate of $\hat{\beta}$ is 0.310, which is similar in magnitude to the mean $\hat{\beta}$ estimate in LSTAR-GARCH.

Not surprisingly, there are substantial fluctuations in the second and fourth moment conditions for ESTAR-GARCH, with 6 and 14 rolling samples failing to satisfy the second and fourth moment conditions, respectively. Moreover, ESTGAR-GARCH has the highest number of rolling windows which fail to satisfy the second moment condition.

Both LSTAR-GARCH and ESTAR-GARCH provide interesting information regarding the threshold value. For LSTAR-GARCH, the transition function exceeds 0.5 after 1991, which suggests that greater weight is allocated to the second regime than to the first regime. A similar interpretation can be given to ESTAR-GARCH. The fluctuations occurring in the early rolling samples are due to the small number of observations in the second regime. As the rolling windows move over time, a greater number of observations from the second regime is included, which stabilizes the threshold estimates.

6. CONCLUDING REMARKS

The paper analysed trends and volatility in ecological patents registered in the USA from 1975 to 1997. Using monthly data, the time-varying nature of the volatility of the ecological patents ratio was examined. LSTAR-GARCH(1,1) was found to be suitable for modelling the volatilities of US ecological patents. Furthermore, the model also provides important information identifying the existence of two different regimes in the ecological patents ratio.

7. ACKNOWLEDGEMENTS

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