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THE EFFECTS OF TECHNOLOGY SHOCKS ON OUTPUT FLUCTUATIONS: AN IMPULSE RESPONSE ANALYSIS FOR THE G7 COUNTRIES

by Silvia Fabiani (*)

Abstract

Direct and country-specific measures of technical progress are used in order to analyse the effects of technology shocks on output fluctuations in the G7. Technology shocks are measured as the unpredicted component in the dynamics of innovation, on the basis of patent statistics provided by the US Patent Office. Two different kinds of shock are identified for each economy: "country-specific", reflecting the national features of technological innovation, and "global", originating from the existence of common trends in patenting activity across the G7. Their effects on aggregate fluctuations are investigated within a multivariate nonlinear model for each country, where nonlinear dynamics are induced by the presence of a ratchet effect in output growth. The method adopted to examine the response of output to technology shocks is the Generalised Impulse Response Function. Both global and country-specific shocks are found to affect the long-run level of output in the G7 economies. Their effects, however, differ significantly across countries both in magnitude and in time profile.

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1. Introduction[1]

Aggregate output growth and fluctuations are difficult to explain without taking into account technological change. Although this difficulty is generally recognised in the literature, the prevailing approaches to the analysis of growth and business cycles tend to formalise technological change as an unobservable process. Technical progress is characterised as a deterministic function of time in the standard neoclassical model of growth (Solow, 1956, 1957), and as an exogenous stochastic process in the real business cycle literature. At the empirical level, a measure of the rate of technical change is obtained by estimating the residual part of output growth not explained by the increase of inputs. Until recent developments in the literature, this rate has usually been assumed to be constant across countries, and the idiosyncratic features characterising the dynamics of technology in different economies have not been taken into account.

The problems related to the formalisation and measurement of technological change are particularly relevant in the real business cycle approach, where technology is recognised as the primary source of economic fluctuations and is represented as a series of random shocks, influencing the behaviour of the system through an endogenous propagation mechanism. Such shocks are quantified on the basis of Solow's residual and are used to simulate "artificial" time series to be compared with the actual ones. However, when the random process generating the shocks is assumed to be uncorrelated, the model is not able to reproduce aggregate fluctuations that are consistent with the observed ones. As a consequence,

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[1] The views expressed in this work do not necessarily reflect those of the Bank of Italy. I wish to thank Hashem Pesaran, Kevin Lee, Richard Smith and an anonymous referee for their helpful comments. Any errors are my responsibility.

productivity shocks have to be assumed a priori to have high serial correlation.[2]

These considerations, together with the recent development of theories that emphasise the role of country-specific technological capabilities in shaping the different patterns of aggregate output,[3] point to the need for a deeper enquiry into the main mechanisms through which technical progress affects the state of the economy. Going back to Schumpeter (1939), technological innovation can be considered as one of the main forces generating both growth and cyclical fluctuations. The introduction of new products or techniques is a discontinuous process that creates opportunities for high profits, causes a "swarm" of imitation and improvements, and generates waves of new investment, thus enabling the economy to expand and grow. In this perspective, technical change can be thought of as a series of shocks, uneven in their incidence over time, and as being characterised by a high component of uncertainty. The latter is particularly pronounced in the early stages of an innovation, but it decreases with the diffusion of the new technology and as the subsequent phases of expansion and further innovation are triggered.

The interaction between technological innovation and the state of the economy has a crucial implication: innovation and diffusion patterns are not identical across countries. If economies innovate and adopt new technologies at different rates, then there is a degree of "country-specificity" in the

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[2] See, among others, Singleton (1988), McCallum (1989), Mullineux and Dickinson (1992).

[3] The endogenous growth theory (among others, Romer, 1986, 1990; Lucas, 1988; Aghion and Howitt, 1992) and the evolutionary theory (Nelson and Winter, 1982; Dosi et al., 1988) represent a significant step forward in the formalisation of technological change and its determinants. In particular, applied works within the evolutionary approach (Fagerberg, 1988; Verspagen, 1992) stress the idiosyncratic features of the aggregate patterns of technology and adopt country-specific indicators to obtain empirical evidence of the effects of technical progress on output growth across countries.

implications of technical progress. The analysis of output fluctuations cannot ignore the idiosyncratic features implicit in the generation and diffusion of innovation.

This work uses direct and country-specific technology indicators to identify and measure technology shocks and to investigate the dynamic links between the evolution of national technological capabilities and aggregate output movements in the industrialised world. For this purpose, aggregate patent statistics are selected, among the available indicators, as a measure reflecting the pattern of innovative activity. In fact, patents are directly related to innovation, as only new ideas can be patented.[4] In this light, technology shocks are identified and measured as unpredicted changes in the dynamics of patenting. Important inventions that lead to a patent are likely to be both preceded and followed by other patents: hence, peaks in patenting presumably indicate significant technological innovations, which can be characterised as unexpected breaks in the dynamics of patenting. These breaks, in a Schumpeterian perspective, attract a "swarm" of imitation and generate a further wave of process innovations and new investment, thus driving business cycle fluctuations.

A problem involved in the use of patent data as a proxy for innovation in a multi-country context is the selection of the appropriate data base. National data do not provide a reliable basis for international comparisons, given the legal, economic and cultural differences among national systems of patent granting. In view of this problem, the majority of applied works analysing international patenting

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[4] See Fabiani (1996) for a detailed discussion of the characteristics of patent statistics and of the relationships between patenting, invention, innovation and R&D activity, as well as an examination of the advantages, disadvantages and methodological issues involved in the use of this variable at the aggregate level.

consider the number of patents granted to different nations in a foreign market.[5] A natural choice is to study foreign patenting in a country with a dominant economic and technological position. Accordingly, this work is based on the data released by the US Patent Office, on the number of patents applied for and granted in the United States, the largest and technologically dominant market in the world. It is reasonable to expect that the more valuable and significant inventions would be patented there.

This database is used here to compile patent time series at quarterly frequencies for each country, to analyse a nonlinear multivariate model of output growth and innovation, and to compute the effects of unpredicted changes in the dynamics of innovative activity on output movements. The method adopted to examine such effects is the Generalised Impulse Response Function (GI), recently developed by Koop, Pesaran and Potter (1996). The GI for a particular shock occurring at time t, given the "history" of the system up to period t, is defined as the difference between two conditional expectations of the level of output at time $(t+n)$, $n=0,1,2,\ldots,N$. The first conditional expectation is based on the past history and the assumed shock, the second only on the past history. As opposed to the "traditional" impulse response function,[6] where all future shocks are "switched off" and assumed to be equal to zero, the GI solves the treatment of the future by averaging out all future shocks. Moreover, it deals with the problems of history, shock and composition dependence that characterise impulse responses for nonlinear and/or multivariate models.

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5 See, among others, Basberg (1983), Fagerberg (1987), Verspagen (1992).

6 Throughout this paper, "traditional" impulse response function denotes the measure of the effect at time $(t+n)$, $n=0,1,2,\ldots$, of a shock of size δ hitting the system at time t, given that no other shocks hit the system between t and $(t+n)$.

The results of the impulse response analysis show that the presence of nonlinearities causes the response function to depend both on the choice of the shock and on the conditions in which the system is assumed to be when such a shock occurs. Technology shocks are found to affect the long-run level of output in the G7 economies, with effects that differ across countries both in magnitude and in time profile.

The plan of the paper is as follows. Section 2 sets up the model used to analyse the contribution of technology shocks to output fluctuations in the G7. Section 3 describes the methodological issues involved in the computation of impulse response functions for multivariate and/or nonlinear models, introduces the concept of GI and presents the Monte Carlo procedure used to calculate it in nonlinear frameworks. The empirical application of such a procedure to the model of output growth and technological change and the results obtained are shown in Sections 4 and 5 respectively. Conclusions are presented in the last section.

2. The model

Within the recent literature investigating the characteristics of international output fluctuations, empirical evidence has mainly focused on the size of the persistence of shocks to different economies. Most studies based on univariate linear models have suggested that, at business cycle frequencies, shocks have persistent effects on output fluctuations,[7] finding also considerable differences across countries. Other authors have analysed the issue of persistence within multivariate frameworks and have found evidence of interactions between shocks to different variables.[8] All these works are based on the idea that the

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[7] Campbell and Mankiw (1987a, 1987b, 1989).

[8] Blanchard and Quah (1989), Lee and Pesaran (1993), Lee (1994).

behaviour of output can be represented as the propagation of random impulses through an invariant linear structure.

An alternative approach to the study of output fluctuations - which draws from the work of economists such as Goodwin, Smithies, Minsky and others - emphasises how nonlinear endogenous mechanisms can generate economic cycles without the need of exogenous driving processes.[9] In order to explain growth and cyclical movements, these authors have mainly introduced reflecting barriers, such as floors and ceilings, into otherwise linear but explosive models, providing economic explanations for their presence. Of particular interest for the empirical analysis carried out here, given the fundamental role attributed to innovation as the main engine of economic fluctuations, is the model developed by Goodwin (1955).[10] The model is based on the Schumpeterian view that the incentive to invest varies over the different phases of the business cycle. One of the main sources of economic fluctuations is improvements in techniques, which raise the opportunity for profits until innovative entrepreneurs introduce them in the market. Innovations will then be followed by a swarm of imitation, leading to an explosion of new investment and higher output. The resulting rise in demand absorbs the increased output per worker and the increased number of workers. When the burst of innovational and accelerational investment ceases, demand and output drop, causing capital and labour to stand idle. However, each time output rises to a new level and it does not fall back to its previous low, because the expansionary phase has generated fixed investment that acts as a reflecting barrier in each cyclical fluctuation. Cycles are thus caused by the internal dynamics of successful

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[9] Papers by these authors can be found in Gordon and Klein (1965).
[10] See also Goodwin (1982).

innovation, subsequent imitation and exhaustion of new techniques.

The implications of nonlinearities in the dynamics of output have been recently investigated at the empirical level, building on the seminal contribution of Hamilton (1989).[11] In the model proposed by Beaudry and Koop (1993), the introduction of an additional variable - which has nonzero value only if output is below its previous maximum - in a simple AR specification for GDP growth generates two regimes with endogenous switching. This variable is denoted as "current depth of recession" and is formally defined as: $CDR_t = \max(y_{t-j})_{j\geq 0} - y_t$. When output falls below its previous peak, CDR_t is positive and is equal to $y_{t-s} - y_t$, where $(t-s)$ is the point in time at which that peak was reached. Hence, if the estimated coefficient of *CDR* in the equation for output growth is positive, the introduction of such a variable has the effect of dampening negative output fluctuations and can be interpreted as a pure ratchet effect: if output falls below its previous maximum, a pressure mechanism is set in motion which pushes it to return to that maximum level; the further the fall in output, the larger the pressure.

Following this approach, the model considered here contains the current depth of recession in the specification of output growth, in order to allow the level of output in the G7 to react asymmetrically to technology shocks over the business cycle. In this nonlinear specification, output movements are driven by technology shocks and another unidentified disturbance. The former are unpredicted changes in the dynamics of innovation, measured on the basis of the growth pattern of patenting activity in each country.[12] The

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11 Beaudry and Koop (1993), Pesaran and Potter (1994), Potter (1995).

12 For a detailed analysis of the time series properties of patents time series and the specification search carried out for the identification of technology shocks, see Fabiani (1996).

econometric analysis carried out for the identification of such shocks points to the presence of common stochastic trends in the time series of patents across the G7, which reflect the existence of common factors affecting the process of technological innovation in these economies. In order to take this aspect into account, a "global" technology shock is identified, reflecting those characteristics of technological change that are common across the G7, generated as the unexpected component in the AR specification of G7 patents growth. Conversely, the national features of innovative activity are captured by a "country-specific" technology shock, identified as the unexplained growth of each nation's share of total G7 patents. Lagged values of these residuals are included as explanatory variables in a nonlinear representation of output growth. Hence, for each country i, (i=1,2,...,7), the model is:

$$\Delta y_{it} = \mu_i + \sum_{\tau=1}^{q_i}\theta_{i\tau}\Delta y_{i,t-\tau} + \sum_{\tau=1}^{h_i}\lambda_{i\tau}z_{i,t-\tau} + \sum_{\tau=a_i}^{b_i}\beta_{i\tau}v_{t-\tau} + \sum_{\tau=c_i}^{d_i}\pi_{i\tau}u_{i,t-\tau} + \xi_{it},$$

(1) $$\Delta \mathbf{p}_t = \alpha_0 + \sum_{\tau=1}^{8}\alpha_\tau \Delta \mathbf{p}_{t-\tau} + v_t,$$

$$\Delta s_{it} = \psi_{i0} + \sum_{\tau=1}^{r_i}\psi_{i\tau}\Delta s_{i,t-\tau} + u_{it},$$

where Δy_{it} is the percentage change in output, $\Delta \mathbf{p}_t$ the percentage change in total G7 patents, Δs_{it} the percentage change in each country's share of total G7 patents, and:

(2) $$z_{i,t-j}=[\log(\max\{y_{i1},y_{i2},\dots,y_{i,t-j}\})-\log(y_{i,t-j})].$$

The model can also be rewritten as:

(3) $$X_{it}=a_i+A_i(\mathrm{L})X_{i,t-1}+B_i(\mathrm{L})z_{i,t-1}+\varepsilon_{it} \qquad i=1,2,\dots,7,$$

where X_{it} denotes $(y_{it},\mathbf{p}_t,s_{it})'$ and a_i is a 3×1 vector of intercepts. A_i(L) and B_i(L) are matrix polynomials in the lag operator so that $A_i(L) = A_{i0} + A_{i1}L + \ldots + A_{ik_i}L^{k_i}$ and $B_i(L) = B_{i0} + B_{i1}L$, where A_{ij} and B_{ij} are (restricted) matrices of constant coefficients. The residual $\varepsilon_{it}=(\xi_{it}, v_{it}, u_{it})'$ is a vector of white noise disturbances, where the ε_{it}'s have mean zero ($E[\varepsilon_{it}]=0$) and nonsingular covariance matrix $E[\varepsilon_{it}\varepsilon_{it}']=\Sigma_i$. In view of the impulse response analysis of the next section, the three components ξ_{it}, v_{it} and u_{it}, are assumed to be contemporaneously uncorrelated.

The estimation of the model is based on the Full Information Maximum Likelihood procedure.[13] The model has first been estimated without restrictions on the lag structure of the three equations. Then, in order to reduce the problem of overparametrisation and improve the precision of the estimates, coefficients with t-ratios less than unity (in absolute value) have been set to zero, with the condition that there are no gaps between the time lags in the regressors included in the model. The validity of the restrictions has been tested computing the log likelihood ratio statistic (distributed as a χ^2 with degrees of freedom equal to the number of regressors set to zero), which did not reject the imposed restrictions. The presence of nonlinearities in each country's output movements has been investigated by means of a specification search which involved the analysis of the statistical properties of the residuals, the computation of Akaike and Schwartz selection criteria, and tests for the inclusion and exclusion of at most two lagged values of the variable CDR defined above. The results obtained, presented in Table 1, show that both types of technology shock have a significant role in the explanation of output growth, with lag

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[13] See Pesaran (1987). The utilisation of the FIML method to estimate all the parameters of the model avoids the "generated regressors" problem that would instead arise with an OLS two-step procedure (see Pagan, 1984, 1986).

structure and total effect that vary across the seven economies.[14] The lags involved between unpredicted breaks in innovative activity and output growth appear, in some cases, to be considerable.[15] This finding is consistent with the idea that the economic impact of innovation is linked to its diffusion, when the profit potential of new products or processes is perceived by the market. Further details of the estimation procedure and comments on the results obtained, which are not the main focus of this work, can be found in Fabiani (1996).

The analysis presented in the remainder of the paper focuses instead on the response of output movements to the three types of shock and on its time profile. For this purpose, an impulse response analysis is carried out for each of the G7 economies, based on the nonlinear model (1) and on the related estimates of the unknown parameters. The following section summarises the methodological issues involved in impulse response analysis and sets up the procedure adopted for the empirical investigation that is the object of this work.

3. Impulse response analysis: methodological issues

The analysis focuses on two methods for analysing the response of output to different types of shocks, based respectively on the so-called "traditional" and the "generalised" impulse response function. To introduce them, consider the following class of multivariate Markov models and assume that the disturbance is additive:[16]

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[14] Once the preferred specification of the three equations in the model for each country was established, the overall impact of the identified shocks on output growth was estimated using the so called "delta method".

[15] See Appendix C for a detailed description of the output growth equation and the related estimates.

[16] See Koop, Pesaran and Potter (1996).

(4) $y_t = F(y_{t-1},....y_{t-p})+\varepsilon_t$,

where y_t is a random vector, F is a known function, and ε_t is a vector of i.i.d. disturbances. The time profile of the effect of a shock $\varepsilon_t=\delta$ on y_{t+n}, $n=0,1,2,....$, is the impulse response function.

3.1 *The "traditional" impulse response function*

The simplest of these functions, which is also the most widely used in the literature, provides a measure of the effect at time $(t+n)$, $n=0,1,2,...$, of a shock of size δ hitting the system at time t, given that no other shock hits the system between t and $(t+n)$. Such a measure is the difference between two conditional realisations of y_{t+n}, the first based on the assumption that the system is only hit by a shock of size δ at time t, and the second on the assumption that no shock hit the system between t and $(t+n)$. Let ε^0_t be a realisation of the random shock and Ω^0_{t-1} a realisation of the information set used to forecast y_t. By iterating forward on (4), the realisation of y at time $(t+n)$ depends on $(\varepsilon^0_t,\varepsilon^0_{t+1},...,\varepsilon^0_{t+n})$ and Ω^0_{t-1}. The "traditional" impulse response function sets all the future shocks to zero, i.e. $\varepsilon^0_{t+i}=0$ $(i=1,2,...,N)$. For $n=1,2,...$, it is hence formally defined as:

$$(5)\qquad I_y(n,\delta,\Omega^0_{t-1}) = E[y_{t+n}|\varepsilon_t=\delta,\varepsilon_{t+1}=0,..,\Omega_{t-1}=\Omega^0_{t-1}] - E[y_{t+n}|\varepsilon_t=0,\varepsilon_{t+1}=0,..,\Omega_{t-1}=\Omega^0_{t-1}].$$

All the shocks except the current one are therefore turned off and the value of y_{t+n} after the shock has occurred is compared with the benchmark case in which the economy has not been hit by any shock. When applied to linear models, this function has the following properties:

- *symmetry*: a shock of size $+\delta$ has exactly the opposite effect of a shock of size $-\delta$;
- *shock invariance*: different values of δ only scale the impulse response function (a shock of size 2 has exactly twice the effect of a shock of size 1);
- *history independence*: the time at which the system is shocked does not affect the impulse response function.

3.2 *The generalised impulse response function*

The concept of generalised impulse response function (*GI*) has been introduced in recent empirical studies as an alternative method for carrying out impulse response analysis.[17] The *GI* for a particular shock δ occurring at time t, given the history of the system up to time t, is defined as the difference between two conditional expectations of the level of output at time $(t+n)$, n=0,1,2,... The first conditional expectation is based on the past history and the assumed shock, the second only on the past history. As opposed to the "traditional" impulse response function, where all future shocks are "switched off" and assumed to be equal to zero, the *GI* solves the treatment of the future by averaging out all future shocks.[18]

Consider for example the time series model (4) and let δ be an arbitrary shock hitting the system at time t and Ω^0_{t-1} the information set available at time t. The baseline is the

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[17] Koop, Pesaran and Potter (1996), Pesaran and Potter (1994). See also Gallant, Rossi and Tauchen (1993).

[18] For linear models, the two procedures provide equal results; for nonlinear models, instead, setting all future disturbances at zero is very different from averaging them out.

conditional expectation of y_{t+n} with respect to the past history Ω^0_{t-1}. The *GI* (n=1,2,...,N) is thus defined simply as:

$$(6) \qquad GI_Y(n, \delta, \Omega^0_{t-1}) = E[\, y_{t+n} | \varepsilon_t = \delta, \Omega^0_{t-1}] - E[\, y_{t+n} | \Omega^0_{t-1}\,].$$

Since Ω^0_{t-1} and δ are realisations from the same stochastic process that generates $\{y_t\}$, the two conditional expectations above can also be viewed as realisations from such a process. Hence, (6) itself is a realisation of the random variable (n=1,2,...,N):

$$(7) \qquad GI_Y(n, \delta, \Omega_{t-1}) = E[\, y_{t+n} | \varepsilon_t = \delta, \Omega_{t-1}] - E[\, y_{t+n} | \Omega_{t-1}\,],$$

which is denoted as "unconditional generalised impulse response function". Two conditional forms of (7) can be obtained by conditioning on either a particular shock or a particular history. For n=1,2,...,N:

$$(8) \qquad GI_S = GI_y(n, \delta, \Omega_{t-1}) = E[y_{t+n} | \varepsilon_t = \delta, \Omega_{t-1}] - E[y_{t+n} | \Omega_{t-1}\,],$$

$$(9) \qquad GI_H = GI_y(n, \varepsilon_t, \Omega^0_{t-1}) = E[y_{t+n} | \varepsilon_t, \Omega^0_{t-1}] - E[y_{t+n} | \Omega^0_{t-1}\,].$$

In equation (8) the variable generating the history is considered as random, while in (9) the stochastic element is the innovation process.

3.3 *Impulse response analysis for multivariate models*

When a multivariate framework is adopted to analyse the persistence of output fluctuations, the computation of the "traditional" impulse response function requires the so-called Choleski decomposition of the covariance matrix of the disturbances. This decomposition is not unique and implies a certain degree of arbitrariness in the measure of persistence.[19] The *GI* function overcomes this problem, since it is conditional on just one element of the vector of shocks occurring at time t and is computed by integrating out the effects of all the other shocks given the fixed one. Consider for example the multivariate model:

$$(10) \quad X_t = \sum_{j=0}^{\infty} A_j \varepsilon_{t-j},$$

where $X_t=(X_{1t},X_{2t},..,X_{kt})'$, A_j are matrices of fixed coefficients and $\varepsilon_t=(\varepsilon_{1t},\varepsilon_{2t},..,\varepsilon_{kt})'$ is jointly normally distributed with mean zero and non-singular variance matrix Σ. If the i^{th} shock is fixed - for example, ε_{it} is equal to the scalar δ - and the effect of the other shocks is integrated out given δ, then the *GI* is:

$$(11) \quad GI_X(n, \delta, \Omega_{t-1}) = E[X_{t+n}|\varepsilon_{it} = \delta, \Omega_{t-1}] - E[X_{t+n}|\Omega_{t-1}] = \left(\frac{A_n \gamma_i}{\sigma_i}\right)\left(\frac{\delta}{\sigma_i}\right),$$

where $\sigma_i^2=E[\varepsilon_{it}^2]$ and $\gamma_i=E[\varepsilon_t \varepsilon_{it}]$. It can be easily noticed that this expression takes into account the correlation between the shocks, expressed by their covariance matrix, and that it coincides with the "traditional" impulse response function when such a matrix is diagonal.

3.4 *Impulse response analysis for nonlinear models*

In the presence of nonlinearities, the properties of "shock" and "history" independence of the impulse response function - observed for linear univariate models - no longer hold: there are asymmetries across shocks and across histories. Moreover, the function crucially depends on the

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[19] The arbitrariness of this transformation may cause difficulties in interpreting the impulse response functions thus obtained. See also Lee, Pesaran and Pierse (1992), Lee and Pesaran (1993), Pesaran, Pierse and Lee (1993), Lee (1994).

assumption that all future shocks are set to zero, which is valid to analyse the dynamics of linear models but can produce misleading information about the dynamics of nonlinear ones.[20]

For nonlinear models, Monte Carlo integration is required to compute the conditional expectations in the definition of the generalised impulse response function. Under the assumption that the specification of the model and the density function of the disturbances are known, the computation of the *GI* can be carried out as follows:

- the horizon of the *GI* is set at *N*; the number of replications is set at *R*; the past history set as Ω_{t-1}, using the observed values of the time series;

- the vector of shocks δ is either arbitrarily fixed or drawn from the joint density of ε_t. Two different approaches can be followed in the second case: i) if ε_t has a multivariate normal distribution, the values of the shocks can be drawn from the joint density; ii) if no parametric form is assumed for the density of ε_t, a bootstrap method can be adopted, sampling with replacement from the residuals of the estimated nonlinear model;

- for the given time horizon *N*, (*N*+1) values of the shocks are randomly sampled using either of the two approaches described above. The result is a realisation of the innovation process, for each replication *j*, (*j*=1,2,...,*R*): $\varepsilon^j_t, \varepsilon^j_{t+1}, \ldots \varepsilon^j_{t+N}$;

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[20] If, for example, the "traditional" impulse response function is computed for the nonlinear two-regime Self-Exciting Threshold Autoregressive model (Potter, 1995), the threshold effect turns out to be active only at the time the shock occurs and not in the rest of the period, irrespective of the value of the shock and of the initial conditions being on the boundary between the two regimes.

- N of the above random errors are used to compute the realisation $y^j_{t+n}(\varepsilon^0_t, \Omega^0_{t-1})$ for $n=1,2,\ldots,N$, iterating on the time series model from the given history Ω^0_{t-1} and the given vector of shocks $\varepsilon_t=\delta$. Assume that the model for y is the nonlinear Markov multivariate model of order p represented in equation (3).[21] The $\varepsilon^j_{t+1}, \varepsilon^j_{t+2}, \ldots, \varepsilon^j_{t+N}$ random errors obtained in the previous step, plus the shock δ, are used to simulate the time series of the level of y:

$$
\begin{aligned}
& y^j_t(\delta, \Omega^0_{t-1}) = F(y^0_{t-1}, \ldots, y^0_{t-p}) + \delta, \\
(12) \qquad & y^j_{t+1}(\delta, \varepsilon^j_{t+1}, \Omega^0_{t-1}) = F(y^j_t, y^0_{t-1} \ldots, y^0_{t-p+1}) + \varepsilon^j_{t+1}, \\
& \ldots\ldots \text{until } y^j_{t+N}(\delta, \varepsilon^j_{t+1}, \varepsilon^j_{t+2}, \ldots, \varepsilon^j_{t+N}, \Omega^0_{t-1}),
\end{aligned}
$$

where the superscript 0 indicates an observed realisation and the superscript j a simulated variable in the j^{th} replication;

- the same N random errors as above plus one additional draw of the random error are then used to compute the realisation $y^j_{t+n}(\varepsilon_t, \Omega^0_{t-1})$ for $n=0,1,2,\ldots,N$, iterating on the model from the same given initial conditions Ω^0_{t-1} as in the previous step:

$$
\begin{aligned}
& y^j_t(\varepsilon^j_t, \Omega^0_{t-1}) = F(y^0_{t-1}, \ldots, y^0_{t-p}) + \varepsilon^j_t, \\
(13) \qquad & y^j_{t+1}(\varepsilon^j_t, \varepsilon^j_{t+1}, \Omega^0_{t-1}) = F(y^j_t, y^0_{t-1}, \ldots, y^0_{t-p+1}) + \varepsilon^j_{t+1}, \\
& \ldots\ldots \text{until } y^j_{t+N}(\varepsilon^j_t, \varepsilon^j_{t+1}, \varepsilon^j_{t+2}, \ldots, \varepsilon^j_{t+N}, \Omega^0_{t-1});
\end{aligned}
$$

- the last three steps are repeated R times and the averages across R of both components are calculated. By the Law of Large Numbers they converge to the conditional expectations used in the definition of the GI. For $n=0,1,2,\ldots,N$:

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[21] The procedure can also be applied to more general set-ups.

(14) $$\hat{y}_{R,t+n}(\delta, \Omega^0_{t-1}) = \frac{1}{R}\sum_{j=1}^{R} y^j_{t+n}(\delta, \varepsilon^j_{t+1}, \varepsilon^j_{t+2}, \ldots, \varepsilon^j_{t+n}, \Omega^0_{t-1}) ,$$

(15) $$\hat{y}_{R,t+n}(\Omega^0_{t-1}) = \frac{1}{R}\sum_{j=1}^{R} y^j_{t+n}(\varepsilon^j_t, \varepsilon^j_{t+1}, \varepsilon^j_{t+2}, \ldots, \varepsilon^j_{t+n}, \Omega^0_{t-1}) \;;$$

- the difference between the two averages forms the Monte Carlo estimate of the *GI*. For $n=0,1,2,\ldots,N$:

(16) $$GI_R(n, \delta, \Omega^0_{t-1}) = \hat{y}_{R,t+n}(\delta, \Omega^0_{t-1}) - \hat{y}_{R,t+n}(\Omega^0_{t-1}) \;;$$

- to compute a standardised measure, "unit shocks" can be considered, that is, shocks of size equal to one standard error of the residuals ($\delta=\sigma_\varepsilon$). Hence, the standardised *GI* is given by ($n=0,1,2,\ldots,N$):

(17) $$GI_R(n, \sigma_\varepsilon, \Omega^0_{t-1}) = \hat{y}_{R,t+n}(\sigma_\varepsilon, \Omega^0_{t-1}) - \hat{y}_{R,t+n}(\Omega^0_{t-1}) \;;$$

- the limit of the cumulative *GI* function obtained in the previous step is a measure of the persistent effect of the shock δ on the long-run level of y.

4. The response of aggregate output to technology shocks

The procedure described above is now applied to the nonlinear multivariate model (1) to investigate the time profile of the effects of the measured technology shocks on the level of output. This approach does not take into account the possibility of uncertainty about the choice of the model and about the statistical distribution of the disturbances. Both the functional form of the specification and the joint density of the residuals are assumed to be known. Moreover, the Monte Carlo procedure does not deal with the computation of standard errors for the measures of persistence.

Three different sets of simulations are carried out, each of them focusing on only one of the three shocks driving output movements: (i) unidentified disturbances; (ii) global technology shocks; (iii) country-specific technology shocks. The simulations are performed in the following steps.[22]

- Output data are taken from *International Financial Statistics*, IMF. They represent quarterly GDP at 1990 prices for Canada, France, Italy, the UK and the USA, and GNP at 1990 prices for Japan and Germany, over the period 1963q1-1993q4. Patents quarterly time series are elaborations from the data provided by the United States Department of Commerce, Patent and Trademark Office, Office of Information Products Development.[23]

- The impulse response functions are derived using the FIML estimates of the unknown parameters a, $A(L)$ and $B(L)$ for the period 1969q1-1993q4, presented in Table 1 and Appendix C.[24] The time horizon is set at N=20 for Canada, France, Italy, Japan, the UK and the United States, at N=24 for Germany.[25] For all countries, the number of replications is set at R=5000.

- The strong assumption that ε_t is normally distributed is made, with zero mean and variance given by the matrix:

$$(18) \qquad \Sigma = \begin{pmatrix} \sigma_\xi^2 & 0 & 0 \\ 0 & \sigma_v^2 & 0 \\ 0 & 0 & \sigma_u^2 \end{pmatrix}.$$

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22 The Monte Carlo simulations have been run on GAUSS 3.1.

23 For a description of the data, see Appendix A.

24 For a detailed description of the estimation procedure, see Fabiani (1996)

25 A different time horizon is chosen for Germany because in this country the high estimated magnitude of nonlinearities makes the propagation effect of shocks last longer than in the remaining six economies. In the simulations and in the resulting figures presented at the end of this paper, the time units are quarters.

- For each replication j, the "future" values of the disturbance ε_t are simulated by randomly drawing each of the three shocks from a normal distribution with mean zero and standard deviation equal to the estimated standard deviation of the residuals in (3). This method provides $(N+1)$ realisations of the disturbance $\{\varepsilon_{t+n}\}$ $(n=0,1,2,...N)$ for each replication j:

$$(19) \qquad \begin{pmatrix} \xi_t \\ v_t \\ u_t \end{pmatrix}^j, \begin{pmatrix} \xi_{t+1} \\ v_{t+1} \\ u_{t+1} \end{pmatrix}^j, \begin{pmatrix} \xi_{t+2} \\ v_{t+2} \\ u_{t+2} \end{pmatrix}^j, \ldots\ldots, \begin{pmatrix} \xi_{t+N} \\ v_{t+N} \\ u_{t+N} \end{pmatrix}^j .$$

- Corresponding to each set of "futures", $\{\varepsilon_{t+n}\}$ $(n=0,1,2,...,N)$, the future values of X_{t+n} are then dynamically simulated from the given history Ω^0_{t-1}. In order to illustrate the history dependence of the *GI* for nonlinear models, two different initial periods of observed economic expansion and recession are considered for each country.[26] In the model considered, the relevant history is captured by q lagged values of the vector X and two lagged values of the *CDR* variable:[27] $\Omega^0_{t-1}=(X^0_{t-1},..,X^0_{t-q},z^0_{t-1},z^0_{t-2})$. The initial periods of observed economic expansion or recession are used to produce baseline forecasts that represent the expected path of the variable $X_t=(y_t,\mathbf{p}_t,s_t)'$ for each country, assuming that no fixed perturbation occurs at time t. By the Law of Large Numbers, the average across the R future values of X_{t+n} will in fact converge to $E[X_{t+n}|\Omega^0_{t-1}]$.

- For each replication, the same set of "futures" for $\{\varepsilon_{t+n}\}$ $(n=1,2,...,N)$ used to simulate the baseline forecast are

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26 In presenting the empirical results in the tables and figures which follow, the observed history for a baseline forecast starting, for example, in period 1980q2 will be denoted as Ω^0_{1980q1}.

27 The country subscript i is dropped for simplicity of notation.

then used to simulate the future values of X_{t+n}, given the initial history $\Omega^0{}_{t-1}$ and the shock vector δ hitting the system at time t. By the Law of Large Numbers, the average of these future values across the R replications represents the expected path of the variable X_t when the system is hit by a shock δ at time t: $E[X_{t+n}|\varepsilon_t = \delta, \Omega^0_{t-1}]$. As already mentioned, three different sets of simulations are performed in order to "isolate" the persistence effect of each component ξ_t, v_t and u_t of the three dimensional vector ε_t. The compositional problem is solved by conditioning the *GI* just on one element of the shock vector δ at the time, integrating out the effects of the other two given its value. The size of the perturbation hitting the system at time t is fixed on the basis of the distribution of the estimated residuals. First, unit shocks are considered, equal in size to one standard error of the estimated residuals. This case yields the computation of the standardised *GI*. Then, in order to show the dependence of the *GI* on the size of the postulated shock, multiples (two and three times) of the standard deviation are considered. Finally, to emphasise the dependence of the *GI* on the sign of the perturbation, all these shocks are imposed to be both positive and negative. Hence, in the three sets of simulations presented below (A, B, C), δ is fixed as:

$$\text{(A)} \quad \delta = \begin{pmatrix} \delta_\xi \\ v_t \\ u_t \end{pmatrix}, \text{ where } \delta_\xi = \pm\sigma_\xi,\ \pm 2\sigma_\xi,\ \pm 3\sigma_\xi,$$

$$(20) \qquad \text{(B)} \quad \delta = \begin{pmatrix} \xi_t \\ \delta_v \\ u_t \end{pmatrix}, \text{ where } \delta_v = \pm\sigma_v,\ \pm 2\sigma_v,\ \pm 3\sigma_v,$$

$$\text{(C)} \quad \delta = \begin{pmatrix} \xi_t \\ v_t \\ \delta_u \end{pmatrix}, \text{ where } \delta_u = \pm\sigma_u,\ \pm 2\sigma_u,\ \pm 3\sigma_u,$$

depending on whether the aim is the computation of the effect of an unidentified shock to the rate of growth of output, to the rate of growth of total G7 patents or to the rate of growth of the national share of G7 patents, respectively.

- The two expectations computed in the previous steps are used to calculate the generalised impulse response function for $n=0,1,2,\ldots,N$: $GI_R(n,\delta,\Omega^0_{t-1}) = E[X_{t+n}|\varepsilon_t = \delta, \Omega^0_{t-1}] - E[X_{t+n}|\Omega^0_{t-1}]$.

- The limit of the cumulative *GI* is then computed in order to measure the persistence effect of the postulated shocks.

5. Empirical results

5.1 *A: Unidentified shocks to output growth*

The first set of simulation experiments is aimed at computing the long-run effect of unidentified shocks to output growth on the level of output. The results can be compared with the ones that would have been obtained if output fluctuations had not been influenced by unexpected changes in patenting activity. The specification of this alternative model is presented in Appendix B: the OLS estimates used to investigate the effects of different shocks on the level of output are shown in Table B1; the time profile of such effects is presented in Figures F, G, I, US, C, J, UK, which also contain a comparison between impulse response functions for linear and nonlinear specifications (for a more detailed description of the procedure adopted to estimate the univariate model, see Fabiani, 1996).

The shock δ hitting the system at time t is defined by fixing the first component of the vector of shocks and by integrating out the effects of the other two given its value (see expression (20) - case A). The benchmark years for the expansionary and the recessionary period are chosen for each country from the observed time series of output; one period of particularly high growth and one of particularly strong economic contraction are identified.[28] Table 2 provides the long-run values of the change in the log level of output in response to the postulated shocks, computed as the limit of the cumulative *GI*. The time shape of the response to each shock, occurring in either an expansionary or a recessionary regime, are shown in Figures A.F, A.G, A.I, A.US, A.C, A.J and A.UK.[29]

For the countries in which output movements present nonlinearities, Figures A.F, A.G, A.I and A.US show that the impulse responses to different values of δ are not symmetrical for positive and negative shocks of the same absolute size. Figure A.F shows that for France the results based on the multivariate model are very similar to those based on the univariate model (Figure F). The only significant difference between the two is that in the multivariate case negative shocks seem to be more persistent in an expansionary regime as compared to the univariate case, and that in a recessionary period the response of output to a negative unit shock does not become positive, nor does the response to a positive unit shock become negative. The results obtained for Germany - presented in Figure A.G - are very interesting: in the multivariate model, the effect of positive shocks with a

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28 The baseline periods are not the same across countries. Clearly, given the nonlinearity of the system, the response of output for past histories different from the chosen ones does not coincide with the impulse response functions obtained here. Averaging out across all expansionary and recessionary phases, which is surely an interesting development of the analysis presented in this work, will be the subject of further research.

29 Note that the title of each figure indicates the simulation experiment it refers to (A, B, C for the three different sets of simulations), followed by the country initials. For example, Figure A.UK presents the results obtained for the United Kingdom in the first set of simulations (A) run for the multivariate model.

recessionary history is much smaller than in the univariate case, and it becomes negative and larger in absolute value than in the univariate model for shocks equal to one and two standard errors. The different shape of the *GI* between the positive growth and the negative growth regime is due to the high significance of the ratchet effect, which, for a recessionary shock, sets in motion strong forces pushing the system back to its trend level. A comparison between Figures I and A.I provides evidence that for Italy the persistence of positive and negative shocks in a period of expansion is larger than that found for the univariate model, while it is smaller in the case of a recessionary history. Figures US and A.US show that in the US positive shocks are less persistent within a multivariate model, independently of the given past history. This feature is accentuated if the *GI* is conditional on a period of economic contraction. In this case, a negative unit shock is also less persistent than in the univariate framework, and it tends to become positive.

The results for Canada, Japan and the United Kingdom are shown in Figures A.C, A.J and A.UK. In these countries the persistent effect of a unit shock to output growth in the multivariate model is lower that in the univariate specification.

5.2 *B: Global technology shocks*

The *GI* computed for the second group of simulations for the multivariate model represents the effect of a shock to the rate of growth of G7 patents on output fluctuations. The response is computed by fixing only the second component from the vector of all shocks and by integrating out the effects of the other two (see expression (20) - case B). Three different (absolute) values of the perturbation δ_v are considered - equal to one, two and three times the estimated standard error of the residuals from the equation of G7 patents growth - and the observed past history is fixed as in the previous simulations. The global technology shock hits the system at time *t*, but its impact starts showing after N_i periods in country *i*. The delay of this effect is different across countries and depends on which are the significant lagged values of v_t in the first equation of model (1). The *GI* is therefore expected to be close to zero until time N_i.[30] Table 3 shows the long-run impact of global technology shocks on the level of output.[31]

The time profile of the change in the log of output in response to the postulated shocks for France, Germany, Italy and the United States is shown in Figures B.F, B.G, B.I and B.US, respectively. Global technology shocks have the highest persistence in Germany, the United Kingdom and the United States. The responses are not symmetrical for positive and negative shocks and depend on the choice of the baseline forecast.

The asymmetry is not very high for France and Italy (Figures B.F and B.I), where the persistence effect of a unit shock is less than 0.5 in absolute value, both in expansionary and recessionary regimes. For Germany, as Figure B.G shows, the persistence of positive shocks for the expansionary baseline forecast is larger than in the recession, and the same is true also of negative shocks. The explanation of the high long-run effect that positive global technology shocks have on the level of output is probably related to the dominant technological position of the country among the G7 group. Negative shocks of the same absolute value do not have such a high persistence because of the strong ratchet effect

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[30] See Appendix C.

[31] For Germany, the time horizon has been set at N=32, since the process of adjustment of the system to the postulated shocks takes longer than the 24 quarters considered in the previous simulations.

introduced by the two lagged values of the current depth of recession. These characteristics are also shown by the *GI* obtained for the United States (Figure B.US). In the US, not only are negative global technology shocks not as persistent as positive shocks of the same size, but they also produce a reaction similar to a trend stationary process, showing the typical hump shape of business cycles emphasised by authors such as Blanchard (1981).

Figures B.C, B.J and B.UK present the *GI* for Canada, Japan and the United Kingdom, respectively. The response to positive and negative perturbations is perfectly symmetrical, given the linearity of the time series model for output growth. In the first two countries, the long-run effect of a unit shock to G7 patents growth on the level of output is less than 0.5 per cent, while in the UK it is above 1 per cent.

5.3 *C: Country-specific technology shocks*

The final group of Monte Carlo simulations examines the persistent effects of country-specific technology shocks on output fluctuations. The resulting *GI* characterises the time profile of the change in the log level of output due to a shock to the rate of growth of each nation's share of G7 patents. The third element of the vector $\{\varepsilon_t\}$ in model (3) is fixed while the effects of the other two are integrated out (see expression (20) - case C). The information set Ω^0_{t-1} is chosen for each country as in the above simulations. The focus of interest is on the effect of multiples of a unit shock to the rate of growth of the national share of total patents on the level of output. In country i this effect becomes significantly different from zero only after M_i periods, where M_i is determined by the significant lags of u_{it} in the first equation in (1).[32] Table 4 shows the different values taken by the limit of the cumulative response of output to country-specific technology shocks.[33]

Figures C.F, C.G, C.I and C.US show the *GI* for country-specific technology shocks for France, Germany, Italy and the US, respectively. For France, these shocks are more persistent if they are positive and, moreover, if they are assumed to hit the system in a period of economic expansion. The results obtained for Germany show that country-specific shocks are much less persistent than the ones considered in the previous exercise. Conversely, in Italy a unit shock in the national share of G7 patents produces a change in the level of output which is larger than that produced by a unit shock in the growth of G7 patents. Moreover, these effects are larger in the recessionary regime (compare graphs (a) and (b) of Figure C.I). In the US, the characteristics of the impulse responses for the six shocks show that the country-specific features of technological change are much less relevant for the movements of aggregate output than the global component. The responses generated in this set of simulations indicate that a unit shock (in absolute value) to the rate of growth of the US share of G7 patents causes a long-run change in the log level of output which is around 0.10 per cent, both in expansionary and recessionary regimes.

The *GI* for Canada, Japan and the United Kingdom is presented in Figures C.C, C.J and C.UK. The shape of the response of output to given shocks is symmetrical for positive and negative values of δ_{it}. A unit shock has the highest persistence in Japan. In Japan the share of total G7 patents grew very rapidly over the period considered and the overall impact of country-specific technology shocks on output growth

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32 See Appendix C.

33 Here too, the time horizon for Germany has been set at N=32.

- shown in Table 1 - is quite large. The evidence provided by the *GI* support the notion that the country-specific features of innovation have a major effect on the Japanese economy. A high persistence of country-specific technology shocks is also found for the UK, where the long-run change in the level of output following a unit innovation occurring at time *t* to the rate of growth of the country's share of total patents is equal to approximately 1 per cent.

6. Conclusions

The impulse response analysis carried out in this work provides empirical evidence on the effects of technology shocks on output fluctuations in the G7 countries.

In the model analysed, output fluctuations are driven by different types of shocks: global and country-specific technology shocks, and unidentified idiosyncratic shocks. Technology shocks are defined as unpredicted changes in the process of innovation and are measured on the basis of the time series properties of two different indicators: the number of patents granted to the G7 group and each country's share of total G7 patents. The computation of the GI function makes it possible to study the time profile of the effects of the three types of shock on the level of output in each economy.

At a general level, the results obtained show that nonlinear models produce impulse response functions which depend on the history of the time series and on the magnitude and sign of the shocks. There are two ways in which asymmetrical responses may occur: first, for any given history, the effects of shocks of different size and sign do not correspond to simple scaling of a unit shock; second, the response to the same shock can vary across different histories. The empirical evidence suggests that theories of economic recession that predict only a temporary decrease in output may be the right way to look at business cycles, even when the output time series is characterised by the presence of a unit root. In fact, in phases of economic contraction, negative shocks tend to be attenuated and sometimes reversed. Conversely, theories that explain permanent changes in output level may be relevant for analysing the effect of perturbations during economic expansions. These findings are in agreement with previous results obtained in the literature on nonlinear models of output growth, such as Beaudry and Koop (1993), Pesaran and Potter (1994), Potter (1995).

The Monte Carlo simulations performed for computing generalised impulse response functions for the identified technology shocks indicate that both global and country-specific technology shocks are persistent in the G7 economies. Their effects on output fluctuations differ, however, from country to country, both in magnitude and in time profile, and depend on the size of the postulated shock and on the information set chosen.

Positive global technology shocks are particularly persistent in the case of Germany, the United Kingdom and the United States, while negative shocks of the same type are less persistent in all countries and show the tendency to revert to zero in the United States. Country-specific technology shocks have instead the highest effect on output fluctuations in Japan and the United Kingdom. For this type of shock too, there seems to be the general tendency for positive perturbations to be more persistent than negative ones, although this evidence is much less striking than for the other type of technology shock and for the unidentified shocks.

Clearly, there are important limitations to the use of patent statistics as an indicator of technological advance.

For example, some patents are never used, the economic impact of patents is not uniform and patents are often a protection against imitation rather than a way to introduce innovations. However, these limitations can be accommodated in the empirical framework developed in this work. The fact that some patents are not used can be interpreted as reflecting the uncertainty of technological activity, while the skewness in the economic impact of patents can be thought of as a consequence of the generally uneven economic impact of inventions and innovations. Finally, the fact that patenting is an appropriation mechanism does not conflict with the assumption that the levels and dynamics of patenting still provide a reasonable overall indication of the technological performance of countries. It is also clear that technical progress involves more than just invention and innovation, while the applied analysis presented here has mainly focused on these elements, measuring innovative activity in terms of patenting. Sufficiently long time series at quarterly frequencies of alternative measures do not exist, and the empirical evidence obtained from a number of studies which have used R&D data instead of patents is rather controversial, especially in the time series dimension. The decision to use patent data is legitimate and defensible on the grounds that the number of patents granted to different countries in a technologically leading market can provide a good indication of these countries' innovative performance and hence of their technological capability. As Schmookler put it, "We have a choice of using patent data cautiously and learning what we can learn from them, or not using them and learning nothing about what they alone can teach us" (Schmookler, 1966, p. 56).

Table 1

FIML ESTIMATES OF THE RELATIONSHIP BETWEEN OUTPUT GROWTH AND TECHNOLOGY SHOCKS

	CANADA (69q1-93q4)	GERMANY (69q1-93q4)	FRANCE (70q1-93q4)	ITALY (69q1-93q3)	JAPAN (69q1-93q4)	UK (69q1-93q4)	USA (69q1-93q4)
System log-likelihood	538.58	579.49	563.85	501.48	577.16	551.82	689.93
Number of parameters	17	27	21	18	31	33	21
$\chi^2(m)$	43.38 (32)	38.98 (21)	24.54 (29)	41.36 (30)	29.48 (25)	19.94 (18)	20.96 (30)
GROWTH RATE OF G7 PATENTS							
α_0	.015 (1.13)	.015 (1.15)	.015 (1.08)	.015 (1.15)	.016 (1.17)	.014 (1.11)	.016 (1.24)
α_1	-.394 (3.95)	-.363 (3.73)	-.452 (4.55)	-.387 (3.81)	-.424 (4.06)	-.375 (3.78)	-.448 (4.41)
α_2	-.407 (3.77)	-.419 (4.05)	-.394 (3.67)	-.416 (3.67)	-.451 (4.07)	-.387 (3.79)	-.421 (3.87)
α_3	-.294 (2.58)	-.354 (3.18)	-.344 (3.06)	-.353 (3.07)	-.368 (3.19)	-.297 (2.92)	-.361 (3.20)
α_4	-.136 (1.23)	-.192 (1.78)	-.122 (1.07)	-.164 (1.49)	-.152 (1.33)	-.128 (1.27)	-.196 (1.75)
α_5	-.309 (2.76)	-.262 (2.41)	-.361 (3.12)	-.364 (3.26)	-.337 (2.93)	-.297 (2.88)	-.372 (3.32)
α_6	-.221 (1.99)	-.204 (1.88)	-.258 (2.24)	-.274 (2.45)	-.246 (2.16)	-.244 (2.35)	-.286 (2.56)
α_7	-.125 (1.18)	-.116 (1.12)	-.106 (.991)	-.155 (1.40)	-.088 (.811)	-.076 (.706)	-.105 (.986)
α_8	-.155 (1.51)	-.248 (2.62)	-.219 (2.22)	-.236 (2.42)	-.229 (2.24)	-.227 (2.47)	-.236 (2.39)
S.E.	0.126	0.126	0.118	0.126	0.126	0.126	0.125
GROWTH RATE OF SHARE IN G7 PATENTS							
ψ_0	.006 (.943)	.003 (.644)	.003 (.571)	.007 (.863)	.011 (1.43)	-.009 (1.51)	-.004 (2.40)
ψ_1	-.575 (5.98)	-.507 (5.86)	-.691 (6.58)	-.527 (5.87)	-.220 (2.12)	-.501 (4.91)	-.382 (3.69)
ψ_2	-.237 (2.56)		-.502 (4.52)		.093 (.915)	-.229 (2.04)	-.103 (.928)
ψ_3			-.258 (2.47)		.111 (1.07)	-.049 (.437)	-.109 (.964)
ψ_4					.048 (.487)	.209 (1.96)	.237 (2.23)
ψ_5					-.087 (.918)		
ψ_6					-.104 (1.09)		
ψ_7					.167 (1.79)		
ψ_8					.233 (2.49)		
ψ_9					.208 (2.22)		
S.E.	0.063	0.043	0.056	0.080	0.049	0.057	0.014
GROWTH RATE OF OUTPUT							
μ	.006 (4.44)	-.003 (.959)	-.002 (1.17)	.001 (.526)	.006 (3.32)	.003 (1.88)	.002 (.949)
$\sum_s \vartheta_s$	.329 (3.55)	.901 (3.93)	.981 (5.99)	.626 (4.25)	.416 (3.35)	.297 (1.96)	.597 (3.61)
$\sum_s \lambda_s$		.634 (2.87)	.891 (4.03)	.445 (2.89)			.229 (1.62)
$\sum_s \beta_s$	.016 (2.08)	.121 (2.29)	.014 (2.42)	.012 (1.49)	.020 (1.40)	.072 (1.64)	.175 (2.58)
$\sum_s \pi_s$	.035 (2.03)	.053 (2.29)	.014 (2.66)	.030 (1.98)	.108 (3.34)	.104 (2.85)	.068 (1.03)
S.E.	0.009	0.009	0.006	0.009	0.008	0.009	0.009

Notes:

Regressions results refer to model (1) in the text, estimated over the period 1969q1-1993q4:

Throughout the table, figures in brackets are absolute values of the asymptotic t-ratio. $\chi^2(m)$ is the likelihood ratio test for the m restrictions imposed in the model and S.E. is the estimated standard deviation of the residuals in each equation. For a detailed specification of the restricted model for the rate of growth of output, see Appendix C.

Table 2

LONG-RUN EFFECT OF UNIDENTIFIED SHOCKS TO OUTPUT GROWTH ON THE LEVEL OF OUTPUT IN A NONLINEAR MULTIVARIATE MODEL OF OUTPUT FLUCTUATIONS AND TECHNOLOGICAL CHANGE
(% change in output level)

shock	CANADA		GERMANY		FRANCE		ITALY		JAPAN		UK		USA	
δ_ξ	EXP.	REC.	EXP.	REC.	EXP.	REC.	EXP.	REC.	EXP.	REC.	EXP.	REC.	EXP.	REC.
σ_ξ	1.37	1.37	2.42	-0.46	1.14	0.18	2.11	-0.19	1.47	1.47	1.34	1.34	1.61	-0.07
$2\sigma_\xi$	2.74	2.74	5.51	-0.30	2.45	0.84	4.51	0.20	2.95	2.95	2.70	2.70	3.45	-0.06
$3\sigma_\xi$	4.11	4.11	8.94	0.16	3.79	1.69	6.92	1.29	4.43	4.43	4.00	4.00	5.31	0.31
$-3\sigma_\xi$	-4.11	-4.11	-2.69	2.59	-2.16	0.49	-4.75	1.10	-4.43	-4.43	-4.00	-4.00	-2.69	0.35
$-2\sigma_\xi$	-2.74	-2.74	-2.94	1.31	-1.92	0.06	-4.10	0.60	-2.95	-2.95	-2.70	-2.70	-2.29	0.18
$-\sigma_\xi$	-1.37	-1.37	-2.55	0.48	-1.29	-0.21	-2.20	0.19	-1.47	-1.47	-1.34	-1.34	-1.63	0.08

Table 3

LONG-RUN EFFECT OF "GLOBAL" TECHNOLOGY SHOCKS ON THE LEVEL OF OUTPUT IN A NONLINEAR MULTIVARIATE MODEL OF OUTPUT FLUCTUATIONS AND TECHNOLOGICAL CHANGE
(% change in output level)

shock	CANADA		GERMANY		FRANCE		ITALY		JAPAN		UK		USA	
δ_v	EXP.	REC.	EXP.	REC.	EXP.	REC.	EXP.	REC.	EXP.	REC.	EXP.	REC.	EXP.	REC.
σ_v	0.29	0.29	2.67	2.37	0.29	0.18	0.17	0.23	0.42	0.42	1.28	1.28	3.44	2.01
$2\sigma_v$	0.59	0.59	6.69	5.86	0.59	0.36	0.34	0.44	0.83	0.83	2.56	2.56	7.75	5.76
$3\sigma_v$	0.89	0.89	12.3	10.63	0.91	0.59	0.54	0.71	1.23	1.23	3.84	3.84	12.6	10.2
$-3\sigma_v$	-0.89	-0.89	-5.06	-4.43	-0.81	-0.45	-0.42	-0.58	-1.23	-1.23	-3.84	-3.84	-5.05	-2.57
$-2\sigma_v$	-0.59	-0.59	-4.06	-3.31	-0.54	-0.32	-0.32	-0.42	-0.83	-0.83	-2.56	-2.56	-4.58	-2.53
$-\sigma_v$	-0.29	-0.29	-2.71	-2.22	-0.28	-0.17	-0.17	-0.22	-0.42	-0.42	-1.28	-1.28	-3.29	-2.00

Table 4

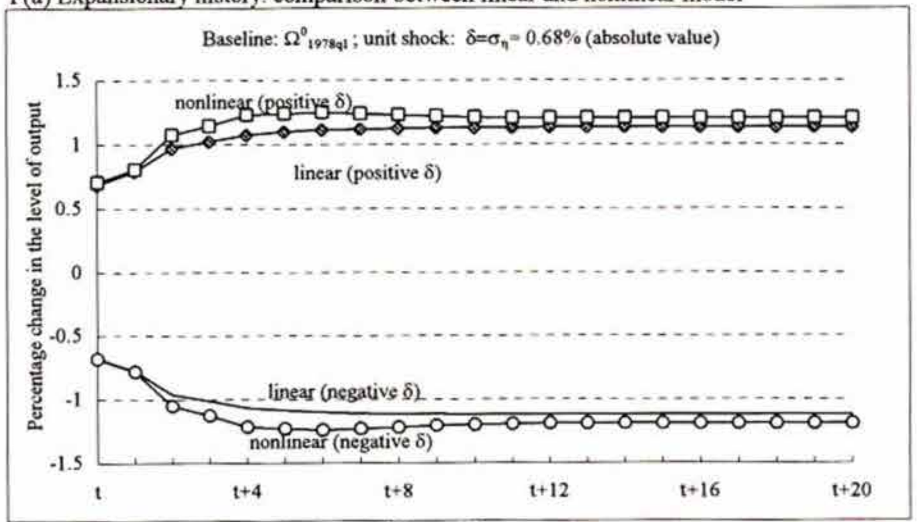
LONG-RUN EFFECT OF "COUNTRY-SPECIFIC" TECHNOLOGY SHOCKS ON THE LEVEL OF OUTPUT IN A NONLINEAR MULTIVARIATE MODEL OF OUTPUT FLUCTUATIONS AND TECHNOLOGICAL CHANGE
(% change in output level)

shock	CANADA		GERMANY		FRANCE		ITALY		JAPAN		UK		USA	
δ_u	EXP.	REC.	EXP.	REC.	EXP.	REC.	EXP.	REC.	EXP.	REC.	EXP.	REC.	EXP.	REC.
σ_u	0.32	0.32	0.48	0.48	0.57	0.49	0.27	0.34	0.91	0.91	0.84	0.84	0.12	0.14
$2\sigma_u$	0.64	0.64	0.97	1.11	1.19	1.05	0.59	0.72	1.82	1.82	1.68	1.68	0.27	0.27
$3\sigma_u$	0.96	0.96	1.55	1.63	1.93	1.70	0.96	1.11	2.75	2.75	2.52	2.52	0.41	0.40
$-3\sigma_u$	-0.96	-0.96	-1.15	-1.31	-1.46	-1.15	-0.72	-0.85	-2.75	-2.75	-2.52	-2.52	-0.39	-0.40
$-2\sigma_u$	-0.64	-0.64	-0.81	-0.92	-1.07	-0.82	-0.49	-0.63	-1.82	-1.82	-1.68	-1.68	-0.26	-0.27
$-\sigma_u$	-0.32	-0.32	-0.44	-0.48	-0.56	-0.49	-0.28	-0.33	-0.91	-0.91	-0.84	-0.84	-0.13	-0.13

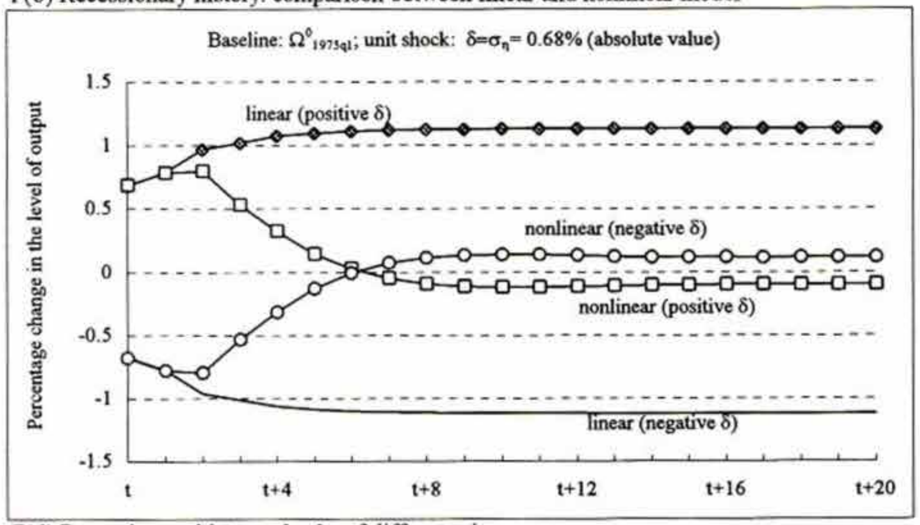
FRANCE: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH IN A UNIVARIATE MODEL

Figure F

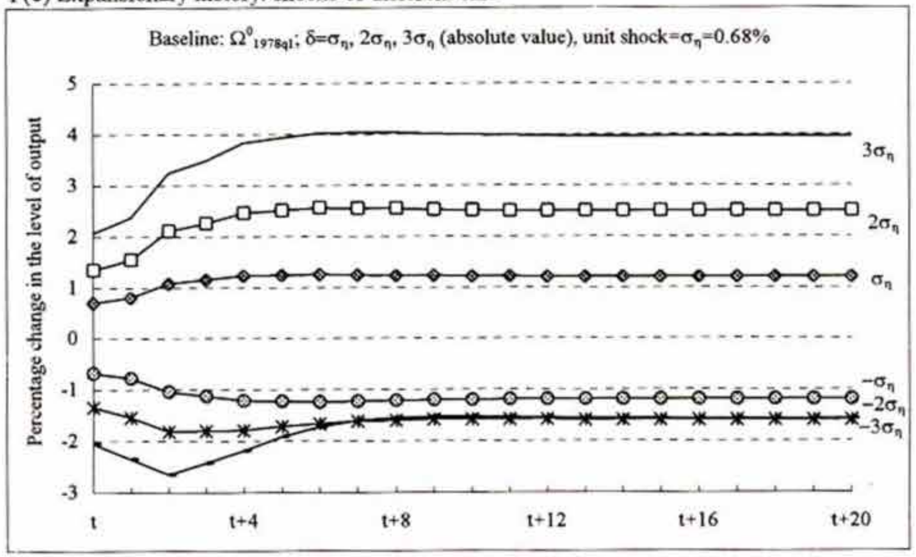
F(a) Expansionary history: comparison between linear and nonlinear model



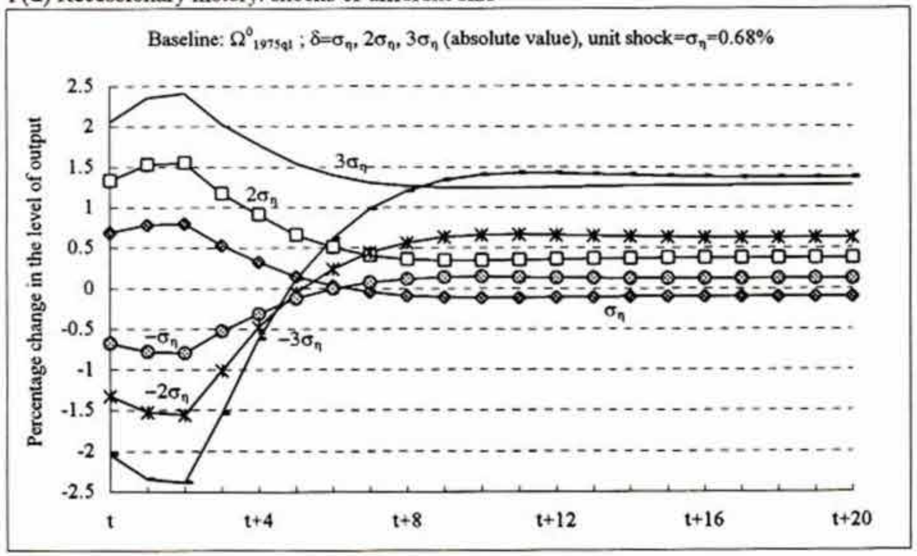
F(b) Recessionary history: comparison between linear and nonlinear model



F(c) Expansionary history: shocks of different size

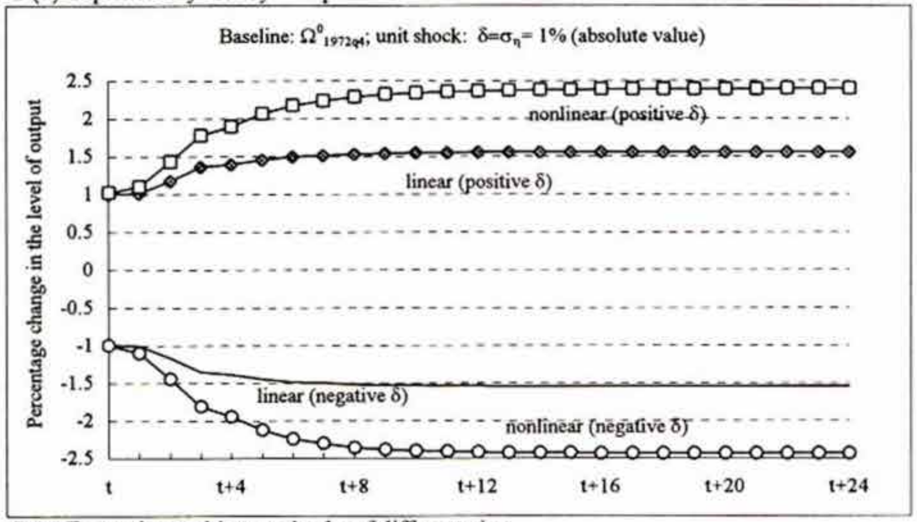


F(d) Recessionary history: shocks of different size

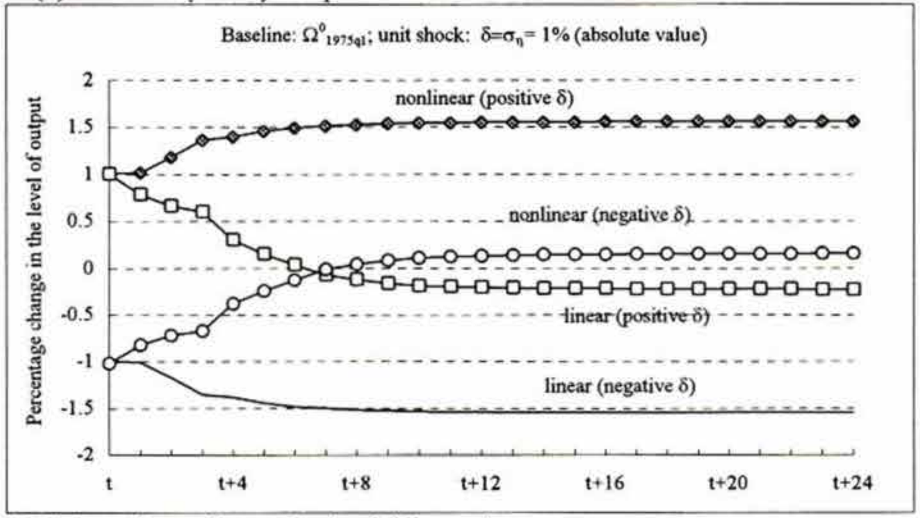


GERMANY: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH IN A UNIVARIATE MODEL

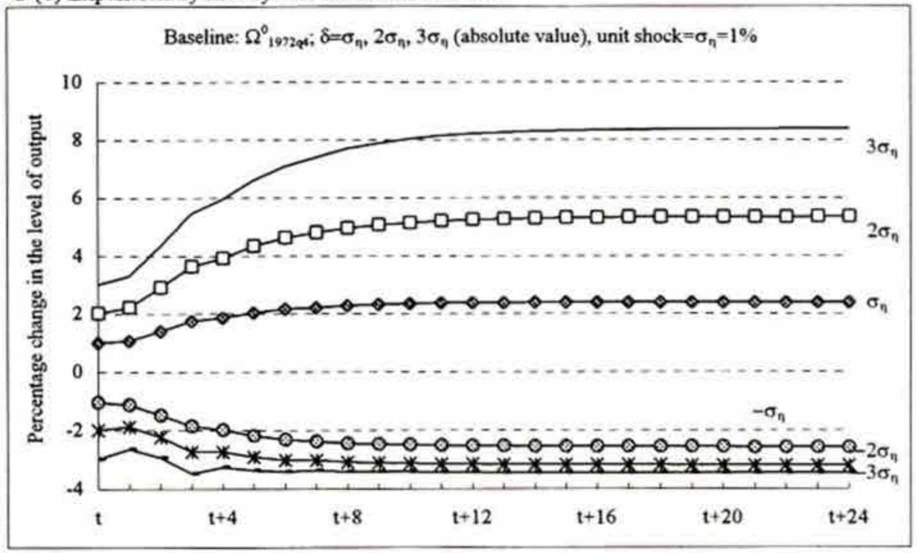
G (a) Expansionary history: comparison between linear and nonlinear model



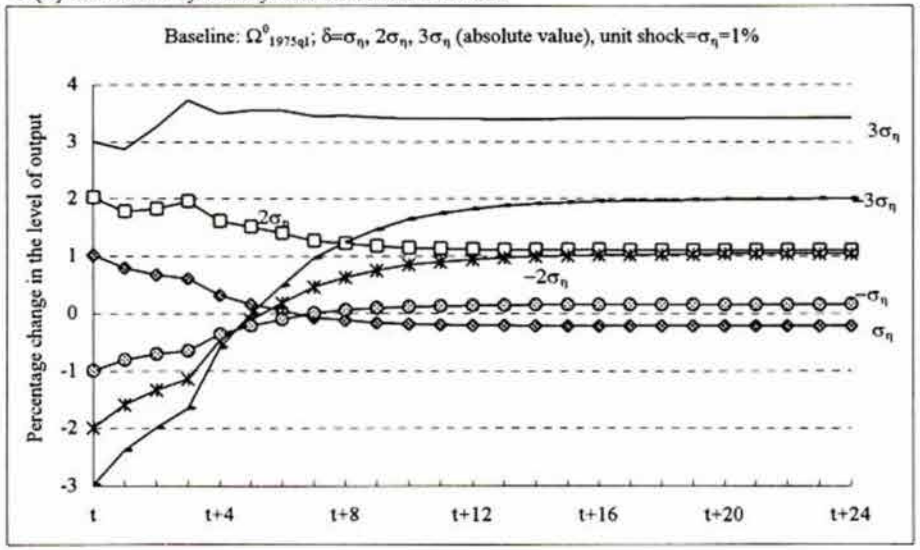
G (b) Recessionary history: comparison between linear and nonlinear model



G (c) Expansionary history: shocks of different size



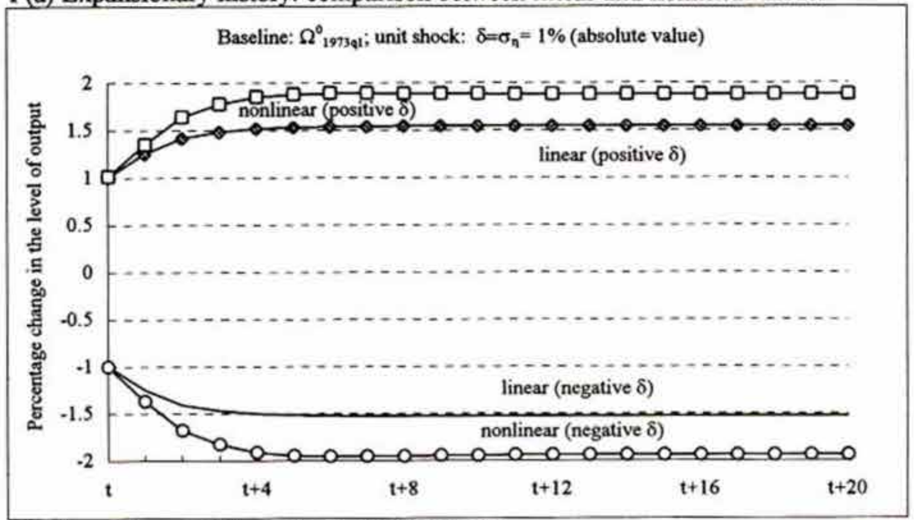
G (d) Recessionary history: shocks of different size



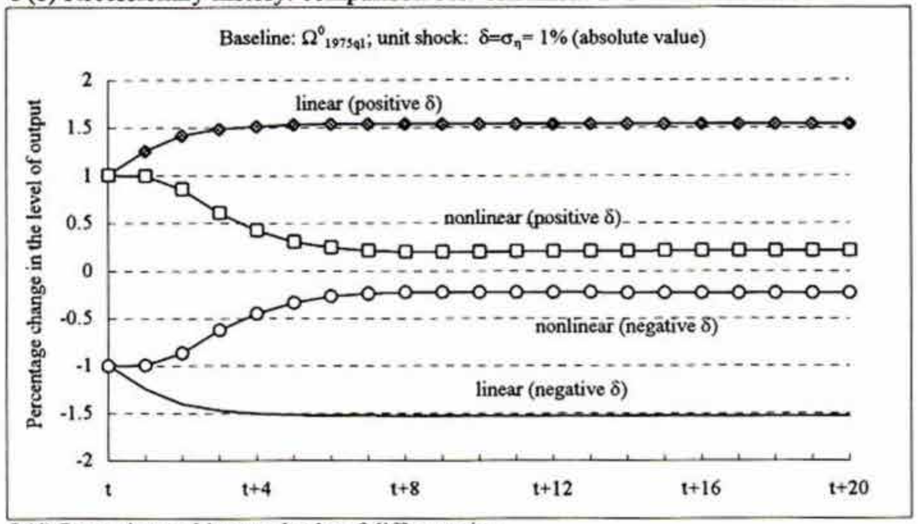
ITALY: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH IN A UNIVARIATE MODEL

Figure I

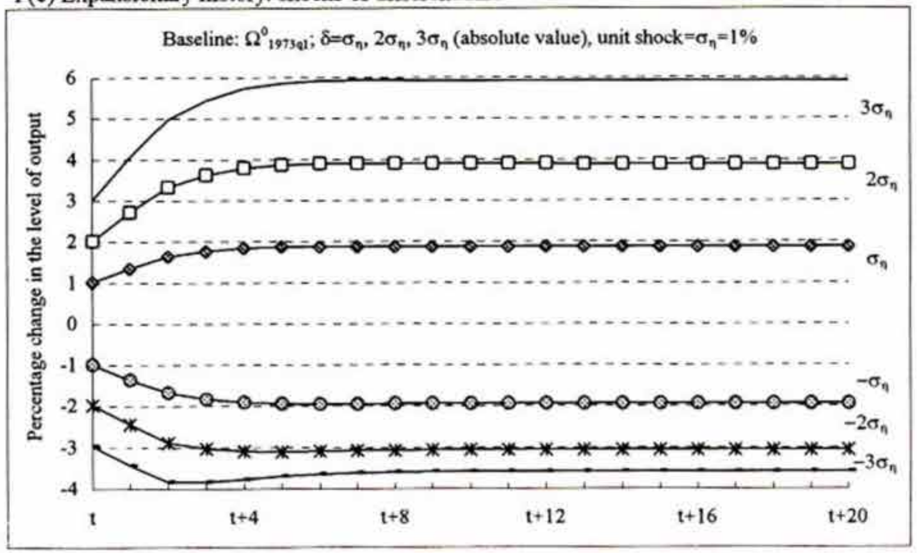
I (a) Expansionary history: comparison between linear and nonlinear model



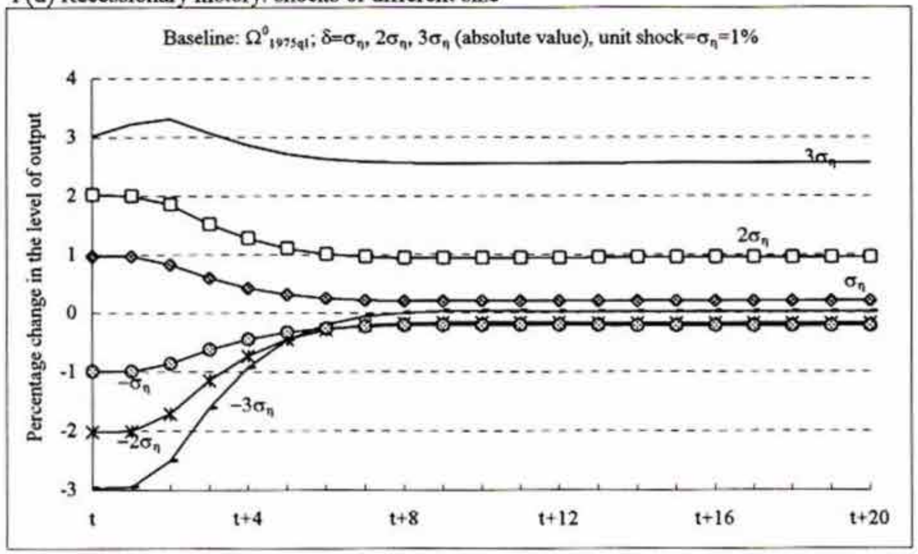
I (b) Recessionary history: comparison between linear and nonlinear model



I (c) Expansionary history: shocks of different size



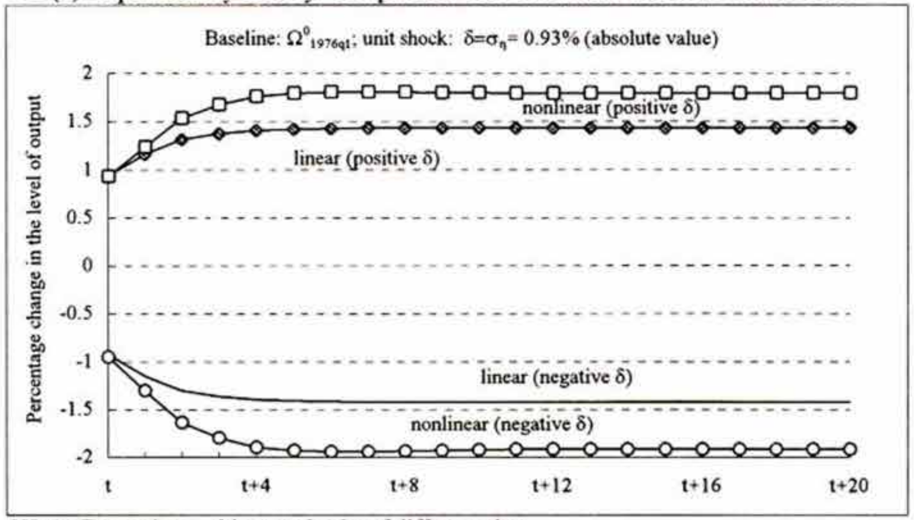
I (d) Recessionary history: shocks of different size



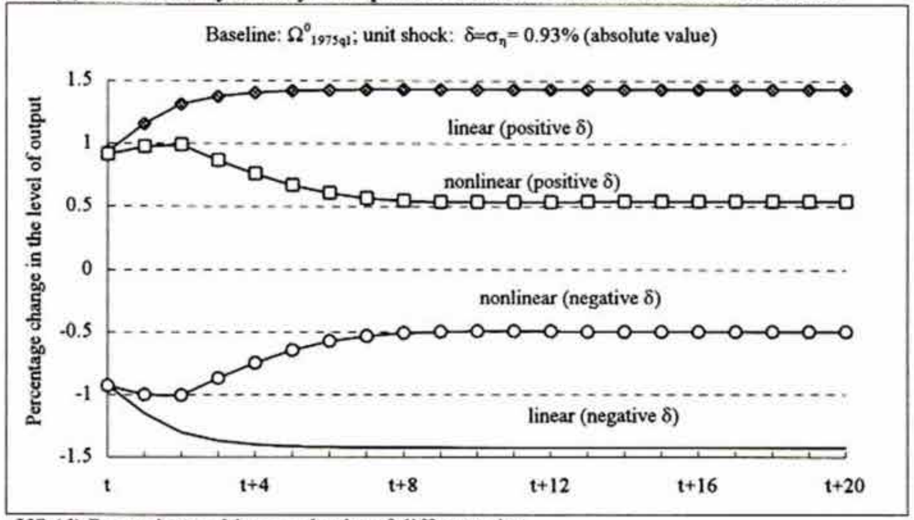
UNITED STATES: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH IN A UNIVARIATE MODEL

Figure US

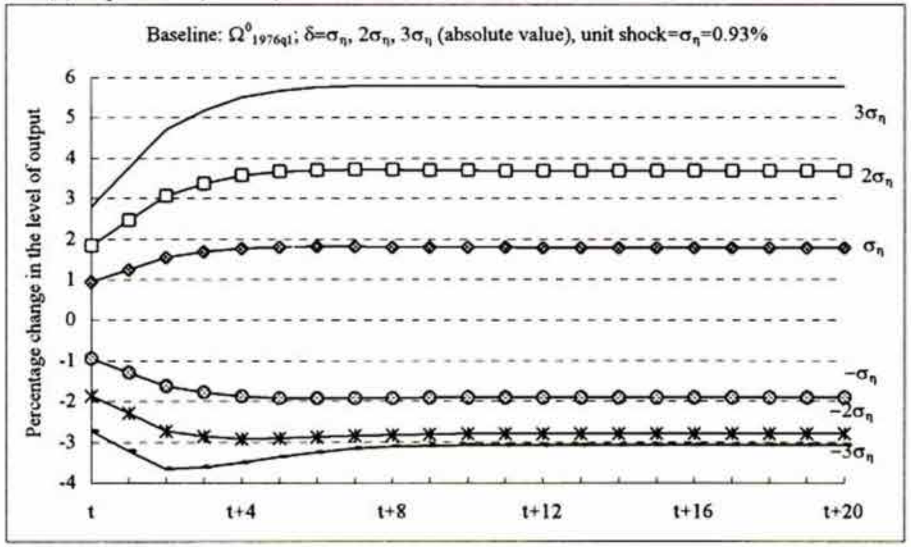
US (a) Expansionary history: comparison between linear and nonlinear model



US (b) Recessionary history: comparison between linear and nonlinear model



US (c) Expansionary history: shocks of different size



US (d) Recessionary history: shocks of different size

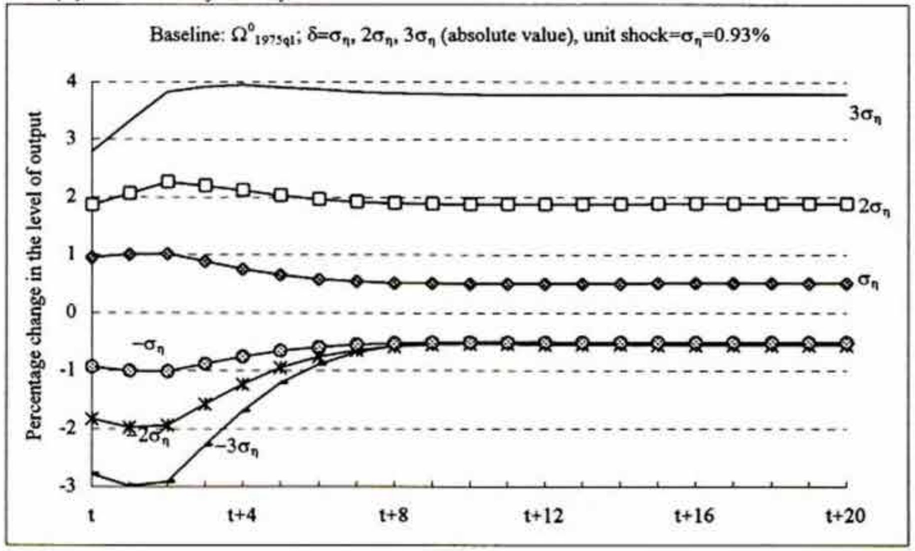


Figure C

CANADA: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH

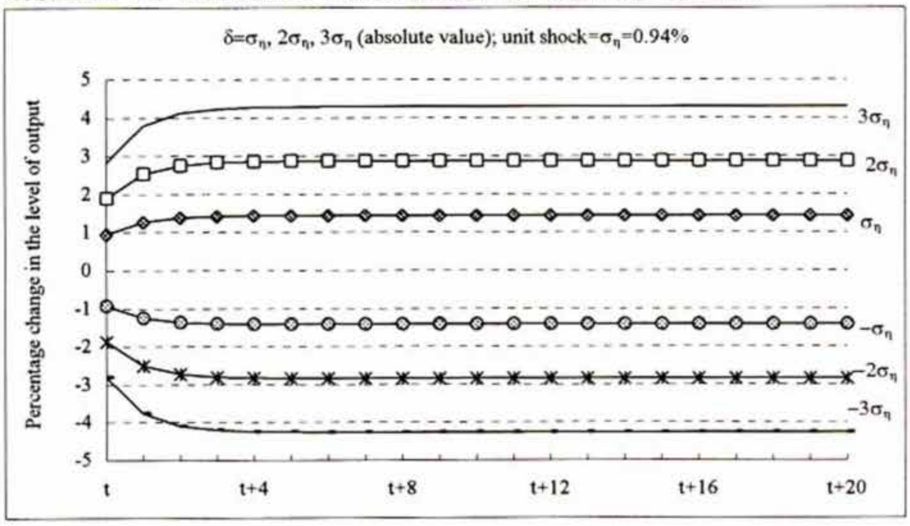


Figure UK

UK: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH

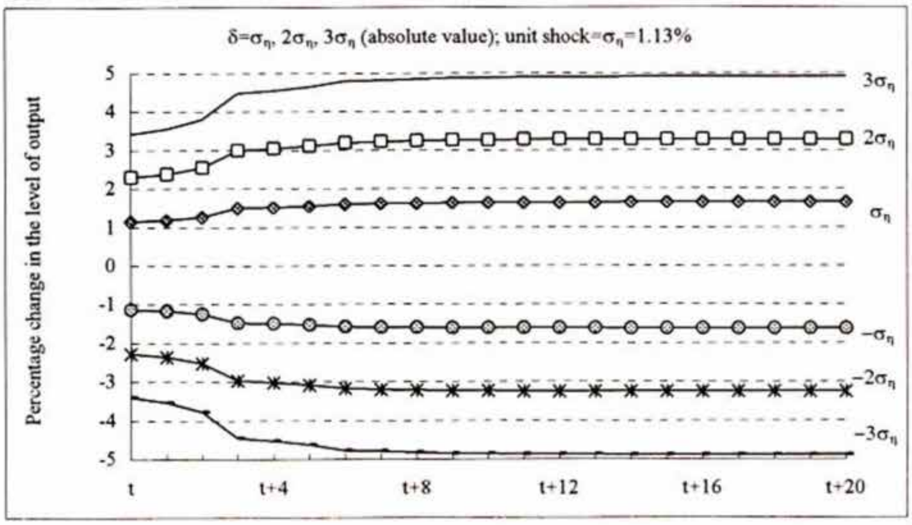


Figure J

JAPAN: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH

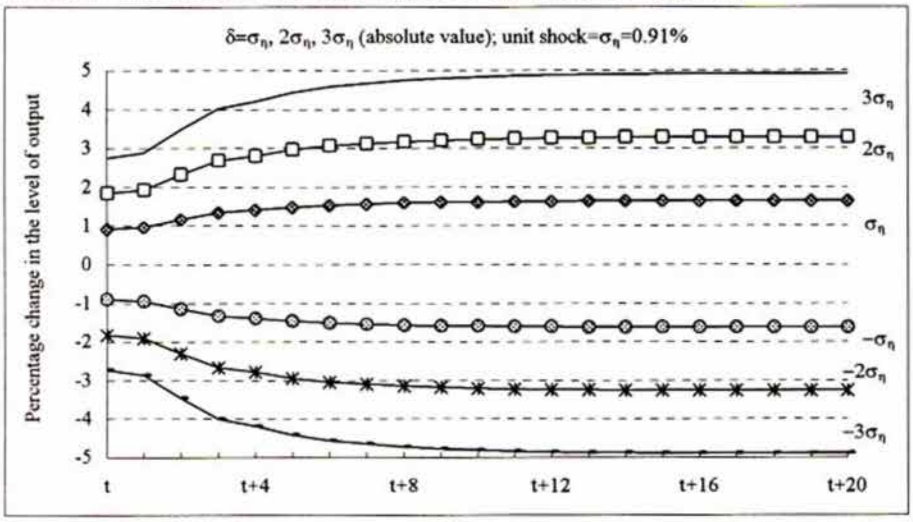
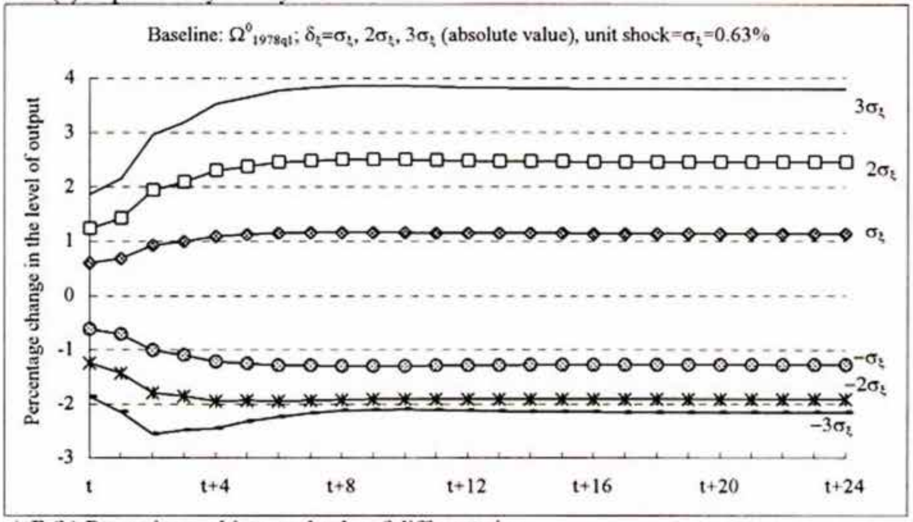


Figure A.F

FRANCE: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH IN A MULTIVARIATE MODEL

A.F (a) Expansionary history: shocks of different size



A.F (b) Recessionary history: shocks of different size

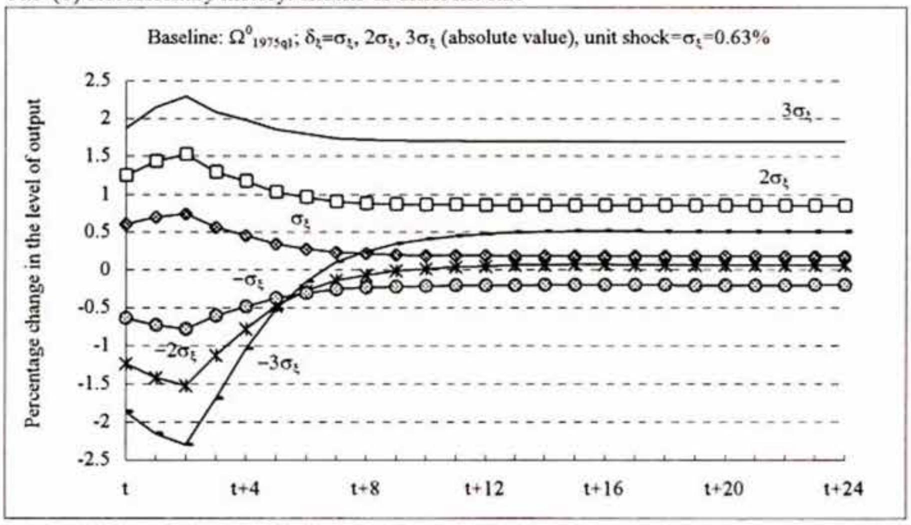
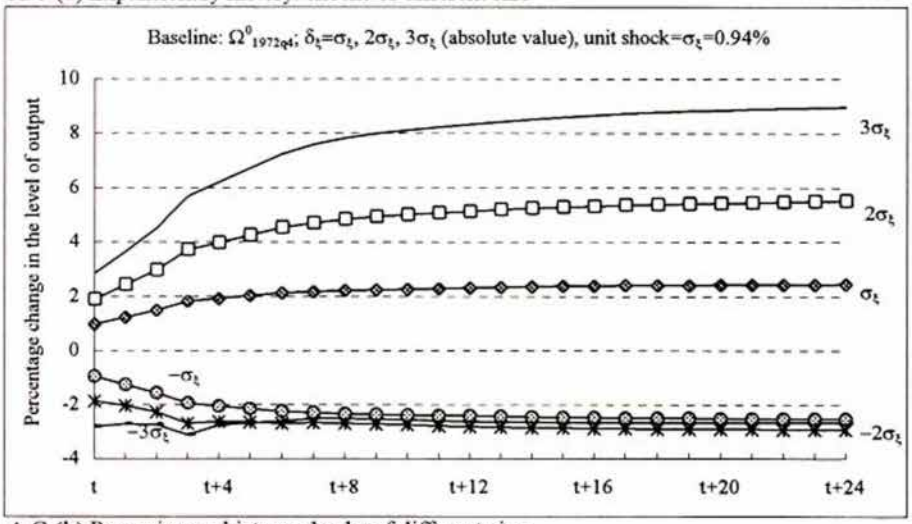


Figure A.G

GERMANY: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH IN A MULTIVARIATE MODEL

A.G (a) Expansionary history: shocks of different size



A.G (b) Recessionary history: shocks of different size

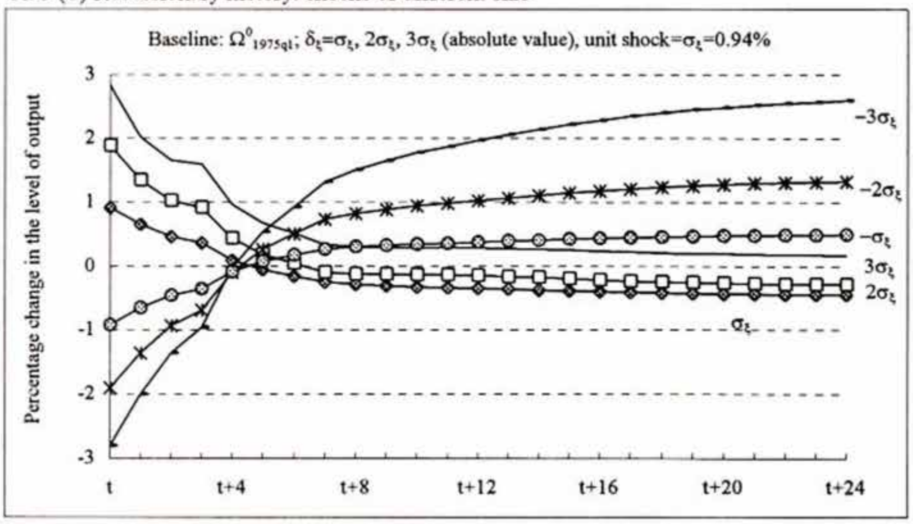
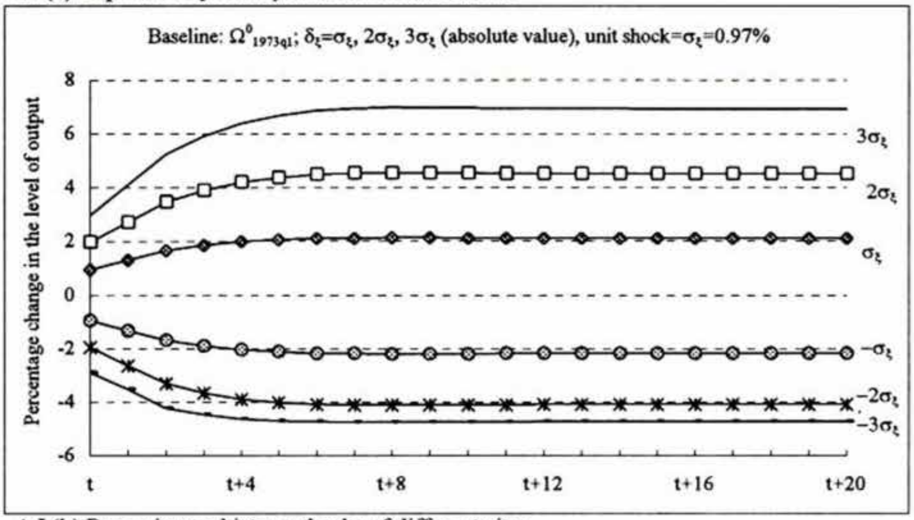


Figure A.I

ITALY: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH IN A MULTIVARIATE MODEL

A.I (a) Expansionary history: shocks of different size



A.I (b) Recessionary history: shocks of different size

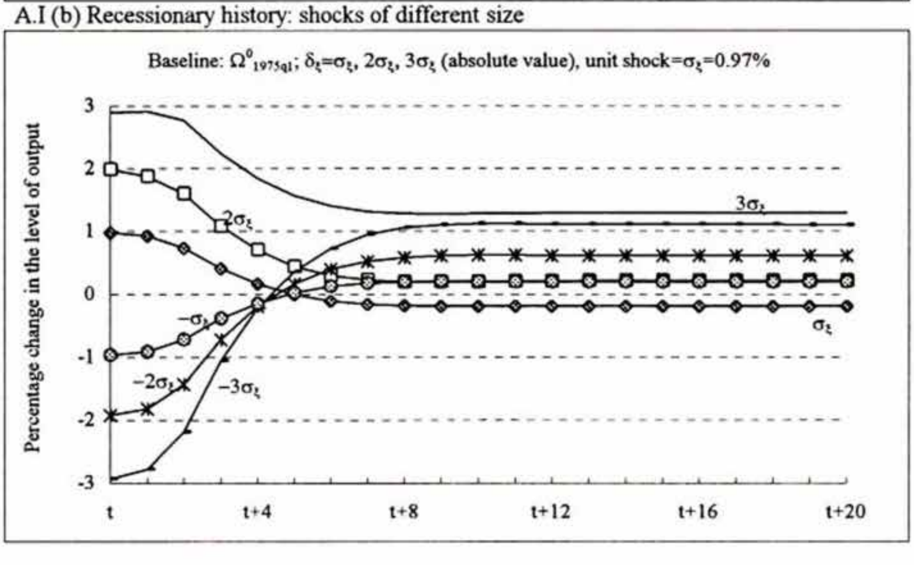
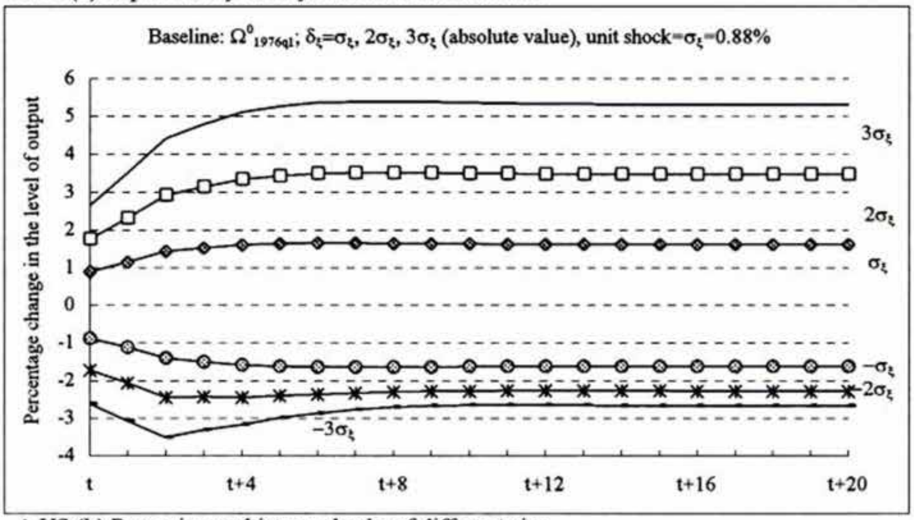


Figure A.US

US: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH IN A MULTIVARIATE MODEL

A.US (a) Expansionary history: shocks of different size



A.US (b) Recessionary history: shocks of different size

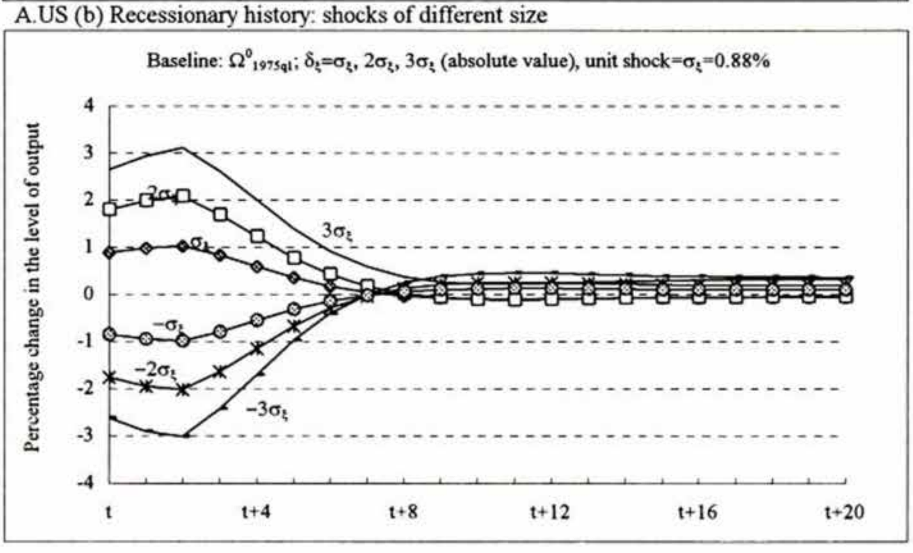


Figure A.C

CANADA: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH IN A MULTIVARIATE MODEL

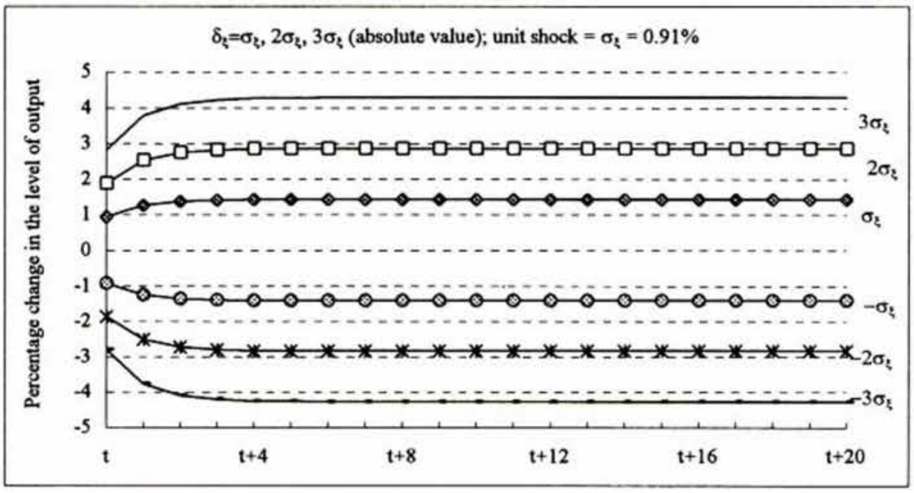


Figure A.UK

UK: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH IN A MULTIVARIATE MODEL

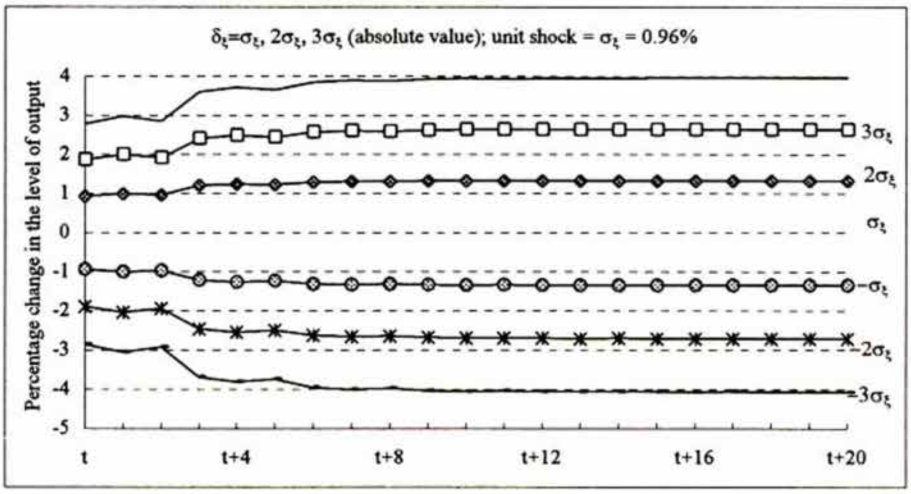


Figure A.J

JAPAN: GI FUNCTION FOR SHOCKS TO OUTPUT GROWTH IN A MULTIVARIATE MODEL

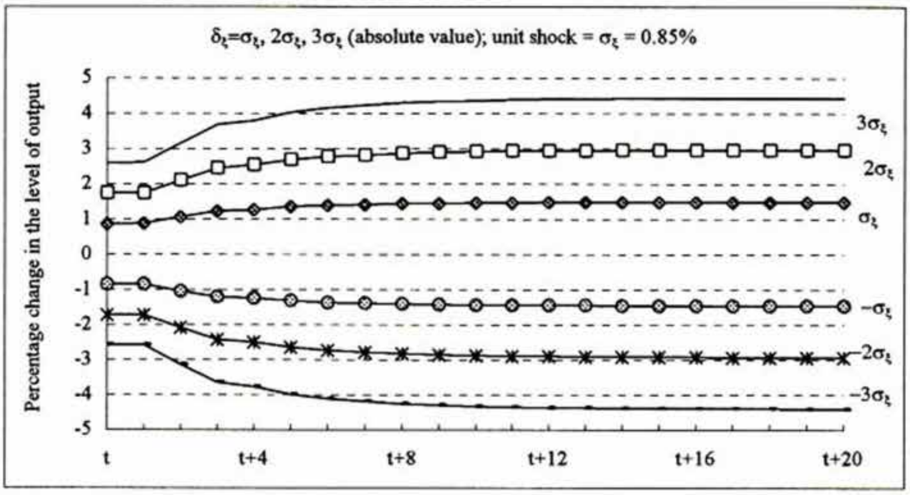
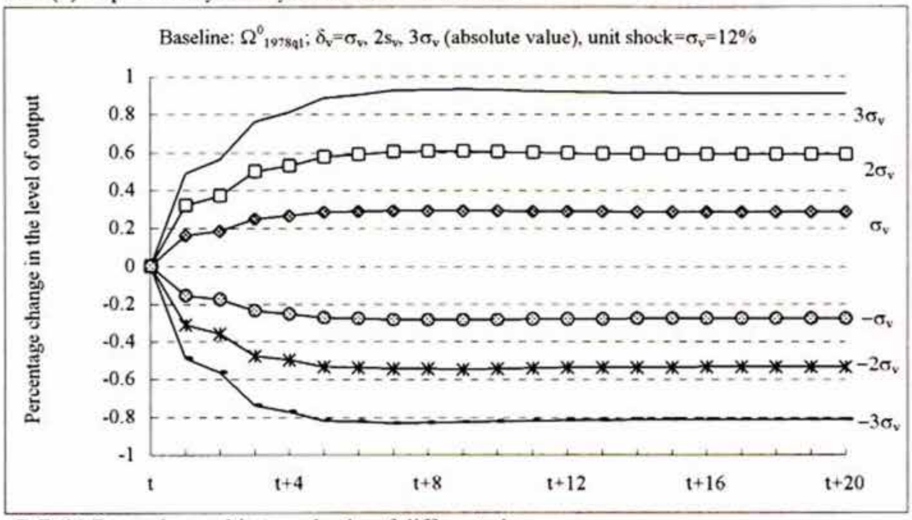


Figure B.F

FRANCE: GI FUNCTION FOR GLOBAL TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

B.F (a) Expansionary history: shocks of different size



B.F (b) Recessionary history: shocks of different size

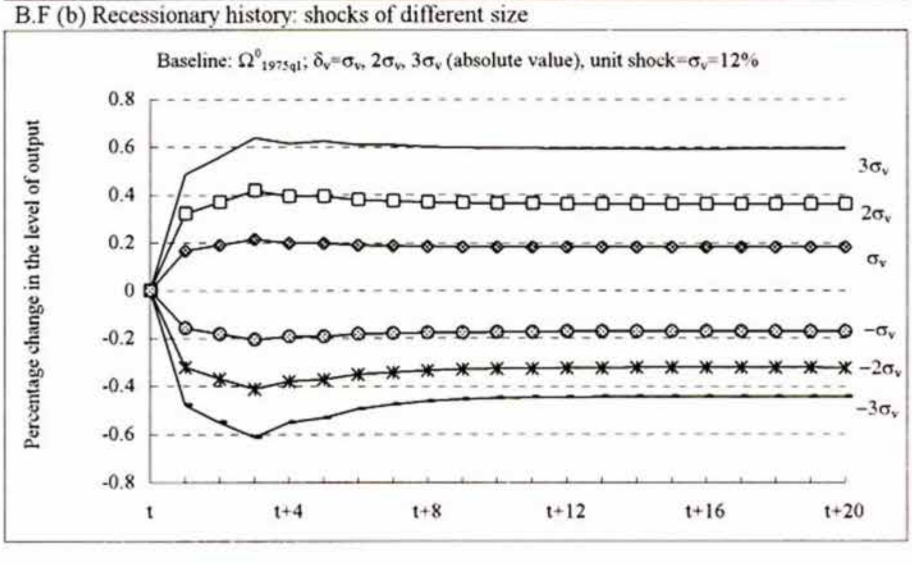
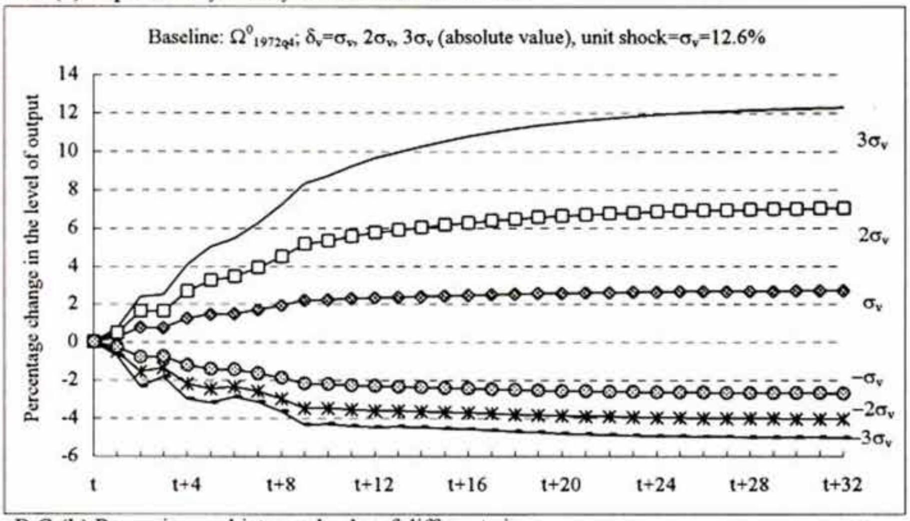


Figure B.G

GERMANY: GI FUNCTION FOR GLOBAL TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

B.G (a) Expansionary history: shocks of different size



B.G (b) Recessionary history: shocks of different size

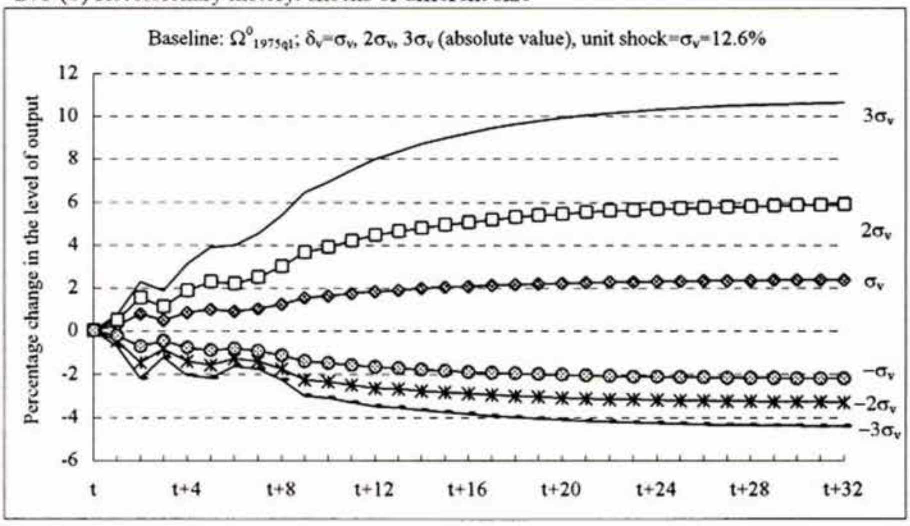
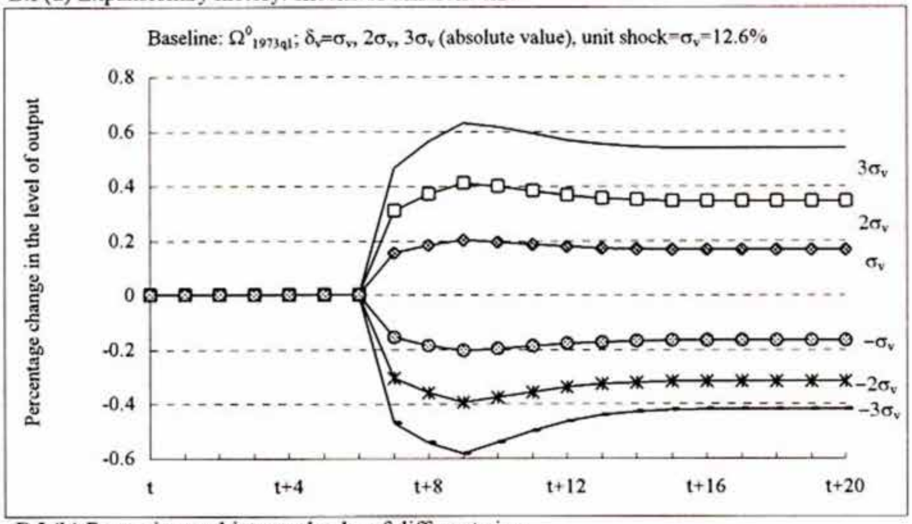


Figure B.I

ITALY: GI FUNCTION FOR GLOBAL TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

B.I (a) Expansionary history: shocks of different size



B.I (b) Recessionary history: shocks of different size

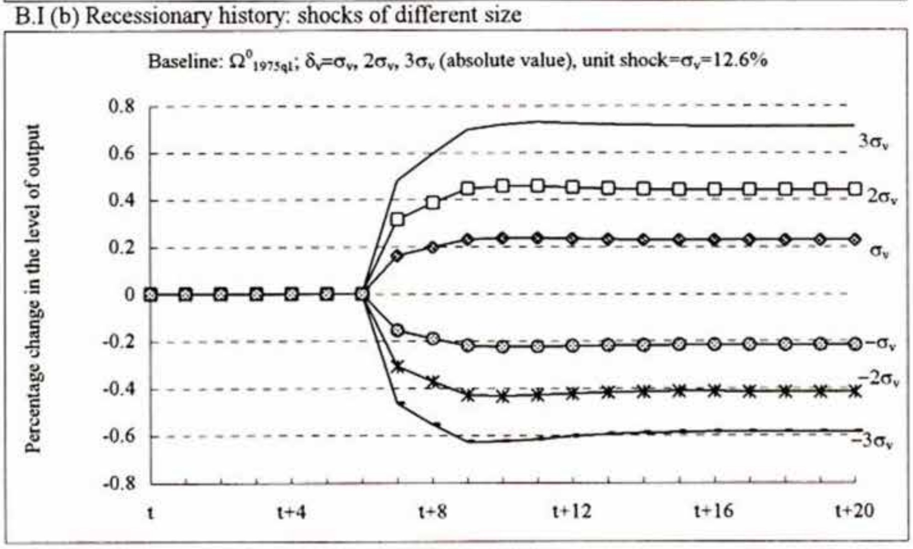
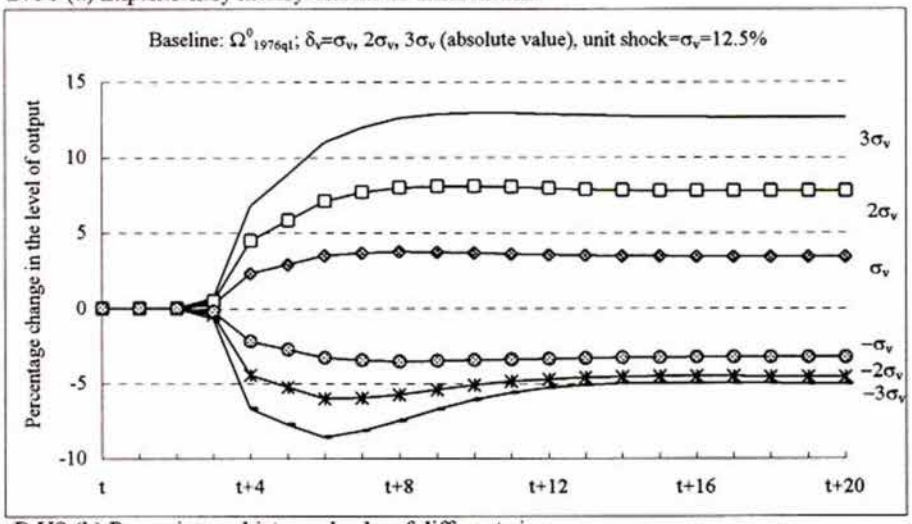


Figure B.US

US: GI FUNCTION FOR GLOBAL TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

B.US (a) Expansionary history: shocks of different size



B.US (b) Recessionary history: shocks of different size

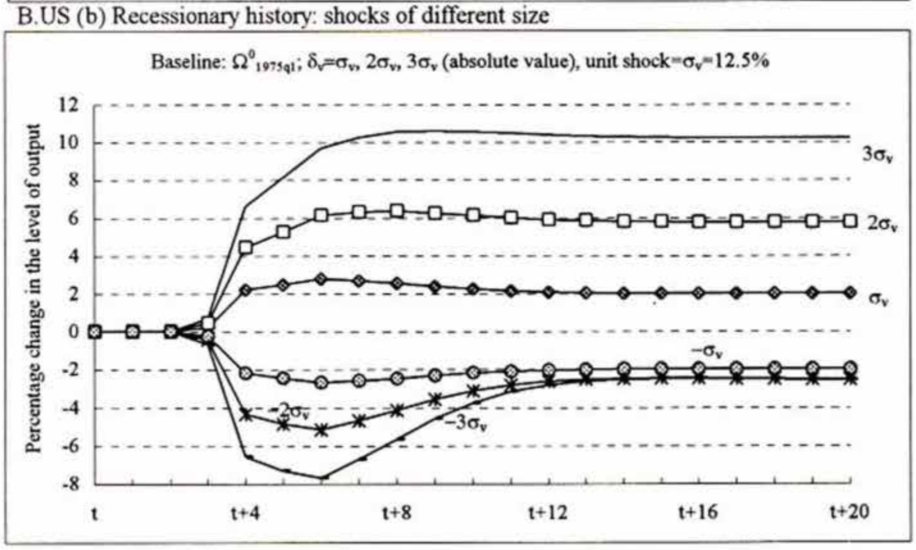


Figure B.C

CANADA: GI FUNCTION FOR GLOBAL TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

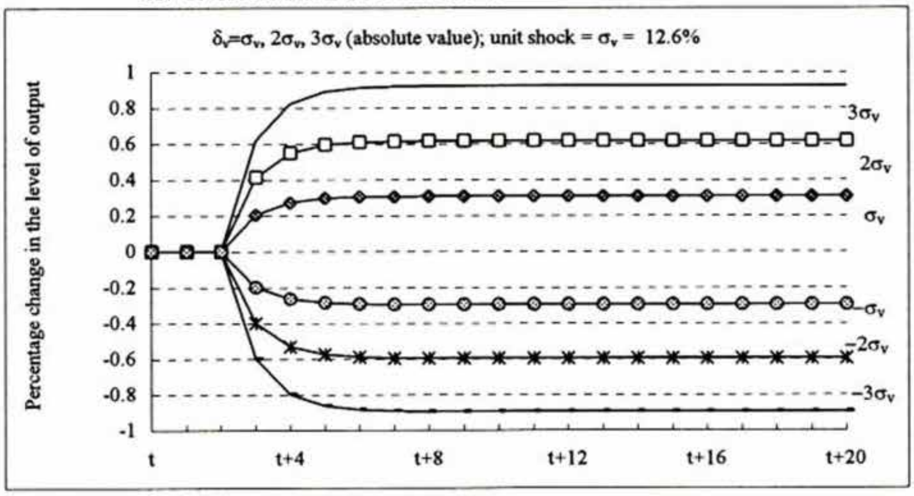


Figure B.UK

UK: GI FUNCTION FOR GLOBAL TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

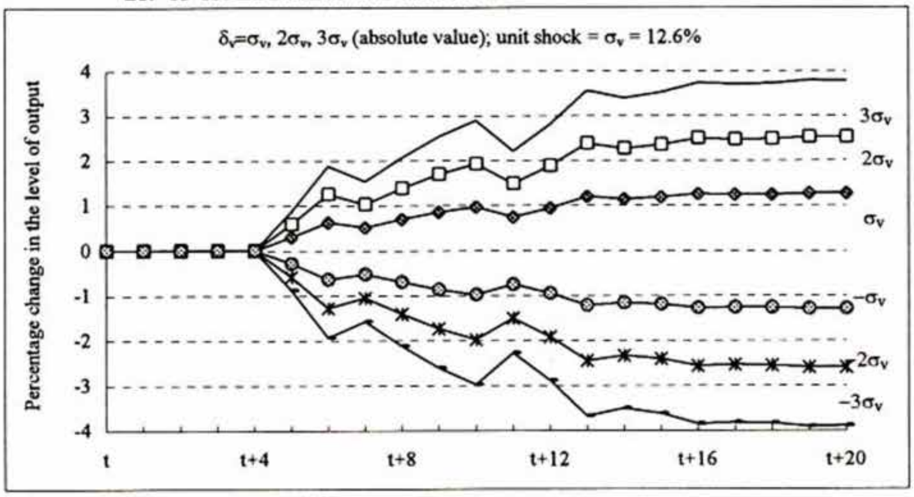


Figure B.J

JAPAN: GI FUNCTION FOR GLOBAL TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

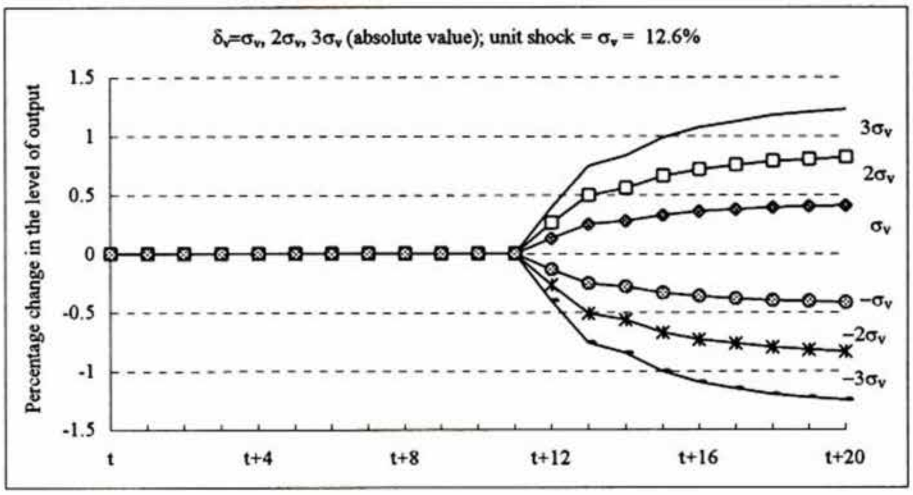
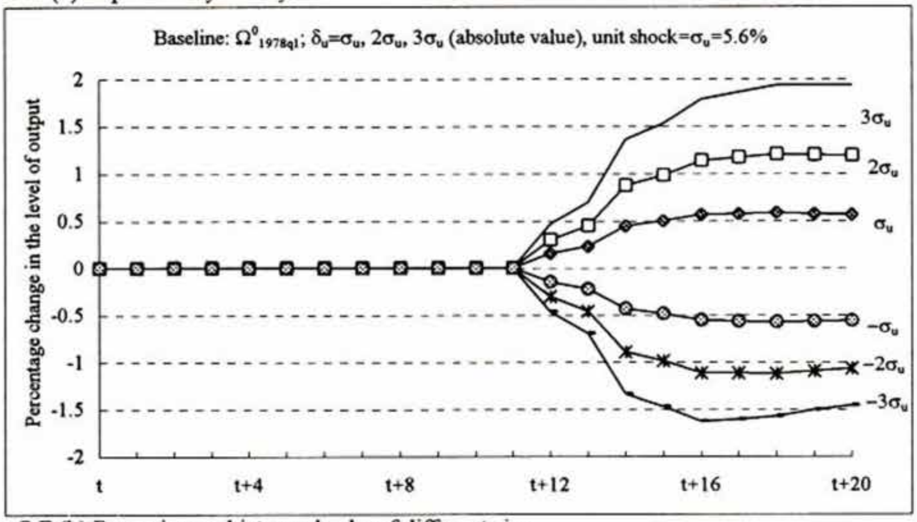


Figure C.F

FRANCE: GI FUNCTION FOR COUNTRY-SPECIFIC TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

C.F (a) Expansionary history: shocks of different size



C.F (b) Recessionary history: shocks of different size

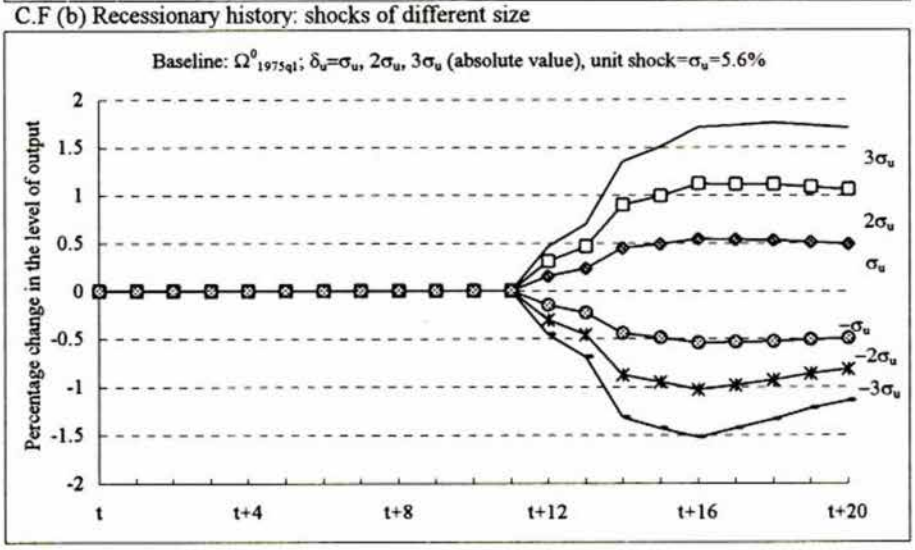
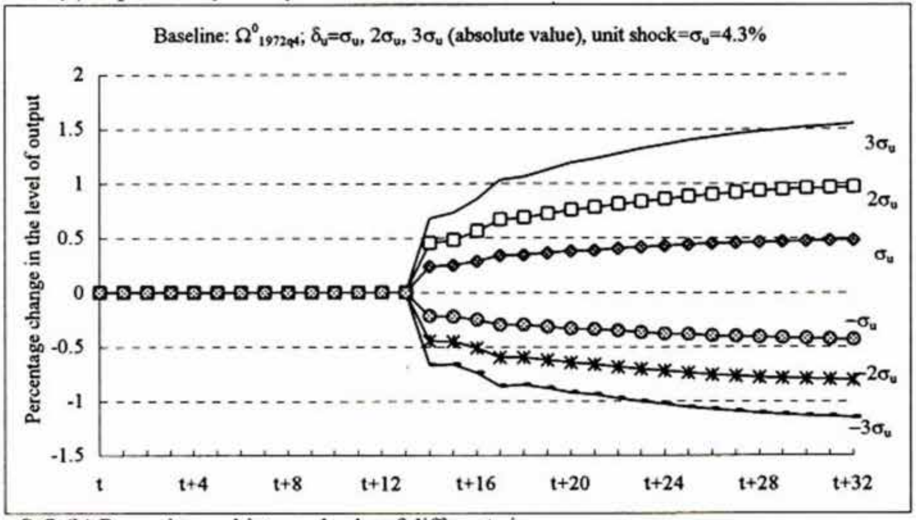


Figure C.G

GERMANY: GI FUNCTION FOR COUNTRY-SPECIFIC TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

C.G (a) Expansionary history: shocks of different size



C.G (b) Recessionary history: shocks of different size

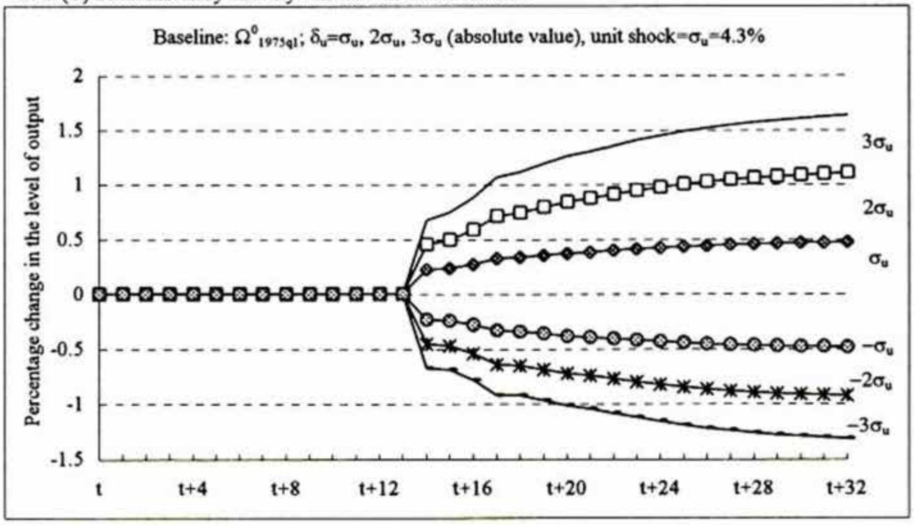
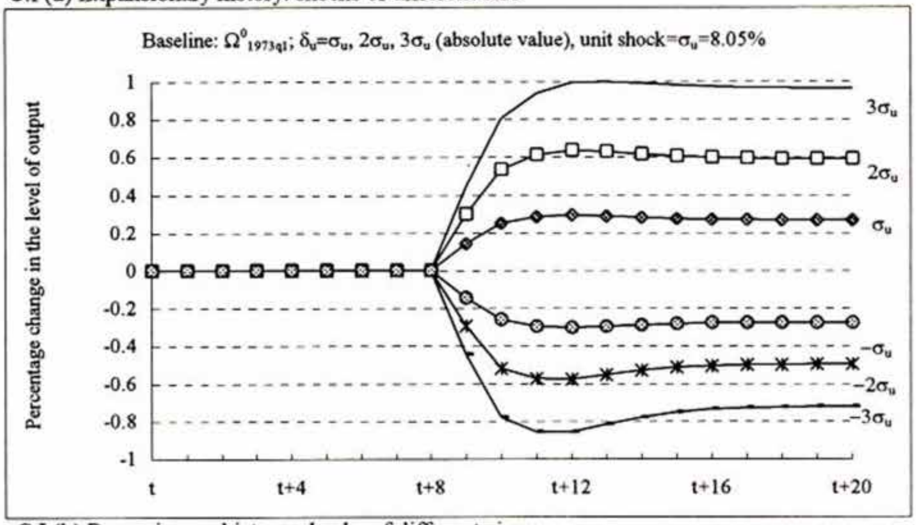


Figure C.I

ITALY: GI FUNCTION FOR COUNTRY-SPECIFIC TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

C.I (a) Expansionary history: shocks of different size



C.I (b) Recessionary history: shocks of different size

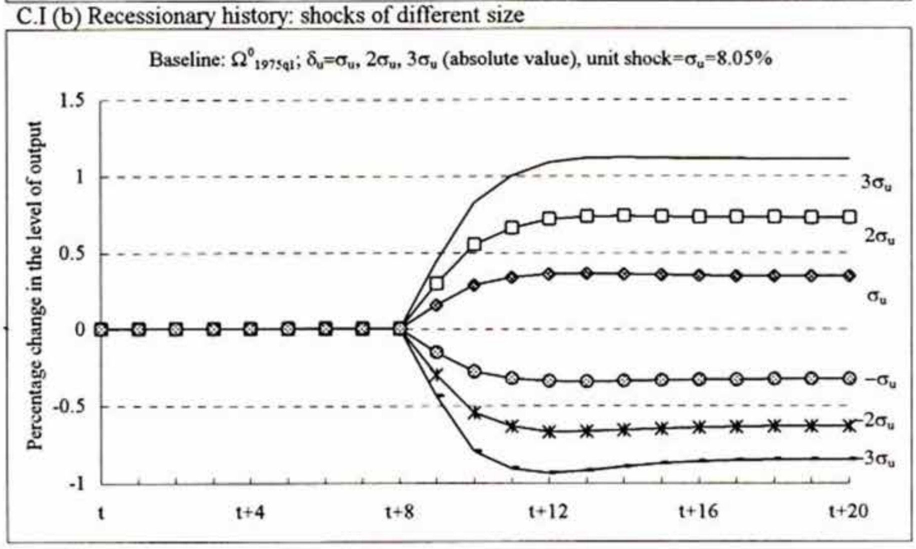
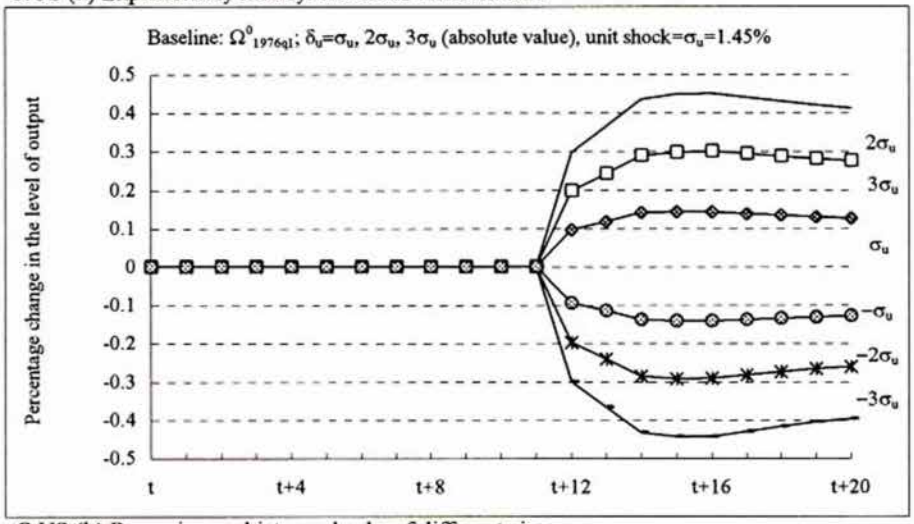


Figure C.US

US: GI FUNCTION FOR COUNTRY-SPECIFIC TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

C.US (a) Expansionary history: shocks of different size



C.US (b) Recessionary history: shocks of different size

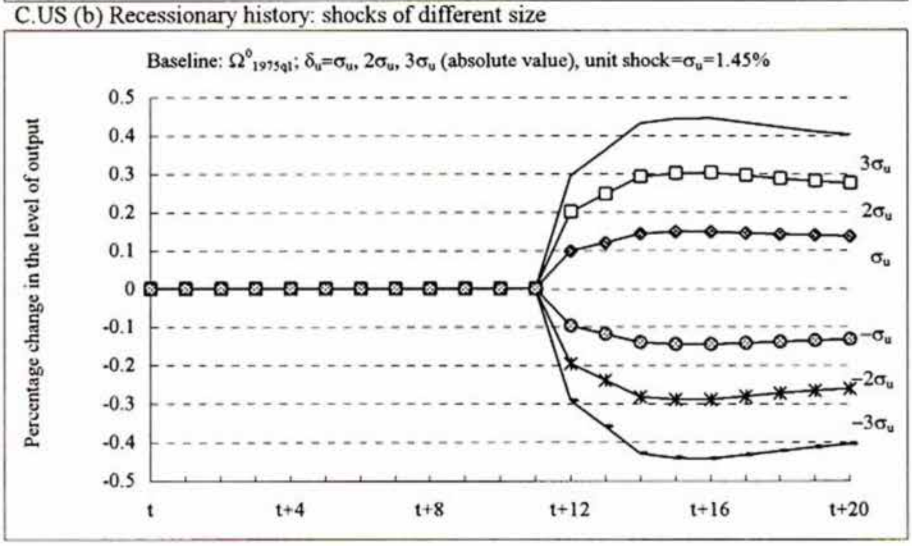


Figure C.C

CANADA: GI FUNCTION FOR COUNTRY-SPECIFIC TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

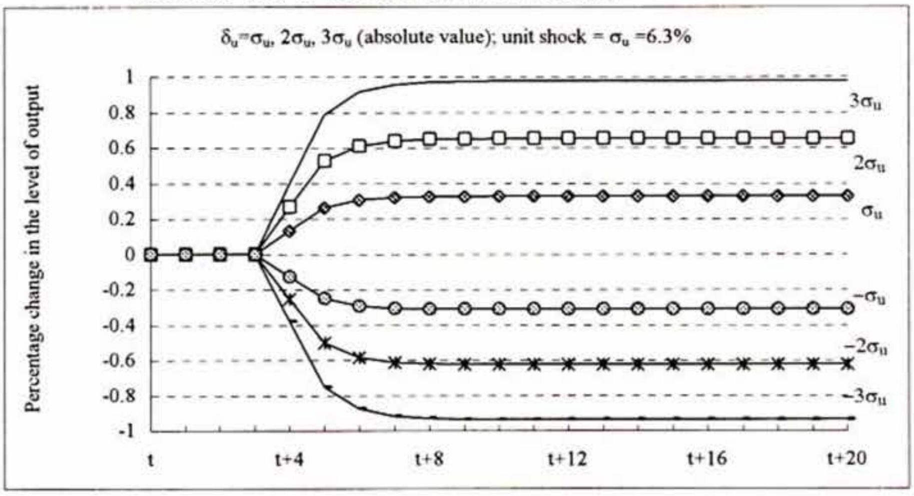


Figure C.UK

UK: GI FUNCTION FOR COUNTRY-SPECIFIC TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL

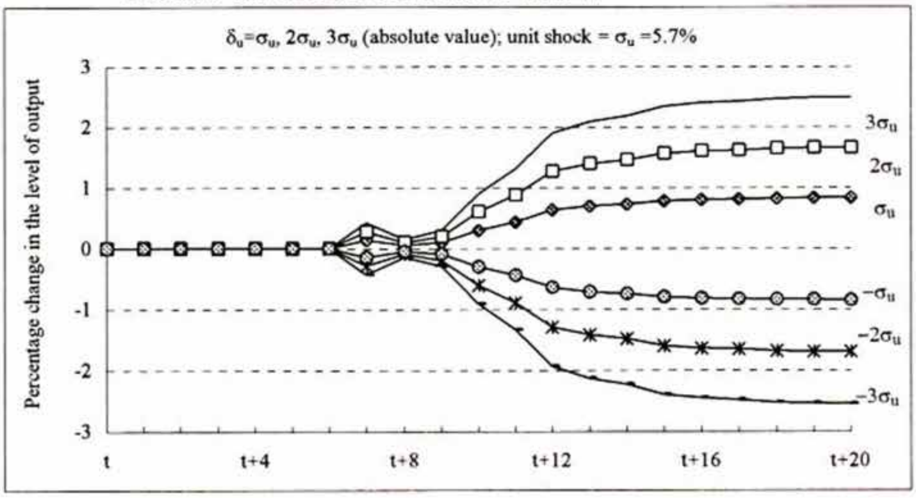
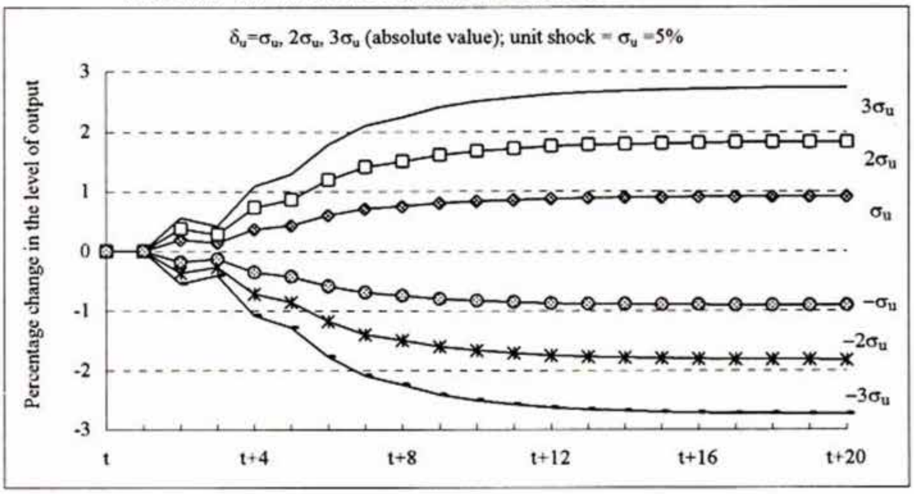


Figure C.J

JAPAN: GI FUNCTION FOR COUNTRY-SPECIFIC TECHNOLOGY SHOCKS IN A MULTIVARIATE MODEL



APPENDIX A

The data

Patents

Patents time series are elaborations from the data provided by the United States Department of Commerce, Patent and Trademark Office (USPTO), Office of Information Products Development. The original data file (PATSIC) contains patents from the TAF (Technology Assessment and Forecast) database, listed by date of issue, for the period 1963-1993. The information contained in such database reflects the US Patent Classification System and coding as of December 31, 1993. Each record in the file has a code number corresponding to the following information:

1) patent number
2) state/country code
3) company code
4) application year
5) issue year
6) assignment code
7) "original" classification
8) SIC code for "original" classification
9) SIC codes for "original" and "cross-references" classifications.

The PATSIC file is sorted by ascending order (patent number) and is restricted to utility patents only, which are patents "issued for the invention of a new and useful process, machine, manufacture or composition of matter, or a new and useful improvement thereof, which permits its owner to exclude others from making, using, or selling the invention for a period up to seventeen years from the date of grant, subject to the payment of maintenance fees" (TAF Report, August 31, 1994).

Approximately 90 percent of the patents issued in recent years by the USPTO have been utility patents. The other patent documents issued by the USPTO are: a) design patents; b) plant patents; c) reissue patents; d) defensive publication and e) statutory invention registration.

The *TAF Report: Issue Dates and Patent Numbers since 1836*, August 31, 1994, has been provided by the USPTO, together with the PATSIC file, and used to derive from the PATSIC file the quarterly time series for the econometric analysis presented in this work.

Clearly, the use of patents issued by one national patenting office has the drawback that trends in patenting might reflect trends in internationalisation rather than innovative activities, and, moreover, that domestic inventors have a home market advantage. On the other hand, national patents cannot be used in an international context, given the differences in novelty requirements and classification and legislation.

One reason for using foreign patent data is to allow comparisons between economies, considering that they usually refer to a recipient country with a dominant position both economically and technologically. In particular, an important factor that weighs in favour of the use of foreign patenting in the United States as a technology indicator is the average quality of such data compared with domestic patent statistics. It is in fact reasonable to assume that only inventions with significant profit expectations in a larger market will be patented in the United States. The quality is also guaranteed by the international legislation governing the priority of foreign applications.

From a theoretical perspective, the literature on technology and innovation has offered various explanations for patenting abroad, and especially in the US. One view is that each economy has the same propensity to patent in the United States in relation to the size of its innovative activities.

Output

Data on output are taken from *International Financial Statistics*, IMF. They represent quarterly GDP at constant prices (1990 prices) for Canada, France, Italy, the UK and the US over the period 1963q1-1993q4. Quarterly data on French GDP is not available for the period 1963q1-1970q1; the series has therefore been constructed on the basis of annual GDP and considering quarterly industrial production as an indicator of GDP variations within the period prior to 1970q1. Data for Japan and Germany refer to GNP at constant prices (1990 prices) for the same time period.[1]

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1 The GDP/GNP time series are based on national data at 1986 prices for Canada, at 1980 prices for France and Italy, at 1985 prices for Germany, at 1975 prices for Japan, at 1987 prices for the United States and at 1990 prices for the United Kingdom

APPENDIX B

Univariate nonlinear model

Table B.1

NONLINEAR REPRESENTATION OF OUTPUT GROWTH

	CANADA (69q1-93q4)	GERMANY (69q1-93q4)	FRANCE (70q1-93q4)	ITALY (69q1-93q3)	JAPAN (69q1-93q4)	UK (69q1-93q4)	USA (69q1-93q4)
λ_0	.006 (3.89)	-.003 (1.22)	-.001 (.827)	.002 (1.02)	.004 (2.21)	.006 (3.61)	.001 (.755)
θ_1	.309 (2.89)	.202 (1.65)	.148 (1.05)	.349 (3.22)	.086 (.847)	-.012 (.107)	.351 (3.04)
θ_2		.315 (2.82)	.467 (3.89)	.196 (1.84)	.237 (2.64)		.229 (1.94)
θ_3		.301 (2.91)	.312 (3.16)		.183 (2.03)		
θ_4		.226 (2.19)					
λ_1	-.065 (.655)	.616 (2.93)	.065 (.223)	.355 (2.33)	.257 (.921)	-.100 (1.34)	.278 (1.93)
λ_2			.722 (2.56)				
$\bar{R}^2$	.104	.115	.239	.109	.105	.001	.089
S.E.	.009	.010	.007	.010	.009	.011	.009
LLF	325.97	323.34	347.86	317.34	330.18	307.13	328.05
$\chi^2_{sc}(4)$	2.78	.895	7.62	2.94	2.97	3.29	4.28
$F(q,n)$	6.78*(2,97)	3.58*(5,94)	6.98*(5,90)	5.03*(3,95)	3.89*(4,95)	1.06 (2,97)	4.23*(3,96)
$\chi^2(m)$	3.93 (6)	3.19 (3)	7.50 (3)	4.19 (5)	3.30 (4)	5.02 (6)	4.50 (5)

Notes:

Regression results are the outcome of a specification search over various models, with the form:

$$\Delta y_{it} = \lambda_{i0} + \sum_{\tau=1}^{s_i} \theta_{i\tau} \Delta y_{i,t-\tau} + \sum_{\tau=1}^{r_i} \lambda_{i\tau} z_{i,t-\tau} + \eta_{it}$$

$i=1,\ldots,7;$

$t=1969q1,\ldots,1993q4$

where Δy_i is the rate of growth of output in country i and $z_{it}=\log(y_{imax})-\log(y_{it})$ represents the current depth of recession.

Figures in brackets are absolute values of t-ratios. '*' denotes statistical significance at the 5% level and '**' at the 10% level.

$\bar{R}^2$ is the adjusted R^2, S.E. is the equation's estimated standard error, LLF is the maximised value of the model's log likelihood, χ^2_{sc} is the Lagrange Multiplier statistic for testing residual serial correlation, $F(q,n)$ is the F test statistic for the joint significance of the q regressors included in the model, $\chi^2(m)$ is the likelihood ratio test for the joint significance of the m regressors excluded from the model (with respect to the most general (6x2) specification).

APPENDIX C

FIML estimates of the relationship between technology shocks and output growth: output growth equation

CANADA (1969q1-1993q4)

$$\Delta y = .005 + .329\,\Delta y(-1) + .016\,v(-3) + .021\,u(-4) + .014\,u(-5) + \xi$$

(4.44) (3.55) (2.07) (1.47) (1.69)

GERMANY (1969q1-1993q4)

$$\Delta y = -.002 + .291\,\Delta y(-1) + .316\,\Delta y(-2) + .294\,\Delta y(-3) + .577\,z(-1) + .057\,z(-2) + .019\,v(-1) + .045\,v(-2) -$$

(.959) (1.76) (2.44) (2.45) (1.97) (.196) (2.36) (1.86)

$$-.012\,v(-3) + .026\,v(-4) + .007\,v(-5) - .004\,v(-6) + .001\,v(-7) + .017\,v(-8) + .023\,v(-9) + .053\,u(-14) + \xi$$

(1.34) (1.03) (.725) (.183) (.139) (.735) (2.64) (2.29)

FRANCE (1970q1-1993q4)

$$\Delta y = -.002 + .150\,\Delta y(-1) + .471\,\Delta y(-2) + .361\,\Delta y(-3) + .065\,z(-1) + .826\,z(-2) + .014\,v(-1) + .014\,u(-7) + \xi$$

(1.17) (1.13) (4.15) (3.83) (.237) (3.09) (2.41) (2.66)

ITALY (1969q1-1993q3)

$$\Delta y = .001 + .392\,\Delta y(-1) + .234\,\Delta y(-2) + .445\,z(-1) + .012\,v(-7) + .018\,u(-9) + .012\,u(-10) + \xi$$

(.528) (3.65) (2.18) (2.89) (1.49) (2.09) (.947)

JAPAN (1969q1-1993q4)

$$\Delta y = .006 + .003\,\Delta y(-1) + .213\,\Delta y(-2) + .199\,\Delta y(-3) + .011\,v(-12) + .009\,v(-13) + .038\,u(-2) - .009\,u(-3) +$$

(3.32) (.029) (2.28) (2.14) (.757) (1.38) (1.89) (1.29)

$$+ .037\,u(-4) + .008\,u(-5) + .025\,u(-6) + .009\,u(-7) + \xi$$

(1.82) (1.01) (1.79) (1.23)

UK (1969q1-1993q4)

$$\Delta y = .003 + .071\,\Delta y(-1) - .051\,\Delta y(-2) + .277\,\Delta y(-3) + .023\,v(-5) + .025\,v(-6) - .010\,v(-7) + .009\,v(-8) +$$

(1.88) (.734) (.524) (2.98) (2.44) (1.37) (1.05) (.536)

$$+ .004\,v(-9) + .012\,v(-10) - .022\,v(-11) + .014\,v(-12) + .015\,v(-13) + .025\,u(-7) - .018\,u(-8) + .011\,u(-9) +$$

(.412) (.635) (2.57) (.745) (1.77) (2.79) (.956) (1.22)

$$+ .027\,u(-10) + .027\,u(-11) + .032\,u(-12) + \xi$$

(1.46) (2.87) (1.59)

USA (1969q1-1993q4)

$$\Delta y = .002 + .338\,\Delta y(-1) + .259\,\Delta y(-2) + .229\,z(-1) + .018\,v(-3) + .156\,v(-4) + .068\,u(-12) + \xi$$

(.949) (3.03) (2.27) (1.62) (2.43) (2.33) (1.03)

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