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# Modeling the impact of technological change across sectors and over time in manufacturing

by

Mario Forni* and Lucrezia Reichlin**

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*Dipartimento di Economia Politica
Viale Berengario, 51
41100 Modena (Italy)
e-mail: forni@merlino.unimo.it

**University of Bruxelles, ECARE and CEPR
39 ave. F.D. Roosevelt
Bruxelles 1050

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Correspondence Address: Lucrezia Reichlin, ECARE, 39 ave. F.D. Roosevelt, Bruxelles 1050.

We would like to thank John Shea for providing the data.

# 1. Introduction

This paper develops a methodology for measuring the contribution of technological change to the dynamics of output and labor productivity. The method is developed so as to exploit the information of a large cross-section of data on real output and hours worked for 450 manufacturing sectors of the US economy for the time period 1958-1986. Our methodology allows us to study the pattern of diffusion of innovations in technology within sectors over time and to compare it across sectors: we distinguish between idiosyncratic and common shocks and between technological and non-technological shocks and we allow common shocks to have heterogenous dynamics across sectors.

Our proposed framework combines dynamic factor analysis with a method for structural identification in Moving Average (MA) models. Our work derives from two distinct traditions in empirical macroeconomics: the first is dynamic factor analysis as, for example, in Sargent and Sims (1977), Geweke and Singleton (1981), Quah and Sargent (1994); the second, is structural Vector Autoregression (VAR) analysis as, for example, in Bernanke (1986), Shapiro and Watson (1988), Blanchard and Quah (1989), Lippi and Reichlin (1994b).

Our methodological contribution is twofold. First, we propose a simple method to measure the common dynamic component in the sample. This method is based on the idea that in the aggregate the idiosyncratic sectoral component dies out (Granger (1987), Forni and Lippi (1995)) so that the common component can be estimated as a sectoral average. The second, is the development of a method for structural identification of the contribution of technology to the common component based on the idea that the distribution of technology shocks, unlike that of demand shocks, should have positive support since it is difficult to imagine negative technological innovations. This method is developed for a bivariate model and the technological component is identified as the one for which the absolute sum of the negative residuals is minimized. The specification chosen is a MA since the latter, unlike the VAR specification, has "nice" aggregation properties and we apply it to the bivariate model of the common components (sectoral averages) of hours worked and productivity.

The analysis procedes in three steps. First, we identify the number of common shocks in the system. Second, we estimate the common component and identify the common shocks by distinguishing between technological and non-technological shocks. Finally, we estimate sectoral regressions of output and productivity growth (respectively) against their common stochastic shocks. In this framework, co-movements are driven by the common shocks (sectoral shocks are mutually orthogonal), but common shocks do not imply co-movements since their dynamic impact might be heterogenous across sectors. The analysis of the cross-sectional distribution of the dynamic impulses and of the correlation between sectoral growth rates and the technological common shocks is potentially interesting to understand the role of externalities (demand and production) in economic growth.

In the application of this paper we obtain a number of interesting results which, at this stage, are preliminary, but indicate that the framework is rich enough to be exploited for further research.

## 2. The model

Let us start from a very general dynamic framework:

$$\Delta y_{it} = \Delta p_{it} + \Delta h_{it} \tag{1}$$

where:

$$\Delta p_{it} = \alpha_i(L)u_t + \beta_i(L)\epsilon_{it}$$
$$\Delta h_{it} = \gamma_i(L)u_t + \delta_i(L)\eta_{it}$$

and $y$, $p$ and $h$ are output, labor productivity and hours worked respectively, $i = 1, \cdots, n$ and $t = 1 \cdots T$ are indexes for sectors and time and all variables are expressed in log. We have the following features:

(i) $u_t$ is a white noise vector of common shocks to productivity and hours worked. Here we will assume that $u_t$ is two-dimensional. This assumption will be verified by the statistical analysis described in Section 3.

(ii) $\epsilon_{it}$ and $\eta_{it}$ are two vectors of white noise shocks which are sector-specific. It has been shown formally by Forni and Lippi (1995) that, for large $n$ and under some regularity conditions[1],

$$n^{-1} \sum_i \beta_i(L)\epsilon_{it} \sim 0$$

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[1] Granger (1987) shows the same result for the simpler case in which the impulse response functions of the common shocks are homogenous across sectors.

$$n^{-1} \sum_i \delta_i(L)\eta_{it} \sim 0$$

The consequence of this result is:

$$n^{-1} \sum_i \Delta p_{it} = n^{-1} \sum_i \alpha_i(L) u_t \tag{2}$$

$$n^{-1} \sum_i \Delta h_{it} = n^{-1} \sum_i \gamma_i(L) u_t \tag{3}$$

Since we have 450 sectors in our sample ($n$ large), we can then exploit (2) and (3) to measure the unobserved common shock on output by average productivity and hours worked and estimate the model in a way which is a great simplification with respect to what is generally suggested in the literature[2]. Whether the idiosyncratic components die out in the aggregate will be then verified for our sample in the statistical analysis of Section 5.

(iii) All shocks are mutually orthogonal at all leads and lags. Results from a formal test for orthogonality of the idiosyncratic component with respect to the common shocks will be reported in Section 5.

## 3. Identification of the number of common shocks

Here we just sketch, without reporting, the procedure used to identify the number of common shocks.[3].

We can rule out the presence of one common shock just by observing that, if the 450 sectors were driven by a single common shock, the growth rates of output and productivity would have to be perfectly coherent. Since they are not, we ask the question of whether there are two or more common shocks. We proceeded as follows:

Test A:

*A 1* : We regressed sectoral output growth rates and sectoral growth rates of productivity (respectively) against the average of two subaggregates containing each half of the sample and computed the average $R^2$.

*A 2* : We performed the same regression against three average subaggregates each one containing the average of a third of the sample. different combinations) and computed the average $R^2$.

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[2] Methods used in the literature are generally based on the state-space representation as, for example, in Quah and Sargent (1994). See Geweke (1994) for a critique.

[3] Results are available on request.

Regressions from *A 1* and *A 2* produce the same average $R^2$. This is a first indication that there are no more than two shocks: by using three sub-aggregates we do not improve on the goodness of fit obtained by using two sub-aggregates[4].

Test B:

*B 1* : We regressed the growth rate of sectoral average output against the average productivity growth rate of the the first 225 sectors and the average hours worked growth rate of the last 225 sectors[5] and computed the average $R^2$.

*B 2* : We regressed the growth rate of average output against the average productivity growth rate of the the even sectors and the average hours worked growth rate of the odd sectors.

In *B 1* we obtained an $R^2$ of .98 and in *B 2* an $R^2$ of .96. This is an additional indication that the two common shocks specification captures the stochastic dimension of our data set.

## 4. Identification of the common technological component

Having identified two common shocks, we can then model a two-element common component. Since output is the sum of hours worked and labor productivity, we can identify the two common shocks of (1) by a model of average productivity and average hours.

Let us denote $\Delta P_t = n^{-1}\sum_i \Delta p_{it}$ and $\Delta H_t = n^{-1}\sum_i \Delta h_{it}$. The vector $X_t = [\Delta P_t \quad \Delta H_t]'$ has Wold representation:

$$X_t = A(L)w_t \tag{4}$$

where $A(0) = I$ and $w_t$ is a vector of serially uncorrelated structural disturbances with a mean of zero and a covariance matrix $\Sigma_w$ which is unrestricted. Then consider the structural form:

$$X_t = B(L)u_t \tag{5}$$

Identification consists in finding a matrix $Q$ such that

$$A(L)QQ^{-1}w_t = B(L)u_t$$

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[4] We tried about 50 different subaggregates and chose two specifications: contemporaneous effect and two lags and contemporaneous effect, two lags and two leads. All experiments produced similar results.

[5] We used the same specifications as in Test A.

satifies conditions deduced from theory. Three parameters are identified by the assumption of orthogonality of the elements of $u_t$ and the normalization $Euu' = I$. If we can identify the fourth parameter, the two shocks will be just-identified. We propose to set the fourth parameter by assuming that the technological shock is that for which the absolute value of the sum of the negative shocks $\mid \sum_t u_{1t} \mid$ is minimized. As said in the introduction, this identification strategy is justified by the idea that technology shocks distinguish themselves from other shocks because they are positive and that examples of negative technological shocks are very rare[6]. In absence of further theoretical restrictions, this assumption seems less controversial than the common one of long-run demand neutrality; however, the empirical results in Section 6 show that our identification scheme produces a long-run effect of the non-technological shock which is close to zero on productivity.

We approximate (5) by a vector MA(2) which is estimated by Maximum Likelihood. This strategy departs from common practice of estimation of VAR models and it is chosen because we want the aggregate model to be consistent with the sectoral models. The latter, which will be estimated in the next Section, are MAs and we know that MAs aggregate into MAs[7]. We call this procedure "structural MA method".

To check the appropriateness of our specification for the model of the common component we have compared two alternative series of estimated shocks: the shocks derived from the estimation of the MA(2) on $\Delta P_t$ and $\Delta H_t$ (solid line in Figure 1) and the shocks derived by the estimation of the same model for the sample of the odd sectors (dashed line in Figure 1). These two processes are very closely related (the correlation coefficient is .95). This result is very conforting for our analysis: first, if two alternative aggregates give us the same estimate of the common technological shock, this justifies our procedure of identifying the common shocks by the use of any aggregate quantity; second, the fact that half of the sample produces the same result as in the all sample in-

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[6] For a detailed description of this method of identification, see Forni and Reichlin (1995).

[7] In the empirical exercise carried out in this paper we assume that the structural model is fundamental. However, an additional potential advantage of the MA framework, is that can be used more easily than the VAR's for the analysis of non-fundamental representations. (on this point, see Lippi and Reichlin (1993)). The investigation of non-fundamental representations will be object of further research.

dicates that there cannot be more than two common shocks (assumption (i)).

[Figure 1 to be inserted about here]

## 5. Estimation of the sectoral models

Having identified $u_t$, we are now in the position of estimating its dynamic impact over time and compare it across the different sectors. To capture the notion of slow diffusion of technological shocks across firms we impose a MA(2) structure for the two common components. The estimated model is:

$$\Delta y_{it} = [\psi_{0i} + \psi_{1i}L + \psi_{2i}L^2]u_t^T + [\chi_{0i} + \chi_{1i}L + \chi_{2i}L^2]u_t^D + idio_{it} \quad (6)$$

where $u^T$ and $u_t^D$ are, respectively, the common technological shock and demand shock. Since $idio_{it}$, the idiosyncratic component, is orthogonal to $u_t = [u_t^T \quad u_t^D]$ and the latter is common to all sectors we can estimate (6) equation by equation by OLS.

To verify the orthogonality between the residuals and the $u$'s we have performed two tests. The first, is a $Q$ test; we found that only 6 % of the $(n^2 - (n+1))/2 = 101025$ couples reject the hypothesis of pairwise orthogonality. To construct the second test, we procede in the opposite way than in Test B of Section 3. There we assumed that the asymptotic result of zero idiosyncratic components on average was true in our sample and asked wether the 2-component common shock specification was verified. Here, we assume that there are two common shocks and ask whether the idiosyncratic components do indeed die out on average in our sample. Under the orthogonality assumption, the aggregate variance of the idiosyncratic component can be computed as $\sum_i \sigma_i^2/n^2$. If the idiosyncratic components die out, this quantity divided by the variance of the aggregate, should be equal to zero. Results are quite encouraging since we obtain ratios of .01 for output, .01 for hours worked and .05 for productivity.

## 6. Empirical results: growth and technology

### 6.1 Aggregate results

Here we report results of estimation and identification of the MA model for average productivity and hours worked described in Section 4.

The impulse response functions on average output and productivity are illustrated in Figure 2 (the impulse on output is implicit in the model for $\Delta H_t$ and $\Delta P_t$).

[Figure 2 to be inserted about here]

There are some interesting features of the dynamics of the two shocks on output and productivity:

(i) The shape of the impulse of the technological shock on both output (dotted line) and productivity (solid line) reproduces the $S$-shape that has been used in the literature to describe slow diffusion of the innovation throughout the economy (Griliches (1957), Mansfield (1973), Lippi and Reichlin (1994a, 1994b), Jovanovic and Lach (1989,1990) amongst others).

(ii) The dynamics of the technological shocks on output and productivity differs for the first impact which is negative on output and positive on productivity. This suggests that when technological innovations arrive, firms reorganize their production process so that in the first year output will grow less than on average. Productivity, however, even in the first year grows more than on average because of the immediate impact that the technological innovation has on the demand of labor. In the long-run the effect is positive on both variables, although slightly larger for productivity.

(iii) The technological component explains the main bulk of the variance of productivity ( 93%) and only 55 % of the variance of output. However, one should be careful in interpreting this result since the weight of the technological component - common and idiosyncratic - depends on the relative weight of the idiosyncratic component as well. As it will be seen in the next Section, productivity has a larger idiosyncratic component than output so that, if shocks other than technology had a large part in it, the information about their impact would be lost in aggregate data.

(iv) The non-technological common shock has an almost long-run neutral effect on productivity (dashed line), but a positive one on output (dotted-dashed line). If we interpreted the non-technological shock "demand", it could be said that our identification assumption on the positivity of technological shocks leads to different results than demand long-run neutrality on output which is a popular identification assumption used in the VAR framework (Blanchard and Quah (1989)).

### 6.2 Sectoral regressions

We obtain several interesting results from sectoral regressions. First, productivity has a larger idiosyncratic component than output. Figure

3 reports the distribution (normalized to have area equal to one) of the adjusted $R^2$ for the 450 regressions of, respectively, sectoral output (dashed line) and sectoral productivity (solid line) against the common factor.

[Figure 3 to be inserted about here]

The mean of adjusted $R^2$ for these regressions is .30 for output and .14 for productivity.

Second, sectoral regressions, unlike what found from aggregate estimates, show that the common non-technological shock has a large role in explaining the variance of productivity. The mean (across sectors) of the variance ratios of the non-technological component to the total common component obtained from sectoral estimates is .59 while the aggregate ratio is .93 (see Section 6.1). This is explained by the fact that the dynamic impulses of the common non-technological shock are heterogenous across sectors and aggregation, by averaging out the heterogenous effects, hides the information on the contribution of shocks other than technology to the total variance.

These two results then explain the fact that sectoral productivity has a much larger variance than aggregate productivity: the ratio between the variance of productivity and that of hours is 1.38 for sectoral results and .17 only in the aggregate.

How similar across sectors is the dynamic of the common technological and non-technological shocks can be seen from Figures 4a-4b and 5a-5b. Although we do not investigate this point in the present paper, it should be noticed that similar dynamics of the common technological shock is a potential indication of the presence of production externalities; our framework can be potentially used to distinguish between types of externalities (see Caballero et al (1994), Cooper and Haltiwanger (1993) and Shea (1994) for a definition of different types of externalities and a discussion of how to measure them.)

Figures 4a and 4b report the distribution of the coefficient of the first impact ($\psi_{0i}$) and the sum of the coefficients ($\psi_{0i} + \psi_{1i} + \psi_{2i}$) associated with the common technological shock. Although on average, as we have seen in Figure 2, the common technological shock has an S-shaped lag distribution, the picture varies sector by sector since some sectors are penalised while other benefit from the innovation. However, the distribution is unimodal and rather concentrated around the mean, which indicates a certain degree of common sectoral dynamics driven by technology[8].

[Figure 4a e 4b to be inserted about here]

The shape of the distributions of the first impact and long-run impact of the non-technological shock are similar to those of the technological shock (Figure 5a and 5b).

[Figure 5a e 5b to be inserted about here]

The Figures illustrate the point that sectoral negative and positive dynamic impulses cancel out in the aggregate. It should be noticed that, while the non-technological shock is almost long-run neutral with respect to productivity on average (see Figure 2), it may have either negative or positive effects in different sectors.

Figure 6 shows the distribution of the adjusted $R^2$ of sectoral regressions of output and productivity against the common technological component.

[Figure 6 to be inserted about here]

Some lights on the propagation mechanism may come from the identification of the sectors with the strongest correlation between output growth rates and the common technological component. Table 1 describes the 20 sectors with the highest $R^2$ (these sectors account for about 5 % of the distribution described in Figure 6 by the dotted line).

[Table 1 to be inserted about here]

These core sectors are mainly in the industrial machinery and equipment goods group and in primary and fabricated metals, ie they are concentrated in sectors producing investment goods and their inputs. These $R^2$ are not an indication of causality between growth and technological

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[8] This statement may seem imprecise and it would be interesting to establish a metric for "closeness" of the impulse response functions. Lippi and Reichlin (1994b) discuss alternative definitions of common dynamics and compare a framework with heterogenous impulses such as the one developed in this paper, with the common feature (Engle and Kozicki (1990)) and the common cycle (Engle and Vahid (1993)) frameworks.

change, but they are consistent with the view that product innovation in the investment goods sectors induce technological change overall. This mechanism should be investigated in further research.

## 7. Summary and conclusions

This paper has proposed a methodology for identifying and estimating the contribution of technological innovations in a sample of a large cross-section and (smaller) time series observations on output and hours worked in the manufacturing sector.

We exploit a recent result in the aggregation literature (Forni and Lippi (1985)) to identify the vector of the common shocks by an average quantity. By applying this method and through exploratory data analysis we are then able to identify and estimate two common shocks to output for 450 sectors.

We then propose to identify the technological component of the bivariate vector of the common shocks as the component for which the sum of the negative residuals is minimized. This method exploits the least controversial feature of technological innovations, ie that their distribution has to have positive support.

We explore the nature of common movements in output and productivity by looking at the source of common shocks and their dynamic impact over time and across different sectors. Our findings indicate that there are stronger comovements in output than in productivity and that comovements in productivity are mainly explained by common technological shocks although the shock other than technology has a large role in explaining the variance at the sectoral level. We also show that, in the aggregate, the technological shock has a cumulated effect on output and productivity which reproduces the familiar S-shape (Griliches (1957), Jovanovic and Lach (1989, 1990), Lippi and Reichlin (1994a)). The distribution of the dynamic impulses over the sectors of both the technological and the non-technological shocks is unimodal and rather concentrated around the mean so that, we can identify some common dynamics of the common shocks. We are able to identify the investment good sectors as those for which the correlation between the common technological component and the rate of growth of output is the strongest. A possible interpretation of this finding is that product innovations in these key sectors affect technological change common to all sectors.

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# LEGEND

FIGURE 1: Common Technological Shocks

common shock identified with the mean of all sectors (solid line); common shock identified with the mean of odd sectors only (dashed line).

FIGURE 2: Impulse Response Functions - Output and Labor productivity

technology shock on productivity (solid line); technology shock on output (dotted line); other shock on productivity (dashed line); other shock on output (dotted-dashed line).

FIGURE 3: Cross-Section Distribution of Adjusted $R^2$ for output and productivity regressions against the total common component.

output (dashed line); productivity (dashed line).

FIGURE 4a: Cross-Section Distribution of the first impact and the long run effect of the common technological shock on output.

First impact (solid line); Long run effect (dashed line)

FIGURE 4b: Cross-Section Distribution of the first impact and the long run effect of the common technological shock on labor productivity.

First impact (solid line); Long run effect (dashed line)

FIGURE 5a: Cross-Section Distribution of the first impact and the long run effect of the common non-technological shock on output.

First impact (solid line); Long run effect (dashed line)

FIGURE 5b: Cross-Section Distribution of the first impact and the long run effect of the common non-technological shock on labor productivity.

First impact (solid line); Long run effect (dashed line)

FIGURE 6: Cross-Section Distribution of Adjusted $R^2$ for output and productivity regressions against the common technological shock.

output (dashed line); productivity (solid line)

# APPENDIX

## Data sources and data treatment

The data set used is the Annual Survey of Manufacturers (ASM) which is a survey of manufacturing establishments sampled from those responding to the comprehensive Census of Manufacturers. This database contains information for 4-digit manufacturing industries from 1958 through 1986.

We have used value added data for output and deflated them by the value of shipments.

All sectoral data on output, productivity and hours were subject to unit root tests. For all data we were not able to reject the null of a unit root (results available on request) at the 5 % level.

The electronic computer sector (SIC 357) was found to have a unit root after being detrended by a segmented trend with change in drift in 1972.

## TABLE 1

### SECTORS WITH HIGHEST ADJUSTED $R^2$
### RESULTS FROM OLS REGRESSIONS:

$$\Delta y_{it} = \left[\psi_{0i} + \psi_{1i}L + \psi_{2i}L^2\right]u_t + \text{resid}$$

| SECTORS | SIC | $\bar{R}^2$ |
|---|---|---|
| GRAY AND DUCTILE IRONS FOUNDRIES | 3321 | .68 |
| MACHINE TOOL ACCESSORIES* | 3545* | .65 |
| CEMENT, HYDRAULIC | 3241 | .65 |
| CONCRETE BLOCK AND BRICK | 3271 | .64 |
| AIR AND GAS COMPRESSORS* | 3563* | .62 |
| MOTORS AND GENERATORS | 3621 | .61 |
| POWER TRANSMISSION EQUIPMENT, NEC* | 3568* | .61 |
| BALL AND ROLLER BEARINGS* | 3562* | .61 |
| STRUCTURAL CLAY PRODUCTS, NEC | 3259 | .60 |
| IRON AND STEEL FORGINGS | 3462 | .56 |
| INTERNAL COMBUSTION ENGINES, NEC* | 3519* | .56 |
| SYNTHETIC RUBBER | 2822 | .55 |
| BOLTS, NUTS, RIVETS AND WASHERS | 3452 | .55 |
| TRUCK TRAILERS | 3715 | .55 |
| SPEED CHANGERS, DRIVES AND GEARS* | 3566* | .54 |
| STEEL PIPE AND TUBES | 3317 | .54 |
| BLAST FURNACES AND STEEL MILLS | 3312 | .53 |
| SPECIAL DIES, TOOLS, J'GS & FIXTURES* | 3544* | .53 |
| SLAW BLADES AND HANDSAWS | 3425 | .53 |
| PUMPS AND PUMPING EQUIPMENT* | 3561* | .52 |

*Note:* Starred sectors belong to the brood classification: industrial machinery and equipment.

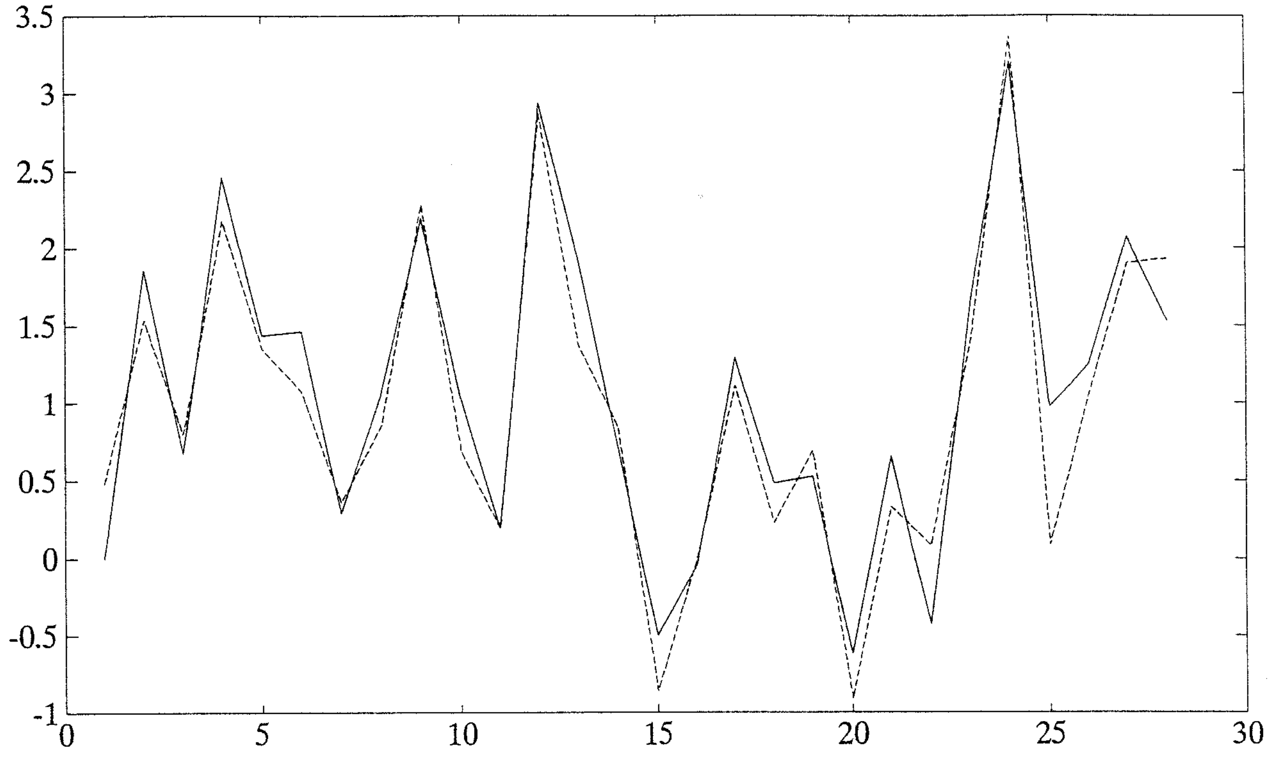

FIGURE 1

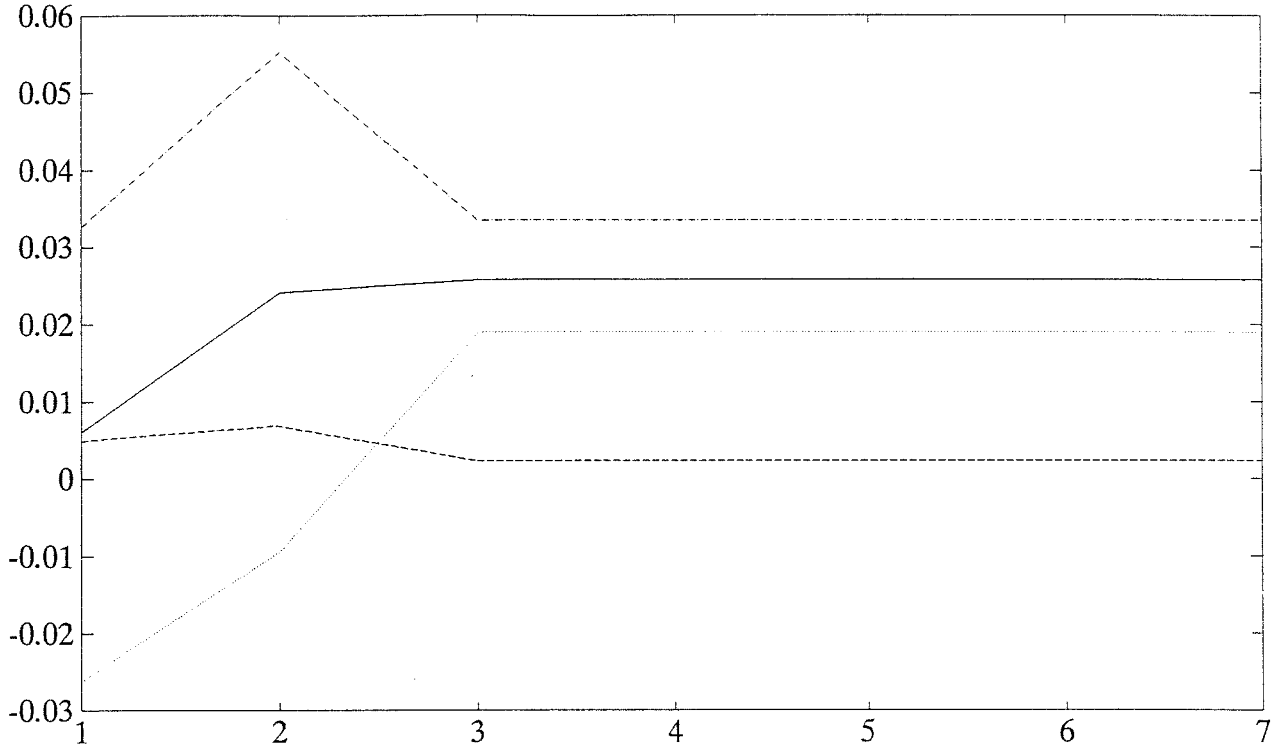

Fig. 2

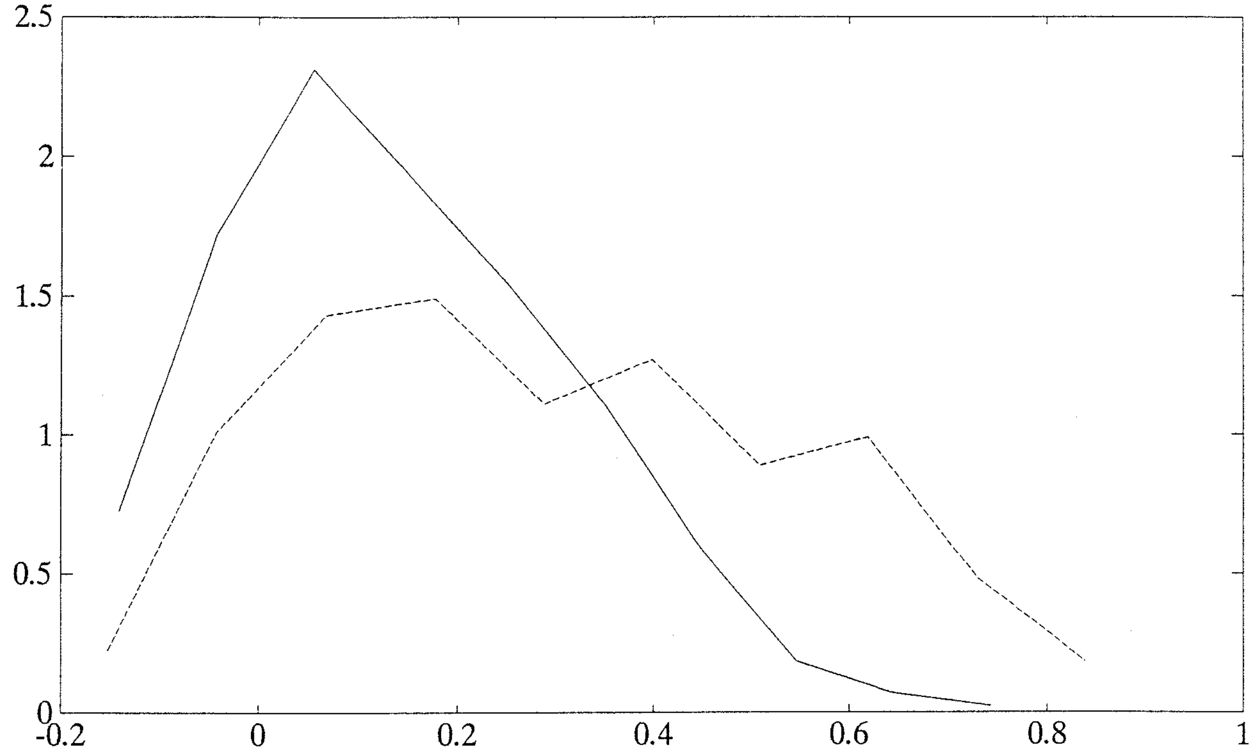

FIGURE 3

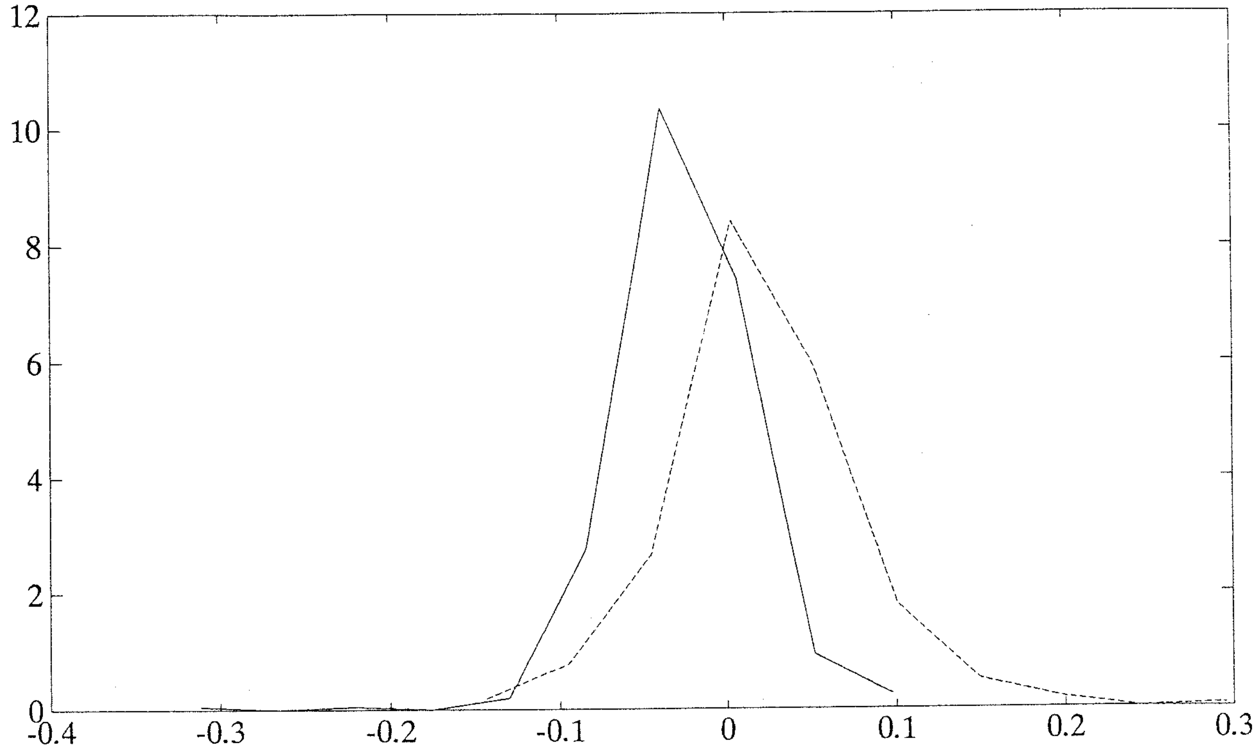

FIGURE 4a

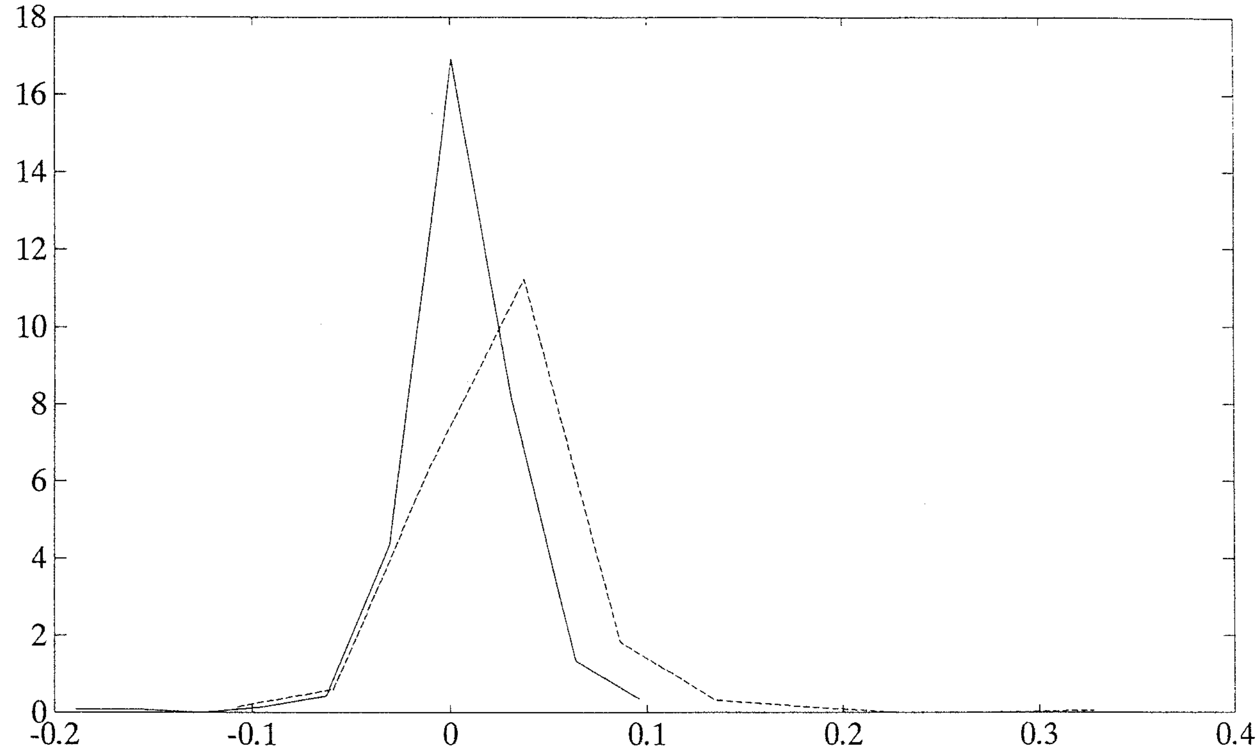

FIGURE 4b

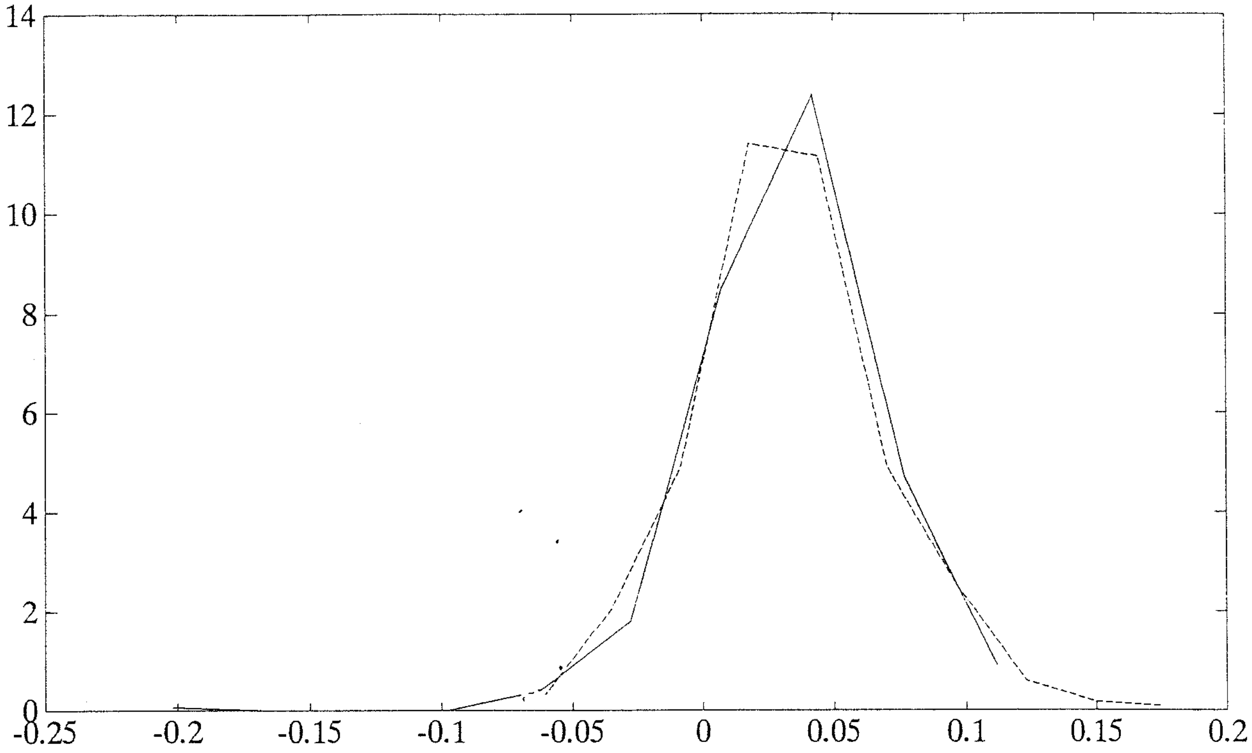

FIGURE 5a

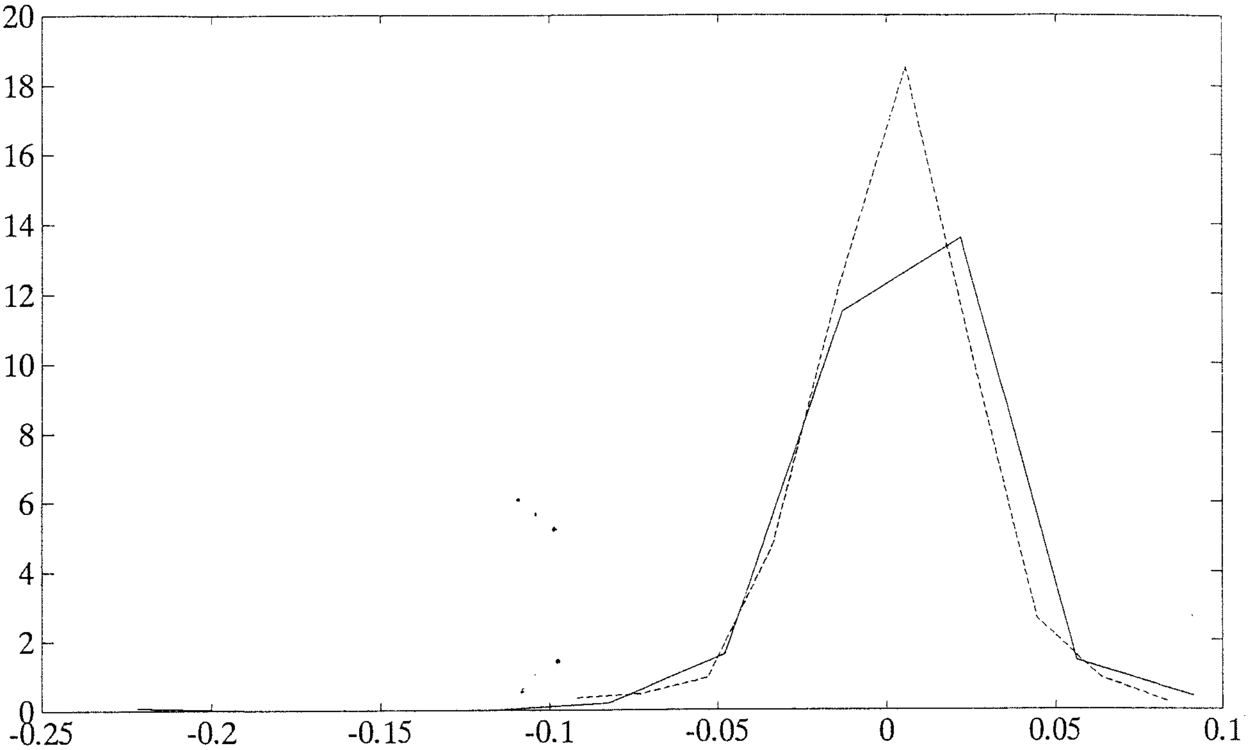

FIGURE 5b

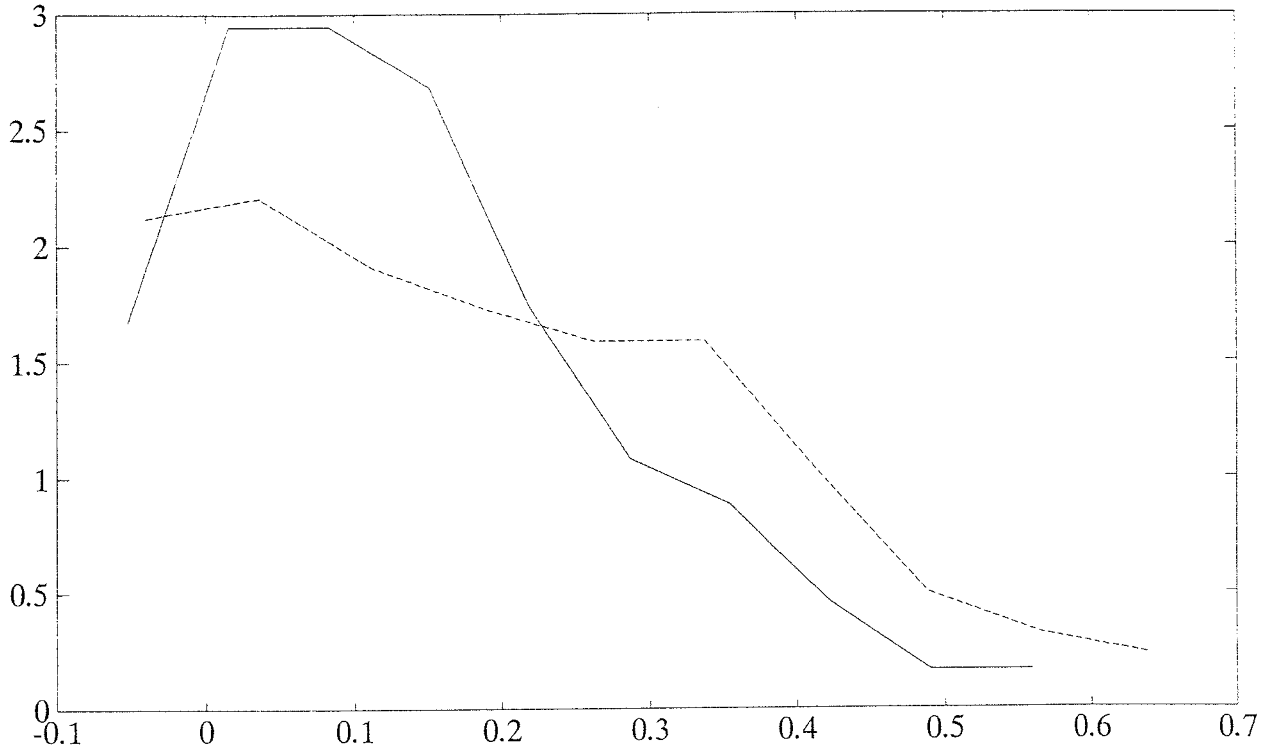

FIGURE 6

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