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ULTIMATE SOURCES OF AGGREGATE VARIABILITY

ROBERT J. SHILLER

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## Ultimate Sources of Aggregate Variability

### ABSTRACT

What, ultimately, is different from quarter to quarter or year to year that accounts for the fact that macroeconomic variables change over these intervals? That is, which are the biggest ultimate sources, in terms we may say of tastes, technology, endowments, government policy, industrial organization, labor-management relations, speculative behavior, or the like, that change to cause this variability?

There are a bewildering variety of claims in the literature for such ultimate sources. Far fewer efforts have been made to give a breakdown of the variance of macroeconomic aggregates by source. The two notable such breakdowns to date are by Pigou (1929) and Fair (1987).

The nature of the evidence for such breakdowns is discussed here, and the possibility that a partial breakdown may be well-determined is put forward. An unsuccessful attempt is made to detect a component of macroeconomic fluctuations that is due to the weather.

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Any empirical model of the macroeconomy tells a story about the exogenous shocks that are ultimately responsible for changes from year to year in macroeconomic variables. The characterization of these sources of aggregate variability is of fundamental importance. Economic theory cannot be applied to data unless we know which economic relations are not themselves shocked, or at least unless we know something about the shocks.<sup>1</sup>

Recent models have differed widely in their characterizations of these ultimate sources of aggregate variability. Finn Kydland and Edward Prescott (1982) and others proposed models of the business cycle in which the only shocks to the macroeconomy are certain kinds of shocks to technology. Robert Barro (1977) proposed a model in which 78% of the variance of a (transformed) U. S. unemployment rate 1946-73 is due to unexpected changes in the money stock, and military employment and minimum wage variables. David Lilien (1982) argued that most of the unemployment fluctuations in the U. S. in the 1970's were due to "unusual structural shifts," such as changes in the demand for produced goods relative to services. James Hamilton (1983) argued that dramatic oil price shocks preceded all but one of the recessions in the U. S. since World War II, and that these oil price shocks were in turn caused by events such as the nationalization of Iranian assets the Suez crisis, and strikes by oil and coal workers.

Others have offered analyses that, while not necessarily claiming to isolate the major source of aggregate fluctuations, do suggest that qualitatively very different exogenous shocks may be quite important: changes in desired consumption (Robert Hall, 1986), breakdowns in the process of borrowing and lending (Ben Bernanke, 1981), breakdowns or estab-

lishments of cartels (Julio Rotemberg and Garth Saloner, 1986), or variations in attitudes toward union membership (Olivier Blanchard and Lawrence Summers, 1986). Moreover, any of these shocks might occur in a foreign country, and be transmitted by trade relations to the domestic economy. Some analyses have even emphasized that something that ought to be, by any fundamental logic, truly irrelevant to the macroeconomy, may well importantly influence it if people think it does, e. g., Michael Woodford (1987). The potential importance of such variables may be even more important than suggested in some papers in the theory literature if we allow for 'near-rational expectations' as well as the strictly rational expectations.

Recent evidence (John Campbell and N. Gregory Mankiw (1987)) suggests that innovations in real gross national product (GNP) show little tendency to be reversed subsequently, and that the apparent tendency of GNP to be trend-reverting may be due to spurious trend estimation.<sup>2</sup> To the extent that this is right, then variations in the same sources that explain long-run growth (and explain why the U. S. is wealthier than India or China) would also play a role in explaining short-run movements. If cultural or institutional factors influencing the dissemination and application of learning are the reason, then changes in these factors may play a role. If economies of scale are a factor determining intercountry differences, then the discovery of new industries or regions of production functions where such economies obtain might also play a role. Other possible factors are changes in government expenditure on "infrastructure" formation, government policies and other factors encouraging or discouraging initiative, or just population growth and natural resource discoveries and depletion.

There seem to be a bewildering array of possibilities for ultimate

sources. It is important to understand that it is in principle possible that they might all contribute substantially. It is technically possible that ten different independent shocks each might make a contribution whose standard deviation is 32% ( $= \sqrt{0.1}$ ) of the standard deviation of the aggregate. Thus, for each of the ten factors there may be evidence that it is often very important and occasionally dominates aggregate fluctuations. Or, it is possible that 100 independent factors each may make a contribution whose standard deviation is 10% of the aggregate standard deviation.

One is naturally led to wonder if there isn't any systematic way to determine what is the relative importance of different sources of macroeconomic variability.

### I. Pigou's Analysis of Ultimate Sources

A. C. Pigou's remarkable book Industrial Fluctuations (1929) appears to be the most recent effort until now to provide such a systematic breakdown of sources. He grouped these sources into three broad categories. "Real Causes" are "changes that have occurred, or are about to occur, in actual industrial conditions and expectations based on these are true or valid expectations." The principal real causes he cites are: (1) harvest variations, (2) inventions, (3) industrial disputes, (4) changes in fashion, (5) wars, and (6) foreign demand and foreign openings for investment. "Psychological causes" are "changes that occur in men's attitude of mind, so that, on a constant basis of fact, they do not form a constant judgment." "Autonomous monetary causes" are events affecting money, such as gold discoveries, or changes in monetary or banking policies.<sup>3</sup> He thought that removal of either the autonomous monetary or the psychological causes might reduce the

amplitude of industrial fluctuations by about a half. Removal of harvest variations might reduce amplitude by about a quarter. He thought that other real causes, such as inventions or work stoppages, had much less effect.<sup>4</sup>

Of the above sources, only one, the psychological, appears largely absent from contemporary macroeconomics, though it might be interpreted as present in some macroeconometric models in the form of error terms. Pigou here describes swings in optimism or pessimism affecting investment that arise "spontaneously," though perhaps ultimately as a "psychological reflex" from some of the same factors that he calls "real" causes.<sup>5</sup> He emphasized that the swings occur simultaneously over a large number of people, because of "psychological interdependence", "sympathetic or epidemic excitement", or "mutual suggestion".<sup>6</sup> He denied what we now call "rational expectations" because there is "instability in the facts being assumed," though he admitted that "if everything were absolutely stable, recurring every year with exact similarity or in a perfectly regular progression, people could not fail to be aware of the relevant facts and to form correct judgments."<sup>7</sup>

What sort of evidence might Pigou have that his list comprises the important sources? Although he made some use of statistics, his method involves judgment that appears to be based on anecdotal and narrative historical evidence. Such a method may in fact be of some use for this purpose. A rough sense of proportion about some economic mechanisms may suggest that if certain factors would change exogenously, there would be important macroeconomic consequences. If these factors did indeed change historically, then the only question that remains is whether such a change could be purely endogenous, i. e., caused ultimately by other economic variables. We may then have some idea whether these factors are likely to be

determined reliably by such other economic variables.

Consider for example the case of the autonomous monetary causes. In the contemporary context, we know that the Fed can and does move interest rates, which have a major impact on the economy. Of course, the announced goal of the Fed currently is to stabilize the economy, and their efforts may indeed attenuate the effects of other shocks. But since their methods are judgmental and imprecise, it is to be expected that they must also serve to add shocks themselves. By analogy, if we analyzed the movements of an airplane in rough weather, we would expect to find that a component of the airplane's movements is ultimately due to the pilot.

Methods like Pigou's are suggestive, but one might hope for something more objective and quantitative.

## II. Evidence from Large-Scale Macroeconometric Models

The large-scale macroeconometric models in the Keynesian tradition appear to be the only models detailed enough to allow a decomposition of output variability into a variety of constituent shocks as broad as that proposed by Pigou. In these models, all macroeconomic fluctuations can be traced ultimately to equation residuals or exogenous variables.

Ray Fair (1987) has undertaken stochastic simulations of Fair Model of the U. S. economy to show what are the important shocks to the model. The Fair model is similar to most large-scale macroeconometric models in that it includes consumption and investment functions, and a national income identity to yield an IS curve, and demand for money equations that gives rise to an LM curve. Monetary policy is modelled by a Fed reaction function, but fiscal policy is taken to be exogenous.



To take account of shocks to exogenous variables, he added simple autoregressive forecasting equations for 23 exogenous variables to the 30 structural equations in his model, producing a 53 equation model with basically no exogenous variables. Taking as given data through 1981 second quarter, a stochastic simulation, the base simulation, was run using a 53 x 53 (block diagonal, with a 30 x 30 and 23 x 23 block) variance covariance matrix residuals, and the variance of actual real GNP for one to eight quarters ahead (that is, 1981 third quarter through 1983 second quarter). He then set residuals for the eight quarters to zero in each of the 53 equations, one at a time and then in groups, and ran new stochastic simulations. The variance in real GNP in any one of these simulations as a percent of the variance in the base simulation is a measure of the importance of the residual that is analogous to the square of the relative amplitudes described by Pigou.

What is striking about the results is that the conclusions differ substantially between one-quarter-ahead simulations and eight-quarter-ahead simulations. For example, if we drop the error term to the inventory investment equation real GNP variance falls by 29% relative to the base simulation in the one-quarter-ahead simulations, but by only 4% in the eight-quarter-ahead simulations. If we drop the error term in all investment equations (consumer durables, housing, inventories and business fixed investment) the corresponding figures are 50.6% and 13.4%. Thus, failure to predict investment accounts for most of the model's difficulty in forecasting one quarter ahead, but relatively little of the difficulty in making longer-run forecasts. Other sources of variability grow faster with time horizon, so that uncertainty about investment is swamped out.

The story told by the Fair model is a complicated one, with no single

source of variability dominating. Consider the percentage variance declines in the eight-quarter-ahead simulations for real GNP. Dropping all exogenous variables' shocks reduced variance by 44%, the remainder being accounted for by equation residuals. The principal grouping of exogenous variables was government expenditure and transfers (federal, state, and local), for 21%, and after that, exports, for 19%. Among endogenous variables, dropping residuals on consumption on services and nondurables reduced variance by 10%, on the wage and price sector by 11%, and on import demand by 7%. Dropping Federal Reserve policy shocks reduced variance by only 3%.

What sort of evidence is behind the Fair Model that gave rise to these variance decompositions? The modelling effort relied on the assumption that a large list of variables is exogenous. Many of these are not plainly exogenous to the model, though one might suppose that their relation to economic activity is in some cases tenuous, complicated, and involving long lags. The modelling effort also relied on a set of restrictions on coefficients that vastly overidentified the model. Because of these overidentifying restrictions, the estimate of the reduced form was not at all the same as if it had been estimated by merely regressing endogenous variables on exogenous and predetermined variables. The restrictions sometimes have the effect, for example, of inferring an effect of an exogenous variable on GNP from an observed effect on a component of GNP.

These overidentifying restrictions were usually not explicitly discussed in the description of the model. Their specification appears to have largely intuitive origins, just as was the case with the theory of Pigou. One would wish that there were a method that was more capable of producing a consensus in the profession as to ultimate sources.

### III. Partial Specifications of Exogenous Sources

Many doubt the assumptions of the large-scale macroeconometric models. But, certainly some of their assumptions must be uncontroversial. Certainly some variables (e. g., the weather) would be judged genuinely exogenous by just about everyone. It would be progress if we could all agree that such a variable explains x% of macroeconomic variability, even if x is very small. Might not a Granger or Sims causality test for causality from such a variable to real GNP produce such an agreement?

But it's hard to think of any single measurable clearly exogenous variable that seems likely to have much impact on the aggregate economy. We have a wealth of data at a finely disaggregated level, for example, information on individual patents each of which represents a component of technological progress. But how to aggregate this information into a data series that might be found to cause GNP? We cannot regress GNP on hundreds of exogenous variables each of which explains a component of it, since we would have more independent variables than available observations.

Weather variables are probably the most obvious candidates for a truly exogenous variable that might really cause macroeconomic aggregates. Regression models explaining individual crop yields (e. g., Wolfgang Baier, 1977) show that weather variables explain a substantial portion of year-to-year crop variability. Often the  $R^2$  is over 0.5. But to achieve such  $R^2$  for individual crops the researcher uses finely focussed weather variables that differ across crops, such variables as "estimated June potential evapotranspiration," or "mean soil moisture reserves (mm) at heading stage in 0-100 cm. depth of soil." To explain aggregates well, these weather variables

should be measured at all the appropriate times and sites for the specific crops to which they pertain. To explain weather effects on nonagricultural productive activities would require yet very different weather variables. To explain housing starts, we may use number of days in the year where temperature is below freezing, to explain restaurant meals the number of evenings of inclement weather and highway conditions in urban areas, to explain electricity demand an average of a nonlinear function of summer temperatures above 75 degrees, to explain heating fuel demand an average of a nonlinear function of winter temperatures below 60 degrees.<sup>8</sup> It is not easy to find a good aggregator of these shocks other than GNP (or its analogues) itself.

I have attempted (see Appendix) to find an effect on net national product of a couple of weather indices that I constructed: a summer precipitation variable and a summer temperature variable. The aggregation of national weather data for these indices took the form of summing summer precipitation data and summer temperature data over four different weather stations across the United States. These are crude indices, only four sites are used, and there is no accounting for the geographical distribution of important crops. No significant effect could be found for net national product 1895-85, or in an earlier sample period 1895-1929. That the weather variables are not completely off the mark is indicated by the fact that the precipitation index is highly significant in explaining gross farm product.

#### IV. Models as Aggregators

Finding an aggregator of very many exogenous shocks means building a highly disaggregated model that explains many components of GNP and shows how they interact to produce the total. If models are to be judged as

aggregators, then models may be deemed successful even if they have known structural defects that would cause them to be rejected by conventional criteria. An aggregator model might be only a naive or crude model. For example, we might build a large Leontief input-output model. Data on the implementation of technological innovations, weather, or other known exogenous shocks could be used to adjust using engineering or statistical data the elements of the input-output matrix and the matrix of factor input requirements. We might find that an index of structural change in the model aggregates successfully (e. g., Granger-causes GNP) even though we know that the assumption of fixed proportions is highly restrictive.

Large macroeconometric model projects that deal laboriously with details may thus yield insight into sources of variability. Existing large-scale macroeconometric models may be viewed, even by those who accept some of the well-known criticism of their theory, as having shown some such success already (see Ray Fair and myself, 1987). It is natural to expect that further progress can be made along these lines, taking account of developments in economic theory and data, if people are willing to do more work at a detailed level, and for many different countries.

#### V. Interpretation

There is as yet no consensus in the profession as to the quantitative importance of any of the various ultimate sources. In my judgment, however, the existing literature does suggest that a great multiplicity of sources is at work: shocks to tastes as well as technology, shocks in government policy, demographic shocks, shocks to organizations in labor or industry, and "psychological" shocks of the kind described by Pigou and others.

Currently popular methodology results in models that attempt to make do with very few shocks. These models are valuable as special cases but should be interpreted as exploratory exercises. We should not consider it an objective of research to simplify or reduce the array of exogenous shocks. Simplicity is of course a virtue, but simple models cannot be construed as an objective if the world is not simple.

## APPENDIX

### Weather Variables as Sources of Aggregate Variability

The idea that weather or other shocks to agriculture is an important cause of macroeconomic fluctuations has a long history. W. Stanley Jevons (1884) and A. Piatt Andrew (1906) thought that harvest data were substantially correlated with the business cycle. Henry Moore (1914) noted a correlation 1871-1908 between pig iron production and yield per acre of crops.<sup>9</sup> However, the statistical significance of these result is questionable, and harvest or yield per acre variables may not be exogenous.

It is perhaps of some interest that Jevons (1884) proposed his theory that sunspots affect real output on the notion that sunspots affect agriculture. Anyone who tries to study weather affects on aggregates must first find an aggregate weather variable. If the solar cycle influences weather, some measure of the solar cycle might be potentially attractive as such a variable. There is an enormous literature, continuing today, claiming evidence that the solar cycle does indeed have substantial effects on weather and agriculture. However, one survey of the literature concludes that "There is at present little or no convincing evidence of statistically significant or practically useful correlations between sunspot cycles and weather or climate at intermediate time scales. This conclusion seems justified despite massive literature on the subject."<sup>10</sup> Sunspots have no discernable effect on real GNP (Sheehan and Grieves (1982)<sup>11</sup>

One might expect that weather variables might be demonstrated to have a measurable impact on aggregates in less-developed countries, where agricul-

ture remains a very important component of total output. However, I have not been able to find evidence that someone has documented such an impact.<sup>12</sup> A computer search revealed no evidence of any concern in the macroeconomic or meteorological literature of the last 15 years with finding an effect of weather on economic aggregates.

In my own explorations with U. S. data, a measure of aggregate economic activity was regressed on six own lagged values and on a current and two lagged values of weather variables in the regression. These are not, strictly speaking, Granger causality tests since the current values of the weather variables are included among regressors. The assumption is that the regressors are known to be exogenous, and we are as interested in effects of current values of the variables as in the effects on lagged values.

Two weather variables were constructed, which were focused roughly on agricultural production. One was a summer precipitation variable, the other a temperature variable. Both variables were based on measurements taken at four sites across the U. S.

In these regressions, no significant impact of either the temperature or the precipitation variable could be found on aggregate net national product. This remains true even in an early sample period, 1895-1929. Of course, reducing the sample size reduces degrees of freedom; we may just not have enough data to detect the impact of weather in this earlier sample period.

The precipitation variable was highly significant in explaining gross farm product. This suggests that weather ought to be considered an input to aggregate variability, but that the effect is too small to be revealed in regressions of NNP on weather variables.



Better-focussed weather variables might yield more substantial results. However, it is perhaps unlikely that we can obtain long historical time series on some finely focussed weather variables.

Table 1.  
F Tests for Significance of Weather in Causing  
Real National Aggregates

Sample	Dependent Variable	Weather Variables	F Statistic
1895-1985	log(NNP/NNP(-1))	P, P(-1), P(-2)	F(3,81) = 0.925
1895-1985	log(NNP/NNP(-1))	T, T(-1), T(-2)	F(3,81) = 0.169
1895-1985	log(NNP/NNP(-1))	P, P(-1), P(-2) T, T(-1), T(-2)	F(6,78) = 0.653
1895-1929	log(NNP/NNP(-1))	P, P(-1), P(-2) T, T(-1), T(-2)	F(6,22) = 0.792
1896-1985	log(GFP/GFP(-1))	P, P(-1), P(-2)	F(3,81) = 4.263 <sup>**</sup>
1896-1985	log(GFP/GFP(-1))	T, T(-1), T(-2)	F(3,81) = 2.182
1896-1985	log(GFP/GFP(-1))	P, P(-1), P(-2) T, T(-1), T(-2)	F(6,78) = 2.814 <sup>*</sup>

\* Significant at the 5% level. \*\* Significant at the 1% level.

Notes: In all regressions, six lags of the dependent variable as well as a constant term and the weather variables indicated were included as independent variables. P is a precipitation index. T is a temperature index.

## Sources of Data

P - Precipitation index, 1893-1985. This is the sum of precipitation indexes for four weather stations: Blue Hill Observatory, Massachusetts, Dickenson Experiment Farm, North Dakota, Fayetteville Experiment Station, Arkansas, and Davis Agricultural College, California (the last starting 1911 only). Each of the constituent indexes is +1 if summer (June, July, August) precipitation is in the top quartile, -1 if in bottom quartile, 0 otherwise. Source: From "description of the year," series J166, J184, J202, and J226, in Historical Statistics of the United States, Colonial Times to 1970, updated using U. S. Weather Service Climatological Data Annual Summary, passim.

T - Temperature index, 1893-1985. This is the sum of temperature indexes for four weather stations: Blue Hill Observatory, Massachusetts, Dickenson Experiment Farm, North Dakota, Fayetteville Experiment Station, Arkansas, and Davis Agricultural College, California (the last starting 1911 only). Each of the constituent indexes is +1 if summer temperature is in the top quartile, -1 if in bottom quartile, 0 otherwise. Source: From "description of the year," series J166, J184, J202, and J226, in Historical Statistics of the United States, Colonial Times to 1970, updated using U. S. Weather Service Climatological Data Annual Summary, passim.

NNP - Real Net National Product in 1929 dollars, 1869 to 1985. For 1869 to 1975, this is from Milton Friedman and Anna J. Schwartz, Monetary Trends in

the United States and the United Kingdom, NBER and U. Chicago Press, 1982.

The series was updated using CITIBASE series GNNP82, net national product in 1982 dollars. Linkage of series is by ratio in 1975.

GFP - Real Gross Farm Product in 1982 dollars, 1889-1985. Data 1889-1946 is Kendrick (NBER) Series A21 from U. S. Bureau of Economic Analysis, Long-Term Economic Growth, 1860-1965. Data starting 1947 is CITIBASE series GPBF82 (Gross Farm Product, Farm Sector) converted to annual series by annual averaging. Linkage of series is by ratio in 1946.

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## Notes

1. Garber and King pointed out that contemporary Euler equation estimation methods always assume that the shocks come in somewhere else in the model, but that this assumption will not do for every equation in the model (1983).
2. Their conclusion has been criticised by Clark (1986), Cochrane (1986), Watson (1986) and others, and so must be regarded as tentative.
3. Pigou, Industrial Fluctuations, pp. 35.
4. *ibid.*, p. 219-25. Note that Pigou's breakdown denies independence of factors: he thought eliminating one may reduce the impact of another.
5. *ibid.*, p. 73.
6. *Ibid.* p. 86. On this point, compare Woodford (this issue).
7. *ibid.* p. 74.
8. Deere and Miron (1986) regressed U. S. layoff rates by state and industry on state-specific (but not finely focussed) weather variables and other variables. The weather variables were significant at the 90% level in about 25% of the regressions, and were very significant overall.
9. H. L. Moore (1914), p. 110.
10. Pittock and Shapiro (1982), p. 72.



11. Oddly, Sheehan, and Grieves (1982) concluded that GNP Granger-causes sunspots. They thought this was an absurd result, and inferred that Granger causality tests are unreliable. Bessler and Kling (1984) argued that the Granger causality tests are less vulnerable to such spurious conclusions if certain precautions are taken.

12. For example, P. K. Pani (1984) attempts to use weather variables to explain aggregates in India, but does not find them significant. His weather variables are not finely focussed.