The Research for the Paper on the Dynamics of the Klein-Goldberger Model

By Irma Adelman.[1]

The genesis of the paper " *The Dynamic Properties of the Klein Goldberger Model" (Econometrica, 1959 pp. 596-625)* , by my physicist husband, Frank, and myself, was my husband's desire to learn how to program the IBM 650, the company's first general purpose digital computer, that had just been installed at the Berkeley Radiation Laboratory where he worked. He came home from work one day, in the fall of 1956, and told me that all physics problems were too complex and asked me whether there existed a numerical economic model that could be used instead. I replied that I thought there was and that I would look for a suitable model. A few days later, I presented him with a copy the book by Laurie Klein and Art Goldberger (*An Econometric Model of the United States 1929-1952*, North Holland 1952) describing their model of the United States, and asked him whether this model would suit. He said it would. So the first application of digital computers in economics occurred through happenstance.

I had always been fascinated by dynamics, business cycles, and uncertainty. (I do not know why). This fascination provided the problematique for the application of the computer to the model. In particular, assuming the Klein-Goldberger model offered an accurate representation of the US economy, the pertinent issue our work could address was whether the actual business cycles experienced by the United States were endogenous to the dynamics of the economy or whether they were due to the economy's response to exogenous shocks. Theory suggested both were possible.

Frank asked his immediate boss, Ernest O. Lawrence, after whom the Berkeley radiation laboratory is named, whether he would permit the use of the IBM 650 for this purpose. Lawrence agreed, with the stipulation that we could have one hour of free computer time but that any further time would have to be paid for at the rate of $600. To put this charge in perspective, my monthly salary at Berkeley as instructor was $200. We lived from hand to mouth. I distinctly recall worrying whether the lab would allow us to pay in installments, so that we could continue to eat, and pay our bills[2]. So the premium on accuracy and computation- speed was exceedingly high.

At the time, there were no programming languages. The programming of the 650 therefore had to be done in machine-language. This was a tedious but empowering process. (I have never since felt that I so totally understood what the computer was doing). Also, computer-memory was relatively small and the machine was relatively slow. The first generation 650 was several orders of magnitude slower than present electronic computers but much faster than the then existing desk- calculators, which were of the hand-crank type.

The programming task started by instructing the computer to store all the variables and constants into particular locations in the computer's memory. I have a vivid recollection of

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[1]The author is Professor in Graduate School at the University of California at Berkeley. I am writing this note at the kind invitation of Charles Renfro, the editor of this Journal. My husband-coauthor, Frank, is now deceased; otherwise, I am sure he would have joined me in the writing.

[2]Frank's salary went to his mother for her subsistence.

having the floor of our den-office covered with 8.5x11 inch lined sheets of paper divided into squares, which were taped together to yield a dynamic map of the computer's memory. Where possible, the same memory locations had to be reused, to save on memory-space. So, while writing the computer code, I crawled on the floor to keep the map of the memory up to date.

The machine-language instructions were primitive. The working core of the computer-mainframe consisted of an upper and lower accumulator, which could be manipulated either independently or interactively. The instructions were specific alphanumeric codes directing the upper or lower accumulators to perform specific operations: load into themselves the contents of a given memory location; store the contents of a particular accumulator in a specific memory-slot or shift to the right or left. The upper and lower accumulators could also be instructed to interact with one another, adding, subtracting, multiplying or dividing their individual contents. The instructions for each activity mimicked long-hand operations. To perform various steps of these simple operations typical subroutines could be invoked by using given alphanumeric codes. There were also "do-loops" for carrying out sequences of repetitive instructions.

I wrote the first draft of the computer program in a few days and Frank then checked it. I was proud of myself that he found only one error in the whole program (!)

The Klein-Goldberger model of the United States offered the most complete and complex representation of the economy to that date. It consisted of a set of 25 difference equations, in as many endogenous variables, with lags up to the fifth order, and described both the "real" and "monetary" sides of the economy and their interactions. The system was non-linear and simultaneous. Given the severe limitation on computer time and memory, before inputting the model into the computer, we introduced some non-altering changes and performed some hand-calculations to simplify the solution process.

We found that we could reduce the set of 25 equations to a core set of 4 simultaneous equations in as many unknowns, followed by a series of function- evaluations using the rest of the equation-system to calculate the values of the remaining endogenous variables. To linearize the model as much as possible, we substituted the inverse of the price level for the price level itself. However, the simultaneous core remained non-linear, in that the equation describing the relationship between real wages and prices continued to be non-linear even after this substitution was made. Methods for solving a set of non-linear simultaneous equations did not then exist. We therefore "linearized" the price-wage relationship and then used a successive-approximation technique based on the Taylor expansion to solve the original non-linear equation-set to a pre-specified degree of accuracy. With these prior manipulations, the Klein-Goldberger model could then be solved by the IBM 650 in less than a minute per year.

We were permitted access to the computer room at the radiation laboratory at night, and Frank was allowed to act as computer operator. The first generation IBM 650 mainframe was approximately 7 feet tall and two feet wide and consisted of a very large number of vacuum tubes. The model was inputted into the computer by means of a set of punched IBM cards. While computations were going on, the computer would display flashing lights in various spots, seeming like a fantastic humanoid that was attempting to communicate. When the computations were finished, it would eject a deck of computer cards which felt warm to the touch, reinforcing the surreal feeling. At the time, using computers was thus a highly personal experience, never duplicated since.

To ensure that the solution was correct, that is that we had made no errors in manipulating and inputting the model, Frank had me substitute the solution values into the original form of the equations and check that the right and left hand sides of each equation matched to a high standard of accuracy. Once we had satisfied ourselves this was the case, we could proceed with the 100-year projections . After extrapolating the exogenous variables , the computer was used to "forecast" the projected path of the US economy for the following 100 years[3]. We found that, following a brief settling-down period, the system was monotonic. I remember feeling quite disappointed in this result. Nowadays, I would feel reassured by this finding, but it admittedly lacks in inherent drama.

The next step[4] in our search for business cycles in the model's dynamics entailed the imposition of random shocks to test whether we could induce cyclical behavior. Two types of shocks were imposed: shocks on the exogenous variables (type 1) and shocks on the equations (type 2). The latter class of shocks could represent: missing variables of episodic impact; slightly misspecified functional forms; omitted interconnections among parts of the model; aggregation errors from micro-behavioral relationships; and model parameters set at their mean values but actually subject to stochastic variation. The introduction of these shocks constituted, I believe, a first application of Monte Carlo techniques to economics.

We assumed that both types of shocks were distributed normally. To implement the shocks in the model economy, we therefore needed two things: a random-number generator to select the magnitudes of the shocks and a Gaussian frequency distribution. No random-number generating subroutines existed at the time. Frank was trying to invent one, on the blackboard in his office at the radiation laboratory, when Lawrence walked in. In the space of ten minutes (!), Lawrence wrote a computer code that would generate random numbers between 0 and 99. To impose the normally distributed random shocks, the Gaussian distribution was subdivided into 100 regions of equal area, but differing in length, and each region was assigned both the normal deviate associated with its midpoint and an integer between 0 and 99. The random number thus selected both a specific area of the normal distribution and its random deviate, producing a set of normally distributed random shocks.

Our computed results indicated that, when compared with actual US experience since the second World War, the type 1 shocks yielded swings of right duration but much smaller amplitude. By contrast, the type 2 shocks resulted in cycles that were right in both amplitude and duration.

At this point, Frank turned to me and said: " There is some *prima facie* evidence that the shocked Klein- Goldberger model offers a correct approximation to actual US reality. It is now up to you to validate the shocked model in detail". I was surprised, since it seemed to me that we had already validated the model in sections 1-8 of the paper. But I accepted his dictum and proceeded to test the model extrapolations under type 2 shocks more stringently. To this end, I applied the National Bureau of Economic Research (NBER) procedures developed by Burns and Mitchell (*Measuring Business Cycles,* National Bureau,1946 and Mitchell *What Happens During Business Cycles*, National Bureau 1951) to the study of business cycles in the United

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[3] We reported on the work to this point at the winter meetings of the Econometric society in December 1957 (abstract in *Econometrica* 1958, p 621.)

[4]We showed the Econometric society paper to Lawrence. He was intrigued and granted us another free hour of computer time. This was sufficient to complete the work, since for the shocked dynamics, since we restated the model in terms of differences from its non-shocked projections, which we inputted.

States to the model-generated extrapolations under type2 shocks. When the model-extrapolations were compared with their NBER-computed US counterparts, the comparison indicated close correspondence. The degree of clustering of peaks and troughs, the mean durations of the expansion and contraction phases of the business cycles, the lead-lag relationships among specific time series, and whether the peaks (troughs) were coincident or inverse all matched very closely. We therefore concluded that the Klein-Goldberger model offered a potentially useful approximation to reality.

Working with Frank on this paper taught me a great many important lessons. In particular, I learned about scientific method. Graduate school had left me with the attitude that *a priori* theory is "king" and that structured empirical fact-finding is "grunt-work". Instead, what I learned from Frank while working on this paper, is that theory provides a set of structured stories based on stylized facts. The validity of these stories needs substantial testing. Furthermore, the stories are provisional and subject to refinement and change as further, or better data become available or as new events (innovations, in Herman Wold's terminology) occur. I also learned about scientific integrity (not shading findings, even if disappointing; standing ready to facilitate replication of results by other investigators– a common procedure in physics[5]) and the duty not to overstate or over-interpret the import of one's findings. In sum, I learned that all science consists of temporary truths that are subject to further refinement, testing, modification, or rejection as more comprehensive, more accurate or new information is acquired or as new econometric techniques are developed.

[5]We carried 3 boxes of computer cards in our several cross-country moves, discarding them only when IBM mainframes became technologically obsolete.