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Introduction

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The two papers in this section describe aspects of econometric computational developments during early years of the use of the electronic computer by economists. These papers and this journal section itself are part of an ongoing effort to bring to light the details of this use, a clarifying effort that began to achieve traction most noticeably in 2004 with the simultaneous publication of a special issue of this journal as a book [17]. Prior to that there was rather minimal general recognition that the common tendency to under-report the computational aspects of applied economic research during the fifty years after the introduction of the electronic computer made it difficult not only to evaluate this research properly, either at the time or subsequently, but also to perceive particular implications [19]. This difficulty is most pronounced for the years that computation facilities were both limited and somewhat rustic, a time period that extends well into the 1970s and perhaps somewhat beyond, but even this aspect was made less apparent by a widespread seemingly blithe acceptance that there was no story to tell beyond the superficial. This surface stillness has cloaked the reality that the development of computer software, and computational facilities generally, have in various important ways both shaped and conditioned research findings and, in addition, played a role in the development of both economic and econometric theory. In contrast, as more complete accounts have been published, it is becoming progressively more evident that with sufficient documentation of applied research findings a much more richly nuanced story quite naturally emerges, among other things leading to a greater general appreciation of the implications of the particular effect of changes in research technologies over time.

The first of the papers is by Irma Adelman, who, with her husband, in 1958 wrote another that has since become recognized as a classic, path breaking in its examination of the dynamic properties of the Klein-Goldberger model and inferentially those of the United States economy this model represented [17]. The original article has been reprinted at least twice: as well as in *Econometrica*, the original locus of its 1959 publication, it can for example be found also in Zellner's *Readings in Econometric Statistics and Econometrics* [25] and Gordon and Klein's *Readings in Business Cycles* [10]. From that day to this, it has continued to be cited, thus further affirming its seminal impact. The specific reason to mention this earlier article is its close relation to the paper published here. This new paper describes for the first time some

generally unknown aspects of both the original research and its particular context. A significant aspect of this research is that it marks a computational milestone, for it involved the first attempt to solve an econometric model using an electronic computer. To someone sufficiently knowledgeable, this aspect was actually evident from the beginning. It is stated on the second page of the article that a computer was used, an IBM 650, but this mention has a disclaiming, "piece of cake" quality: "Since the problem is about the right size for the IBM 650 calculator, and since the appropriate computing facilities exist[ed] at the University of California Radiation Laboratory, we programmed the equations for that machine." The paper published here demonstrates the degree of laconic understatement that this comment actually represents.

The machine used is itself historically interesting. The IBM 650 was originally announced in July 1953, and was later installed both at the University of California and the Thomas J. Watson Scientific Computing Laboratory at Columbia University, among a final total of approximately 2000 places worldwide during the 1950s. It was a Magnetic Drum Data Processing machine (sometimes called the "Magnetic Drum Calculator" or MDC). Not quite correctly, it has sometimes been described by IBM as it first computer, but there is no question that it was IBM's first significantly profit-making computer. The machine was programmable in decimal, rather than binary. It was a punched card machine with, as just indicated, a magnetic drum memory. It used vacuum tubes. It was, for that day, a relatively cheap machine, costing approximately a half-million dollars. However, it is also true that a modern Palm PDA, selling for less than $300, is considerably more powerful and faster, with many times the storage capability, not to mention wireless connectivity and other aspects not shared with the IBM 650.

There are several both interesting and notable aspects of Irma Adelman's paper, describing the use of this machine. The first is the sheer cost of use: an hour of machine time considerably exceeded her monthly salary then; therefore, the possibility of a mistake, leading to a few minutes extra machine operation, was obviously something to ponder each step of the way. The second is that the Adelmans worked at night. Throughout the entire mainframe era, those who needed to get something done quickly worked through the night. Computers in those days had multiple users; this was the time of day that provided the best turnaround, when only the most serious were awake. Third is the quite significant absence of any high or medium level programming language. Actually, Fortran had been introduced in 1957 [1], but its spread was slow, so that their use of the IBM 650 involved the need to program in its much more primitive machine language. Machine language is directly the native language of a computer, a set of *numeric* instructions specific to its particular Central Processing Unit, designed to be processed without translation. An example of an IBM 650 machine language instruction is:

1 271 314 577

which, as Donald Knuth [14] recounts, means "Add the (floating point) number in location 271 to the (floating point) number in location 314 and put the result in location 577". Building a program from such instructions is like building a house brick by brick. Actually, the alphanumeric codes to which Adelman refers in her paper indicate her use of Assembly Language, the instructions for which correspond one for one with machine instructions, yet providentially provide some mnemonic assistance. Even using Fortran, to invert a matrix or other similar operation can involve as many as 60 or more code statements. However, using either Assembly or machine language instructions, rather than Fortran or some other "high level" language, can involve literally thousands of primitive commands of this type, a factor of 10 or more comparatively. The appropriate inference to draw is that operating a computer in this way, as the Adelmans did, is essentially analogous, in its immediacy and ability to concentrate the mind, to flying an airplane within the first few years after the Wright brothers' first flight.

The second paper is written by Meghnad Desai, who describes his use of the Univac I and II in the early 1960s, as well as a particular desktop calculator, the Monroematic, as it was called. Desai describes particular aspects of his applied economic research then, including his construction of the first econometric model of an industry, the world tin industry. The Monroematic calculator is historically interesting, in part because not only was it used by economists during the early 1960s and before, in much the way that Desai describes, but also because of its sustained use by some economists, such as Michael Evans, even as late as 1967–1968 to solve even relatively large econometric models, like the Wharton Quarterly Econometric Model of the United States. At about that time, the electronic computer finally came into its own for this purpose, albeit only comparatively speaking in these years [18, 20]; more years would pass before it actually became *easy* to solve such a model. Desai's paper is interesting for its depiction of a transitional time during which both desktop calculators and the electronic computer were used, much as horses and internal combustion vehicles shared the roads even into the 1930s. The last cavalry charge apparently occurred in Poland in 1939 and pitted horses against German tanks. Somewhat analogously, but without the same tragic results, Desai describes how he spent hours mechanically calculating the solution of an econometric model, or estimating its parameters, before economic software was commonly available to perform these tasks, notwithstanding the ostensible availability of a computer.

The computers Desai employed are also notable. The Universal Automatic Calculator, which Desai refers to as Univac I, although used by him well after its original introduction in 1951, was in fact the first electronic computer to be commercially produced and sold. The prototype was delivered to the US Bureau of the Census that year. Another Univac I was famously used in an election night television broadcast in 1952 to predict the outcome of that year's presidential election. Prior to this, electronic computers were themselves university research projects, although the ENIAC (Electronic Numerical Integrator and Calculator), the first fully electronic computer, developed by a team led by Presper Eckert and John Mauchly at the University of

Pennsylvania beginning in about 1943, was in fact funded by and developed for the use of the US Army as part of the war effort [3,8,9,21,22]. However, in 1945, before this machine became operative, a successor machine also began to be created by this team, the Electronic Discrete Variable Computer (EDVAC), which was designed as a *stored program* electronic computer, the type of machine that is called a computer today. The Univac I was the direct successor to the EDVAC, although actually they both began operation at about the same time in the early 1950s. The design of the EDVAC was the subject of a famous course of lectures in the summer of 1946, the *Moore School Lectures* [4], which communicated aspects of the design of both it and the ENIAC to a group of attendees who gathered from many parts of the world. The first unified description of the EDVAC's design was written in 1945 by a consultant, John von Neumann [15], who as it happens is also credited with writing for it the first prototype computer program [13], and who is perhaps much better known to economists for his seminal work on Game Theory. The first stored program computer to become operative, in 1947, the Electronic Delay Storage Automatic Calculator (EDSAC), also coincidentally the first computer actually to be used by economists, in 1951 [18], was developed at the University of Cambridge, but was a near relative to the EDVAC [23,24]. Such were the historical complexities of this design story, which is too involved to be considered further here.

Desai's paean to the Monroematic serves as an interesting counterpart to Arthur Goldberger's previous description, in an earlier issue of this journal [7], of his and others' use of desktop calculators for the estimation of the Klein-Goldberger model. As Goldberger points out there, these machines were such a general part of an applied economist's life in the 1950s and early 1960s that the first edition of Klein's textbook, in 1953 [11], as well as Goldberger 1964 textbook [6] each explain, "in gory detail," the so-called Doolittle method employed in order to obtain parameter estimates using them. Milton Friedman, in another context [5] also recalls, not altogether fondly, that in the late 1940s it could take hours to calculate OLS estimates, possibly an entire day. Robert Summers, in an email, has described trekking from Yale University to Columbia University as a graduate student in the 1950s, in order to make use of the IBM 650 there, instead of a desktop calculator. Prior to the middle 1960s, most economists who did applied research had at least some contact with these electromechanical machines. Consequently, Desai's account can be read as describing a common experience of the time.

However, as his paper also makes clear, he is in fact a member of that generation of economists who, as graduate students in the early 1960s, were on the leading edge of the more general use of computers. The Adelman experience was an unusual one for an economist in the 1950s. As she by implication explains, even as late as 1958–1959 the electronic computer was difficult for the average economist to gain access to, as well as being even extremely expensive to use. In contrast, Desai, in common with many member of his generation, found computers to be more plentiful and accessible, if often still expensive to use. The newest of these might even incorporate transistors, rather than unreliable and slower vacuum tubes, but were nevertheless

almost always made available to potential users bereft of econometric, or any other application software [2,16,18]. Particularly if they had no prior experience with desktop calculating machines, graduate students at that time found themselves at a fork in the computational road, forced to decide whether to learn to program or to crank for hours. In reality, the amount of time then required to perform the necessary calculations as research assistants, or to write an applied dissertation, was probably quite nearly the same, whichever choice was made: time spent in brute force Doolittle-type calculations or time spent learning Fortran and writing computer programs from scratch. Almost a coin flip. This was the situation in the early to middle 1960s.

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