

# The History of the Phillips Machine

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## 1 Introduction

When A.W.H. ‘Bill’ Phillips died in Auckland in March 1975 aged sixty he was mourned in a very personal way by many friends, who remembered a gentle, shy man with a wry sense of humour, and one who (in their eyes) was always absurdly modest about his major contributions to post-war economics.

He was best known to the world at large for the original exposition of what later became known as the ‘Phillips Curve’ (a name he would never have given it himself). The curve summarised the UK experience of the associated movements of the level of unemployment and the rate of wage inflation over the course of the business cycle. The relationship was seized on as showing the trade-off between unemployment and inflation faced by government policy. It was subsequently argued that the relationship was more complex than Phillips’ formulation allowed, in that the trade-off disappeared if the Phillips Curve was extended to include certain types of expectations mechanism. In a sense, therefore, Phillips’ work was an indirect progenitor of important later theoretical developments, in particular the systematic analysis of the role of expectations in macroeconomics.

To a smaller group of friends he was remembered also for the ‘Phillips Machine’, a hydraulic model of the UK economy about 7 feet high × 5 feet wide × 3 feet deep, in which the circular flow of income was represented by red water flowing round in clear plastic tubes. The machine was initially developed in 1949–50, and its heyday was the early 1950s.

This article is about the machine and its origins. It is in part a chapter in the biography of a remarkable man; in part a chapter in the history of economic thought; and in part a chapter in the life of the London School of Economics.

## 2 Bill Phillips

### *Pre-LSE days<sup>1</sup>*

Bill Phillips was born on 18 November 1914, the son of a New Zealand dairy farmer. He left school at fifteen and was an apprentice engineer until 1935. Succumbing to a travel bug which he had resisted for some time, he then set off for Australia. After a number of casual jobs (which included running a cinema) he worked for six months in the outback as a maintenance shift electrician. Thereafter came a spell of hunting crocodiles, an electrician's job at a gold mine, and a job with the Brisbane Council Electric Department.

In early 1937 he decided to go to Britain via China and Russia and, after various complications (including the Japanese declaration of war on China), reached London via the Trans-Siberian railway in November 1937.

Before and during the journey to Britain he had been taking a correspondence course, and obtained his formal qualification as an electrical engineer in London in 1938. He had several jobs, including one with the County of London Electricity Supply Company, and also registered as a part-time student at the LSE in 1939–40.

When war came he joined the RAF, and in January 1941 was sent as an Armament Officer to Singapore. He worked in Burma and Singapore, which he left on the *Empire State* bound for Java in February 1942. The ship was attacked by enemy aircraft, whereupon

he obtained an unmounted machine gun, quickly improvised a successful mounting and operated the gun from the boat deck with outstanding courage for the whole period of the attack, which lasted for 3 1/2 hours. Even when the section of deck from which he was operating was hit by a bomb, Flying Officer Phillips continued to set a most valuable example of coolness, steadiness and fearlessness to all in his vicinity (citation accompanying his MBE, cited by Blyth 1975, 304–5).

In Java, he was eventually captured by the Japanese, and spent the rest of the war in a POW camp, where he learned Chinese and also some Russian from fellow prisoners, became interested in sociology, and developed a bad nicotine habit (anyone who remembers Bill sees him with an untyped cigarette in his hand).

### *At LSE 1946–50*

#### *Student days*

Returning to England, Phillips registered for the B.Sc. (Econ) 1946–49, special subject sociology. '[H]e embarked on it partly as a result

of being unsettled about his future at the end of the war and intended it merely as an adjunct to future engineering work' (letter from Valda Phillips, 7 April 1988). During the degree, however, he was deflected from sociology. In those days all B.Sc. (Econ.) students were required to do at least one paper in each of part I and part II of the degree in each of economics, government and history. Faced with compulsory economics, he developed a great interest in the subject and, like many of his generation, became very caught up by Keynesian theory.

Though he was fascinated by economics, the Keynesian model was hard going. He found help in two forms. First, he fell back on his engineering training: he saw that money stocks could be represented by tanks of water, and monetary flows by water circulating round plastic tubes. Second, his growing understanding of economics and increasing ability to translate economic concepts into hydraulic ones was fostered by his association with Walter Newlyn, an economics student one year ahead of him, who was shortly to take up a Lectureship at Leeds University (and who later became Professor of Development Economics there). It was from Newlyn, at least as much as from the Professors of Economics, that Phillips learned his monetary economics. Newlyn saw the rough early drawings of the machine, encouraged Phillips to build one, and was later instrumental in arranging for the Economics Department at Leeds to pay an advance of £100 for materials, thereby, as it subsequently turned out, commissioning the first machine (Newlyn 1950).

With hindsight it is clear that in the latter part of his student days, economics must have taken up almost all of Phillips' time. He ended up with a Pass degree in sociology, which subject he then practically abandoned.

After completing his degree in summer 1949, he received the Leeds advance of £100 (about £2,000 at 1998 prices), bought a number of perspex tubes and valves and:

found in Mr and Mrs Langley of Croydon a host and hostess who were ready to take him into their house and to turn their car out of their garage, in which improvised workshop Mr Phillips constructed the hydraulic model... (Meade 1951b)

### *The Robbins seminar*

Having spent the summer and early autumn of 1949 working on the machine:

Mr Phillips had next to persuade the scientific world that it was a serious instrument. There are rumours of learned professors and dignitaries of the Royal Economic Society, as they walked from the entrance of the School, towards the

lift, being interrupted by a wild man from New Zealand waving blue prints in one hand and queer shaped pieces of Perspex in the other. (Meade 1951b)

Reminiscing about this incident a year later in a letter to James Meade (28 September 1950) commenting on a draft of the article from which the previous paragraph was taken, Phillips wrote:

I particularly like your description of my approaching Professor Robbins at the lift. I should perhaps have apologised for my abruptness. Yet it was all intended for the good of the School. I had accepted an invitation by Professor Brown to go to Leeds the next day to discuss the model with him, and was making a desperate effort to give the School another opportunity to get in first.

Robbins asked James Meade (then Professor of Commerce at the School, and well-known as someone fascinated by things mechanical) to see this 'wild man' who had accosted him by the lift. Phillips met Meade for the first time in Meade's office in early autumn 1949, explained the idea of the machine and showed Meade the blueprints. Meade encouraged him to finish building the machine and, because he was impressed (and also to get Phillips out of his office), promised him the chance, if and when the machine was complete, to demonstrate it at Robbins' seminar.<sup>2</sup>

Robbins (1972) on his own admission was sceptical – 'all sorts of people had invented machines to demonstrate propositions which really didn't require machines to explain them'. Nevertheless, in fulfilment of Meade's promise, Phillips was invited to demonstrate his machine at Robbins' seminar on 29 November 1949.

Both Phillips and the machine acquitted themselves well. Everyone who mattered was there (some, according to Meade, having come mainly to laugh). They gazed in wonder at this large 'thing' in the middle of the room. Phillips, chain smoking, paced back and forth explaining it in a heavy New Zealand drawl, in the process giving one of the best lectures on Keynes and Robertson that anyone in the audience had heard. He then switched the machine on. And it worked! He really had created a machine which simplified the problems and arguments economists had been having for years.

#### *Appointment as a temporary engineering consultant*

That the machine made a deep impression is clear from a proposal by James Meade (30 November 1949) to his fellow Professors (W.T. Baxter, E.H. Phelps Brown, R.S. Edwards, F.A. Hayek, F.W. Paish, Sir Arnold Plant, L.C. Robbins and R.S. Sayers). The memorandum played a key part in the Phillips story, and is worth quoting at some length.

I was very much impressed yesterday by the demonstration which Mr A.W. Phillips gave in Professor Robbins' seminar of the hydraulic model... I thought that the machine (quite apart from its obvious qualities of great ingenuity and supreme craftsmanship) served a really useful role as a teaching device. It seemed to me, for example to show with great clarity the connection between the Keynesian and the Robertsonian ways of looking at the market...<sup>3</sup>

From conversation with Mr Phillips, I know that he is very anxious now to write a really scientific account of his model which will show exactly what it is demonstrating about the monetary circulation, and also to consider any modifications which might be made to it both from the point of view of economic analysis and also from the point of view of an instrument of teaching.

I would accordingly like to propose to the Director [Sir Alexander Carr-Saunders] that the School offer to Mr Phillips a Fellowship or Grant at an annual rate of, say £700 for a period of six to nine months for the purpose of writing up for us an account of his model which we could then publish in *Economica*...

Mr A.W. Phillips is a New Zealander, 35 years old, an electrical engineer by training and profession, who... took the B.Sc (Econ) in the summer of this year... specialising in Sociology. He obtained only a pass, but it is clear that in fact Mr Phillips spent most of his time here studying monetary theory – with, I venture to suggest, very considerable success. He studied here with a rehabilitation grant from the New Zealand government, and is under an obligation to return to New Zealand in a few weeks' time.<sup>4</sup> Indeed, I have already had to write to New Zealand House to obtain permission for Mr Phillips to stay as long as this in England to finish the proto-type of his machine. Mr Phillips thinks that we might be able to obtain a further extension of this time but we shall have to act quickly if we wish to keep Mr Phillips here.

The proposal was revised in the light of a number of potential problems pointed out by Sir Arnold Plant. The final form of Phillips' initial appointment was set out in a letter (7 December 1949) from Meade to his fellow Professors and to the Director.

I have been much impressed by Professor Sir Arnold Plant's minute of 2nd December. He mentions two difficulties in the way of my former proposal: first, that Phillips has only a Pass degree so that it is difficult to employ him academically at a high salary; and, second, that Phillips is trying to patent his machine,<sup>5</sup> so that we might be in danger of using the resources of the School to assist a private business enterprise.

To meet these points I revise my proposal as follows: that the School should ask Mr Phillips to build, or have built, for the School a new model of the machine, and that for this work we should pay Mr Phillips at the rate of £50 a month for a maximum of six months plus the cost of the materials and other proper expenses of construction, the total cost of the machine not to exceed £700. This would allow £300 for Mr Phillips' salary for six months plus £400 for the cost to him of getting the machine made...

This proposal should meet both of Professor Plant's points. We should be having a machine constructed in the best manner available to us; and we should be unconcerned with the formal academic record of the constructor or with the question of whether he tries to patent the machine or not...

I have discussed the matter with the Director who sees no objection to this proposal. It would presumably be necessary to have a small committee to watch the construction of the machine...

The New Zealand authorities agreed to extend Phillips' stay up to the end of 1950, though even before the extension came through, Phillips had already announced his decision in a letter to James Meade (11 December 1949): 'I definitely accept the proposal you outlined on Friday [that in the previous paragraph]. I would, if necessary, buy myself out of the bond to return immediately, rather than leave this job half done.'

### *The LSE machine*

The deliberations of the overseeing committee (Professors Edwards, Meade and Phelps Brown) are summarised in a memo by Professor Edwards dated 20 January 1950. The proposal *ex ante* was to pay Phillips £300 (£6,000 at 1998 prices) for the period January–June 1950 to produce a more advanced machine with the assistance of Philip White of White-Ellerton Ltd, a small engineering firm in north London. White was to be paid £400 (£8,000 in 1998 terms) to cover the cost of materials and his own time; and the machine was to be delivered to the School by the end of June. Phillips was also to produce a written description of the machine.

*Ex post* the machine was not delivered until 13 October, mainly because Phillips and White over the course of the spring and summer were unable to resist a variety of ideas for improvement:

Phillips and White have thrown themselves without reserve into the development of the machine and into improving it... Probably if they had been somewhat more businesslike and had refused to be interested in fiddling about to find ways of improving it, we might have got a much less well developed machine by the contract date (letter from Meade to the Director, 7 November 1950).

Phillips and I demonstrated it to my seminar on Thursday; and it's a beauty (letter from Meade to Professors Edwards, Paish and Robbins, 16 October 1950).

A description of this machine both as a mechanical device and as an economic model is given in chapter 10, which, when it was first published in 1950, fulfilled his obligation to produce something in writing (see also Vines, chapter 9).<sup>6</sup>

*Appointment as bona fide economist*

The period August to December 1950 saw a confusing flurry of activity which, with hindsight, can be divided into two separate sets of events. First, by late summer 1950, James Meade was becoming uncomfortable about the amount of unpaid time Phillips had devoted to the machine:

... I feel that Phillips has made rather excessive financial sacrifices. Making the first machine which is now at Leeds University, he lived practically on air for six months while he could have been making a very good income as an engineer; his temporary employment by us was at a substantially lower rate than he could have got as an engineer; and again, from the end of June... he had to live on nothing (letter to the Director 7 November 1950).

Partly to compensate Phillips retrospectively, and partly because the arrangement would be genuinely useful to the Department, Meade therefore proposed to his fellow professors

to pay Mr Phillips at the normal hourly rate for class work which, I understand, is £2.2.-. an hour, for his assistance in demonstrating the machine as and when required during the Michaelmas Term. I would propose a maximum of £100 for the total payment.

Those were unbureaucratic times. The proposal was dated 21 September 1950. Within a few days it had been approved by the professors and then by the director. Phillips' letter of acceptance to James Meade was dated 28 September.

This arrangement, however, was overtaken by the second set of events, which culminated in the offer of an assistant lectureship for the 1950–1 academic year. According to James Meade, some of the professors of economics had wanted to offer Phillips such an appointment in the immediate aftermath of his lecture and demonstration at the Robbins seminar the previous November. But the economists, having earlier criticised the sociologists for appointing people with what they (the economists) regarded as weak academic records, were hoist with their own petard. Phillips was therefore encouraged to embark immediately on a Ph.D. under Meade's supervision, and registered on a part-time basis in January 1950.

It was the reaction to Phillips' article in *Economica*, published in August 1950, which changed things. The paper was doubly original, in that it described the machine and was, in addition, the first application of dynamic control theory to macroeconomics. The story is taken up in a letter from Lionel Robbins to the Director dated 4 October 1950.<sup>7</sup>

Considering the burden of work . . . we [the Professors of Economics] were of the opinion that an effort should be made to provide a further reinforcement here and now.

In this connection we discussed the name of Mr Phillips, the inventor of the hydraulic machine . . . I ought to explain that at an earlier date we had considered the desirability of offering Mr Phillips an appointment. Some of us were in favour of doing so forthwith. Others felt that in view of Mr Phillips' poor performance in the final examination . . . action should be suspended until he had demonstrated by some written contribution to the subject, that this poor performance was to be explained in terms of his somewhat lamentable experiences during the war when confined in a Japanese [POW] camp, he contracted so strong a habit of chain smoking that, without cigarettes in an examination room, he was completely at a loss after an hour. Mr Phillips has now published an article in *Economica* which, we are all convinced, at once puts him on the international map as an economist of profound grasp and originality. As a result of this article, enquiries have already begun to come in from the United States about the further manufacture of machines . . . We do not know whether Mr Phillips could be induced to stay in this country by the offer which we should feel able to make. But it was our unanimous desire that Mr Phillips should be immediately offered an assistant lectureship at the top of the scale. We none of us feel that any further interview at our level is desirable since we all know Mr Phillips very well. If, therefore, you felt that this recommendation was acceptable, all that would be necessary would be for you yourself to see Mr Phillips, and if you were satisfied with him, make him an offer. We feel that this is a matter of some urgency because we know that Mr Phillips is in for a job in New Zealand and we suspect that there may be others coming along from the United States.

The chronology of events is thus:

August 1950	Paper in <i>Economica</i> .
4 October	Meeting of Professors of Economics recommends to the Director the appointment of Phillips as Assistant Lecturer.
Sometime between 5 and 10 October	Director saw Phillips.
12 October	Official letter offering appointment as from 16 October.
19 October	Letter of acceptance from Phillips.
23 October	Phillips took up duties.

Once the appointment had been confirmed, Meade proposed in a letter to the Director (7 November 1950) that to compensate Phillips for unpaid work over the summer, the appointment should be made retrospective by six–eight weeks.<sup>8</sup> In the same letter he raised the possibility of an *ex gratia* payment of up to £50 to Philip White. Thus the School got a machine



that was more expensive, but also much better, than anticipated, and also an Assistant Lecturer in Economics with a Pass degree in Sociology.

The rest, as they say, is history. Phillips' Ph.D., *Dynamic Models in Economics*, was examined by Professor (later Sir) John Hicks on 10 December 1953, and the degree was awarded on 27 January 1954.<sup>9</sup> The New Zealand authorities waived the requirement of his rehabilitation grant that he return to New Zealand. He became Lecturer in Economics in 1951, Reader in 1954, and Tooke Professor of Economic Science and Statistics in 1958.

### 3 Other actors and later years

#### *The machine*

The success of the prototype machine together with the *Economica* paper in 1950 thus gave Phillips the possibility of an academic career. The initial opening was the reward for his ability and his tenacity working on the first machine in the garage in Croydon over the summer of 1949. Even so, little might have come of these efforts, apart possibly from a long-forgotten mechanical curiosity, had it not been for James Meade's enthusiastic support. Meade encouraged Phillips while the machine was being built; lobbied academic colleagues at LSE and elsewhere on Phillips' behalf; wrote to the New Zealand authorities supporting Phillips' request for an extension of his stay in Britain; and organised sufficient employment to keep body and soul together.

The relationship between the two of them, on the surface, appeared formal, as fitted the custom of the times. Phillips' letters always started 'Dear Professor Meade', Meade's letters began 'Dear Phillips'. In a rather English way, however, informality crept in between the lines. Phillips' letters were always handwritten, sometimes scrawled on rather tatty bits of paper with crossings out from time to time, and with occasional glimpses of what was obviously becoming a warm friendship. The texture of the relationship emerges in a letter of 6 September 1950, at a time when Phillips, his six months contract having expired at the end of June, was working unpaid with Philip White on the first LSE machine.

Dear Professor Meade,

Thanks for your note. I was sorry to hear of the tragic ending to the great kite enterprise, just when it was so near to success. I think even the fish must have felt a little sad about it. Better luck next year!

Thank you for writing to Auckland for me. I enclose a copy of my application...

Miss Bevan has typed out Professor Robertson's letter, and I enclose the original and two copies. I will let you have a copy of a reply in a few days, and also try to decide about difference and differential equations, though my knowledge of the former is, to put it mildly, rather sketchy.

The machine is going fairly well, it does at least look a little like a machine and if there are no unexpected snags should be ready by the end of the month. Production has also started on the next four, though an official order has been received only from Manchester. Cambridge have still not confirmed their order in writing, but I hope they will do so soon.

Professor Lerner was here the other day and was quite intrigued by the machine. He will try to arrange for Roosevelt College, Chicago, to order one as soon as he returns at the end of this month. The AEA [American Economic Association] Conference takes place in Chicago this year, and he would like to install a machine at his College for demonstrations. He has a new book in print in which he uses a lot of diagrams of water tanks and things; but it is based on definitional identities between  $S$  &  $I$ , and  $Y$  &  $E$ . He said he was rather puzzled by the fact that they could be different in our model; but I don't think he was really so puzzled as he professed. I find this rather amusing, since it was my dissatisfaction with his article using the  $S$ ,  $I$  identity to 'prove' that the 'classical' theory was completely fallacious that started me off looking for a technique which would show the process more clearly than is possible with two-dimensional graphs.

I should be at White's place most of the time for the next few weeks, so come along at any time if you would like to see how things are going.

Yours sincerely,  
A.W. Phillips.

It is a tribute to Meade that he took steps to make sure Phillips was not exploited, and a tribute to Phillips that at the time the letter was written he had no idea that within six weeks he would be offered an Assistant Lectureship.

As we saw earlier, other members of the teaching staff were involved to a lesser extent in the machine's early days, notably Robbins, and also Edwards and Phelps Brown who, with Meade, oversaw the building of the first LSE machine. Once the initial model was delivered, its presence was made known by a circular from James Meade dated 20 October 1950.

The Phillips-Hydraulic Machine is now installed, locked up in a cupboard, in Room 216. The key of the cupboard is being kept in the Porter's Lodge. The Porter's Lodge have instructions to give the key to all Professors and Readers in the [Economics and Statistics] departments, and to all other members of the teaching staff whose names are given to them. Would you let me know if you would like to have your name added to this list? It would be a wise precaution if, before using the machine, you would get Mr Phillips to show you how to operate it – and, incidentally, how to operate the cupboard!

To those who knew them later in their careers, the replies from a number of Young Turks were characteristic.

Could my name please be entered on the list of persons authorised to interfere with the employment engine? John [Jack] Wiseman

I should be grateful if my name might be added to the list of those who may obtain the key of the machine. H.C. Edey

Please add my name to the list of those entitled to the key of the machine cupboard. R. Turvey

Will you have my name put on the list of those able to use the key to the machine please? Alan Day

Work on the machine continued into the early 1950s and, as discussed later, a number were sold to other institutions both here and in the USA. But the advent of computers meant that the machine was not the success in purely commercial terms that Phillips, in its very early days, might have hoped. Colleagues continued enthusiastically to use the machine as a teaching device. But even the last generation of machines could be temperamental, and eventually Phillips tired of going to the rescue of colleagues whose classrooms were flooded with water and filled with giggling students. The LSE machines therefore stopped being used sometime during the later 1950s.<sup>10</sup>

### *Other interests*

Phillips, in the meantime, had increasingly become caught up in other academic pursuits, among them a more general interest in the application of computers to economics. In that context he first met Richard Tizard, who in the early 1950s was in charge of the Automatic Control Group at the National Physical Laboratory (NPL), where he had developed a powerful electronic analogue computer. Phillips went to see Tizard, set up a macroeconomic model on the computer, and became very excited at the research prospects it opened up.

Around this time (the early 1950s), however, analogue computers began to be overtaken by digital ones (the difference is explained in n. 16). One of the first digital computers, the Auto Computing Engine (ACE) had been developed after the war at NPL by Alan Turing and others. The ACE never left the drawing board, but the prototype of a smaller version, the DEUCE, was built at NPL, and about six were subsequently produced by English Electric, one of which was installed in their Aldwych office.

A friendship between Phillips and Tizard grew up alongside what became a close working relationship. In consequence Tizard came to the LSE from 1956 to 1958 on a two-year Fellowship in Analytical Economics to work with Phillips and to use the Aldwych DEUCE, to which he was given access out of business hours.<sup>11</sup> Phillips' main interest at the time was the application of dynamic control theory to economic processes, and he and Tizard spent many evenings at each other's homes educating each other, Tizard learning about economics and Phillips developing a substantial expertise in control theory and digital computers.

This line of research (chapters 16 and 17), though highly innovative and, by most people's standards, very successful, was less fruitful than Phillips had hoped and, ever curious, he was moving into new fields, including the work which made his reputation internationally, as described earlier, on the Phillips Curve (chapter 25). He also developed an increasing interest in Chinese economic development.

In 1967 he moved to a chair in Economics at the Australian National University. The move was partly because he and his wife, Valda, wanted their daughters to grow up nearer their relatives; partly to further his Chinese studies; and partly because he was becoming restless and, after over twenty years there, increasingly unenthused about London (Yamey, chapter 35).

His years at ANU were active and fruitful, and included the foundation of a Centre for Contemporary Chinese Studies. In 1969 he suffered a major stroke and retired to Auckland, where for his last five years he continued to conduct a seminar in Chinese economic development.

## **4 The machine**

### *Description*

I shall describe the machine only in outline, since it is essentially so visual that attempts to explain it in writing almost inevitably become laborious. Readers seeking more detail are referred to Phillips (chapter 10), and Vines (chapter 9), or for detailed mechanical description to Moghadam (1988).

#### *The machine as an economic device*

A very simplified version of the machine is shown in figure 11.1. The circular flow of income leaves the transactions balances tank at the bottom, is pumped up the tube on the left, and then cascades down the central column. The government sector (top left) consists of taxes leaving

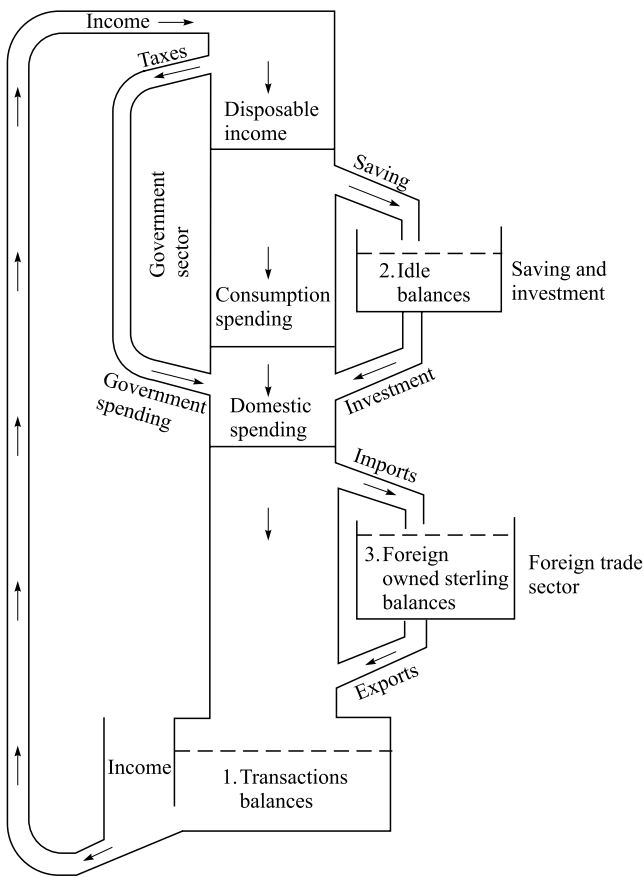


Figure 11.1 A simplified view of the Phillips machine

the circular flow and government spending entering. Saving (top right) leaves the circular flow, and investment adds to spending. The foreign trade sector (bottom right) consists of imports leaving the domestic spending cycle, and exports adding to it.

In terms of simple national income accounting, total income,  $Y$ , enters at the top; taxes are siphoned off leaving disposable (that is, after-tax) income; saving flows out of the central column, leaving consumption spending. To consumption,  $C$ , is added investment,  $I$  (flowing in from the right) and government spending,  $G$  (flowing in from the left) to give total domestic spending, from which imports,  $Q$ , are then deducted and exports,  $X$ , added. The machine thus shows visually the equilibrium condition

$$Y = C + I + G + (X - Q)$$

which should raise at least familiar echoes for those who once-upon-a-time did first year economics.<sup>12</sup>

The three tanks in figure 11.1, representing stocks of money, are crucial to understanding the machine. Transactions balances (tank 1) are used to finance expenditure: water flows from tank 1 through a slot into the adjacent box, the rate of flow being proportional to the height of water in the tank. Other things being equal, therefore, the higher the level of water in tank 1, the larger the income flow. Idle balances (tank 2) are broadly what Keynes called speculative balances; other things being equal, the higher the level of water in the tank, the lower is the interest rate. Foreign-owned sterling balances are contained in tank 3; the higher the level of water in the tank, the lower the foreign exchange value of sterling/the larger the UK balance of payments deficit.

Figure 11.2 shows the machine in somewhat more detail. The inflows and outflows are determined by a system of valves which open and close depending on the level of water in the three tanks, and on the flow of income. The connection is complicated in practice, but simple enough in principle. In some cases a float on top of one of the tanks is connected to the relevant valve via a cord and a pulley; as the level of water in the tank falls so does the float, exerting a downward pull on the cord. The downward pull, depending on the economic relationship involved, either opens or closes the valve. Thus if income goes down, consumption also goes down (that is, the consumption valve will partly close); if the interest rate goes down, investment will go up (that is, the investment valve will partly open). In other cases (for example, the effect of domestic expenditure on imports in figure 11.2) a similar effect is achieved by a small float connected to the relevant valve via a servo mechanism, which uses a small motor to amplify any downward or upward movement of the float.

The underlying economic model is as follows:

Saving, at a given level of taxation, is determined by the level of income (that is, the rate of flow of water into the top of the central column) and the interest rate (that is, the level of water in tank 2). Consumption is what is left of disposable income after saving has taken place; consumption and saving are thus determined simultaneously by the level of income and the interest rate.

Investment is determined by the interest rate (tank 2) and the *rate of change* of income. (This so-called accelerator model of investment is amazingly cleverly done mechanically, but explanation would be laborious.)

Taxes and government spending are determined by the level of income.

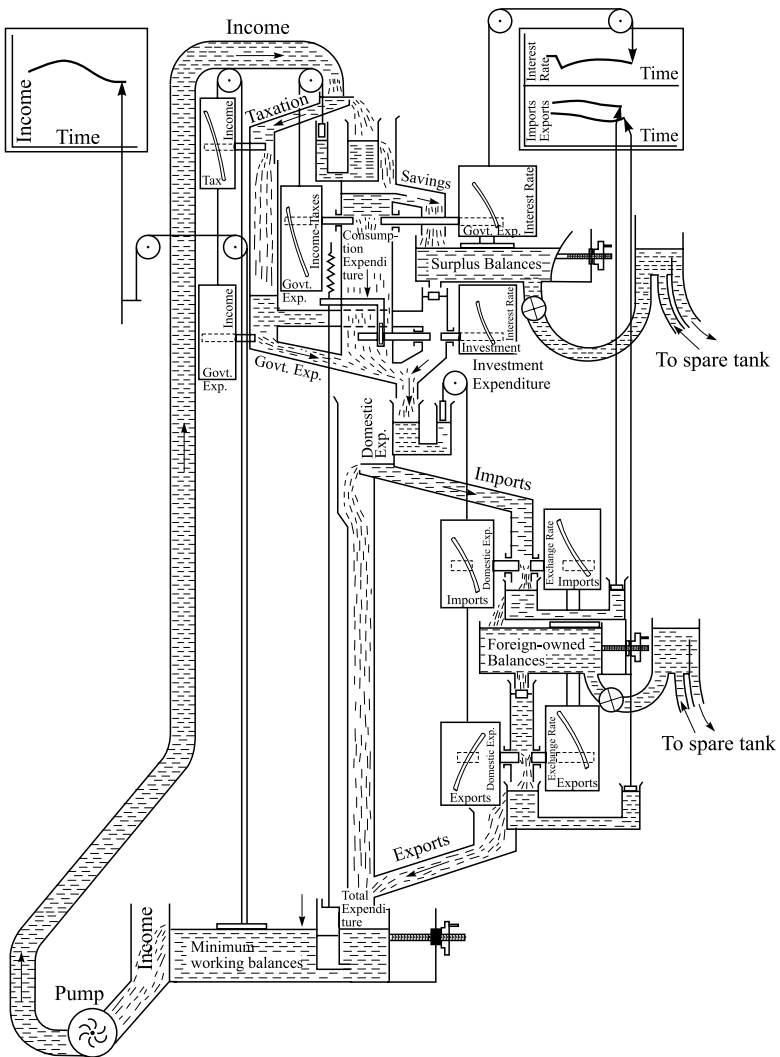


Figure 11.2 The Phillips Machine in more detail

Imports and exports are determined by domestic expenditure (via a servo mechanism – see figure 11.2) and by the exchange rate (tank 3).

In terms of economic theory the machine represents an open-economy IS-LM model.<sup>13</sup> The theoretical set up is very flexible. The operator can

change the form of any of the relationships determining consumption, investment, etc. Depending on the exact way in which the monetary sector is set up, it is possible to have either a 'Keynesian' model, in which expansionary fiscal policy (e.g., higher government spending or lower taxation) is effective in increasing output and employment, or a 'Classical' model, in which fiscal policy has no effect on output. It is also possible for government to engage in deficit financing by tapping idle balances (tank 2) to increase its own spending, thus avoiding the need to increase taxes.

In addition, tanks 2 and 3 are connected to a spare tank (see figure 11.2). Opening the connection between tank 2 and the spare tank acts to keep the level of water in tank 2 constant (that is, the interest rate is fixed, and the money supply is free to vary); if the connection is closed, the money supply is fixed and the interest rate will vary. Similarly, opening the connection between tank 3 and the spare tank acts to keep the level of water in tank 3 constant, thereby fixing the exchange rate. It is thus possible to have different monetary regimes and either a fixed or a floating exchange rate.

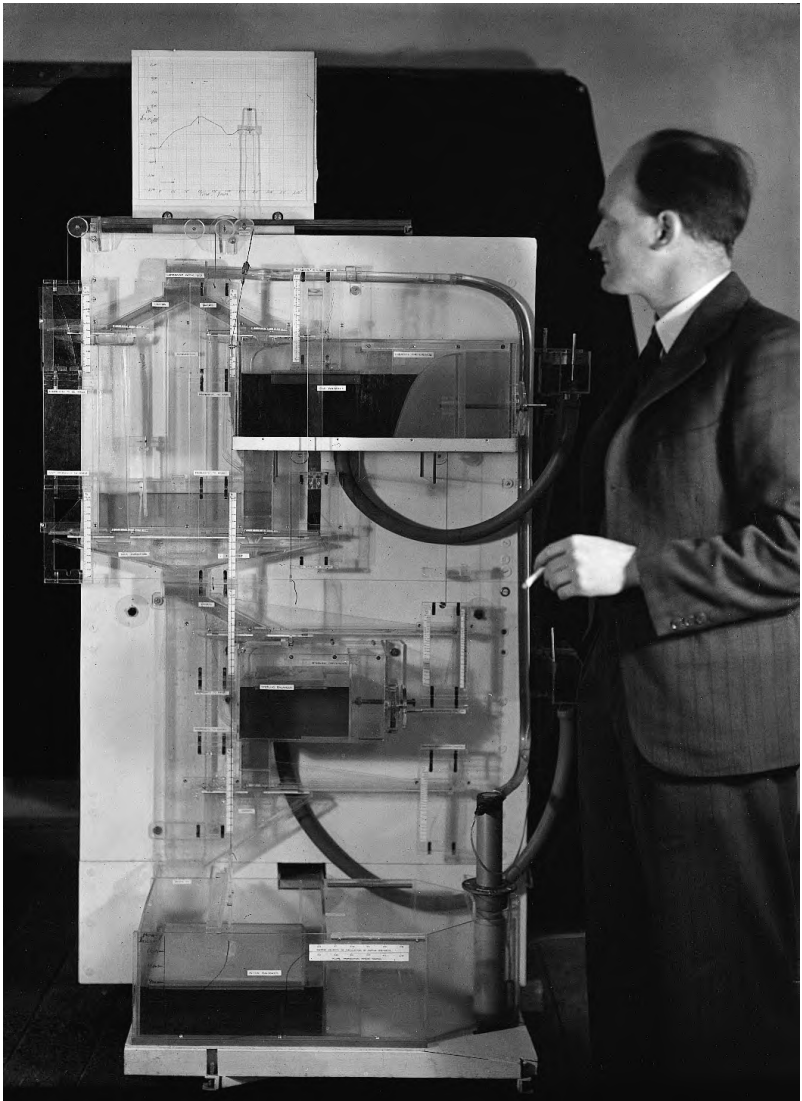
We could therefore use the machine to examine the effect on income, the interest rate and the exchange rate of, say, a tax cut in a world of floating exchange rates, and with fixed UK money supply. The machine does not merely give a qualitative answer: it is calibrated to an accuracy of  $\pm 4$  per cent; and the IS-LM model on which the machine is based has an explicit dynamic structure. In plain English, both the new level of income and the other variables, and the time path from the old level to the new level are accurate in terms of the underlying theoretical model. The time path of income, the interest rate, imports and exports is traced out by plotter pens (see figure 11.2), making it possible to analyse the quantitative effects of policy.

#### *The machine mechanically*

A photograph survives (see p. 105) showing Bill Phillips some time in 1950, cigarette in hand, with the machine, which visually has the magic of a Heath Robinson device at its finest, as red water flows through the complex system of tubes, valves and tanks. Whilst this adds to the enjoyment (without exception, the machine in action gives people pleasure), it should not be allowed to obscure the machine's originality,<sup>14</sup> all the more since the early models were built very much on the cheap, using war surplus items (the pumps on the original machine came from a Lancaster bomber).

It was the Heath Robinson aspect which attracted *Punch* (15 April 1953, p. 456; see p. 107 below).





[The machine] will tell at a glance the exact effect of a recession in sheet-music on, say, the Birmingham fancy-goods trade. It is held, virtually *incommunicado*, at the London School of Economics. But it should properly belong to the world...

Our point could scarcely be made more aptly than on this post-Budget morning. To-day the whole of Britain is talking finance... And the sad thing is that none of them really know what they are talking about – while all the time, tucked

away in Houghton Street, W.C.2, is a creature capable of clarifying the whole situation before the man in the street could say John Maynard Keynes.

The machine is taller than the man in the street, and wider and heavier and much, much cleverer. It is also less reticent about its inner feelings, which are ... exposed in the frankest manner – a complex pattern of transparent tubes, of plungers, sluices, checks, balances, buttons, levers and pulleys, all combining to present an instantaneous picture of the nation's economy... Using coloured water for money (a convenience denied the man in the street) it reacts obediently to every morsel of economic information communicated to it.

... In our view there should be an installation in every town hall (or recreation ground, railway station or dog-track) in Britain... If the State will not step in... what of Commerce? Will not some public-spirited biscuit baron or marmalade mogul, now presenting winners of slogan competitions with the routine £5,000 house, television set and two seats for the Coronation, instead present their home town with one of these invaluable educational aids?...

Meanwhile, and in default of appropriate action by either State or Citizen, a simple model is under construction at this office from the data, necessarily incomplete, at our disposal [see figure 11.3].

*The machine elsewhere.*

The very first prototype (built in summer 1949 in the Langleys' garage in Croydon) was demonstrated at the Robbins seminar, and subsequently at the 1950 meeting of the Association of University Teachers of Economics. As discussed earlier, it then went to Leeds University where, at Walter Newlyn's instigation, Professor Arthur Brown, the head of the Economics Department, had used the departmental equipment budget to buy the machine for £100.<sup>15</sup> The second machine, built by Bill Phillips and Philip White in the spring and summer of 1950, was delivered to the School early in the Michaelmas term 1950. At least one more machine was supplied to the School by White-Ellerton in 1952 at a price of £450. Cambridge University also bought one (which still survives), and so did Oxford, Birmingham, Manchester and Melbourne (Blyth 1975, 305).

Amongst the many people excited by the machine was Abba Lerner, a member of the economics department at the School in the 1930s and, by the early 1950s, at Roosevelt College, Chicago. He had an animated correspondence with Meade and Phillips, and saw the first prototype on a visit to London in the summer of 1950. Lerner became Phillips' US agent, and it was through his efforts that machines were sold to Roosevelt College, Harvard, the Ford Motor Company and the Central Bank of Guatamala. The US machines were calibrated in dollars, and some additional development work went on in America in parallel to Phillips' own work.



## 5 The Machine's significance in the development of economic analysis

The machine contributed to the subject in at least four ways. First, 'it shows the continuous process of change through time of a multi-variable system, after a change in one or more of the variables' (Phillips in a letter to the New Zealand authorities, 10 December 1949). It was thus a dedicated analogue computer,<sup>16</sup> and as such one of the earliest uses, and certainly one of the most persuasive, of computers in economics.

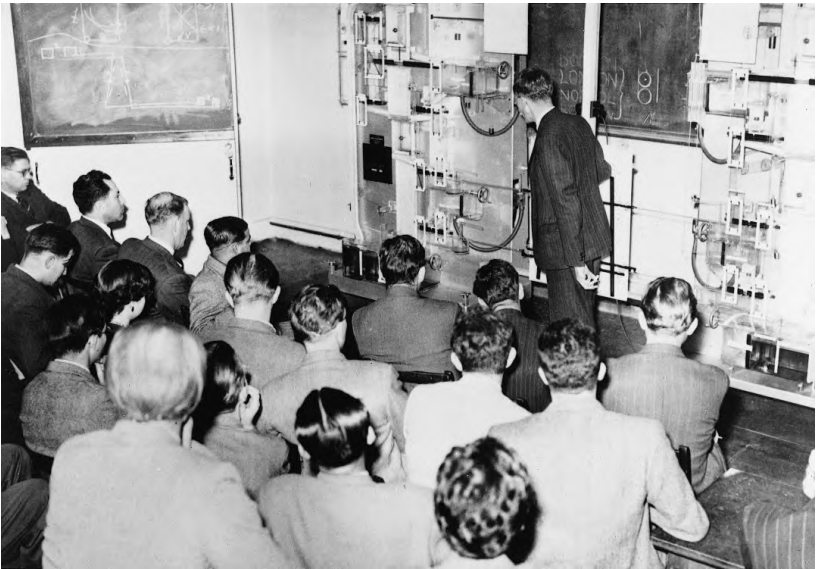
Second, the machine resolved at least one major theoretical controversy, that between the Keynesian and Robertsonian schools of monetary theory. The debate was about the determination of interest rates. Keynes argued that the equilibrium interest rate is determined by liquidity preference, i.e., is that which induces people to hold exactly the available stock of money and the available supply of bonds. According to Robertson, the rate of interest is determined by the demand and supply of loanable funds, i.e., is that which equates the flow of saving with the flow of investment. The Phillips Machine showed clearly how in equilibrium both formulations are valid.<sup>17</sup> 'Keynes and Robertson need never have quarrelled if they had had the Phillips Machine before them' (Robbins 1972).

Third, the machine facilitated policy analysis in a number of ways. At Meade's request the School acquired another machine which was a mirror-image of the first. As he observed:

by far the most important, and from any point of view very exciting, thing which [Phillips] has done is to invent and construct a foreign exchange market. This has enabled us to link two machines together so that the exports of one control the imports of the other at a fixed or at a variable rate of exchange . . . This, of course, is of very great importance for teaching in a country which . . . is so dependent on its foreign trade position (letter from Meade to Andrew T. Court, 6 February 1953).

Thus the two machines formed a two-country world economy: it was possible to show the effect on the UK of, say, a budget deficit in the USA; and it was possible to show the effects of a trade war. The picture (p. 109) shows Meade lecturing with the two machines.

One of the uses to which Meade put the machines was to show the destabilising consequences of ill-considered policy intervention. He would make one student Chancellor of the Exchequer, with instructions to manipulate taxation and government spending so as to achieve a target level of national income; he would then make another student Governor of the Bank of England with instructions to use monetary policy to similar ends. Each student was instructed to ignore the other, to show how counter-cyclical fiscal and monetary policy, if uncoordinated, can



end up making matters worse. With the two machines connected, he would add the US Secretary of the Treasury and the Chairman of the Federal Reserve, and the four students, each acting independently of the others, would show how destabilising policy in one country can readily be transmitted to another and how, in the extreme, an inter-linked international economy can be even more unstable than a domestic economy. Richard Cooper subsequently US Assistant Secretary of the Treasury and Professor of Economics at Yale, said at the time that it was the Phillips Machine which first showed him how much one thing depended on another.

Finally, the machine was visual. It was therefore immensely useful as a teaching device though possibly, given its complexity, more useful for relatively advanced students. Though its calculating functions were fairly rapidly overtaken by digital computers, it still remains the only *visual* model of its type.

## 6 The Machine in recent years

From some time in the mid 1950s the LSE machines were used less and less, and eventually fell into disuse, though rumours still buzzed among students in the mid 1960s.<sup>18</sup>

*Harry Johnson's initiative*

By the early 1970s, Meade was in Cambridge, Phillips retired in Auckland, and LSE's two machines were gathering dust in a cellar. In autumn 1971, Harry Johnson, who had come across the machine in Cambridge in the early 1950s, set in hand a project for restoring at least one of the machines, and roped me in to give a hand. An American undergraduate volunteer, Joe Grundfest, spent most of the 1971 Christmas vacation cannibalising one of the machines to get the other one going.<sup>19</sup> Grundfest was immensely enthusiastic, and with an understanding of economics beyond his years and vacation work experience with swimming pool filtration systems, was ideally equipped for the task. He rapidly established himself as the resident expert on the machine, and his ingenuity and enthusiasm made it possible to demonstrate it to Harry Johnson's M.Sc. Group in the Lent term 1972, as described in the *LSE Magazine* at the time (Barr 1973).

It was clear, however, that the machine was in a very fragile state and really required resources of time and materials beyond those of a vacation project. Johnson therefore suggested a threefold arrangement: I was to track down White-Ellerton (who had moved from their former premises) to see if they could refurbish the machine; he would put up some money and persuade others to do likewise; and the LSE library would be asked to place the machine on permanent exhibition.

White-Ellerton was eventually found. I spoke to Philip White in early 1974. He remembered Bill Phillips with pleasure, and though he no longer had the drawings (they had been thrown out only a year earlier during a spring clean) remembered the construction so well that he felt that the lack of drawings would be no serious problem. Though a great deal of work would be involved, he would be happy to do it.

Nothing came of the venture for two reasons. Harry Johnson, having had a stroke, resigned in mid 1974 and returned to Chicago. His interest in the project continued but, inevitably given the distance, some of the urgency was lost. Second, and crucially, Philip White also had health problems and by mid 1975 felt that the task was too large for him to take on, much though he would have liked to have worked on the machine again.

Though the project was stalled, interest in the machine continued. The Museum of Science and Industry in Chicago, at Johnson's instigation, briefly entertained the idea of restoring it, and there were enquiries from the Science Museum in London, from the BBC (the machine made guest appearances on *The Money Programme* and on *Panorama*), and from Italian television.

*The Imperial College initiative*

Partly as a result of this continuing interest, help was sought from Imperial College. Professor J.R.D. Francis of the Department of Civil Engineering looked over the machine (by then back in the basement and rather the worse for wear) in November 1977, expressed his willingness to help, and was guardedly optimistic about the possibility of overhauling it.

The School gave its permission for the machine to be moved to Imperial College and, after some delay over the organisation of transport, it was on the point of being moved when Professor Francis died. Appointing his successor took time, and was followed by increasing financial stringency, culminating in the major change in the overseas student fees regime in late 1979 after which Imperial College, like LSE, had to concentrate on putting its own financial house in order.

*The STICERD initiative*

The machine continued to gather dust over the 1980s, and though interest and enquiries continued, nothing much happened until spring 1987. Bill Brainard, Professor of Economics at Yale University, visiting the Suntory-Toyota International Centre for Economics and Related Disciplines (STICERD) at the School, asked after the machine, and one afternoon he, Tony Atkinson and I paid it a visit. Tony Atkinson, then chairman of STICERD, took up the running. At his request Bill Brainard and I gave a rough assessment of the necessary work, on the basis of which STICERD's Planning Sub-Committee authorised funding for the machine's restoration.

A post was advertised in May 1987. Remembering Joe Grundfest's success, given his 'double major' in economics and plumbing, I sought someone with a similar background, and appointed Reza Moghadam, who was just completing an M.Sc. in economics at the School, and whose first degree at Oxford was in mathematics and physics.

Moghadam started work in July 1987. The initial intention was that he would put together a set of detailed instructions as to the necessary work, the work itself to be done by an (unspecified) firm of engineers. Moghadam, however, showed great initiative in tackling the job; wanted to do the repair work himself; and brought in Colin Carter, an aeronautical engineer, to add depth of technical expertise.

The two of them worked through the summer; they stripped and cleaned many of the parts; made, or ordered from outside experts, parts to replace those which had broken; installed new pumps and servo mechanisms; and more or less remade the plotters from scratch. The task was largely one of painstaking mechanical detective work,

greatly assisted by permission to inspect the Cambridge machine which, though not working, was much better preserved.

By mid October, after an injection of additional funding from STICERD, the machine, apart from a few small areas, was working well enough to be shown to a fascinated group of STICERD personnel, and to be filmed in action as part of a project on the life of Keynes. Valda Phillips attended the unveiling of the restored machine in 1989. James Meade gave an enthralling lecture and demonstration in 1990, and another in 1992 when the LSE machine was linked with one restored at Cambridge. Care and maintenance of the elderly, brittle material, however, turned out to be difficult. Both for that reason and to make it available to a wider public, the restored machine was transferred to the Science Museum in 1995. It is now on permanent display in the computing section.

The Phillips Machine, like some strange creature striding through the life of the School from 1949 onwards, has left footprints involving some of the LSE's greatest names: James Meade, Lionel Robbins, Abba Lerner, Bill Phillips himself, and in later years Harry Johnson and Tony Atkinson. The machine commemorates a remarkable man and exciting times in the School's history. Bill Phillips made major innovative contributions to economics, of which the machine was only the first, and he rose, seemingly effortlessly, from a Pass degree in Sociology to a Chair in Economics in nine short years. But he was remarkable also in human terms – adventurous, tenacious, insatiably curious, shy, and with a lovely sense of humour. He is one of those rare people memories of whom always bring a warm smile to those who knew him. As E.H. Phelps Brown wrote in the concluding words of Bill Phillips' obituary in *The Times* (6 March 1975):

His personality was as fresh and endearing as his mind was creative. The world of economics was enriched by his restless originality; to be his colleague was to be his friend.

### Notes

Two people in particular have brought the Phillips machine project to life: Professor Tony Atkinson's enthusiastic support made the restoration project possible, Professor James Meade gave permission to consult and quote from his personal papers and both gave valuable comments on an early draft of this paper. I am very grateful also to Mrs. Valda Phillips for permission to quote from Professor Phillips' letters, to Dr G.E.A. Raspin, the Manuscript Librarian at the British Library of Political and Economic Science, for help with the archival material, and to Dr C. Bean, Professor Arthur Brown, Professor W.T. Newlyn, Dr M. Perlman, Mr R. Tizard and the LSE administration for factual informa-



tion and help with earlier versions. None of them should be implicated in errors which remain. The cartoon in figure 11.3 and the extract on pp. 105–6 are reproduced with the kind permission of *Punch*. The restoration work described in this paper was financed by the Suntory-Toyota International Centre for Economics and Related Disciplines (STICERD), London School of Economics.

- 1 Most of the information on Bill Phillips' early years is taken from Blyth (1975), which is based on his biographical note for the *Festschrift* given to Bill Phillips on his sixtieth birthday. A draft of the biographical note was read and corrected by Bill Phillips.
- 2 Recollections of the seminar by Robbins (1972) and Meade (telephone conversation in January 1988), on which this and the following paragraphs are based, are vivid and in complete agreement.
- 3 See p. 108 below.
- 4 New Zealanders who had spent time in a POW camp were eligible for a Rehabilitation Grant from the New Zealand government to pay for their studies. A condition of the award was that recipients studying abroad thereafter returned to New Zealand.
- 5 In the event Phillips decided not to attempt to patent the machine.
- 6 Phillips' paper was written in early summer and published in August – in sharp contrast with today's publication lags.
- 7 The extract from Robbins' letter and the subsequent chronology of events come from the School's records.
- 8 This letter was put before the Appointments Committee on 6 December 1950. The next day the Director wrote to Phillips extending his original appointment as temporary engineering consultant from 1 July to 30 September 1950, and ante-dating his appointment as Assistant Lecturer to 1 October 1950.
- 9 The thesis was submitted after exactly four years, the minimum permissible for part-time registration, a fact which evoked a deep sigh from the current Dean of the Graduate School, beset by the problem of Ph.D. completion rates.
- 10 Those at the School between the late 1950s and mid 1960s might remember a 7 foot high shapeless bundle by the wall in room 237 (now called room A347) near the Robinson Room. The machine at Cambridge was in use for much longer. Tony Atkinson remembers attending a course 'The National Income Machine' in 1964/1965 taught on Saturdays by Richard Goodwin (see chapter 13).
- 11 Most of Tizard's work on the DEUCE was concerned with the development of a comprehensive set of statistical programmes for generating and testing sequences of random numbers for work by Professor Maurice Kendall and Alan Stuart (later Professor of Statistics at LSE). In a telephone conversation, Richard Tizard painted a riveting picture of a large room filled with a mass of valves and wires to which, on occasion, he had to take a soldering iron to repair a faulty connection. Today the equivalent of five million valves is contained in a microchip about the size of a postage stamp.

- 12 Readers wishing to refresh their theory by looking at a first year text should consult one of Begg, Fischer and Dornbusch (1997), Lipsey and Chrystal (1995), or Stiglitz (1993); for an intermediate (that is, second year) text see Dornbusch and Fischer (1994).
- 13 An open economy includes international trade; for details of the IS-LM model see any of the references mentioned in n.12.
- 14 A handwritten comment by Lionel Robbins in May 1978 on a rather facetious article about the machine reads: 'I can't help feeling that [the journalist] has no real conception of the pathbreaking significance of the Phillips invention.'
- 15 In the Department's account to the University of its expenditure, the machine appeared as 'calculator'.
- 16 A dedicated computer has only one use, for example, a computer which is set up *only* to be a word processor. An analogue computer performs its calculations by measuring the strength of an electric current or, in this case, the rate of flow of water, as opposed to a digital computer, which performs its calculations by manipulating binary digits.
- 17 In terms of the IS-LM model, Robertson argued that the interest rate is the outcome of equilibrium in the flow-of-funds market, which is the financial counterpart of saving and investment decisions; the equilibrium interest rate, according to Robertson, is thus a point on the IS curve. Keynes, in contrast, argued that the interest rate is the outcome of equilibrium in the money market, that is, a point on the LM curve. When the IS-LM model is in equilibrium, the interest rate is a point on both the IS *and* LM curves, that is, in equilibrium the Keynesian and Robertsonian formulations are consistent.
- 18 As a nervous undergraduate I was talking to Bill Phillips at a social gathering and told him of the rumours I had heard about a 'pink lemonade national income machine'. 'Yes', he said, 'I built it'. Given the education and enjoyment I have had from the machine since then, I am glad that the large hole in the ground for which I devoutly wished at the time did not materialise. It was typical of his modesty that none of us undergraduates knew anything about his life prior to the Phillips Curve.
- 19 The two machines were Meade's two-country world economy described earlier. The standard Phillips Machine is that illustrated in figures 11.1 and 11.2. Its companion in the two-country model was in all respects a mirror-image. When we inspected the machines in 1971, the latter was in better condition, and so the standard machine was cannibalised to restore it. As a historical accident, therefore, the restored machine is a mirror-image of all the other machines (and also a mirror-image of figures 11.1 and 11.2).