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The Phillips Machine and 3D Models in Economics

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Introduction

Economics can be argued to be a rather abstract science. Sciences such as physics, biology, and history are characterized by intriguing objects. Museums are full of items like celestial spheres, dissected animals, and paintings of historic events. Yet, it is rare to find objects related to economics as a science. It is in fact difficult to picture how such an object might look. Economics is known for its theorems and graphs. Since the birth of economics as a separate science in the eighteenth century, numerous economic models have been developed but the bulk of these remained on paper. The models took the form of graphs, theoretical tales, or, more recently, statistical programs. One fascinating exception can be named, however, namely the Phillips Machine. This is a 2 by 1.2 by 1 meter three-dimensional model. The first version was built in 1949 by the engineer and economist Bill Phillips as a representation of the Keynesian macroeconomy. The Phillips Machine captivated economists at its first introduction and it is still an object of fascination nowadays. Around fourteen machines were built. They can be found at display in universities, museums, and economic institutions all over the world. Nevertheless, it remained the only well-known three-dimensional economic model, despite its success. This begs the question: Why? Bill Phillips showed that constructing a three-dimensional economic model was feasible and fruitful, so why were no other 3D models built? This is the question that this thesis seeks to answer. More formally, the research question can be stated as: Why have no other 3D models of significant meaning been developed in economics, after the Phillips Machine? The question will be analyzed from two different viewpoints. On the one hand, a methodological or philosophical approach will analyze the advantages and disadvantages a three-dimensional model might have in conveying knowledge. On the other hand, a historical approach will link the modeling practice in economics to the different economic traditions that were considered mainstream in the second half of the twentieth century.

In order to answer the research question, the Phillips Machine must first be investigated further. This will be done in the first chapter of the thesis. The chapter will give a detailed account of the history of the machine and its mechanics. This information allows us to understand why and in what ways the Phillips Machine was special. Questions to be answered here are: With what goal(s) in mind was the Phillips Machine constructed? And how was it received by the academic world? Interestingly, the machine was admired and became famous quickly in the years after its construction but during the following decades it slowly lost its hold on the economic field. Many economists nowadays still know of the existence of the machine. Yet, it did not acquire such a prominent place in the field as was expected early on. What reasons can be named for its decrease in popularity? The goal of the first chapter is to provide a complete and clear overview of the Phillips Machine as the only three-dimensional economic model of significant meaning. In the second chapter, the methodological advantages and disadvantages of a three-dimensional model compared to a two-dimensional model will be discussed. It could be argued that 3D models benefit from the allusion to intuitive, three-dimensional knowledge. However, three-dimensional models face more modeling constraints than graphical representations, for example. To represent the macroeconomy with water running through tanks and tubes, the laws of macroeconomics must be sufficiently similar to the laws of hydraulics. Also, the laws of hydraulics limit which economic relations can be represented.[1] Water cannot defy gravity, although this might be what the economic relation requires. This argument and others for and against the use of 3D models will be discussed in depth. Next to that, the modeling practice of economics will be compared to that of other sciences, specifically those sciences in which three-dimensional models are more common. The third chapter investigates a change in economic traditions as a reason for the nonappearance of other three-dimensional models. The Phillips Machine is a representation of macroeconomics in a Keynesian sense. Keynes was the first to provide a detailed theory of the interactions between different macroeconomic entities. Before him neoclassical economics was the mainstream interpretation of economics. Here a clear account of the macroeconomy had been lacking. It could be said that Keynesian economics lent itself well to be represented three-dimensionally. Keynesian economics and the related neoclassical synthesis were the standard macroeconomic model in the 1940s until the 1970s. However, in the 1970s stagflation and other events led other economic traditions to gain popularity, namely monetarism and new classical economics. This caused a shift away from the more machine-like understanding of the economy of Keynes. It could be argued that monetarism as an economic theory did not allow for a three-dimensional representation in the same way as Keynesian economics did. This leads to the questions: What aspects of the monetarist tradition, if any, were not suitable for 3D representation? And why did a partial return to a Keynesian understanding of the economy, when New Keyesian economics became mainstream, not result in the development of other 3D models? In short, chapter 3 investigates how the economic tradition in which a model is situated, affects its form. In the

[1] Mary Morgan and Marcel Boumans. "The Secrets Hidden by Two-Dimensionality: Modelling the Economy as a Hydraulic System." In S. de Chadarevian & N. Hopwood (eds), *Models: the Third Dimension of Science*. Stanford: Stanford University Press, 2004: 383.

conclusion, I hope to provide a well-argued answer to the research question, which will be based on the findings of the previous chapters.

In general, this thesis focuses on the history and methodology of economics as a science. With this thesis I hope to contribute to a better understanding of the use of models in economics. The Phillips Machine has been at the center of research in economics and philosophy before, but the question why no other three-dimensional models were created has not been investigated yet. I would like to fill this gap. Marcel Boumans and Mary Morgan analyzed the Phillips Machine as a 3D model from a philosophical perspective in their 2004 paper. I would like to continue this research and add to it by analyzing its success from a historical perspective. Furthermore, with this thesis I aim to give a historical overview of economic theory of the second half of the twentieth century with the (non)existence of 3D models as focal point and, in doing so, contribute to the research on economic history.

Chapter 1: The Phillips Machine

This chapter is meant to provide a clear understanding of the Phillips Machine, of its workings but also of its historical background and reception. Understanding the machine well, will help us to ascertain the reasons for its uniqueness as a three-dimensional model in economics.

1.1 History of the Phillips Machine

The life of Bill Phillips

The history of the Phillips Machine starts with the history of its creator Alban William 'Bill' Phillips (1914-1975). Bill Phillips' life experiences and skills were a substantial ingredient for the construction of the machine. Already from an early age, Bill was interested in engineering. He grew up on a farm in New Zealand in the 1910s and 1920s. His parents were known to come up with inventive solutions for everyday problems.[2] For example, Bill's father Housego built a water wheel powered by a dammed spring to generate electricity for the milking machine. Bill himself inherited this creative spirit. In order to get to the local highschool, he acquired an old car and rebuilt it. All before the age of fifteen.[3] In 1929, Phillips graduated but was too young to go to university. He was lucky to find a job as an apprentice electrician at the Tuai hydroelectric power station in the north of New Zealand, which opened just before he arrived there. Bill worked at the power station for five years and returned home in 1935 as a qualified electrician.[4] Then he decided to travel the world with London as the end point. First, he shipped to Australia where he wandered around the country and took on jobs like mining gold, running a cinema, and even crocodile hunting. In 1937, he was meant to take a boat to Shanghai but due to the outbreak of the Second Sino-Japanese War, the boat was diverted to Japan.[5] Bill saw this as an opportunity for traveling around the newly opened-up and militarized country. In Hiroshima he made the mistake of taking photos of the troops and was arrested on the suspicion of espionage. Fortunately, he was let go and was even given a sightseeing tour after the forbidden pictures were confiscated.[6] Next, he

[2] Alan Bollard. *A Few Hares to Chase: the Economic Life and Times of Bill Phillips*. Oxford: Oxford University Press, 2016: 19.
[3] Robert Leeson. "A.W.H. Phillips: An extraordinary life". In *A.W.H. Phillips: Collected Works in Contemporary Perspective*. Cambridge: Cambridge University Press, 2000: 3.
[4] Bollard 2016: 31.
[5] Alan Bollard. "Man, Money and Machines: The Contributions of A. W. Phillips." *Economica (London)* 78, no. 309 (2011): 2.
[6] Bollard 2016: 39.

traveled to China via Korea and later to the Soviet Union. Here he looked for a job in the mines to sustain himself but found that all of them were already ‘taken’ by political prisoners.[7] Bill took the Trans-Siberian railway to Moscow and eventually found his way to England, traveling through Poland and Nazi Germany. Looking back, Phillips witnessed the unfolding of multiple significant historical events in his two years traveling the world.

During his time in Australia Bill Phillips had followed a correspondence course at the British Institute of Technology. In London he arranged to take the examinations and get accreditation for the course.[8] Bill passed the exams in 1938 and was granted Associate Membership of the Institute of Electrical Engineers. This meant he could take on a much needed job in the engineering field. He started a job testing new electrical components at the Aeronautical Inspection Directorate of the Air Ministry, but soon moved on to supervise cable-laying operations in the city. Living in London allowed him to take courses in multiple subjects that interested him. For example, he took classes in several languages and developed an interest in economics.[9] In July 1939 Phillips signed up as a part-time student at the London School of Economics (LSE), known as a respected institute with a focus on economic policy. However, war intruded. At first, Bill stayed in London. His job maintaining the electricity supply was considered crucial, especially during the bombings. At the end of 1939 he joined the Air Ministry again. He was not accepted as a pilot but was trained as an engineer at the RAF instead.[10] In 1941 Phillips was sent as an Armament Officer to Singapore, with the job to rearm the RAF fighter fleet for the defence of Singapore. His work in Singapore was essential and revered. Bill was even awarded the MBE for his assistance to the RAF (and for his actions during the attack of Singapore and in the prisoners of war camps on Java) in 1946. The MBE citation noted:

> “Flying Officer Phillips was armaments officer at the Royal Air Force station, Kallang, Singapore, in 1941–1942. He displayed outstanding ability, both academically and technically, and showed great energy in overcoming the initial difficulties experienced in operating the Buffalo aircraft. Flying Officer Phillips introduced a number of necessary modifications, which were accepted by the Air Ministry. It was due to his efforts and guidance that the fighter aircraft on the station were able to complete the maximum operations.”[11]

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[7] Leeson 2000: 3.
[8] Bollard 2016: 43.
[9] Bollard 2011: 2.
[10] C. A. Blyth. “A.W.H. Phillips, M.B.E.: 1914-1975.” *The Economic Record* 51, no. 3 (1975): 304.
[11] Bollard 2016: 54.

In 1942 the Japanese forces invaded Singapore. Phillips was on the last ship to leave the city. Unfortunately, the ship was attacked and severely damaged. Bill helped to improvise mountings for machine guns to fight the enemy aircrafts off and the ship made it to Java.[12] However, the Dutch East Indies were in the hands of Japanese forces as well. Phillips and several mates managed to evade the Japanese for a while. They traveled to the south coast. Here they found an old bus and started to rebuild it into a boat. The plan was to sail across the Indian Ocean to Australia. However, they were discovered and captured.[13] The rest of the war years Bill Phillips spent in prisoner of war camps. Yet, even here he showed courage. He used his engineering skills to build a small radio, so the prisoners could receive information from outside. Next to that, he made tea for the prisoners in the evening.[14] Both of these actions would have cost him his life if they had been discovered. In August 1945 after the Japanese capitulation, Phillips and the other prisoners of the camp were released. Bill went home to New Zealand for a while, to recover. He returned to London in early 1946.

Phillips and Newlyn at the LSE

Bill Phillips was offered an ex-servicemen's grant to complete a bachelor's degree.[15] He took the opportunity and started studying at the LSE in October 1946. His major was sociology with economics as subsidiary. The war, especially his time in the prisoner of war camps, had invoked an interest in social relations for Bill. It turned out that he did not enjoy studying sociology, however, and he only barely passed most of his courses.[16] His economics lectures were given by economists like Lionel Robbins, Dennis Robertson, and Nicholas Kaldor. In 1949 Phillips followed a lecture series by professor Richard Sayers, which he found difficult to understand. According to him, the interest theory explained by Sayers was muddled with confusion between stocks and flows.[17] He proceeded to approach the theory from a mathematical perspective and soon realized that the theory showed considerable similarities with a hydraulic system. He wrote a paper about his findings in which he argued that monetary theory could be illustrated by a hydraulic analogy of stocks and flows. He excitedly showed the paper to a good friend and colleague of his, Walter Newlyn. Newlyn immediately recognized the value of Bill's ideas and together they started working on what later became known as the Phillips Machine.

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[12] Blyth 1975: 305.
[13] Bollard 2011: 3.
[14] Leeson 2000: 7.
[15] Bollard 2016: 79.
[16] Bollard 2011: 3.
[17] Blyth 1975: 305.

At the LSE there was a large group of ex-servicemen undergraduates, who regularly spent time together. Both Newlyn and Phillips were part of this group. They met in 1946 and soon became good friends. Newlyn majored in economics and was one year ahead of Phillips in the bachelor's degree. In 1949, Bill's final year of the undergraduate programme, Newlyn had already left the LSE for a lectureship at the Department of Economics of Leeds University.[18] Phillips showed him the idea of the hydraulic model when he made a visit to London at the beginning of the year. The contributions made by Walter Newlyn in the construction of the Phillips Machine must not be understated. Phillips had the engineering knowledge, but Newlyn was the expert when it came to economics. That is why the machine is sometimes also called the Newlyn-Phillips Machine. Walter worked Bill's ideas out further, adding the missing sectors to the model so that it was a representation of the whole economy. Bill had not used the IS-LM framework, as introduced by the economist John Hicks, because his courses in economics had not covered this yet.[19] Newlyn explained it to him and they came to the conclusion that the IS-LM framework provided a useful way to organize the hydraulic model. Furthermore, Newlyn contacted the head of his department at Leeds University, Arthur Brown, and convinced him to fund the project.

Now the building could start. During the Easter vacation of 1949, Bill dedicated most of his time converting the diagrams drawn by Newlyn into physical plans. Newlyn worried that this distracted Bill from his final examination at the end of the summer term, when he learned about his poor results.[20] Looking back, he would not have needed to worry. Partly due to the success of the Phillips Machine, Bill made it from assistant lecturer to professor in only seven years. The actual construction of the machine was carried out during the summer. Mr. and Mrs. Langley, Bill's current landlords and friends, offered their garage as a workshop.[21] Newlyn spent the vacation in London, which allowed him to help Bill wherever he could. His job mostly consisted in giving economic input and aiding Bill by sanding and gluing pieces of perspex together.[22] Phillips was the engineer of the project. When the construction was finished, the machine was presented in a seminar at the LSE in November 1949. Bill Phillips designed and built an updated version of the Phillips Machine a year later. To distinguish between the first and second version the 1949

[18] Walter Newlyn. "The Origins of the Machine in a Personal Context". In *A.W.H. Phillips: Collected Works in Contemporary Perspective*. Cambridge: Cambridge University Press, 2000: 31.
[19] Bollard 2016: 100.
[20] Newlyn 2000: 34.
[21] Bollard 2016: 100.
[22] Newlyn 2000: 35.

machine is commonly called Mark I, while the later version came to be known as Mark II. The main difference between the two was the addition of an accelerator. Next to that, the Mark II was larger and technically more efficient.

1.2 Description of the model

This section of the chapter is dedicated to a comprehensive description of the Phillips Machine, more specifically, of the Mark II. To understand the significance of the machine for economics, one must understand how it works. The Phillips Machine was built to go beyond words in explaining economics, so understanding the machine itself from text alone might prove to be difficult. That is why multiple pictures and drawings are added to the text. Moreover, the reader is encouraged to watch videos about the Phillips Machine in action or even visit one of the machines on display.

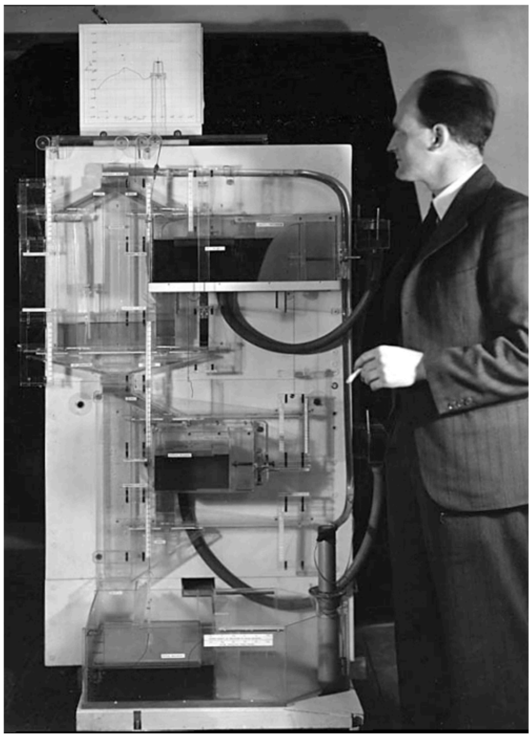

Figure 1: Bill Phillips with his machine (Mark I)

General overview

The Phillips Machine is a representation of a macroeconomy, in which money flowing around the economy is represented by water flowing around the machine. The economy can be divided into many stocks and flows, which are depicted by water tanks and tubes respectively. Figure 2 shows a schematic drawing of the Phillips Machine. The tank at the bottom is a representation of minimum working balances, also called active or transaction money balances. Bill Phillips called this M_1.[23] This tank can be interpreted as the money in the economy that is needed to carry on a given level of economic activity. The money in the economy in excess of the minimum working balances, Phillips named M_2. This is represented by the 'surplus balances' tank in the upper right part of Figure 2. Water flows out of the bottom tank as national income and is pumped up to the top of the machine. Here some of the income flows down to the government sector on the left as taxation. Further down, water flows from the government sector back to the middle as government spending. The income

[23] A.W. Phillips. "Mechanical Models in Economic Dynamics." *Economica (London)* 17, no. 67 (1950): 288.

left after taxation is split between the households as consumption and the financial sector as savings. Water flowing from the financial sector back to the middle represents investment.

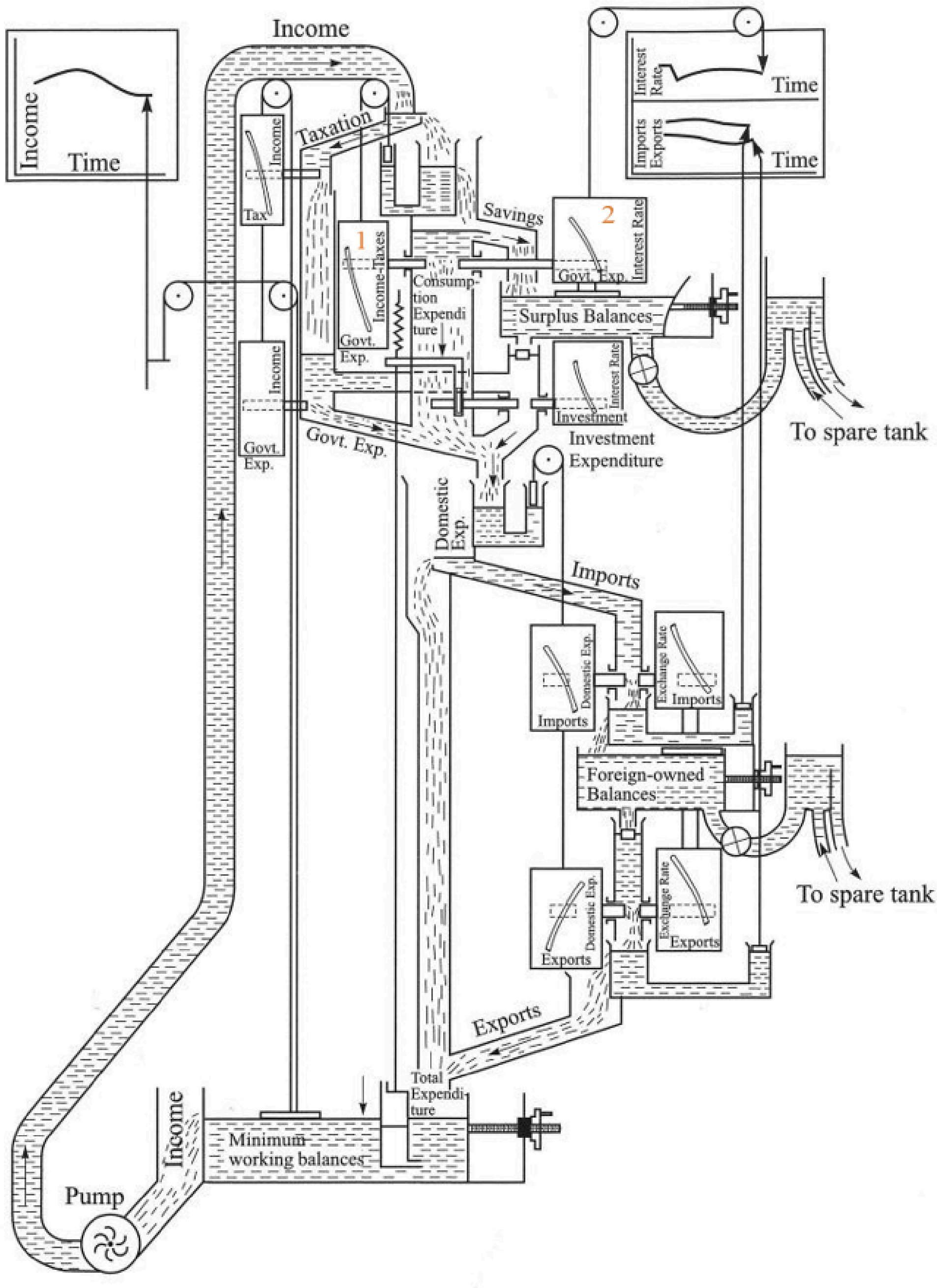

Figure 2: Schematic drawing of the Phillips Machine
(correction: Govt.Exp. should be Consumption in Graphs 1 and 2)

Government expenditure, consumption expenditure, and investment together constitute domestic expenditure. Part of this domestic expenditure flows to the international sector as imports. Water flowing from the international sector back to the middle represents exports and together with what is left from domestic expenditure makes up the total expenditure. Total expenditure is a flow that fills up the ‘minimum working balances’ tank. Water runs out of this tank as income, and the whole cycle starts anew. The model can be said to be a physical representation of the economic entity $Y = C + I + G + (E - M)$. The description of the model so far provides a general overview but, as Figure 2 shows, the Phillips Machine is more complicated and interesting than this. In what follows the four different sectors of the economy (consumption, financial sector, government, and international sector) will be explained in more detail. Yet, in order to grasp the workings of the different sectors, some of the mechanical mechanisms used in the machine must first be understood.

Explanation of important mechanisms

At some places in the machine a linear relationship between a stock and a flow needs to be shown. For example, the relationship between active money balances, or M_1, and national income is linear. These entities are represented by the tank at the bottom of the machine and the water flow running out of it. Now, if the opening governing the flow were a simple circular hole or straight slot, the relationship between the water level and the flow would be nonlinear. So, Bill Phillips gave the opening a particular shape.[24] This shape is called a sutro weir and can be seen in Figure 3. Due to this shape the relationship between the water level in the tank and the flow of water running out of the tank is linear. This means that if the quantity of water in the tank doubled, for example, the water flowing out per specified time period (e.g. second or minute) would double as well.

Furthermore, at multiple places the water flow running through the tubes is governed by sliders that open or close as the machine runs. For example, in the tube representing the taxation flow a slider can be seen that is connected to a graph showing the relationship between income (Y) and taxation (T). Via pulleys this graph is linked to a float in the minimum working balances tank. Due to this system the slider closes, and thus taxation is decreased, as the water level in the bottom tank drops (representing a drop in national income since national income is proportional to minimum working balances). In Figure 4 this mechanism is illustrated in a simpler form. If the water level in the tank of Figure 4 drops, the float lowers with it and pulls up a board via the rope and pulleys. The board (on rails) can only move vertically. A slot in the shape of a downward-sloping graph is cut out of the board. A pin connects the slot to a horizontal beam which can only move horizontally. Now, when the board is pulled up, the beam will move to the right because of the downward-sloping

[24] University of Cambridge, Faculty of Economics. 2022. “The Phillips Machine (MONIAC). Demonstrated by Professor Allan McRobie and Emily Evans”. Youtube, June 11, 2022.

form of the slot. In this way, the vertical movement of the board is converted into the horizontal movement of the slider (or beam). Such a system is applied in multiple instances in the machine. The steepness of the slots, and thus the relationship between the two factors at hand, can be adjusted by moving the board. In this way, the responsiveness of e.g. taxation due to an increase or decrease in national income can be adjusted. For example, a relatively flat slot means that a drop in income will cause a large decrease in taxation, while the same drop in income will only lead to a minor decrease in taxation if the slot is steep.

Via a pulley system, pencils are connected to some floats as well. These pencils can be set on a paper, like the one in the upper left corner of Figure 2. As the machine runs, the paper moves to the left and the pencil is pulled up or down, depending on the movement of the water level to which it is connected. This allows the machine to draw graphs of income over time, interest rates over time, and the level of imports and exports over time.

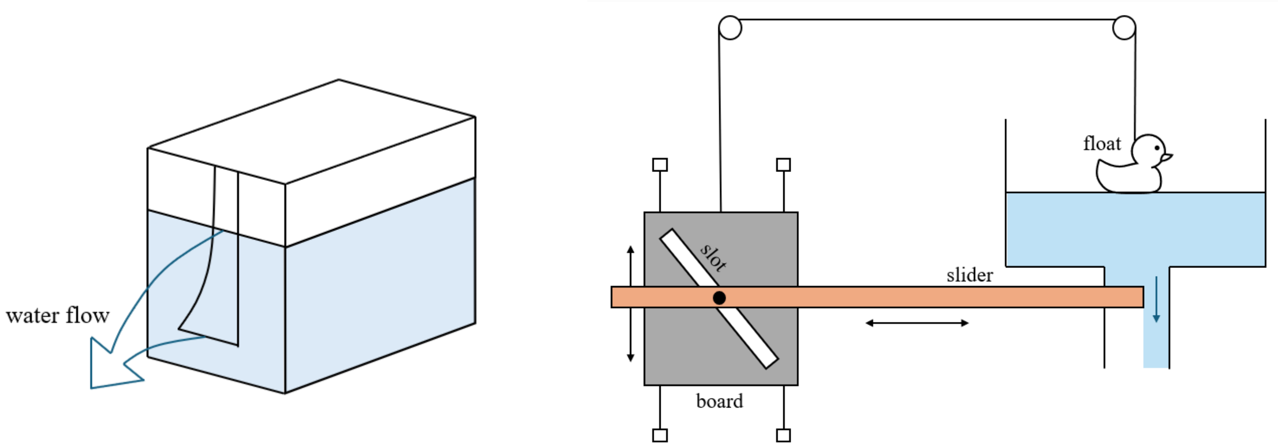

Figure 3 & 4: Sutro weir & Slider system

Government sector

Now to the explanation of the separate sectors. We start with the government sector. As was explained earlier, part of the national income which is pumped to the top of the machine flows to the government sector as taxation. The amount of national income determines the volume of taxation. A slider relating taxation and income, via a float in the minimum working balances tank (a stock proportional to the income flow), governs the taxation flow. The water flows further down the machine as government spending, which can also be interpreted as dependent on national income. A graph showing the relationship between Y and G controls a slider opening or closing the government spending tube as the water level in the M_1 tank increases or decreases. In Figure 2 the relationship between Y and G is not specified, because it depends on the intentions of the government. For example, if the government wants to stimulate the economy in times of low national income (fiscal policy), the relationship would be upward-sloping. This would lead to an increase in government spending if the water level in the M_1 tank is low, and vice versa. If the taxation and the government spending flow are equal to each other, the government has a balanced budget. If, instead, a budget deficit would arise, the government can draw money from the financial sector as government borrowing. This flow is represented by the horizontal tube between the government sector on the left and the financial sector on the right.[25]

Consumption

The income left after taxation flows down the middle of the Phillips Machine. First, it flows into a small measuring box. The outflow slot of this box has the shape of a sutro weir, so the outflow is proportional to the water level in the box. The consumption flow is controlled by two sliders, one depending on the level of income after taxation and the other on interest rate (determined by the water level in the M_2 tank). The small measuring box is too small for a float-slider system to work satisfactorily, so Phillips used a small servo-motor to achieve the same effect. Moreover, he made it possible to lag consumption behind income after taxation.[26] The opening between the measuring box and the small tank to the left with the servo-mechanism in it, is quite small (and adjustable). This means that the small tank will not fill up as quickly as the measuring box, and thus the servo-mechanism will control the slider with a lag. In economic terms this means that there exists a lag between income and expenditure.

Financial sector

In Figure 6, an economy without the government sector and foreign trade is shown. This allows us to concentrate on the workings of the financial sector. Part of the income after taxation flows to the financial sector as savings. The amount of savings is a function of income and the interest rate, as is shown by the sliders connected to the graphs with relationships between Y and S, and i and S. The savings flow fills up the M_2 (or surplus balances) tank. Surplus balances are broadly what Keynes called speculative balances.[27] The curved right hand side of the tank represents the liquidity preference function, as introduced by Keynes. Liquidity preference is the demand for money which is highly dependent on the interest rate. People want to hold money for their everyday transactions and for unforeseen expenses, but they also have a speculative motive for holding money.[28] For example, they

[25] Phillips 1950: 300.
[26] Phillips 1950: 299.
[27] Barr 2000: 102.
[28] Michael Stewart. *Keynes and After*. 3. ed., reprint. London: Penguin Books, 1991: 74.

may want to hold money to take advantage of an expectation of a price drop of certain shares. Money demand for speculative reasons is highly dependent on the interest rate. If interest rates are high, money demand is low, and vice versa. The curved side of the M_2 tank in the Phillips Machine can be interpreted as the curved liquidity preference function or the money demand curve in the money market (see Figure 5). The money supply is represented by the water level in the M_2 tank. The intersection between the two determines the interest rate in such a way that if the water level is low, interest rates are high and if the water level is high interest rates are low. External shocks can shift the liquidity preference function. In the machine this is done by shifting the curved side of the tank to the right or to the left. The central bank can perform expansionary or contractionary monetary policy, allowing it to influence the interest rate. The spare tank on the right represents the central bank. By pumping more water into the M_2 tank the interest rate decreases (expansionary monetary policy), while taking water out increases the interest rate (contractionary monetary policy).

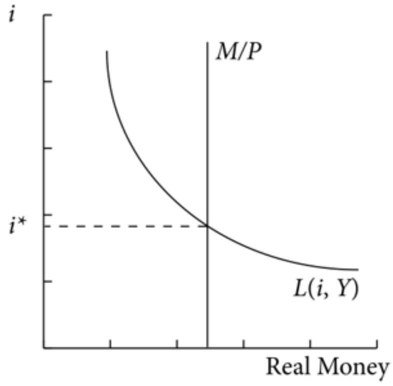

Figure 5: The money market equilibrium

Water flows out of the surplus balances tank as investment. Investment is dependent on the interest rate and on national income via the accelerator effect. According to the accelerator effect, businesses become more confident when the economy is booming, which leads them to invest more. This effect is lagged, however. Bill Phillips incorporated the lagged accelerator effect in the machine. A slider controlling the investment flow is connected to float in the M_1 tank. This long float has a small hole in the bottom, which means that it needs more time to adjust to the water level in the tank if that were to change, creating a lagged effect between a rise in income and an increase in investment.[29]

International sector

To understand foreign trade, we need to return to Figure 2. Part of domestic expenditure flows abroad as money paid for imports. Imports are a function of domestic expenditure and the exchange rate. Domestic expenditure flows into a small box, allowing the flow to be measured (using a servo-mechanism). If the domestic expenditure flow is high, imports are high as well. The imports flow into the foreign-owned balances tank. The water in this tank represents the foreign holdings of the domestic currency. If imports are higher than exports (trade deficit), the water level in this tank increases and the domestic currency depreciates.

[29] Phillips 1950: 291.

Likewise, if the country has a trade surplus, the exchange rate of the currency increases. The water level, and thus exchange rate, can be fixed by connecting the foreign-owned balances tank to the spare tank on the right. Now, money can be tapped into or out of the foreign-owned balances tank. This is a representation of the government selling or buying its own currency on the open market. In this way, the model can run under a fixed exchange rate regime. The international sector of one Phillips Machine can also be connected to the international sector of another (mirrored) Phillips Machine. This may help to show how trade between two countries works.

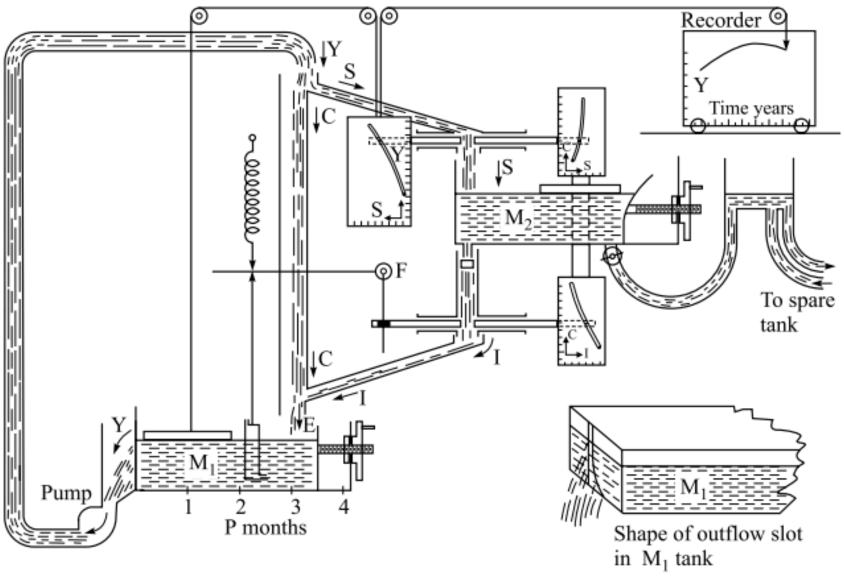

Figure 6: Hydraulic mechanism showing the economy without government sector and foreign trade

Experiments

The Phillips Machine is an ingenious model of the Keynesian macroeconomy, as the description so far has shown. The machine can do more than just illustrating the workings of the macroeconomy, however. It can also be used as a computer to estimate the effects of certain economic shocks or policy changes. For example, a Keynesian multiplier experiment could be done with a balanced budget and fixed interest rates in a closed economy.[30] Say the economy has national income (or GDP) of €4 billion, of which consumption makes up €2 billion and government spending and investment both €1 billion. So, we have

$$Y = C + I + G$$

$$4 = 2 + 1 + 1$$

Now we increase investment by €1 billion by opening up the sliders controlling investment and let the machine run a few cycles. One cycle (taking about half a minute) is roughly equal

[30] David Vines. "The Phillips Machine as a 'Progressive' Model." In *A.W.H. Phillips: Collected Works in Contemporary Perspective*. Cambridge: Cambridge University Press, 2000: 43.

to three or four months.[31] We would expect the income to increase to €5 billion because of the addition of €1 billion to investment, but we find that income has increased to €6 billion. The increase in investment has boosted consumption with €1 billion as well. This effect is known as the multiplier effect. In a similar way, many other experiments can be done on the Phillips Machine. The machine, in fact, provided one of the first ways to simulate macroeconomic experiments and gauge the effects on the different sectors involved. The accuracy of the model's calculations were found to be within about 4%.[32]

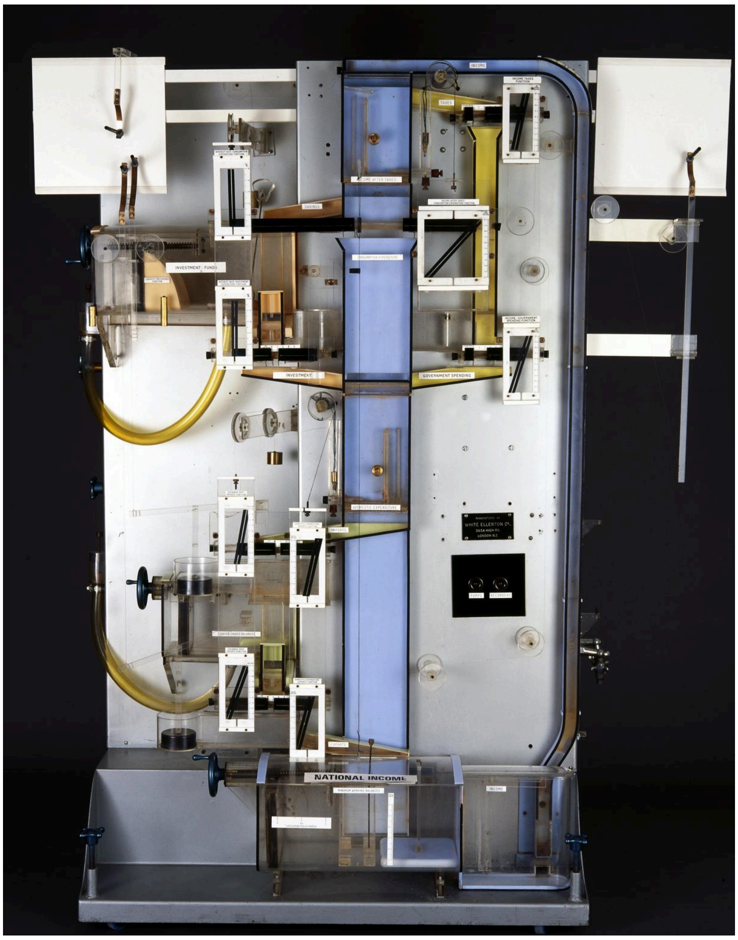

Figure 7: A mirrored Phillips Machine (Mark II), displayed at the Science Museum in London

1.3 Initial reception

The LSE seminar

The first version of the Phillips Machine was completed in the autumn of 1949. Bill Phillips and Walter Newlyn were supposed to present the machine at Leeds University, because Arthur Brown of the economics department at Leeds had funded the project.[33] Yet, Phillips

[31] Phillips 1950: 290.
[32] Phillips 1950: 283.
[33] Bollard 2016: 105.

wanted to interest academics from other institutions as well. The London School of Economics was on the top of his list. He and Newlyn were connected to the LSE as former students. The main reason for getting the LSE involved, however, was its reputation as a prestigious school open to new approaches to economics. Phillips especially wanted to gain the attention of Lionel Robbins, the current director of the LSE. James Meade remembered Phillips' attempt at approaching the professor:

> "There are rumours of learned professors and dignitaries of the Royal Economic Society, as they walked from the entrance of the School, toward the lift, being interrupted by a wild man from New Zealand waving blueprints in one hand and queer shaped pieces of Perspex in the other."[34]

Robbins was not convinced by the idea of an economic machine. He argued that many people had invented machines to illustrate theories that did not need a machine to explain them. Nevertheless, he brought Phillips into contact with James Meade. Meade was Professor of Commerce at the LSE at the time and he was, much to the benefit of Bill, fascinated by gadgets and mechanisms. In their first meeting Phillips showed Meade the blueprints and explained the hydraulic machine. Meade was impressed and offered him the chance to demonstrate the machine at one of Robbins' seminars. From their first meeting onwards, James Meade was an admirer of Phillips' work and he encouraged Bill to develop his ideas. Later, the two became colleagues and good friends.[35] The seminar took place on November 29th, 1949. Many esteemed and influential economists attended the seminar, although some had mainly come to have a laugh.[36] Phillips started with a lecture on Keynes and Robertson. He walked up and down the room, chain smoking, explaining the theory on which the machine was based with a strong New Zealand accent. But it was one of the best lectures on the topic that anyone in the audience had ever heard, according to Nicolas Barr.[37] Next, Phillips switched the machine (Mark I) on. The audience was surprised to see how the machine could illustrate and even solve arguments economists had been having for years. Even Lionel Robbins, who had been sceptical before, was impressed.

The Mark II and the road to professorship

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[34] Barr 2000: 91-2.
[35] James Meade. "The Versatile Genius". In *A.W.H. Phillips: Collected Works in Contemporary Perspective*. Cambridge: Cambridge University Press, 2000: 19.
[36] Reza Moghadam and Colin Carter. "The Restoration of the Phillips Machine: Pumping up the Economy." *Economic Affairs (Harlow)* 10, no. 1 (1989): 22.
[37] Barr 2000: 92.

The day after Bill Phillips had presented his economic machine in the LSE seminar, James Meade sent a memo to his fellow professors. He wrote how impressed he and the audience had been, and that the machine served a useful role as a teaching device.[38] Meade knew that Bill wanted to perfect his model and to write a scientific paper on how the machine illustrates monetary circulation. He proposed that the LSE offer Phillips a fellowship or grant, so he would have the time and the funds to work out his ideas. At this time, Bill's ex-servicemen grant had run out because he had finished his bachelor's degree. He did not have a job and was supposed to return to New Zealand soon. The return to New Zealand was a condition of the ex-servicemen grant he had received. Phillips described himself as 'practically living on thin air' during this period.[39] In the memo, Meade sketched Phillips' situation and wrote that he wanted to proceed quickly with the job or grant offer, so he could contact the New Zealand authorities with the request for Phillips to stay in England. Some objections to Meade's proposal were voiced. A colleague pointed out that it was difficult to employ Phillips academically with a high salary as he only barely passed his sociology bachelor. Next to that, he pointed to the danger of potentially funding a private business if Phillips were to patent his machine.[40] Meade acknowledged the objections and adjusted his proposal. The LSE would ask Bill Phillips to build a new model of the machine for the School, for which he would be paid a small salary and the expenses of construction for a period of six months. This proposal was accepted and the New Zealand authorities agreed to extend Phillips' stay in England.

During the following months Phillips worked out his plans for the new and better version of the machine, the Mark II. He was assisted with the construction by Philips White of White-Allerton Ltd, a small engineering firm in London.[41] The six months soon ran out but Bill continued to perfect the machine. Meade was uncomfortable with the fact that Bill devoted so much unpaid time to the machine, so he secured a job as teaching assistant for him. The Mark II was completed in October 1950. It was presented by Phillips and Meade at the LSE and received with enthusiasm. An academic paper formulating the underlying framework of the machine had been a requirement of the LSE as well, so Phillips had devoted part of his time to writing. The paper, called 'Mechanical Models in Economic Dynamics', was published in *Economica* in August 1950. The staff at the LSE had been hesitant to employ Phillips academically before due to his bad grades, but the paper showed that he had the academic skills. Lionel Robbins wrote to the LSE Director in October 1950:

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38 Barr 2000: 93.
39 Bollard 2016: 102.
40 Barr 2000: 93.
41 Bollard 2016: 109.

> "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 [...]. 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."[42]

Thus, Bill Phillips became an Assistant Lecturer in 1950. Three years later he received his Ph.D. with the publication of the paper 'Dynamic Models in Economics' (examined by Professor John Hicks) and in 1958 he became Tooke Professor of Economic Science and Statistics. Most of his academic work focused on dynamic modelling and stabilization policy, an interest of which the Phillips Machine was the first product.

Reactions of contemporaries

As we saw before, the Phillips Machine was received well in the academic world. Many of the LSE professors admired Phillips' model. Yet, the machine was also attracting attention from outside the LSE. In 1950, before the completion of the first Mark II, multiple universities in England had already made enquiries about acquiring a Phillips Machine for themselves.[43] After its completion in October 1950, the machine was shown to visitors of the LSE like the economist Abba Lerner from the US and the Governor of the Bank of England. Many of the visitors became fascinated by the machine. Lerner declared himself the US agent for the sale of the machine and was responsible for the machine sold to Roosevelt College in Chicago.[44] Similarly, Friedrich Hayek encouraged the staff at Harvard to buy a Phillips Machine. Due to the enthusiastic reception Bill Phillips at one stage thought he might be able to mass produce the machine and sell it as a universal teaching tool. This never happened, however. In total around 12 to 14 machines were built, which mostly ended up in universities (e.g. Cambridge, Melbourne, Istanbul). Interestingly, the Ford Motor Company and the Bank

[42] Barr 2000: 96.
[43] Bollard 2016: 121.
[44] Graeme Dorrance. "Early Reactions to Mark I and II." In *A.W.H. Phillips: Collected Works in Contemporary Perspective*. Cambridge: Cambridge University Press, 2000: 117.

of Guatemala bought a Mark II as well.[45] The Phillips Machine is also known as the MONIAC. Lerner suggested this name for the machine as an acronym for Monetary National Income Analogue Computer or an association between money and the ENIAC, an early electronic computer.

The Phillips Machine received some criticism as well. According to the economist Graeme Dorrance, this criticism was mostly due to a misunderstanding of its purpose. Some viewers thought the machine was a multiple regression calculator. With an error of approximately 4%, it was not an accurate one and basically unusable for precise calculations. It must be kept in mind that in the early 1950s the development of electronic computers was in full swing. If the Phillips Machine is placed in this tradition, it can indeed be argued that it lacked behind the newest developments. The progress in electronic computers was especially noteworthy in the United States. Here the Phillips Machine was not received as well as in England. Illustratively, at the demonstration of the MONIAC at the 1950 meeting of the American Economic Association by Abba Lerner, the audience was in general skeptical.[46] Only the directors of General Motors and the International Monetary Fund were enthusiastic and ordered a Mark II for their respective organizations.

The Phillips Machine did not gain much attention outside the academic and economic world. Yet, some popular reactions were recorded. Already in January 1950 the *Yorkshire Evening Post* reported on the Mark I at Leeds University. A London newspaper soon picked up the story. Both reports showed interest in the machine and stressed the fact that it could be a useful teaching tool.[47] Other stories on the Phillips Machine appeared in the American version of *Fortune Magazine* and in some New Zealand papers, but the model never gained widespread recognition. The most well-known account of the Phillips Machine in the popular media is presumably the article in *Punch* (April 1953), a satirical British magazine. The author of this article argued that, although the Mark II is held at the LSE, it should belong to the world. The main reason being that it could finally make the complex workings of economics known to the average man in the street.[48]

Impact on the field of economics

Although the Phillips Machine was received positively overall, its relevance for the field of economics as a whole must not be overstated. The fame of the machine was confined to the

[45] Dorrance 2000: 117.
[46] Ibid.
[47] Bollard 2016: 123.
[48] Barr 2000: 106.

economic faculties of a group of British universities and a few outside the United Kingdom. It could be argued that economics as a science is largely guided by a small group of influential economists. The main center of economic ideas and interpretations in the 1940s and early 1950s was England, more specifically, Cambridge and the LSE. Here the big names of the time worked. Think of Lionel Robbins, Friedrich Hayek, John Hicks etc. By convincing these influential economists of its relevance, Phillips could have had a profound impact on economics as a science with his machine. However, this is not what happened. Whereas written economic ideas are easy to copy and spread, it is more difficult to convince people of the relevance of a machine they know just from hearsay. The fact remained that only a few people had seen the Phillips Machine in action. So, its reach was limited. Next to this, the Phillips Machine did not provide much opportunity for an economic discourse to unfold. The machine was mainly a teaching tool. It did not put forth a theory to be developed or criticized. Also, its potentiality for research activities remained limited.

1.4 Decrease in popularity

The initial reactions to the Phillips Machine were mostly positive, especially in (small) academic circles. In the first years after its construction several economists visited the LSE or other institutions in possession of a Mark II, so they could see the 'economic modeling wonder' with their own eyes. The Phillips Machine became a popular teaching tool in macroeconomics classes in England, and many students retained fond memories of their lectures on the machine.[49] However, after some years the popularity of the machine began to wane. From the mid 1950s onwards, the machines were used less and less in lectures and were eventually stored away in the basement.[50] Rumours about the ingenious economic machine still buzzed among students throughout the 1960s, but even those slowly dwindled. What was the reason for the decrease in popularity? On the one hand, it can be argued that a shift away from Keynesianism towards a new type of economic theory lessened the relevance of the Phillips Machine. This claim will be investigated further in Chapter 3. On the other hand, practical considerations led the model to fall into disuse.

Reasons for disuse

[49] Bollard 2016: 117.
[50] Moghadam and Carter 1989: 23.

The Phillips Machine was not particularly easy to operate. Bill Phillips and Philip White had written an operating manual to help lecturers and students handle the machine.[51] Next to that, a small group of students acquired a more extensive understanding of its mechanisms so they could assist others operating the machine. The machine occasionally showed problems that only Phillips or White themselves could fix, however. Moreover, leakages were not uncommon. These were due to an incorrect use of the machine or occurred because of inflation. Phillips had not found a satisfactory way to deal with the problem of inflation and had needed to drill a hole in one of the tubes through which the water flowed out whenever inflation occurred.[52] Once in a while the machine had to be drained and cleaned. During the 1950s and early 1960s Bill was always close and happy to help colleagues in need. When he left for Australia in the mid 1960s, however, it became increasingly difficult to maintain the machine.[53] The Phillips Machine was slowly abandoned. For many of the other institutions in possession of a Phillips Machine the reasons for the decreased use were similar. In the early 1950s a person who knew how to operate and fix the machine was often available. When this person left, however, the machine fell into disuse.

Another reason for the decrease in popularity of the Phillips Machine is the rise of electronic computers and econometric models. The Phillips Machine can be seen as one of the first analogue economic computers. It represents a system of nine differential equations and can calculate macroeconomic outcomes, although not with high accuracy.[54] This was considered highly impressive at its introduction in 1949. However, technological progress soon made the Phillips Machine as a computer irrelevant. In the 1940s the first electronic computers were built. These were further developed over the course of the following decades and could perform very exact calculations. The rise of electronic computers enabled the emergence of econometric models. The new electronic computers and econometric models took over the calculating role of the Phillips Machine, and showed significant improvements when it comes to accuracy and computing power. So, the Phillips Machine lost part of its relevance. Nevertheless, it remained a meaningful economic teaching tool.[55]

Restoration attempts

[51] Bollard 2016: 117.
[52] Dorrance 2000: 116.
[53] R.M. Goodwin."A Superb Explanatory Device." In *A.W.H. Phillips: Collected Works in Contemporary Perspective*, edited by Robert Leeson, 118-19. Cambridge: Cambridge University Press, 2000: 118.
[54] Bollard 2011: 4.
[55] Vines 2000: 58.

In the last decades some attempts have been made to restore the Phillips Machine. Some were successful, others were not. In the 1970s professor Harry Johnson came across the machine in Cambridge, gathering dust in the cellar, and set up a plan for restoration. A student with engineering experience made the machine operational again, so it could be used for occasional demonstrations.[56] Johnson contacted Nicolas Barr to plan a more thorough restoration. Barr tracked down Phillips White, with whom Bill Phillips had built the Mark II. White was willing to help, but eventually the restoration never started. Both Johnson and White had to withdraw from the project due to health problems.[57] An initiative for restoration on the Chicago machine failed because of similar reasons. Eventually, a committee at the LSE organized a successful restoration of the Phillips Machine. The economist Reza Moghadam and the engineer Colin Carter revived the mirrored machine since it was in the best condition.[58] It found its way to the Science Museum in London, where it is still on display. The other LSE Phillips Machine was given to the New Zealand Institute of Economic Research. In 2002 Professor Allan McRobie of the engineering department of the University of Cambridge restored the Phillips Machine at Cambridge. Demonstrations with this machine are occasionally still given for a live audience.[59]

1.5 Conclusion: The Phillips Machine as the only 3D model

The goal of this chapter was to provide a clear understanding of the Phillips Machine and its historical background. Especially questions regarding its mechanisms, reception, and decrease in popularity were important for comprehending the success of the Phillips Machine. Now these have been answered, we can continue with a methodological approach for understanding the Phillips Machine as the only three-dimensional economic model. The second chapter will take a step back and situate the Phillips Machine in the modeling practice of economics. A discussion of the advantages and disadvantages of using a three-dimensional model over a two-dimensional one, will provide some clues for the question why no other successful 3D models were created after the Phillips Machine paved the way.

[56] Bollard 2016: 125.
[57] Barr 2000: 110.
[58] Moghadam and Carter 1989: 26.
[59] University of Cambridge, Faculty of Economics. “The Phillips Machine (MONIAC). Demonstrated by Professor Allan McRobie and Emily Evans”

Chapter 2: Methodology of 3D Models

The focus of this chapter will be the methodology of three-dimensional models in economics. More specifically, the epistemic advantages and disadvantages of three-dimensional models over non-three-dimensional models. In order to analyze the methodology of 3D models, we must first agree on a definition of such models. So, the first part of the chapter aims to provide a sensible definition of three-dimensional models. Early examples of modeling in economics will be discussed in this section to substantiate the differences between distinct types of models and to situate the Phillips Machine in the modeling practice of economics. Next, the epistemic advantages and disadvantages of three-dimensional models will be specified and explained. Moreover, the three-dimensional modeling practice of economics will be compared to that of other sciences. The comparison helps to discern reasons why economics as a science has not produced additional 3D models.

The goal of the chapter is twofold. On the one hand, the chapter aims to provide a methodological answer to the question why no other three-dimensional models were successfully built after the Phillips Machine. On the other hand, the methodological approach allows us to formulate criteria an economic tradition must adhere to, in order to lend itself to the construction of three-dimensional models. Formulating these criteria will be useful for the third chapter on economic traditions and 3D models. Throughout the chapter references will be made to the Phillips Machine. As the previous chapter provided us with a solid understanding of this economic model, the references help to substantiate the claims made in the chapter.

2.1 Defining three-dimensional models

In the introduction and in the first chapter the Phillips Machine was described as a three-dimensional economic model. This raises the question: What is precisely meant by a three-dimensional model? This question may seem trivial at first, but after some thought about the definition of 3D models a few issues emerge. For example, do we view a two-dimensional representation of a physical machine (like in Figure 2) as a three-dimensional model? What about an interactive computer simulation? And how do we deal with econometric models with multiple variables/dimensions? For the purposes of this thesis I define a three-dimensional model as a physical object relating to three-dimensional space. That is, the object has the dimensions of length, width, and height (or depth). Strictly speaking, the Phillips Machine is a four-dimensional model because time plays an important role as well. By running the water through the machine, economic processes through time are shown.[60] It is also a three-dimensional model, however, since it relates to three-dimensional space. Therefore, I group the Phillips Machine in the category of 3D models. This allows the argumentation of this thesis to apply to a broader group of models.

In what follows different economic 'models' will be presented and three-dimensional models will be juxtaposed with non-three-dimensional models. Examples might help to elucidate the distinction between the different types of economic models. The first example of a non-three-dimensional model is the price-specie flow mechanism, developed by David Hume. In his 1752 text *Of the Balance of Trade* Hume presents an economic mechanism that, according to him, explains how exchange rates are maintained for a country operating under the gold standard. With words and a few numerical examples he explains how a trade deficit of a country leads to a gold outflow to pay for imports. The consequence is a fall in the price level. The fall in domestic price means that imports become more expensive, while exports become cheaper. So, more will be exported and less imported, and the trade deficit disappears. A similar reversed mechanism is given for a trade surplus. Hume compares the price-specie flow mechanism to the movements of water.[61] Different bodies of water that are connected to each other will have the same water level. The water level might be temporarily disturbed by external factors, but it will return to balance in the long run. The same goes for the quantity of money in different countries and thus the exchange rates between them. Hume uses a metaphor between water and money as a model.[62] The benefit of adopting a metaphor is that the workings of the economy can be portrayed in terms of another, already-known world, making the mechanism more straightforward. To link money with water offers new ways to think about the economic issue at hand, but it tells us little.[63] The use of imagination is required to fill in the details that are not specified by the metaphor. Hume fills in some of the details. It is clear that the property of water to level is the essential factor, for example. However, he leaves many gaps open for the reader to fill in. The degrees of freedom of a metaphor as a model are high and so the model does not constrain our imagination.[64] Metaphors are typically conveyed in words (be it written or spoken). This seems logical as

[60] Morgan and Boumans 2004: 379.
[61] David Hume. "Of the Balance of Trade." Chapter. In *Hume: Political Essays*, edited by Knud Haakonssen, 136–49. Cambridge Texts in the History of Political Thought. Cambridge: Cambridge University Press, 1994: 138.
[62] Mary Morgan. *The World in the Model*. 1st ed. New York: Cambridge University Press, 2012: 174.
[63] Ibid.
[64] Morgan and Boumans 2004: 377.

this way of communication does not require the same amount of specification needed for drawings or physical objects.

One of the first two-dimensional models in economics was constructed by François Quesnay, around the same time as Hume's model, in the 1750s. Quesnay drew a table or matrix, representing the French economy (see Figure 8). The adorned model is called the *Tableau Économique*. It shows how wealth is distributed between the classes of people in the French agricultural economy.[65] At the top the three classes can be seen: the productive class (labourers), the proprietary class (landowners), and the 'sterile' class (craftsmen, merchants). The diagonal and horizontal lines indicate how goods (or payments) flow between them. Interestingly, the *Tableau Économique* is not simply a static picture of the economy. Quesnay devised it to perform numerical exercises and to reason with it. The exercises were to determine whether an agricultural economy could grow in a stable way.[66] The model aided Quesnay to argue for the physiocratic point that trade and industry were not sources of wealth. The *Tableau Économique* is often interpreted as a forerunner of modern economic models. The supply and demand model is one of such modern economic models and is another example of a two-dimensional model. Supply and demand (SD) can be considered a function of price and thus lend themselves well to graphical representation. In the nineteenth century both curves were introduced separately. Yet, Alfred Marshall combined and popularized them in his book *Principles of Economics* (1890). The *Tableau Économique* and the SD model are both pen-and-paper models, constructed to be reasoned with. They are two-dimensional graphical representations that abstract away from unnecessary information. This allows them to focus on one specific assertion. In Quesnay's model the assertion is that trade and industry are not sources of wealth. The assertion in the SD model is that price determination of a good in a market is dependent on the quantity supplied and the quantity demanded. The models do not simply put forth these claims, however. They provide reasoning for the assertions in graphical form. The viewer of the model can follow this reasoning by studying the model. Pen-and-paper graphical representations provide some benefits compared to explanations in words. Graphs typically need less space to prove the same point and tend to be more accessible. Next to that, some things are easier to show in graph-form. Think of the flows between the three classes in the *Tableau Économique*. Lastly, a connection to existing knowledge can be made, which offers the viewer new ways to think

[65] Loic Charles. "The Tableau Economique as Rational Recreation." *History of Political Economy* 36, no. 3 (2004): 449.
[66] Morgan 2012: 3

about the concept at hand. For example, by representing demand and supply by mathematical curves, a viewer with adequate mathematical knowledge is given a straightforward way to conceive of price determination in a market.

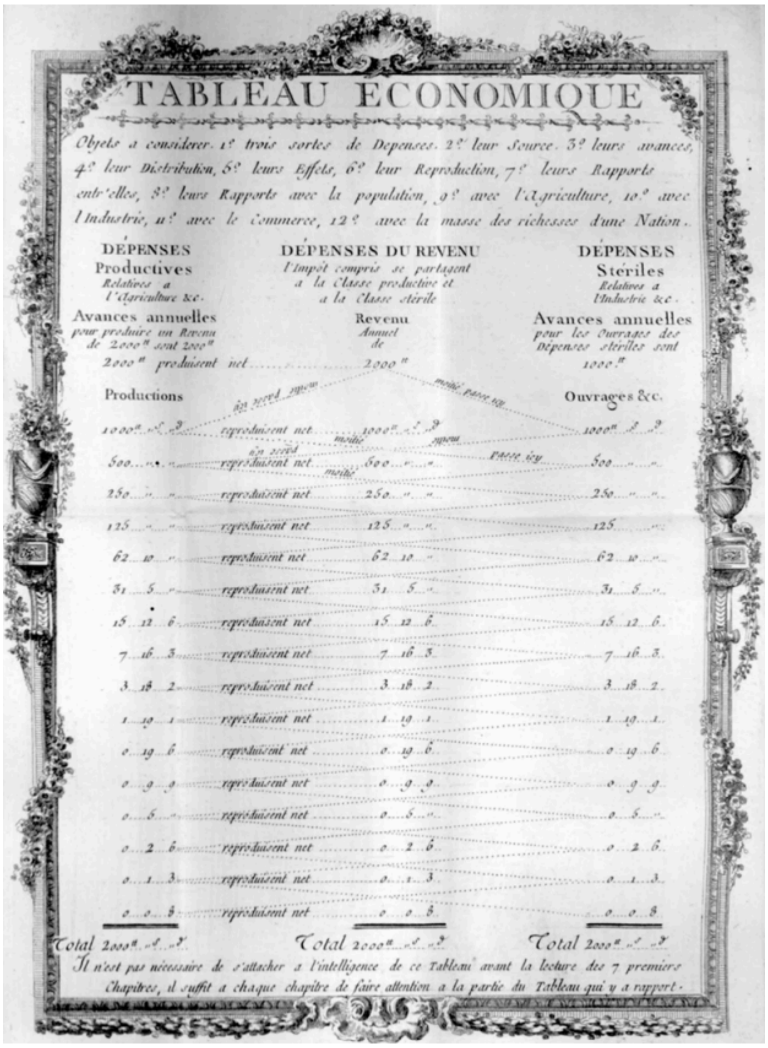

Figure 8: The *Tableau Économique* by François Quesnay in Philosophie Rurale (1763)

Another type of two-dimensional model is a drawing of a physical set-up. This is best illustrated by the example of Irving Fisher's mechanical balance model (see Figure 9). Fisher believed that the quantity theory of money was an essential rule in economics.[67] The quantity theory of money holds that the general price level in an economy is proportional to the amount of money circulating in that economy. Fisher aimed to formulate this theory in terms of the 'equation of exchange' ($M * V = P * Q$). According to this equation, the price level (P) must increase when the quantity of money (M) or the rate of circulation of money (V) increases. That is, there must always be a balance between the quantity of money, the rate of

[67] Mary Morgan, and Margaret Morrison. *Models as Mediators: Perspectives on Natural and Social Sciences*. Cambridge: Cambridge University Press, 1999: 349.

circulation, the price level, and the quantities traded in an economy. The mechanical balance in Figure 9 shows this well. If one of the weights or arms on the balance were to change, a movement in one or more of the others is required to maintain balance.[68] The model also shows in what direction the movement must take place. By constructing a model in the form of a mechanical balance, Fisher makes use of our familiarity with the workings of a balance to understand an economic theory. This model is different from the two-dimensional graphs we saw before. Fisher's model is two-dimensional but it prompts us to think of a three-dimensional object and its mechanics. It partly derives its epistemic benefits from the alleged three-dimensionality. It could be argued that such a model stands in between the two-dimensional graphs and actual three-dimensional models like the Phillips Machine.

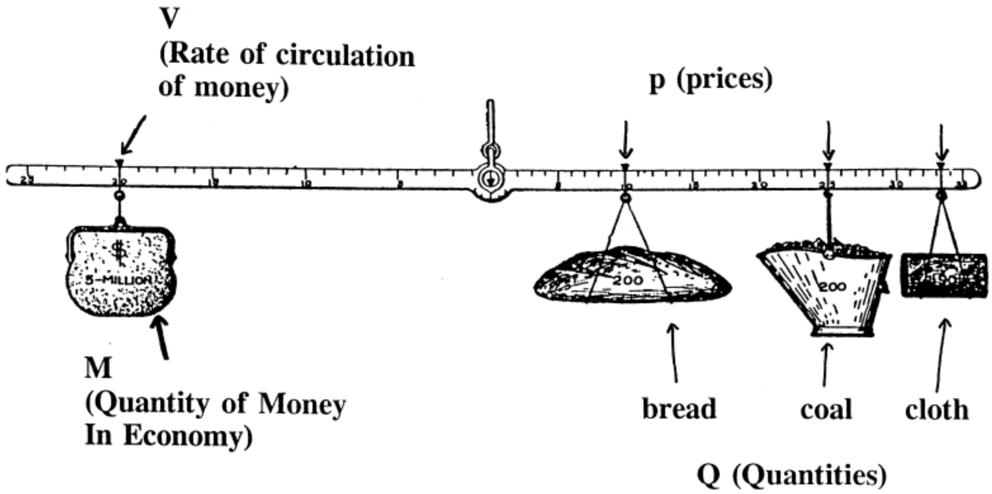

Figure 9: Fisher's mechanical balance model

Certain computer simulations can also be categorized as two-dimensional economic models. Yet, here distinctions between the model types are more difficult to make and dependent on several factors. A computer simulation of the Phillips Machine could be either categorized as a two-dimensional or a three-dimensional model, although it is depicted on a two-dimensional computer screen. When the simulation considerably resembles three-dimensional space, e.g. you can view the model from different sides and you can see the water moving, I would define it as a three-dimensional model for the purposes of this thesis. A simulation lacking allusions to three-dimensional space falls into the category of two-dimensional models. Similarly, a video of the Phillips Machine can be categorized as three-dimensional, provided that the machine is shown from different sides and the viewer is informed about the mechanical workings of the machine. Interestingly, an attempt was made

[68] Morgan and Morrison 1999: 357.

to create a (two-dimensional) computer simulation of a hydraulic system representing a macroeconomy in the 1980s. The computer animation, called FYSIOEN, was designed for the Dutch Central Bank to help users understand a complex macroeconometric model (MORKMON). The mathematics of the macroeconometric model were translated into a computer animation of a hydraulic system.[69] Yet, this led to an inconsistent picture. You only saw coloured areas increasing and decreasing without knowing the direction of the water flow. Sometimes areas even filled up without a tap being opened.[70] The idea of the model had been to translate the complex mathematics into the familiar language of hydraulics, but the model did not adhere to the laws of hydraulics. So, the computer simulation did not help to increase the understanding of the macroeconometric model behind it, and therefore, it did not achieve its goal. FYSIOEN is a good example of how models can fail. The last issue to cover regarding a definition of a three-dimensional economic model is the existence of multi-dimensional econometric or computer models. In this thesis I do not consider econometric models with multiple variables when discussing *n*-dimensional models. The dimensions continually relate to space (and time). However, econometric or computer models provide a good reference point for how to value the epistemic (dis)advantages of three-dimensional models. The following section will provide a brief comparison between three-dimensional models and computer models.

The exposition of different economic models given on the previous pages was meant to clarify the distinction between different modeling types. The main focus being the difference between non-3D models compared to 3D models. Now that we have a clear definition of three-dimensional economic models, we can move on to a discussion of the epistemic benefits and costs that such models possess.

2.2 Epistemic advantages and disadvantages

In what follows, I will claim and explain reasons why three-dimensional models as learning tools provide an epistemic advantage over non-three-dimensional models. That is, I will explain in what ways 3D visualization helps to give knowledge. Next, the epistemic disadvantages, reasons why 3D models might impede knowledge acquisition, will be discussed. The discussion will be general so that it could be applied widely, but the examples are from economics.

[69] Marcel Boumans. “Visualisations for Understanding Complex Economic Systems.” In *Ways of Thinking, Ways of Seeing*, edited by Chris Bissell and Chris Dillon, 145-166. Berlin: Springer, 2012: 147.
[70] Morgan and Boumans 2004: 394.

Epistemic advantages of 3D models

Models can be claimed to give knowledge because of their connection with other areas of knowledge. They make use of available theoretical and empirical knowledge.[71] For example, by representing supply and demand as mathematical curves, a modeler taps into a viewer's mathematical knowledge to explain price determination, as we saw before. Although it is an advantage of all types of models, the benefit of alluding to already existing knowledge is most profound with three-dimensional models. Furthermore, the type of knowledge that a model aims to make use of partly determines the form of the model. If a modeler wants to tap into knowledge of algebra or calculus to explain an economic concept, she will likely construct a two-dimensional model because algebra and calculus themselves are mostly conveyed in numbers and graphs. Yet, if the modeler aims to allude to hydraulic knowledge, it is more likely that the model will have three dimensions since hydraulics deals with three-dimensional systems. Why do 3D models benefit from the reference to available knowledge the most? The answer to this question is twofold. Firstly, the type of knowledge alluded to in 3D models tends to be intuitive knowledge. We live in a three-dimensional world and human thinking is for a large part guided by experiences in this world. Or, in other words, we as humans are most comfortable thinking in three dimensions. Laymen find Newton's laws of motion easier to comprehend than the rules of differentiation, because they have everyday experience with the first but not with the second. Such everyday experience creates intuition and models benefit from intuition. By connecting a complicated concept or theory to readily available knowledge (i.e. intuition), the concept or theory is more likely to be understood. Morgan and Boumans define this as 'understanding through the mind's eye'.[72] Next to that, the model will be useful to a larger group of people because 'everyday knowledge' is more widespread than 'expert knowledge' like algebraic proficiency. Secondly, the knowledge referred to by a three-dimensional model tends to be more articulated than the knowledge referred to by models of fewer dimensions. That is, it is clear what knowledge the 3D model makes use of. This is not always the case for non-3D models. Because models with fewer dimensions require fewer specifications, they can more easily be misinterpreted. Take Hume's price-specie flow mechanism with the analogy between water and the quantity of money in different countries. Hume compares money with water because both seem to have a tendency to level. However, you could take the analogy further and attribute other

[71] Tarja Knuuttila, and Mieke Boon. "How Do Models Give Us Knowledge? The Case of Carnot's Ideal Heat Engine." *European Journal for Philosophy of Science* 1, no. 3 (2011): 331.
[72] Morgan and Boumans 2004: 388.

characteristics of water to money which should not be attributed to money. Or the reader can be fooled about the timing of the leveling of the quantities of money between countries. Water levels in seconds, minutes, or hours (depending on the type of bodies of water you have in mind). But the process of money leveling described by Hume takes months or even years and can easily be disturbed by external factors. Since a three-dimensional model requires more specifications, misinterpretations of the model do not occur as often. An increase in understanding through three-dimensional visualization comes at the cost of constraints and commitments for the modeler, however, as we will see in the discussion of the epistemic disadvantages of 3D models.

Another advantage of three-dimensional models can be summarized by the expression 'learning by doing'. Three-dimensional models have the benefit that you can interact with them on some level. You can walk around them, touch and turn them etc. The Phillips Machine is a good example of how extensive such interaction can be. The machine allows you to experiment with monetary and fiscal policy under different macroeconomic conditions by adjusting the position of the slots (graphs) and governing the connection with the spare tanks. James Meade, as professor at the LSE, would link an original and a mirrored Phillips Machine together in class and appoint students to perform fiscal and monetary policy on each machine. The original machine would represent the British economy and the mirrored machine the US, so a Chancellor of the Exchequer, a Bank of England Governor, a Secretary of the US Treasury and a Chairman of the US Federal Reserve were appointed. These small experiments often ended in an unstable economy for both countries and showed how uncoordinated fiscal and monetary policy can make matters worse.[73] Interaction with economic theory in this way contributed to the understanding of the students. Interestingly, multiple students of James Meade who were taught on the Phillips Machine later came to fill positions at the US Treasury and the Bank of England. For example, Paul Volcker, a student at the LSE in the early 1950s, later became the Chairman of the Federal Reserve.[74] Models are types of visualizations that help learners to offload some of their cognitive processes onto perception.[75] Cognition is still needed but a model externalizes some lower-level cognitive processes like memory, while at the same time enhancing the performance of higher-level cognitive processes like reasoning. Quesnay's *Tableau Économique* illustrates this well. The

[73] Barr 2000: 109.
[74] Bollard 2016: 120.
[75] Hai-Ning Liang, and Kamran Sedig. "Role of Interaction in Enhancing the Epistemic Utility of 3D Mathematical Visualizations." *International Journal of Computers for Mathematical Learning* 15, no. 3 (2010): 194.

model visualizes the economic flows between the different classes, removing the need to remember them and freeing up cognitive power to analyze the underlying patterns. Models of different dimensions all benefit from this visualization feature. Yet, three-dimensional models allow for interaction which can extend the epistemic power of the visualization. Interaction enables features or relationships to be made explicit through the discourse between learner and model, and enhances learning.[76] This interactive type of learning is often called learning by doing or active learning. It goes beyond the scope of this thesis to give a psychological explanation of why active learning is beneficial. Yet, some established benefits can be named. Active learning gives the learner the opportunity to receive feedback and promotes adjustment of thought.[77] The learner can experiment with the model by testing some hypotheses. For example, in the case of the Phillips Machine, a learner could increase investment by opening up the investment slider and see how this changes national income. The process and result may look different than the learner expected. The interaction with the model thus provides the learner with feedback and adjusts the learner's thought to understand Keynesian macroeconomics better. Static models lack this possibility for giving feedback. Next to this, active learning increases the chance of discussion between teachers and learners, and among learners. By interacting with the model, learners get a better idea of what features of the underlying theory they do not understand, which leads to more specific questions and useful discussions. Lastly, active learning or learning by doing has been found to enhance material retention as interaction with a model provides learners with more time and more tools to process the information at hand.[78] It must be kept in mind that active learning is not exclusive to three-dimensional models. Other types of models depend on it as well, especially computer models and programs. Think, for example, of the spreadsheet editor program Excel. Excel allows its users to display calculations in multiple, interrelated steps and play around with the numbers. Such interaction increases understanding and enhances learning. The same reasoning applies to other interactive computer programs and models.

The third epistemic advantage of three-dimensional models is the following: a 3D model gives you a different perspective and allows you to see things you otherwise would not. By showing a theory or hypothesis in a different form, the mind is opened up to new interpretations. This may sound a bit up in the air. An example will help to concretize the point. In the 1930s a lively debate unfolded in the macroeconomic field between Keynes and

[76] Liang and Sedig 2010: 194.
[77] Mohamed Hamada. *Active and Collaborative Learning: Practices, Problems and Prospects*. Hauppauge, New York: Nova Science Publishers, 2013: 11.
[78] Hamada 2013: 12.

the economist Dennis Robertson, regarding the determinants of the interest rate. According to Keynes' liquidity preference theory, the interest rate is a result of the equality of saving and investment and the demand and supply of money. Robertson, on the other hand, argued that the interest rate is determined by the supply and demand of loanable funds. Loanable funds refers to all forms of credit (e.g. bonds, loans, saving deposits). Bill Phillips showed that both theories were special cases of a more generalized framework.[79] One of his students wrote:

> We poor students had been almost forced to read the enigmatic papers in the Economic Journal by Keynes and Robertson who argued bitterly about the determinants of the key variable, the rate of interest. Prof. Lionel Robbins told us to read these mystifying papers to make up our own minds whether or not Keynes had won the battle and beaten the classical economists. I find it hard now to understand why he did not tell us that both were right as Bill Phillips had in point of fact shown with crystal clarity! The proof provided by the water machine was so simple. It rested on the understanding of stocks and flows in economic theory. Looking at the machine you could actually see the rate of interest, measured by the height of water in a tank, being affected by both its size and the volume of water (stocks) as well as by flows of water into and out of the tank.[80]

So, Phillips' 3D representation of the macroeconomy with stocks and flows helped students and economists to understand the differences and similarities between the liquidity preference theory of Keynes and the loanable funds theory of Robertson. The Phillips Machine provided a new perspective on a topic that was until that point mostly discussed in complicated economic papers, and it allowed for new interpretations to arise. In this way, it led to a better understanding of a topic on which many had found themselves stuck.

Modeling constraints and epistemic disadvantages

Three-dimensional models have epistemic benefits over metaphors and graphical models, but some disadvantages and costs can be named as well. Firstly, three-dimensional models require more specifications than models of fewer dimensions. The modeler faces more constraints and has to make more commitments. This is not an epistemic disadvantage per se, since it does not impede knowledge acquisition provided by the final model. Yet, it poses a significant cost to the model-maker. Constructing a three-dimensional model is demanding, which partly explains why 3D models are not as prevalent as models of fewer dimensions. To

[79] Bollard 2016: 115.
[80] Ibid.

explain why constructing a three-dimensional model implies more constraints and commitments, we take the Phillips Machine as an example again. More specifically, we compare a 2D drawing of the Phillips Machine (like Figure 2) with the actual 3D machine. Morgan and Boumans (2004) provide a list of the physical elements that Bill Phillips had to commit to in order to define the economic elements and relations. For the 2D model the following three physical elements must be specified:

1. the flows and stocks in the system
2. the size, shape, and relative positions of the tanks
3. how the flows go between different stocks

In the case of the 3D machine seven additional specifications are required:

4. the nature of the connections between flows and stocks
5. the motive power(s) and their position in the system
6. the viscosity of the fluid
7. the shape of the outflow slots in the tanks
8. the devices to maintain a constant head of water over the sliders
9. measuring devices to monitor the flows in order to regulate the sliders
10. registration devices to see the effects of the manipulations

As this list shows, a 3D visualization of the same theory requires significantly more commitments than a 2D visualization does. Items 4-10 remain secret in the 2D drawing, because they are not needed for the model to function and can easily be omitted.[81] They need to be specified fully for the 3D machine, however, because the machine as a hydraulic system does not work otherwise. Take item 7, for example. Bill Phillips had to make sure that the relationship between some stocks and flows was linear. For the 2D drawing it could simply be stated that this is the case, so no specification for the shape of the outflow slot in a tank is needed. For the 3D machine Phillips had to introduce the sutro weir as the shape of the outflow slot to achieve the linear relationship (see Figure 3). Coming up with such a solution requires mental effort and a certain familiarity with the language of the analogy at use. In the case of the Phillips Machine, this language is the laws of hydraulics. In some cases a hydraulic analogy of a certain economic relationship might not even exist. Thus, the modeler of a three-dimensional model is constrained by the analogy she chooses. In a similar way, she

[81] Morgan and Boumans 2004: 383.

is constrained by her commitment to the theory she wants to visualize.[82] If a hydraulic analogy of an economic relationship were not to exist, the modeler could choose to modify implicit assumptions or decisions about the details of the economic theory. Yet, this would change the economic theory she wants to model.

An epistemic disadvantage of three-dimensional models is that they can impede knowledge expansion by limiting how learners interpret theories. For many economic models an analogy is made between economics and some other form of knowledge like mathematics, mechanics, game theory etc. The analogy is constructed to help learners understand the economic theory better, but sometimes the analogy can be limiting. The analogy of the model leads learners to think of the economic entities and relationships in a certain way. For example, the Phillips Machine lets learners understand macroeconomics in terms of hydraulics. Although the analogy helps learners to comprehend the visualized economic theory better, it might limit how they perceive and think of related theories.[83] Not all macroeconomic theories can be depicted in the language of hydraulics and it will be more difficult for learners to understand such theories if they were taught to think of macroeconomics in terms of hydraulics. The limiting aspect of a model poses a problem for research and the formulation of new hypotheses in particular. If your mind is wired to think of a theory in a certain way, it is difficult to come up with hypotheses that do not fit this picture. The epistemic disadvantage of a model to limit thinking applies to models of all dimensions. However, three-dimensional models suffer from it the most. Because 3D models are specified further, they do not allow for much wiggle room, that is, less hypotheses and alternative theories will be compatible with the picture created by the three-dimensional model. More phenomena and theories can be described with words and drawings than with physical objects.

When it comes to the creation of 3D models, the role of the modeler and audience should not be overlooked. Bill Phillips was a trained engineer at the moment he came into contact with Keynes' macroeconomic theory. He spotted the similarities between the economic theory and hydraulics quickly and his engineering expertise served him in specifying and building the Phillips Machine. As an engineer, he himself can be argued to benefit significantly from a mechanical representation of the macroeconomy. Phillips had been wired to think in terms of mechanical systems when trying to understand complex phenomena. When faced with the complexities of macroeconomics, constructing an analogy

[82] Morgan and Boumans 2004: 383.
[83] Liang and Sedig 2010: 222.

with hydraulics served him much because his hydraulic knowledge was well-developed. It is likely that the mechanical representation provided less epistemic benefits for people less familiar with mechanics and hydraulics. Although the argument that 3D models are helpful because of their connection with more intuitive knowledge still stands, the usefulness of a 3D model depends for a part on the available knowledge of the audience. This is an important limitation of 3D models to keep in mind.

2.3 3D modeling practices of other sciences

Now that we have a better understanding of the epistemic advantages and costs that three-dimensional models entail, it will be helpful to compare economics to other sciences regarding the use of 3D models. In certain sciences 3D models are more prevalent than in economics, while other sciences have produced no 3D models at all. It will be interesting to see how different sciences deal with the epistemic advantages and costs established in the previous section. This section will give a rough overview of 3D model practice in different categories of science, with the aim to contextualize the modeling practice of economics. Only a few examples will be given to illustrate the main arguments. For the purpose of comparing the use of 3D models, the sciences are divided into three categories: sciences dealing with natural phenomena (natural sciences), sciences dealing with societies and human interaction (social sciences), and mathematics.

The natural sciences

In natural sciences like physics, chemistry, biology and geology, three-dimensional models are employed frequently. They have been used to help comprehend and explain natural phenomena since antiquity.[84] Good examples of such three-dimensional models are armillary spheres, anatomical wax models, and vulcano models. One needs only to visit a science museum to be overwhelmed by the range of 3D models available in the natural sciences. What explains this prevalence of 3D models in these sciences? The answer to this question is fairly simple: three-dimensional models of natural phenomena are relatively easy to construct because the natural phenomena they represent are three-dimensional. The modeler does not need to find a distinct analogy or connect the theory to be explained to a wholly different area of knowledge. Most 3D models in the natural sciences do not allude to fully distinct knowledge but to related knowledge, albeit on a different scale. Armillary spheres show the

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[84] Joshua Nall and Liba Taub. "Three-Dimensional Models." In *A Companion to the History of Science*, 572–86. Hoboken, NJ, USA: John Wiley & Sons, Inc, 2016: 572.

entire solar system in a mechanical model of only a few cubic meters. Likewise, the double helix model shows the structure of DNA even though the model is many times larger than an actual DNA strand. For both examples the phenomenon depicted and the form of the model relate to similar types of knowledge. The workings of the solar system can be described by laws of physics, as can the mechanics of the armillary sphere. Other forces act on the solar system and armillary sphere and they are made of different materials, but the knowledge to be explained and the knowledge used to build the model are fairly similar. The leap between the phenomenon to be explained and the language of the model is not as large as in the Phillips Machine, for example. This means that 3D models in the natural sciences are bothered less by modeling constraints and commitments. The three-dimensional models still require more specifications than models of fewer dimensions, but these specifications are less problematic since the connection between the phenomenon to be explained and the model is more straight-forward. The modeler does not need to make the step from an economic theory to a hydraulic system, for example, but from celestial mechanics to a (smaller) mechanical system. Next to this, the epistemic disadvantage of impeding knowledge expansion by limiting how learners interpret theories, is less of a problem for the natural sciences for similar reasons. It is less likely that learners will misinterpret and be limited by the analogy between the phenomenon to be explained and the language of the model because they are closely connected.

The natural sciences are bothered less by the epistemic disadvantages and costs of three-dimensional models, but they still profit from the epistemic advantages. 3D models allow for interaction, which enhances understanding. Take anatomical wax models as an example. These wax models are often made on the same scale as the body parts they represent. Yet, unlike the body parts, they allow learners to easily interact with them: pick them up, view them from different sides, take them apart etc. This kind of interaction is not possible with the object to be studied because of practical, ethical, or material reasons. The other epistemic advantage of 3D models is that they allude to a different, more intuitive, type of knowledge. Although the leap between phenomenon and model is often smaller for natural science models, they still profit from the allusion to more intuitive knowledge. The double helix model by Francis Crick and James Watson shows the structure of DNA on a much larger scale than actual DNA strands. By enlarging the phenomenon to the size of a person, it becomes easier to reason with.[85] This is because we as humans find it difficult to comprehend tiny phenomena, but we are trained to think on a 'life-size' scale.

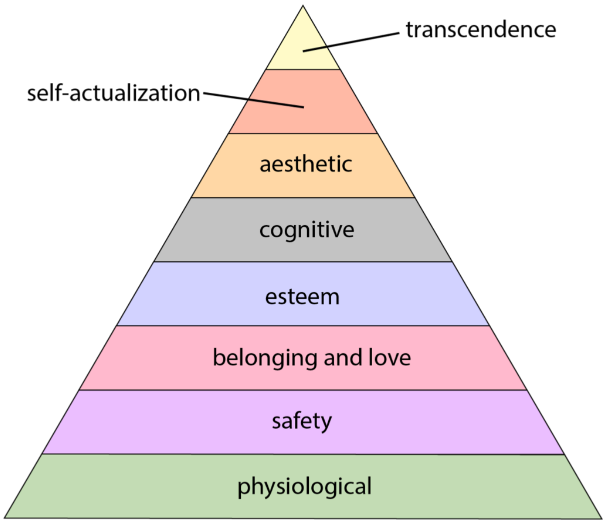

Figure 10 & 11: James Watson and Francis Crick with their double helix model & Maslow's hierarchy of needs in pyramid form

The social sciences

The Phillips Machine as an economic model has to be grouped in the social science modeling practice, since economics is a social science. The other social sciences (psychology, sociology, linguistics, history etc.) face the same problems as economics, regarding 3D modeling. The epistemic disadvantages and constraints discussed in the previous section apply fully to the social sciences, because their object of study is not a natural object but a rather abstract one. Social sciences research societies and the relationships among individuals in these societies. The relationships between individuals are not physical and thus not three-dimensional phenomena. Constructing a 3D model for these sciences implies that an analogy with a different type of knowledge must be made that can be depicted in three-dimensional space. Such an analogy must exist and be worthwhile to construct. Maslow's hierarchy of needs is a psychological theory classifying different human needs on the basis of how essential they are to human functioning. This hierarchy of needs theory is often illustrated with a model in the form of a pyramid, with the most essential human needs at the bottom (see Figure 11). An analogy is made between a psychological theory and a geometrical shape, helping learners to visualize and understand the theory. Although the model is called a 'pyramid', which implies three-dimensionality, it usually does not extend

[85] Nall and Taub 2016: 576.

beyond two dimensions. Strictly speaking, the model is a triangle, not a pyramid. Extending the model to three dimensions does not add to its epistemic or explanatory power. This is a good example of a case where it is not worthwhile to construct a 3D model, even though the analogy exists. In many other cases in the social sciences such an analogy to 'three-dimensional knowledge' does not exist or requires a very bright mind to come up with and develop. This does not mean that three-dimensional models cannot be useful for the social sciences, the epistemic advantages as given in the previous section remain, but the modeling constraints weigh heavier than for the natural sciences. That is the main reason why 3D models are prevalent in the natural sciences but rather unusual in the social sciences.

Mathematics

Mathematics as a science is given its own category in this discussion because it does not belong to the natural or the social sciences, and because its modeling practice serves to illustrate some of the main arguments of this chapter well. Mathematics is a science dealing mostly with abstract phenomena, similar to the social sciences. For the abstract areas of mathematics like calculus or statistics, three-dimensional models are not common. However, for some areas of mathematics the modeling constraints entailed by 3D models weigh not as heavy because the areas partly have three-dimensional (or *n*-dimensional) phenomena as their object of study. One of such areas of mathematics is geometry. Mathematics has produced multiple useful 3D models.[86] An interesting example are the knitted mathematical models of the chemist and mathematician Alexander Crum Brown. Crum Brown was interested in knot theory and topological problems. He knitted multiple models of interpenetrating surfaces in order to think through the problems he faced.[87] The knitted models were not simply visualizations of the theory studied. Crum Brown himself emphasized how working in wool helped him to think through surfaces that he later published as abstract mathematical formulations.[88] This example serves to show how interaction with a model can enhance the performance of higher-level cognitive processes like reasoning.

2.4 Conclusion: Methodological answer and criteria for 3D representation

One of the aims of this chapter on the methodology of 3D models was to provide a methodological answer to the question why no other three-dimensional models were

[86] Liang and Sedig 2010: 198.
[87] David Dunning. "What Are Models For? Alexander Crum Brown's Knitted Mathematical Surfaces." *The Mathematical Intelligencer* 37, no. 2 (2015): 62.
[88] Nall and Taub 2016: 574.

successfully built after the Phillips Machine. Economics as a science does not deal with natural phenomena but with rather abstract theories. This means that a modeler faces significant constraints and has to make many commitments when constructing a 3D model. An analogy with three-dimensional and intuitive knowledge must be found and developed. 3D models benefit from epistemic advantages: they give knowledge because of their allusion to intuitive knowledge; they give an opportunity for active learning; and they can provide you with a new perspective or allow for different interpretations. However, the modeling costs weigh heavy for economics making the construction of 3D models less likely. Furthermore, as the first chapter showed, the significance of the right individual with the right skill-set and peers to recognize his or her contribution, should not be overlooked. If Bill Phillips, or another bright-minded economics student with engineering experience, had not been present, the Phillips Machine might not have been built at all.

The next chapter will investigate why and in what way the historic conditions have not been right for the construction of other economic 3D models. For different economic traditions in the second half of the twentieth century, it can be examined whether the criteria needed for 3D representation were present. The criteria are the following: (1) a useful and worthwhile analogy with intuitive, 'three-dimensional' knowledge was available, that is, the modeling constraints and commitments did not outweigh the epistemic advantages, (2) the right individual with the right skill-set was present, and (3) the value of the model was recognized by peers. The focus of the next chapter will be on the first criterion.

Chapter 3: Economic Traditions and 3D Models

The following chapter aims to provide an historical answer to the question why no other successful economic 3D models were built after 1950. The previous chapters provided us with multiple criteria for a successful 3D modeling practice. The most relevant criterion for this chapter is the following: A useful and worthwhile analogy between economic theory and intuitive, 'three-dimensional' knowledge is available. The other criteria, especially the presence of the right person with the right skill-set, are partly up to chance and therefore difficult to study systematically. This chapter will discuss the four main economic traditions of the second half of the twentieth century. In the discussion of each economic tradition the main ideas of the tradition will be shortly explained and some historical context will be provided. Also, one or two substantial models of the tradition will be discussed. Next, the question whether the tradition lent itself well to three-dimensional representation will be investigated.

Since 1950 many macroeconomic theories have been developed and popularized. It is a challenging task to group all these theories in distinct economic traditions or schools. In this thesis I do not claim to have the right way to categorize the theories. I will simply follow the more or less mainstream categorization. The following list is a very rough outline of the main economic traditions since the 1930s:

1. Keynesianism (1930s-1940s)
2. The neoclassical synthesis (1950s-1970s)
3. Monetarism and new classical macroeconomics (1970s-1990s)
4. New Keynesianism (1980s-1990s)

The focus on the chapter will be on macroeconomic theories. Keynesianism and the neoclassical synthesis will be discussed first. The Phillips Machine was largely constructed on the basis of Keynesian ideas. It is worthwhile to investigate in what way Keynesianism lent itself well to 3D representation as a comparison for the later economic schools. Economists of the neoclassical synthesis worked to reconcile Keynesian macroeconomics with earlier neoclassical theories. In the 1970s neoclassical economics was revived in an economic tradition that is now often referred to as new classical (macro)economics. Monetarists and new classical economists criticized Keynesianism, especially the importance it attributed to monetary policy in combating economic recessions. New classical macroeconomics and monetarism are closely related. New Keynesianism arose as a response to new classical criticisms of Keynesian macroeconomics. Its main aim was to provide microeconomic foundations for Keynesian macroeconomics. The terminology of the economic traditions since 1950 can be confusing. The main economic traditions often go by different names, which can be similar to names of other traditions. For example, neo-Keynesianism is another name for the neoclassical synthesis and is thus distinct from New Keynesianism. In an attempt to reduce confusion I will stick to the names of the economic traditions I introduced here and explain their main objectives carefully. Moreover, in this thesis I can only provide a short overview of each economic school, which means that the discussion will rarely extend beyond the main ideas and lines of argument of the tradition.

3.1 Keynesianism

The writings and work of John Maynard Keynes (1883-1946) were and still are influential in the field of economics. An economic school was even named after him: Keynesian economics or Keynesianism. Keynes' most important book, *The General Theory of Employment, Interest, and Money* (1936), introduced new economic focal points and suggestions for policy makers, causing a revolution in the history of economic thought.[89] In the following section Keynes' main ideas will be outlined by juxtaposing them to the ideas of neoclassical economics, the dominating economic tradition before Keynes. The relationship between Keynesianism and the Phillips Machine will be discussed afterwards.

Neoclassical economics vs. Keynes

Economics as a science is often said to have originated in the eighteenth century with Adam Smith's *Wealth of Nations* (1776) and over the following century and a half it continually evolved due to contributions by economists such as Ricardo, Malthus, Marx, Jevons, Marshall, and Pigou. The early stage of this development is known as classical economics. With the rise of the marginalists in the 1870s mainstream economics is typically classified as neoclassical economics. This was the dominating economic school of thought when Keynes started to develop his revolutionary ideas in the 1930s. Neoclassical economists believed in the inherent recuperative powers of the market mechanism. Keynes was the first to convincingly challenge this belief and put forth a different theory which acknowledged market imperfections.[90] One of the most profound assertions by Keynes was the rejection of the idea that full employment is maintained by some self-adjusting mechanism.[91] According

[89] Mark Blaug. *Economic Theory in Retrospect*. Fifth edition. Cambridge: Cambridge University Press, 1997: 642.
[90] Blaug 1997: 643.
[91] Stewart 1991: 67.

to neoclassical economists wages move by themselves in such a way as to ensure full employment (that is, no involuntary unemployment). Keynes stressed that full employment is not the normal state to which the economy continually returns. Instead, long periods of high unemployment can occur. The level of employment is determined by the level of output in the short run and output is dependent on effective demand (or actual expenditure). In a closed economy effective demand consists of three components: consumption, investment, and government spending. This gives us the equation: $Y = C + I + G$. If effective demand and thus output is low, unemployment is relatively high and will stay that way unless one or more of the three components increases. Keynes' theory assigns an important role to the government. The government can reduce unemployment by stimulating investment (monetary policy) or consumption, or by increasing government spending (fiscal policy). This insight meant a significant break with the economic school of thought before Keynes which believed in an automatic return to full employment and a small role for government intervention. Keynes found an audience willing to accept his ideas quickly. The Great Depression, which had started in 1929, led people to search for an explanation of the sustained period of low output and high unemployment, and maybe more importantly, search for ways to combat the depression. Keynes provided both the explanation and the tools to fight the depression. Other meaningful contributions by Keynes concern the multiplier effect, the relationship between saving and investment, liquidity preference, and the paradox of thrift (see chapter 1).

Many Keynesian notions find their origin in earlier economic theories. For example, the idea that a government can spend its way out of a depression derives from the quantity theory of money and was discussed by economists before Keynes.[92] Yet, Keynes was the first to combine these distinct theories and formulate one general theory of economics. Next to this, he shifted the perspective from the micro-level to the macro-level and from the long run to the short run. Furthermore, the work of Keynes has been interpreted differently by different economists. The overview of the Keynesian theory presented here is only one of such interpretations, although it is considered the standard one and is closely related to the neoclassical synthesis. Other interpretations emphasize the significance of animal spirits or presence of a liquidity trap, for example.

Hydraulic Keynesianism

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[92] Blaug 1997: 648.

The Phillips Machine was largely based on Keynesian economics, although Phillips and Newlyn made use of different interpretations of Keynes' writings by other economists as well. For example, the IS-LM model as introduced by John Hicks (1937) proved helpful in designing the machine. So, the Phillips Machine can be argued to be a product of the neoclassical synthesis instead (see following section). I subscribe to this claim but it must be noted that only the early Keynesian interpretations of this tradition were relevant. The theories developed later and the synthesis with neoclassical economics played a marginal role in the design of the Phillips Machine. The Phillips Machine remains mostly based on (interpretations of) Keynesian ideas. Keynesianism as the first large macroeconomic theory lent itself well to 3D representation. Keynes described output or aggregate demand as consisting of different components. The level of output is affected by changes in the components ($C + I + G$) and in turn the components are affected by the level of output (Y), creating a cycle. Furthermore, the Keynesian economy seems to be made up of flows and stocks of money. Saving being a flow and money supply (or surplus balances, see Figure 2) being a stock, for example. These observations led Bill Phillips to notice similarities between economics and hydraulics, and to eventually construct an hydraulic analogy of Keynesianism. Moreover, throughout the history of economic thought a connection between money and water has been made frequently. Money is often called liquid and several intellectuals constructed metaphors based on the similarities between water and money. Hume's price-specie flow mechanism is a good example of this. Yet, Hume was neither the first nor the last to compare money to water. Bill Phillips was likely influenced by the widespread association between money and water, prompting him to notice the worthwhile analogy between Keynesian economics and hydraulics.

3.2 The neoclassical synthesis

Keynes' *General Theory* is notoriously difficult to read. The book contains many lines of argument while it is not clear what the most important points are.[93] In the years and decades after the publication of the *General Theory*, multiple economists formulated their interpretation of Keynes' ideas. Some translated the arguments into mathematics or graphs in an attempt to make sense of what Keynes was saying. The dominating economic school of thought soon after the publication of the *General Theory* is known as the neoclassical

[93] Roger Backhouse. *The Penguin History of Economics*. London: Penguin, 2002: 233.

synthesis. Economists of this tradition worked to explain the writings of Keynes and tried to combine it with neoclassical economics, with the aim to create a comprehensive macroeconomic theory.

Main ideas

It is difficult to identify the exact starting point of the neoclassical synthesis. Economists such as John Hicks and Franco Modigliani gave their own interpretations of Keynes' work in the late 1930s and early 1940s. Soon mainstream economics centered around these interpretations and no pure Keynesian ideas were used anymore. Paul Samuelson coined the term 'neoclassical synthesis' for the time in his book *Economics: An Introductory Analysis* (1948).[94] The neoclassical synthesis can be said to be the dominating economic tradition in the 1950s until the 1970s. The main objective of the tradition was to reconcile Keynesianism with neoclassical economics. Keynesian economics and its implications for government intervention were widely accepted in the 1940s. Yet, neoclassical criticism arose centering around the argument that Keynesian policies might lead to inflation. Economists of the neoclassical synthesis accepted both the need for government intervention and the role of market forces. They argued that neoclassical principles apply to the long run, while Keynesian economics provides policy options for the short run. The short run was thought to be characterized by (wage) stickiness and non-clearing markets, whereas the long run showed market clearing and flexibility. So, Keynes' ideas were accepted and developed, but at the same time the worries of neoclassical economists were recognized. This led to the formulation of a more complete macroeconomic theory. John Hicks translated Keynes' theory into a graph, which was later called the IS-LM model or curve. The IS-LM model may serve to illustrate the main ideas of the neoclassical synthesis.

The IS-LM model and the Phillips curve

Already in September 1936, half a year after the publication of the *General Theory*, John Hicks presented the IS-LM model as a summary of Keynes' theory. In the late 1930s and in the 1940s Hicks, together with Alvin Hansen, refined and developed the model further. In short, the IS-LM model shows the relationship between output and interest rates in an economy (see Figure 12). The investment-saving (IS) curve gives the equilibrium in the goods market and the liquidity preference-money supply (LM) the equilibrium in the money market.[95] In the goods market of a closed economy output is dependent on consumption,

[94] Olivier Blanchard, Olivier. *Macroeconomics*. Seventh edition, global edition. Boston: Pearson, 2017: 518.
[95] Blanchard 2017: 126.

investment, and government spending ($Y = C + I + G$). If interest rates increase, the output will lower because investment decreases. Furthermore, the decrease in output further lowers consumption and investment through the multiplier effect. So, in a graph with interest rates as the independent variable and output as the dependent variable, the IS curve is downward-sloping. The IS curve is shifted to the right or left in the case of external changes. For example, the IS curve shifts to the right (left) when government spending is increased (decreased). The LM curve gives the equilibrium in the money market. The money market equilibrium is determined by money supply and money demand (see Figure 5). The downward-sloping liquidity-preference function gives the willingness to hold cash or the demand for money. Money supply is in the hands of the central bank and is not affected by interest rates. This makes money supply perfectly inelastic and thus, the curve is vertical. If output rises, the liquidity preference function would be shifted to the right and thus interest rates on the money market are increased. This would mean that the LM curve is upward-sloping. However, in reality central banks do not simply choose the money supply and let the interest rate adjust.[96] They choose an interest rate and adjust the money supply in such a way as to achieve the chosen interest rate. So, the central bank sets the interest rate directly, which means that the LM curve is horizontal. The IS and LM curve together comprise a model which allows economists to analyze how monetary and fiscal policy affect the economy, among other things.

Another important model of the neoclassical synthesis is the Phillips curve. Like the Phillips machine, this model was named after Bill Phillips. In 1958, the year in which he became professor at the LSE, Phillips published a paper on the relationship between the rate of unemployment and the rate of change of money wages.[97] His main finding was that in the period 1861-1913 in the United Kingdom money wage rates increased at an accelerating rate when the unemployment level fell below 5% (see Figure 13). Yet, at high levels of unemployment money wage rates decreased. Soon other economists published similar findings, although the focus shifted to the relationship between unemployment and inflation. The rate of change of money wages was taken to be a proxy of inflation. In 1960 Paul Samuelson and Robert Solow made the trade-off between unemployment and inflation explicit, using data from the US.[98] This research resulted in the formulation of the Phillips

[96] Blanchard 2017: 115.
[97] A.W. Phillips."The Relation Between Unemployment and the Rate of Change of Money Wage Rates in the United Kingdom, 1861-1957". In *A.W.H. Phillips: Collected Works in Contemporary Perspective*. Cambridge: Cambridge University Press, 2000: 258.
[98] Richard Lipsey. "The Famous Phillips Curve Article". In A.W.H. Phillips: Collected Works in Contemporary Perspective. Cambridge: Cambridge University Press, 2000: 238.

curve: an inverse relationship between inflation and unemployment. This model soon became famous among economists and affected policy making. The Phillips curve helps to show how expansionary fiscal or monetary output will lead to higher inflation rates. The Phillips curve also played an important role for later economic traditions like new classical macroeconomics and new Keynesianism (see following sections), although sometimes in adjusted form.

The IS-LM model and the Phillips curve are good illustrations of the main ideas of the neoclassical synthesis. On the one hand, the IS-LM model stands for an interpretation and reformulation of Keynesian ideas. On the other hand, the Phillips curve allows policy makers to gauge the effects of government intervention on the price level, thereby incorporating the worry of neoclassical economists into the framework.

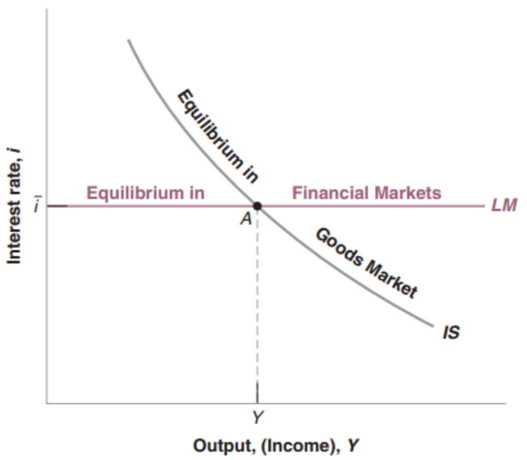

Figure 12 & 13: The IS-LM model & the original Phillips curve (1958)

The neoclassical synthesis and 3D representation

The Phillips machine was partly based on early ideas of the neoclassical synthesis. Yet, when the economic tradition was fully developed and became mainstream, no other 3D models of significant meaning were constructed. Why not? A few reasons can be named. Firstly, the neoclassical synthesis, unlike Keynesian economics, focused on different time horizons. A distinction was made between the short, medium, and long run, all with different characteristics and equilibria. The shift between these distinct time horizons made it more difficult to find an appropriate three-dimensional analogy. Fitting the three periods into one 3D model would have proved complicated. Also, there is no readily apparent type of 3D knowledge (e.g. mechanics) that could accommodate these distinct time horizons all at once, since shifts between different time horizons are not common in sciences with 3D phenomena as their object of study. A three-dimensional model of a partial theory of the neoclassical synthesis might still have been possible, if the right creative mind had been present. Yet, constructing a 3D model which incorporates the main ideas of the neoclassical synthesis as a comprehensive theory (like the Phillips machine for Keynesianism) would have been challenging. Secondly, two-dimensional representations of the main ideas of the neoclassical synthesis had already been found and developed. Graphs and mathematics helped economists understand the important theories of the tradition. The IS-LM model is a good example of this. The availability of useful 2D representations removed the need for a 3D model. Lastly, the neoclassical synthesis was a partial return to neoclassical economics in that it tried to combine the new, Keynesian theories with older neoclassical theories. The modeling practice of neoclassical economics had centered around stories, graphs, and mathematics. A partial return to this tradition meant a partial return to its methodology as well. Keynes had caused a revolution in economics which opened the door to a new methodological approach. The partial return to earlier economic tradition closed this door again. So, although the neoclassical synthesis shared some similarities with Keynesian economics, in its fully developed form it did not lend itself well to 3D representation.

3.3 Monetarism and new classical macroeconomics

Starting from the 1950s new economic theories were developed that would come to be known as monetarist and new classical theories. These ideas gained prominence in the 1970s. One cause for its popularity was a period of stagflation (low growth and high inflation), which could not be explained by economists of the neoclassical synthesis satisfactorily. Monetarism and new classical macroeconomics criticized the mainstream Keynesian economic theories of the 1950s and 1960s, and formulated their own ideas which showed similarities with neoclassical economics.

Main ideas

Monetarism and new classical macroeconomics are two distinct economic traditions, but they share many similarities and gained prominence around the same time. That is why they will be discussed together. Monetarism and new classical macroeconomics center around the assumptions of market-clearing and optimization. They rest on the assumption that individuals optimize utility and businesses optimize profits in the sense that they make rational decisions to bring their optimal situation about and then stick to those decisions.[99] Market-clearing means that demand and supply in markets will consistently equate, and thus excess demand or excess supply is not possible. When applied to the labour market, monetarists argue that involuntary unemployment does not exist. Workers might lose their job but they could always find a new one if they were willing to accept a sufficiently low wage. If not, they are not involuntarily unemployed but they choose leisure over employment. Monetarists, in particular, believe that government intervention through fiscal and monetary policies causes more harm to the economy than good. It is extremely difficult to gauge the effects of a particular policy because of unexpected situational changes and time lags, so it is better to refrain from attempting to influence the economy through policies. Also, in the long run expansionary policies will have no effect on real variables like GDP but will only cause inflation. So, the Phillips curve is vertical in the long run. Money supply is crucial for growth, however. That is why Milton Friedman, a key figure of monetarism, proposed a constant-money-growth rule, according to which the money supply should be made to grow at an annual rate of around 3 to 5%.[100] Money demand was thought to be relatively stable and not a determinant for economic growth. Another key feature of monetarism is the focus on the distinction between real and nominal variables.

In the late 1970s and early 1980s monetarists lost some influence because of multiple reasons. For example, the claim that aggregate demand was stable and unimportant for economic growth was found to be incorrect.[101] Furthermore, the rational expectations hypothesis gained prominence. New classical macroeconomics is centered around this hypothesis. Economists before the 1970s had recognized the importance of expectations for economic theory. Examples are Pigou and Keynes. However, proponents of the rational expectations theory were the first to formulate an extensive theory of expectations.[102] In short, according to the rational expectations theory the outcomes of many economic situations depend in part on what people expect to happen. For example, the price of a product depends on how many products manufactures decide to make (i.e. the supply), which in turn depends on the price manufactures expect to get for the product. Rational expectations play a substantial role in the work of the economist Robert Lucas Jr. Lucas formulated some of the most important new classical theories.

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[99] Stewart 1991: 158.
[100] Bennett McCallum. “Monetarism.” Econlib. https://www.econlib.org/library/Enc/Monetarism.html.
[101] Ibid.
[102] Backhouse 2002: 299.

The Lucas critique

The Lucas critique, based on a series of papers by Robert Lucas starting in 1972, captures some of the main new classical ideas. It argues that the behavior of individuals and firms depends on their expectations of what the government is going to do.[103] For example, if the private sector expects the government to decrease the tax rate, they will behave like the lower future tax rate is a fact and incorporate the information into their predictions and decisions. When the government then actually lowers the tax rate, no effect on the economy will be brought about because the policy change was anticipated. In short, policies that are systematic will be expected by individuals and firms, which means that they do not have any real effects on the economy. According to Lucas, only unanticipated governmental policies can have real effects. However, because they are unanticipated, they cannot be systematic and thus, they cannot be used to direct the economy.[104] Lucas formulated a model to illustrate the link between money supply, changes in the price level and output, using rational expectations. If we take the private sector to be fully rational, it is likely that inflation and real output are correlated in the short run. A firm might mistake a nominal price increase for a real price increase and thus increase its output. So, an expansion of the money supply causes inflation, which leads to higher output.[105] This exhibits a Phillips curve. The government cannot exploit the Phillips curve, however. Governments had used the Phillips curve as a policy rule in the 1960s. The private sector expects the government to increase money supply and thus raise the price level, if the employment rate falls below a certain threshold. The policies aimed at reducing unemployment are systematic and anticipated by individuals and firms. They have no real effect on the economy because the private sector will discount the policy changes in advance. This critique of policy effectiveness is also called the policy non-invariance critique. Furthermore, individuals and firms expect inflation in the long-run and incorporate it into their predictions. While they might make errors in distinguishing nominal from real price level changes in the short run, this does not happen in the long run. So, in the long run the Phillips curve is vertical. According to new classical economists, the effects of policies can only be understood by investigating the underlying parameters that govern the behavior of individuals and firms, e.g. preferences and technology. That is, microfoundations need to be given for macroeconomic phenomena.

[103] Backhouse 2002: 299.
[104] Thomas Sarget. "Rational Expectations." Econlib. https://www.econlib.org/library/Enc/RationalExpectations.html.
[105] Max Gillman and Robert Lucas Jr. "Expectations and the Neutrality of Money." In *Collected Papers on Monetary Theory*, 1–24. United States: Harvard University Press, 2012: 2.

Monetarism, new classical macroeconomics, and 3D representation

Monetarism and new classical macroeconomics did not lend themselves well to three-dimensional representation because of multiple reasons. Firstly, monetarist and new classical theories were mostly critiques of earlier theories. For example, monetarists argued that the Keynesian idea that fiscal policy can be used to combat a recession successfully, was incorrect. They went even further by claiming that fiscal policy does in fact more harm than good. Critiques such as this one did not require the exposition of new concepts or a new theory. They mostly consisted of written criticism and the occasional reference to a conceptual mistake in the models of Keynesian economics or the neoclassical synthesis. Think, for example, of the new classical claim that the long-run Phillips curve is vertical. Lucas and other new classical economists explained this claim by pointing out the false assumptions made by earlier economists, such as the failure to recognize the role of expectations in the model. Since monetarist and new classical theories were critiques of earlier theories, or started as critiques, the language of their ideas was similar to those earlier theories. Although new models were developed, they remained pen-and-paper models. Secondly, monetarism and new classical economics can be seen as a revival of neoclassical economics in some aspects. A good example is the rejection of involuntary unemployment. A return to neoclassical economics also meant a return to its two-dimensional modeling practice. Thirdly and most importantly, the monetarist and new classical conception of the macroeconomy was in some ways more complicated than the Keynesian one. Economists in the 1970s and 1980s focused on the relation between microeconomics and macroeconomics. The consensus soon seemed to be that macroeconomics cannot be viewed on its own but must be understood in relation to its microfoundations. That is, macroeconomic events can only be explained by references to the behavior of individuals and firms. This introduces an extra layer to the macroeconomic theory at hand, complicating it significantly. Similar to the distinction between different time horizons (short, medium, and long run) in the neoclassical synthesis, the introduction of microfoundations in macroeconomics made it more difficult to find an appropriate three-dimensional analogy. Also, the monetarists and new classicals shifted away from a stock-flow interpretation of the economy, which meant that the straight-forward analogy with hydraulics was lost. It does not mean that it would have been impossible to construct a 3D model that served to explain a monetarist or new classical notion, however. The reasons given here only serve to demonstrate that within the monetarist tradition the construction of a 3D model is less likely to occur than within the Keynesian tradition.

3.4 New Keynesianism

While new classical economics was still on the rise in the late 1970s and early 1980s, economic theories were developed that would later be put under the header 'new Keynesian economics'. In the 1980s and 1990s new classical and new Keynesian economics existed side by side, until attempts were made at unifying the two schools during the 1990s and 2000s.[106] New Keynesian economics arose as a response to new classical economics. It aims to give microfoundations for Keynesian conclusions.

Main ideas

The new Keynesians adopted the rational expectations theory from the new classical economists. However, whereas the new classicals used it to argue for a laissez-faire approach from the government, new Keynesians showed that rational expectations are compatible with Keynesian insights regarding government intervention. One of the main assumptions around which new Keynesian economics is centered, is market failure. As we saw before, the monetarists and new classical economists believed in market-clearing. That is, markets will automatically return to equilibrium, the optimal situation to be in. New Keynesians reject this belief in automatic market-clearing. Instead, they argue that markets are characterized by market failure. Market failure can take many forms. Think, for example, of coordination failure among firms or information asymmetry. New Keynesians assume that there exists imperfect competition, which results in prices and wages that do not immediately adjust to new economic conditions.[107] Such prices and wages are called 'sticky'. Sticky prices and wages can be explained in multiple ways. Firstly, adjusting prices is costly for firms. Firms will have to distribute new price lists, update websites, or print new menus. The costs associated with adjusting prices are called menu costs. Next to this, price changes bring externalities with them. Firms do not operate independently from each other. If one firm lowers its prices, the overall price level will decrease slightly, leading to an increase in real income. Because of the increase in income individuals will buy more, not only at the firm that lowered its prices but also at other firms. This is known as an aggregate-demand externality. The firm in question might dislike the increased demand for the other firms and thus be hesitant to change its prices. Another reason for sticky prices is coordination failure between firms or labor unions. A firm's profit does not only depend on its own pricing decisions but

[106] Gregory Mankiw. "New Keynesian Economics." Econlib. https://www.econlib.org/library/Enc/NewKeynesianEconomics.html.
[107] Gregory Mankiw. "A Quick Refresher Course in Macroeconomics." *Journal of Economic Literature* 28, no. 4 (1990): 1654.

also on the pricing decisions of other firms. Incorrect expectations about the behavior of other firms or reluctance to act before knowing the decision of other actors, may result in sticky prices.[108] According to the new Keynesians, sticky wages and prices are a reason why fiscal and monetary policies are useful tools to combat recessions in the short run.

Another way in which new Keynesians deviate from new classical macroeconomics, concerns the belief in involuntary unemployment. According to new Keynesian economics, persistent high unemployment rates can occur. This can be explained by efficiency wages. New Keynesians claim that workers are not necessarily paid a market-clearing wage. Instead, workers are paid wages that maximize productivity. The main idea behind this is that high wages make workers more productive. Explanations for this idea can be given based on adverse selection, loyalty to the employer, or reduced shirking.[109] The new Keynesian explanation of persistent unemployment shows that, like the new classicals, new Keynesian economists are concerned with providing microfoundation for macroeconomic phenomena.

Staggered contracts models

Some of the most influential models within new Keynesian economics are staggered contract models. The idea of staggering provides another reason for why prices and wages do not immediately adjust to new economic conditions. The first staggered contract model was developed by John B. Taylor around 1980. The basic idea of the model can be explained as follows: Consider an economy in which two labor unions set wages. Each period only one labor union can adjust nominal wages for the next two periods. Say the price level is increased in the first period through an increase in the money supply. Only one of the unions can adjust its wages in the second period to account for the increase in the price level. The union is aware of the changes that happened in the first period, but it will have to form expectations about the following two periods.[110] In this model half of the wages are based on the latest information, while the other half still reflects old information. After a shock to the economy, a portion of nominal wages remains fixed for a while and the economy needs some time to adjust to the new situation. The point that Taylor wanted to prove is that even when we assume rational expectations, wages are not flexible in the short run and thus monetary (or fiscal) policies can affect output and unemployment. This finding goes against the new classical assertion of policy ineffectiveness. The model shows that decisions that do not

[108] Gregory Mankiw. "New Keynesian Economics."
[109] Mankiw 1990: 1658.
[110] John B. Taylor. "Staggered Wage Setting in a Macro Model." *The American Economic Review* 69, no. 2 (1979): 109.

matter much on the individual level (e.g. when to adjust prices or wages) cause large aggregate effects.[111] Guillermo Calvo later improved the staggered contracts model by dropping the assumption that the length of a wage contract is fixed and by introducing the probability that a union can reset its prices in any period (later called the Calvo probability). The Calvo model soon became the leading model of nominal rigidity.

New Keynesianism and 3D representation

The name 'new Keynesianism' suggests a return to Keynesian economics of the 1930s and 1940s. This is partly true. New Keynesians argue for the use of countercyclical fiscal or monetary policy. Unlike the new classicals, they believe that such (systematic) policies can have a significant effect on real economic variables like unemployment and GDP. Furthermore, like Keynes, new Keynesians accept that unemployment can be persistent. Explanations for this claim are based on theories of market failure. It could be argued that the rise of new Keynesianism also meant a return to a more mechanical understanding of the macroeconomy, where relationships between the important macroeconomic entities can be established. These similarities with Keynesian economics suggest that three-dimensional models might be useful for the new Keynesian school, in the same way as the Phillips Machine was for Keynesian economics. However, no 3D models were constructed when new Keynesianism was one of the mainstream economic traditions. How can this be explained? Some characteristics of the new Keynesian school can be named that obstructed three-dimensional modeling. New Keynesianism is not a complete return to Keynesian economics. A more accurate description would be: new Keynesianism builds on the findings and methodology of the neoclassical synthesis and new classical economics, while endorsing Keynesian conclusions. It is best to illustrate this with an example. New Keynesians endorse the claim that unemployment can be persistent. They do not explain this by referring to other macroeconomic entities (like Keynes) but by looking at the micro-level (like the new classicals). The ideas and concepts of new classical macroeconomics and the neoclassical synthesis which new Keynesians also use, are exactly those that do not lend themselves well to three-dimensional representation. Think of microfoundations or the distinction between different time horizons. Furthermore, new Keynesian economics does not only owe essential ideas and concepts to earlier economic traditions, it also builds on their methodology. The IS-LM model and the Phillips curve play an essential rule in new Keynesian economics, although in an adjusted form. Also, the rational expectations assumption is integral to the new

[111] Blanchard 2017: 526.

Keynesian school. New Keynesians constructed new models as well. A well-known example is the model of monopolistic competition by Olivier Blanchard. These models introduced or popularized economic concepts which are now widely accepted. Yet, they stayed close to the prevailing methodology of earlier traditions, which was centered around stories, graphs, and mathematics.

3.5 Conclusion: Keynesianism as an outlier

In this chapter the different economic traditions of the second half of the twentieth century and their relationship with three-dimensional representation were investigated. The neoclassical synthesis, monetarism and new classical macroeconomics, and new Keynesian economics did not produce any successful three-dimensional models. This might be a surprising finding at first sight, since the Phillips Machine showed that three-dimensional economic models are possible and might be helpful. Can reasons be given why Keynesian economics produced a 3D model but the later economic traditions did not? Keynesian economics was special in that it broke with earlier traditions. Keynes introduced many new concepts and insights to economics in a short period. He rejected some of the key ideas of neoclassical economics and shifted the perspective from microeconomics to macroeconomics. The conceptual break with earlier traditions opened the door to a break with the methodology of those traditions. For a while macroeconomics as a new field was open to new methodological approaches and deviant ideas. The Phillips Machine can be considered such a new methodological approach. However, economics soon returned to its long run path. Economists of the neoclassical synthesis worked to combine Keynes' ideas with earlier neoclassical understandings of economics, which also meant a return to its modeling practice. Over the following decades macroeconomics as a field developed, with new theories being added, rejected, and refined. This meant an ever more extensive and complicated understanding of macroeconomics. Naturally, the content of Keynesian economics was also important regarding the construction of a 3D model. Keynesian economics was simpler than the subsequent traditions, in that it only focused on the short run (remember Keynes' statement that 'in the long run we are all dead') and did not incorporate microfoundations in its understanding of the macroeconomy. So, with macroeconomics continuously progressing and expanding, it became increasingly difficult to engage in three-dimensional modeling.

It must be noted that the argument provided above mostly applies to macroeconomic modeling. Even though no 3D models were constructed in economics after 1950, this does not mean that it is impossible. Some concepts or theories might benefit from a 3D representation, for research or teaching purposes, or both. However, constructing a comprehensive model that illustrates the workings of a whole system at once, has become more challenging. This is precisely the task of macroeconomics.

Conclusion

This thesis investigated the question why no other three-dimensional economic models of significant meaning were constructed after 1950, even though the Phillips Machine proved that the development of such a model is possible. The first chapter served to introduce and analyze the Phillips Machine and its background. The second chapter approached the research question from a methodological perspective and the third chapter took a historical approach. The main findings will be summarized here. The discussion of the Phillips Machine gives us an indication of the practical problems related to a three-dimensional model. The machine gained recognition among British economists soon after its construction. However, over the decades that followed its popularity quickly waned. The main reasons were practical issues concerning the operation and maintenance of the machine, and the rise of electronic computers. Three-dimensional models such as the Phillips Machine require more looking after than pen-and-paper models do. If the resources or willingness to provide the necessary care fail, it is less likely that a 3D model will be a lasting success. Next to this, electronic computers and econometric models took over some of the important tasks of possible three-dimensional models, like computing and calculating. Yet, other ways in which 3D models might prove useful remain. For example, three-dimensional models might be more suitable for visualizations and teaching purposes.

In the second chapter three-dimensional models were defined and situated in the modeling practice of economics. The most important findings of the chapter concerned the epistemic (dis)advantages and modeling constraints of 3D models. Three-dimensional models have epistemic advantages over non-3D-models. The connection with other types of knowledge, often more intuitive knowledge, enhances the learning potential of three-dimensional models compared to pen-and-papers ones. Furthermore, 3D models provide more opportunity for active learning and allow you to view theories and ideas from a different perspective. These epistemic benefits come at the costs of epistemic disadvantages and modeling constraints. Three-dimensional models require significantly more specifications than pen-and-paper models, which complicates their construction substantially. Also, 3D models can limit a learner's understanding of specific theories. Next to that, the epistemic advantages are partly dependent on the available knowledge of the audience. So, from a methodological point of view it can be stated that, although 3D models have epistemic benefits, the modeling constraints and epistemic limitations often weigh heavier. This is a reason why no other three-dimensional economic models were constructed after the Phillips Machine.

In the third chapter four different economic traditions were presented and discussed, with the aim to identify which characteristics facilitate three-dimensional visualization and which obstruct it. It was found that the stock-flow interpretation of Keynesian economics lent itself well to three-dimensional representation. Macroeconomic theory developed with the neoclassical synthesis, monetarism and new classical macroeconomics, and new Keynesianism. New theories were continuously added, rejected, and refined. The ever more extensive theories with distinct time horizons and microfoundations proved more difficult to visualize in three dimensions. Next to that, whereas Keynes broke with the methodology of the previous traditions, the economic schools after him partly returned to it. This reduced the possibility of the development of new, three-dimensional models. All in all, the question why no other 3D models were constructed after the Phillips Machine can be answered as follows: The construction of new three-dimensional economic models is unlikely due to practical reasons and because the epistemic benefits rarely outweigh the modeling constraints. The fact that the content of the economic traditions of the second half of the twentieth century did not lend itself well to 3D representation meant that no single 3D economic model of significant meaning was built.

It must be noted that this thesis has a rather limited scope, in that it only researched one particular type of model in one scientific field. A short comparison was made with the 3D modeling practices of other sciences, but this comparative analysis could be extended in further research. Furthermore, in the construction of new models the creator plays an essential role. As we saw in the case of the Phillips Machine, the right person with the right skill-set has to be present at the right time. Although this is partly up to chance, some generalizations could be made. Sciences interact and the development of a specific theory in one field (e.g. mechanics) affects the modeling practices of other fields (e.g. economics), which might allow a practitioner of the first field to introduce new concepts or perspectives in the second. Studying such generalizations has been left aside in this thesis, but it might be interesting for future research.

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Illustrations

Figure 1: https://www.nzier.org.nz/moniac-machine

Figure 2: Barr 2000: 103.

Figure 3: Made by author.

Figure 4: Made by author.

Figure 5: https://en.wikipedia.org/wiki/IS%E2%80%93LM_model

Figure 6: Phillips 1950: 74.

Figure 7: https://collection.sciencemuseumgroup.org.uk/objects/co64127/phillips-economic-computer-analog-computer

Figure 8: Morgan 2012: 4.

Figure 9: Morgan 1999: 357.

Figure 10: https://www.science-photo.de/bilder/12491626-Watson-and-Crick-with-their-DNA-model

Figure 11: https://en.wikipedia.org/wiki/Maslow's_hierarchy_of_needs

Figure 12: Blanchard 2017: 116.

Figure 13: https://en.wikipedia.org/wiki/Phillips_curve

Appendix 1: Abstracts

Abstract (English)

This thesis investigates the 3D modeling practice of economics, with the aim to answer the question of why no other three-dimensional models of significance have been constructed after the Phillips Machine (1950). The Phillips Machine as the only 3D model in the field of economics is described and historically contextualized in the first chapter. The discussion reveals that practical problems regarding the operation and maintenance, together with the rise of electronic computers and econometric models, led to a decrease in use. The second chapter provides a definition of three-dimensional models and places the Phillips Machine in the economic modeling practice. Epistemic advantages of 3D models over non-3D-models are given. 3D models allude to intuitive knowledge, which enhances the learning potential of three-dimensional models compared to pen-and-papers ones. Furthermore, 3D models allow for active learning and can provide new perspectives. These epistemic advantages come at the cost of modeling constraints and epistemic limitations, which often outweigh the benefits. In the third chapter the economic content of four economic traditions of the second half of the twentieth century is analyzed, with the aim of pinpointing which characteristics lend themselves well to three-dimensional representation. It is found that after Keynesianism in the 1940s, macroeconomic theories have become more extensive with the addition of microfoundations, different time horizons etc. Also, economists shifted away from the stock-flow interpretation of the macroeconomy and partly returned to the methodology of the economic schools before Keynes. This reduced the possibility of the development of new, three-dimensional models.

Abstrakt (Deutsch)

Diese Arbeit untersucht die 3D-Modellierungspraxis in den Wirtschaftswissenschaften, um herauszufinden, warum nach der Phillips-Maschine (1950) keine weiteren bedeutenden dreidimensionalen Modelle gebaut wurden. Im ersten Kapitel wird die Phillips-Maschine als einziges 3D-Modell in den Wirtschaftswissenschaften beschrieben und historisch eingeordnet. Die Diskussion zeigt, dass praktische Probleme bezüglich des Betriebes und der Wartung, sowie das Aufkommen elektronischer Computer und ökonometrischer Modelle zu einem Rückgang der Nutzung führten. Das zweite Kapitel bietet eine Definition von dreidimensionalen Modellen und ordnet die Phillips-Maschine in die ökonomische Modellierungspraxis ein. Es werden die epistemischen Vorteile von 3D-Modellen gegenüber Nicht-3D-Modellen dargelegt. 3D-Modelle knüpfen an intuitives Wissen an, was das Lernpotenzial von dreidimensionalen Modellen im Gegensatz zu Pen-and-Paper-Modellen erhöht. Außerdem ermöglichen 3D-Modelle ein aktives Lernen und können neue Perspektiven eröffnen. Diesen epistemischen Vorteilen stehen jedoch Modellierungseinschränkungen und epistemischen Nachteilen entgegen, die die Vorteile oft überwiegen. Im dritten Kapitel werden die ökonomischen Inhalte von vier Wirtschaftstraditionen aus der zweiten Hälfte des 20. Jahrhunderts analysiert, um herauszufinden, welche Inhalte sich für eine dreidimensionale Darstellung eignen. Diese Analyse zeigt, dass nach dem Keynesianismus in den 1940er Jahren die makroökonomischen Theorien aufgrund von Mikrofundierung, verschiedenen Zeithorizonten usw., umfangreicher geworden sind. Zudem haben sich Wirtschaftswissenschaftler von stock-flow Interpretationen der Makroökonomie entfernt und sind teilweise zur Methodologie ökonomischer Denkschulen vor Keynes zurückgekehrt. Dadurch wurde die Möglichkeit der Entwicklung neuer, dreidimensionaler Modelle eingeschränkt.