MEMORANDUM

No 03/2011

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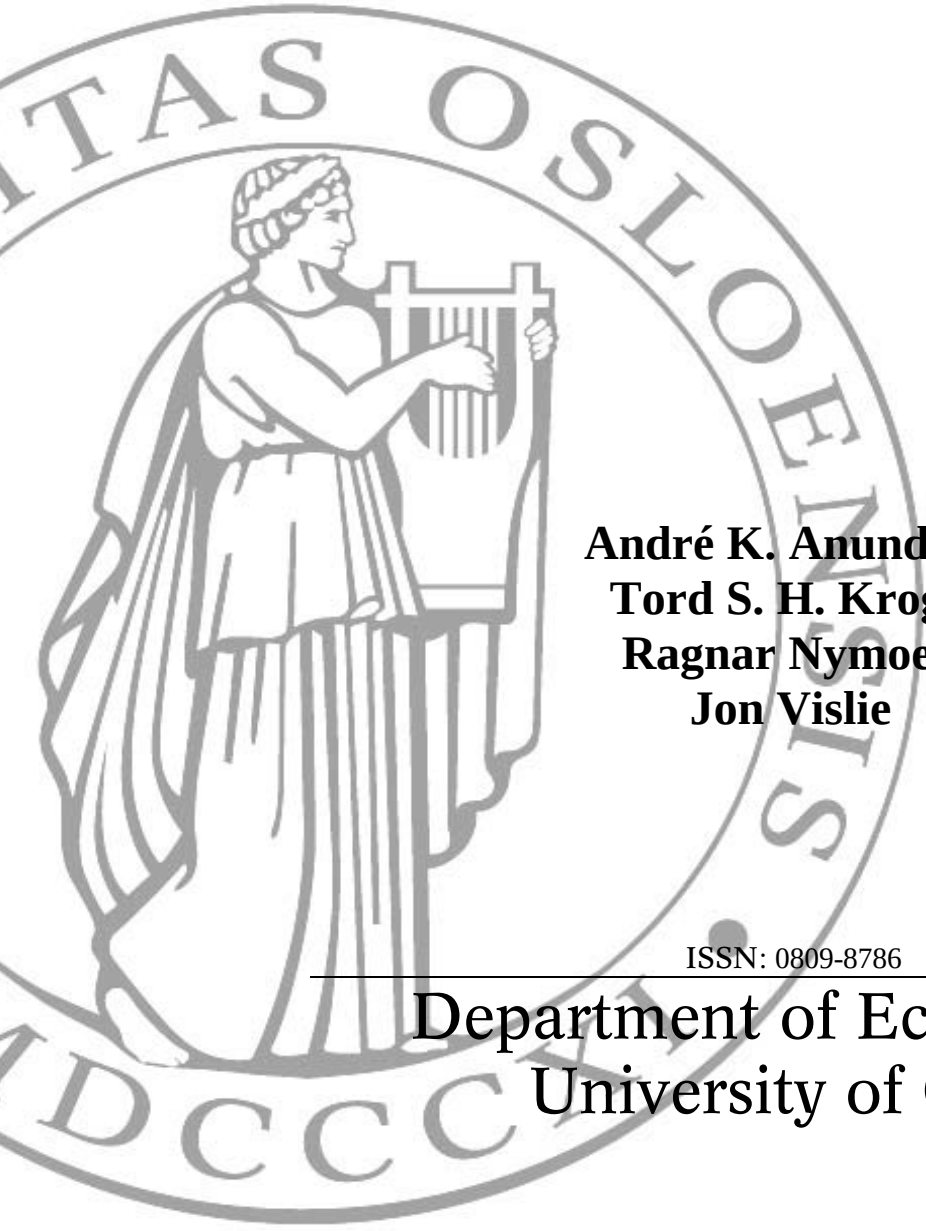

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ISSN: 0809-8786

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This series is published by the
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Department of Economics

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Overdeterminacy and endogenous cycles: Trygve Haavelmo's business cycle model and its implications for monetary policy*

André K. Anundsen, Tord S. H. Krogh, Ragnar Nymoen and Jon Vislie†

February 15, 2011

Abstract

This paper presents the business cycle model that Trygve Haavelmo developed as part of his research program in macroeconomic and monetary theory. Driven by a mismatch between the marginal return to capital and the rate of return required by capital owners, this model generates endogenous cycles. The theory leads to a distinct analysis of the scope and limitations of monetary policy. A main message of the model is that care should be taken when conducting 'autonomous' monetary policy and that special emphasis should be put on the soundness of financial markets. Adopting a strict nominal anchor as the main objective of monetary policy might generate imbalances in the capital market.

Keywords: investments, business cycles, monetary policy.

JEL classification: E22, E32, E44, E52

The importance of the interest rate for continued economic expansion is not determined by whether it is high or low, whether it is adjusted upwards or downwards etc, the whole point is to keep the inequality in favor of the marginal product of capital.

Haavelmo, 1969, p.153, the authors' translation.

*We are indebted to Eilev S. Jansen and Olav Bjerkholt for valuable comments.

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1 Introduction

A number of countries now have inflation targeting as the main goal of monetary policy. Implementation has been delegated to independent Central Banks setting their key policy rate with the aim of keeping inflation close to the desired level. The financial crisis starting in 2007 has triggered a debate about this policy in a world with a "not-too-transparent" financial sector and emerging economies like Brazil, China and India. Because the terrain is transforming, we need to correct the map as well. In a changing world, the profession needs to consider whether to rely on supplementary medicine other than monetary policy instruments so as to cope with financial crises, government debt, global imbalances, unemployment and inflation. Time has come to reconsider the way economies with liberalized capital markets should be managed.

In our opinion, the theoretical foundation of mainstream monetary economics and monetary policy might benefit from supplementing current understanding with insights from the grand masters in economics. Too often we feel that "the old wines" are thrown away even before being tasted, and replaced by young (and sometimes sharp) wines. By strict adherence to a short retrospective view, contemporary economists might suffer from neglecting good and relevant theory. Hoping for changes within the discipline, we will here revive some ideas or hypotheses put forth by the Norwegian economist Professor Trygve Haavelmo (1911 - 1999). Not only was he a pioneer in the development of econometrics, for which he was awarded the Nobel Memorial Prize in Economic Sciences in 1989, but he made important contributions to macroeconomics, monetary and business cycle theory, under influence of Frisch, Keynes and, not least, Wicksell.

Haavelmo wrote at the high tide of Keynesian fiscal policy activism and he lived in a country known for economic planning and regulated markets where sudden falls in the activity level, unemployment and other business cycle phenomena were thought to be plagues of the past. Given this, it may seem surprising to claim that Haavelmo wrote anything of interest for "the science of monetary policy", to phrase Clarida et al. (1999). The solution to this paradox is that Haavelmo studied the role of monetary policy in models where markets are assumed to be completely liberalized and where firms and households in important respects behave in accordance with the classical theoretical paradigm. Thus, Haavelmo formulated theories that may have seemed far-fetched and of little relevance for the practically oriented economists of *his* day. The course of history has changed this and Haavelmo's macroeconomic theory now represents a perspective that seems surprisingly fresh and with many useful insights. The analysis is not directly applicable in an operational sense (it was never meant to), but we hold it to be of considerable value for understanding the fundamental driving forces and dynamics of the modern macroeconomy.

Haavelmo's main idea in monetary economics can be found in his book on "Investment Theory" (Haavelmo, 1960). In Chapter 33 he outlines what he believed was the real issue in a market economy with decentralized investment decisions, money holdings and autonomous interest rate setting, namely what he called "a fundamental overdeterminacy": If the money market rate of interest is set autonomously by the Central Bank, then due to standard arbitrage principles in the agents' portfolio decisions – including financial assets as well as real capital – equilibrium in the financial market gives the rate of return on capital that induces capital owners to retain the existing stock of real cap-

ital. The implications of the "law of indifference in the capital markets"seems to have gone unnoticed in macroeconomic theory. The pivotal point is that when incorporating this relationship in a rather standard macrodynamic model, along with firms' demand for real capital, the rate of return on real capital will be determined both by the real and the financial side of the economy – and there are no mechanisms that will prevent these rates from differing. Hence, we have an overdetermined system. In later writings, Haavelmo shows how these considerations can be the building blocks for a genuine business cycle model with endogenous regime switching induced by periods of disequilibrium. He returned to this issue over and over again in lectures at the University of Oslo and let it be incorporated in notes that were intended for a textbook in macroeconomics. In December 1966 these notes were published as a Memorandum at the Department of Economics, though only in Norwegian, under the title "Orientering i makro-økonomisk teori" ("A Study in Macroeconomic Theory"). The textbook was unfortunately never completed, but the notes were published by The University Press in Oslo in 1969. "A Study in Macroeconomic Theory", henceforth referred to as SMT, was on the reading list for many generations of Norwegian economists.

SMT is an example of what DeGrauwe (2010) calls Bottom up Macroeconomics. In Haavelmo's theory, the agents' behavior is explicitly modeled. However, it is not assumed that agents are able to enforce the stable outcome, or that they can correctly predict the aggregate outcome, being the product of the interaction between individual agents' decisions. Hence it differs from the Top Down school of macroeconomics, which applies rational expectations and representative macro agents. The book is full of subtle analyses and is rich in insights, and is marked by Haavelmo's brief, but precise style of presentation. A main topic is how to design a logical system for understanding and managing a complex decentralized market economy, consisting of rational agents (households, firms, investors and banks) pursuing individual goals.

Moene and Rødseth (1991) provide an excellent presentation of Haavelmo's contribution to our discipline.[1] Our paper supplements theirs by focusing on the aspects of Haavelmo's theories that are relevant for modern monetary policy and for understanding the business cycle.

The rest of the paper is organized as follows: We start out in Section 2 by presenting Haavelmo's "law of indifference in the capital markets", while the Appendix covers an extension of the arguments to fit a small open economy. In Section 3 it is shown how this implies a fundamental overdeterminacy in macromodels where a monetary authority stipulates the interest rate. Disequilibrium will be an intrinsic feature of such models, and we explain how Haavelmo translated the overdeterminacy into dynamic forces by utilizing the desire to purchase new or get rid of existing capital equipment. His endogenous regime-switching business cycle model is reproduced in Section 4, whereas the scope of his ideas today are discussed in Section 5. Section 6 concludes.

[1]Morgan (1990) is the first academic appraisal of Haavelmo's Probability Approach to Econometrics, see Bjerkholt (2005, 2007) for a recent contribution. The reader is referred to Nerlove (1990) for a more critical appreciation of Haavelmo's contributions.

2 The Law of Indifference in the Capital Market

A line of thought characterizing a lot of Haavelmo's writings is how an unregulated capital market will work and the implications for private investment activity. Like in other Western economies, the Norwegian capital market remained heavily regulated for a long period of time after the Second World War.[2] Even long before full deregulation had taken place, Haavelmo repeatedly discussed the role of monetary policy within a deregulated and decentralized context. Of special interest was his proposition that a fundamental overdeterminacy might originate in models where a monetary authority (say, the Central Bank) imposes additional constraints on the money market rate of interest.

To see more closely what Haavelmo had in mind when he referred to this fundamental overdeterminacy, we will present a "skeleton"model, i.e. a rather clean model that was typical for his approach to almost any issue. The model presented in this section is based on Chapter 23 of SMT.[3]

Consider a closed economy with two sectors - a private sector and the monetary authorities (representing the entire banking industry as well as the Central Bank). The private sector consists of households and capital owners renting real capital to producing firms. At any point in time, the private sector has a given nominal wealth, W, which can be held in cash (as deposits in the banking sector, given by M) and in real capital, with a nominal value pK.[4] At any instant the stock of capital available in the economy is fixed. The banking sector's balance sheet will require that deposits (M) are transformed to loans (L) to the private sector.[5] Therefore, the following balance relations have to hold in this economy:

$$W = pK + M - L \tag{1}$$

$$M = L \tag{2}$$

We consider the private sector as one agent, with different roles and a well-defined preference function. This function specifies the underlying desire for how the given wealth should be allocated. Real capital will provide some return when capital owners are renting equipment to private firms. The rent accruing to capital owners is given by the capital rental rate, r, whereas money holdings in the form of deposits give a return, equal to rate of interest in the credit market, as given by i. Because we should expect the various rates of interest to differ, the private sector might have some preferences for no-interest bearing liquidity.[6] Here we introduce real money holdings (or deposits) along with an aggregate measure of the general level of activity in the economy, Y, which can be interpreted as a measure of GDP.

The preference function underlying the choices made by the private sector can then

[2]For a description of the deregulation process in Norway, see Krogh (2010).

[3]Over the years he addressed the same issue in many different versions of some basic model.

[4]K is a physical measure of the stock of real capital at some point in time, whereas p is the price level.

[5]The liability side of the balance sheet might also consist of equity, or private ownership shares in the banking sector. The lack of decomposition of the liability side into deposits and equity has no impact on our results.

[6]Patinkin (1956) formalized such preferences by incorporating real money balances in the preference function. We might say that (3) captures the Pigou and Fisher effects, as discussed by Tobin (1980).

be expressed as:

$$V\left(K, \frac{M}{p}, \frac{L}{p}; \frac{W}{p}, r, i, Y\right) \tag{3}$$

where the choice variables are $\left(K, \frac{M}{p}, \frac{L}{p}\right)$, with exogenous parameters given by $\left(\frac{W}{p}, r, i, Y\right)$. The private sector is assumed to maximize the expression in (3) subject to a wealth constraint, as given by (1). For a given set of exogenous parameters, the optimization will provide standard "demand functions" like those in (4) - (6) below, where the star indicates an optimized value:

$$K^* = k\left(\frac{W}{p}, r, i, Y\right) \tag{4}$$

$$\left(\frac{L}{p}\right)^* = l\left(\frac{W}{p}, r, i, Y\right) \tag{5}$$

$$\left(\frac{M}{p}\right)^* = m\left(\frac{W}{p}, r, i, Y\right) \tag{6}$$

In an overall equilibrium, with Y and p given in the short run, and the two balance relations (1) and (2) satisfied, we automatically must have $pK = W$. Hence, we end up with a single equilibrium condition, which can be reexpressed as:

$$m\left(K, r, i, Y\right) = l\left(K, r, i, Y\right) \tag{7}$$

This condition provides a linkage between the two rates of interest in equilibrium, which alternatively can be written in the form:

$$r^* = f\left(i; K, Y\right) \tag{8}$$

The condition in (8) conveys the equilibrium relationship between the money (or credit) market rate of interest and the rate of return on real capital. For any value of the money market rate of interest, there is a corresponding rate of return required by the capital owners so as to induce them to retain their stock of real capital. Haavelmo refers to this as "the law of indifference in the capital markets". In principle, it is nothing but a no-arbitrage condition, but it will play a crucial role in the model outlined below when the return to capital as an asset is considered dually with its rate of return in the real economy.

The normalization on r in (7) that leads to r^* in (8) pre-supposes that the money market interest rate, i, is set by the monetary authorities – which will be the case in the model of Section 4. By instead normalizing on i, the link to Wicksell's classical model is evident. In the context of both Haavelmo and Wicksell, r will be determined from the real economy. In Wicksell's world i adjusts in such a way that "the law of indifference" holds. This equilibrium rate of interest is Wicksell's (Wicksell, 1907) concept of a *normal rate of interest*, see Haavelmo (1987).[7]

[7] One could therefore argue that the model of Haavelmo that we present here is an extension of Wicksell's results in a world without fully flexible prices.

3 Fundamental Overdeterminacy

Chapter 33 of Haavelmo (1960) provides the first description of his notion of "a fundamental overdeterminacy"in market economies with liberalized credit markets. By considering a neoclassical model, with the capital stock fixed in the short run, in combination with agents that make portfolio decisions according to the model in Section 2, Haavelmo focuses on a simple, yet rather crucial point. Equilibrium in the asset market requires (8) to hold. At the same time capital equipment, owned by households, is used by firms to produce output according to the aggregate production function $\phi(K)$. The private firms are renting the equipment K. With depreciation being proportional to capital in use, profits are given by $\phi(K) - \delta K$, and the marginal return to capital is given by $\phi'(K) - \delta$.

Suppose that the money market rate of interest i is autonomously set by the monetary authorities in order to meet, say, a target on the inflation rate. One question to ask is then: Is there any reason to believe that the required rate of return in the asset market, as determined by the equilibrium relationship $r^* = f(i; K, Y)$, will coincide with the actual marginal rate of return, $\phi'(K) - \delta$, for the available stock of capital? We have no reason to expect that to be the case. Alignment of r^* and $\phi'(K) - \delta$ will only happen by accident.

The next question follows: If $\phi'(K) - \delta \neq r^*$, what are the implications, and what will happen? First, an equilibrium in this model must be characterized by a "state of silence", in the sense that, given the equilibrium rates of return, no agent will have any incentive to act differently. Such an equilibrium will require $\phi'(K) - \delta = r^*$. If this condition is not satisfied, capital owners receive either more or less from renting out capital than what is required from equilibrium in the asset markets; hence disequilibrium constellations arise and new actions will be taken. Therefore, by imposing $\phi'(K) - \delta = r^*$ for an exogenously determined money market rate of interest, a fundamental overdeterminacy is created. There are too many conditions to be satisfied. What will happen now? It is rather obvious that the model, as it has been formulated above, cannot describe a state of equilibrium. To cope with this, we have to look for supplementary mechanisms that will start to operate or set in motion. One could hope that only minor modifications of the existing model would be sufficient to get a fully determined model providing us with realistic predictions. As Haavelmo himself puts it:[8]

> "It is obvious what an actual economy does under such circumstances: It operates under a different model that does have a solution. Why, then, should we take even the slightest interest in an overdetermined model? If we do, the only acceptable reason would seem to be that we believe that, somehow, the economy first "tries out" the hopeless model, and then *derives* a practicable alternative *in a way which could be predicted by studying the overdetermined model.*"

What practical alternatives are available? Haavelmo's suggestion was to to exclude $\phi'(K) - \delta = r^*$ as an equilibrium requirement, while at the same time model the disequilibrium behavior of investment explicitly. This is a natural way to attack the issue since a state of disequilibrium plays an important role in explaining investment behavior in his 1960-treatise. A point he stressed was that in a classical model there is no way to

[8] Haavelmo (1960, pp.200–201)

derive the demand for investment from the first-order condition for capital. The theorist therefore has to look for other reasons than the classical profit motive in order to get a precise theory of investment, this being for instance supply side constraints or time-lags in the production of capital goods. Several authors have recognized these insights, see *e.g.* Nickell (1978, p. 12). Without exploring these matters, a small step towards a better theory might be to acknowledge that investments can be motivated by the fact that the first-order condition *fails* to be satisfied.[9] We run into a similar situation here. Let us introduce the following notion "Strategy", which is a set of decision rules for the capital owners. Define it as:

$$\text{Strategy} = \begin{cases} \text{A if } \ \phi'(K) - \delta > r^* \\ \text{B if } \ \phi'(K) - \delta = r^* \\ \text{C if } \ \phi'(K) - \delta < r^* \end{cases}$$

where $\{A, B, C\}$ is a set of descriptions as to what actions will be taken by the firms in each state of the world. Imposing strategies like these is an unconventional way of closing a model, but it must be regarded as a formal way of incorporating *into* the model what happens *outside* equilibrium. In order to finish the job, it is of vital importance that each of the decision rules in $\{A, B, C\}$ are defined in such a way that the model has a solution. This will lead us to define state dependent investment strategies in Section 4.1.2.

4 A Business Cycle Model

In Part VI of SMT, the implications of overdeterminacy and the possible investment responses are taken into a macrodynamic model. It is a Keynesian type macro model for the closed economy, where the investment response of firms in the economy plays a fundamental role. Haavelmo included a brief presentation of this model in his article on business cycles in the International Encyclopedia of the Social Sciences, see Haavelmo (1968). But the only full-fledged presentation is provided in SMT.

4.1 Momentary equilibrium

We assume there is a representative firm producing aggregate output at every instant according to a standard macro production function:

$$Y(t) = \phi(N(t), K(t)) \tag{9}$$

where $N(t)$ denotes labor input and $K(t)$ is capital input.[10] Seen from the perspective of any period t the capital stock is a predetermined variable. The firm can hire one unit of labor or capital at prices $w(t)$ and $r(t)$, respectively.

The labor market is modeled relatively superficially by assuming that the entire labor force, $H(t)$, is willing to work as long the wage they receive exceeds some reservation level $\underline{w}$. During periods of unemployment, competition on the *supply* side drives the wage down to the reservation level. Under full employment, competition on the *demand*

[9] This was a point Haavelmo made already in Haavelmo (1949).

[10] The function in (9) is assumed to be constant returns to scale, strictly increasing and concave in both arguments. The input factors are assumed to be technical complementarities (positive cross-derivative).

side (interpreting the representative firm as a collection of firms) will push the wage up to the marginal product of labor. We therefore have the following conditions for the labor market:

$$N(t) \leq H(t) \tag{10}$$

$$w(t) = \begin{cases} \dfrac{\partial \phi}{\partial N}, & \text{when } N(t) = H(t) \quad (11a) \\ \underline{w}(t), & \text{when } N(t) < H(t) \quad (11b) \end{cases}$$

It is assumed that $\underline{w}(t)$ corresponds to a minimum wage set by the government at a "reasonable" level.[11] It should be noted that these labor-market assumptions are not fully compatible with those of SMT, but rather a special case of equation (26.8), where the only wage-requirement is that the entire labor force is always willing to work for a wage not exceeding the marginal return of the representative firm.

In the rental market for capital, owners of capital (the household sector) rent out capital equipment to the representative firm. Behaving as a price taker, the latter party will demand a stock of capital obeying the well-known condition:

$$\frac{\partial \phi(N(t), K(t))}{\partial K} - \delta = r(t) \tag{12}$$

Aggregate demand consists of aggregate consumption, $C(t)$, and investment, $I(t)$, defined as:

$$C(t) = g(R(t)) + C_g(t) \tag{13}$$

$$I(t) = I_1(t) + I_2(t) + I_g(t) \tag{14}$$

where R is households' net disposable income and C_g and I_g is public consumption and investment, respectively. $g(R)$ is the private sector's "consumption function". The marginal propensity to consume, $g'(R)$, is positive but less than one. Private investments comprise investments made by existing firms to expand the capital stock for a given technology, I_1, and technologically motivated or autonomous investments, I_2. For the rest of this section we will make the assumption that the sum of technologically motivated and public investments is exogenously given:

$$I_2(t) + I_g(t) = \hat{I}, \text{where } \hat{I} \leq I \tag{15}$$

A definition of R follows from subtracting depreciation and taxes from total output. We also add a national accounts identity that must hold:

$$R(t) = Y(t) - \delta K(t) - T(t) \tag{16}$$

$$Y(t) = C(t) + I(t) \tag{17}$$

[11] For practical purposes (e.g. simulation) one suggestion for the minimum wage at time t could be

$$\underline{w}(t; u) = \max \left[\underline{w}(u; v), \min_{\hat{t} \in [u,t]} \frac{\partial \phi(H(\hat{t}), K(\hat{t}))}{\partial N} \right]$$

which is the lowest *hypothetical* marginal return to labor at full employment that has been possible in the time span $[u, t]$ given a development of the stocks H and K, provided that it is higher than what the minimum wage was at time u. In the stationary economy developed here, this corresponds to the wage rate at the beginning of every economic boom. In a non-stationary setting the minimum wage would be increased after every boom period.

where T is the amount of taxes collected by the government.[12]

Concerning the capital market, a structure similar to that used in Section 2 is implicitly assumed. The household sector seeks to hold an optimal portfolio, investing its wealth either in capital or deposits. Capital earns an interest rate r from the *rental market* for capital, while deposits yield an interest rate i. Money *demand* (i.e. supply of deposits) is assumed to take the form:

$$M(t) = m(i(t), Y(t)) \tag{18}$$

Combining (18) with a balance equation for total wealth, we can find an expression for the demand for capital. Combining this with the condition that the household sector must be willing to hold the entire stock of capital, we get the law of indifference. In its simplest form, this can be expressed as:

$$r^*(t) = f(i(t)) \tag{19}$$

where r^* is the rent on capital that makes the household sector indifferent between holding capital and deposits.

4.1.1 Overdeterminacy revisited

Haavelmo assumes that the interest rate i is controlled by the monetary authorities. This will produce a fundamental overdeterminacy since, even though demand equals supply in the rental market for real capital, no mechanism is in place to ensure that demand equals supply in the market for the *capital stock* – we cannot expect $r = r^*$ to be fulfilled.

With reference to the discussion in Section 3, Haavelmo's "emergency exit" given the problem of an overdetermined model was to drop the equilibrium requirement of $r = r^*$ and rather formally define the investment strategies depending on whether the return to capital is higher or lower than the required rate. This would make sure that we have a model for the disequilibria as well as for a stable equilibrium.

How do we interpret this in the model? The household sector is willing to hold the existing capital stock as long as the return from doing so does not fall below r^* from (19). At the same time, equilibrium in the rental market gives the actual return from holding capital, r, see (12). This means that if $r > r^*$, the household sector earns more from holding capital than what they require, given the money market rate of interest i. It is therefore reasonable to assume that they will invest as much as possible in an attempt to increase their stock of capital. When $r < r^*$ we are in the opposite situation – they are not getting their required return and would, if they could, get rid of capital. Of course, gross investments cannot be lower than zero, but this will at least result in a negative net investment given sufficient depreciation. This yields the following discontinuous private investment relation:

$$I_1(t) = \begin{cases} \phi(H(t), K(t)) - g(R(t)) - C_g(t) - \hat{I}, & \text{when } r(t) \geq r^*(t) \quad \text{(20a)} \\ 0, & \text{when } r(t) < r^*(t) \quad \text{(20b)} \end{cases}$$

where the first case represents maximum investments and the second is minimum investments. We are beginning to suspect that the rate of investment and its linkages to the capital market will play a crucial role in this model.

[12] Alternatively we could define R as the sum of labor and capital income plus profits from the firm, but that would amount to the same.

4.1.2 Multiple regimes

Equations (9) - (20) describe the momentary equilibrium. By a simple counting exercise it seems like we have one condition too many (i.e. the model looks overdetermined). However, by inspecting the conditions more thoroughly we observe that one less of these conditions are effective.[13] Assume first that $r \geq r^*$. Then (20) coincides with (17) (hence effectively we have one less condition), while (10) is binding and (11) determines the wage rate. In the opposite case ($r < r^*$) equations (17) and (20) represent independent relationships, while (10) can be ignored. Hence we do not have one definite momentary equilibrium, but *two* possible equilibria – or regimes – depending on which equations are relevant:

Regime A: a "high activity "state (boom), characterized by capacity constraints on the supply side. This occurs when investment is given by (20a) – as much as possible is invested. The result is full employment with (10) binding and (11a) determining the wage.

Regime B: a "low activity "state (recession) which is demand determined. This occurs when investment is given by (20b) – as little as possible is invested. The result is unemployment [(10) is not binding] and wages left at the level in (11b). Employment, $N(t)$, follows from (9) and (17).

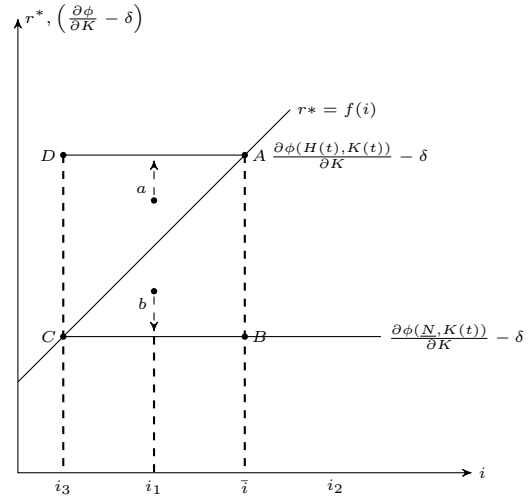
Which regime is prevailing depends on aggregate investment activity in the following way: If the effective return to capital is greater than the cost of capital, firms' investment response will be to invest as much as possible and the demand for labor will increase to the point where $N(t) = H(t)$. This corresponds to regime A, and we denote the values of our macro variables in this state with an upper bar, with reference to Figures 1a-1c. If, however, the marginal return to capital is less than the cost of capital, aggregate investments will be determined only by $\hat{I}$ since capital owners will invest nothing in such a case. Demand for labor will then be such that this investment activity is carried out and we are in Regime B with low activity. Again with reference to Figure 1a-1c, we denote the macro variables with a lower bar in this case.

Let us now take the capital and labor stock as given and see how the level of interest i determines which regime that will be active. Suppose we start out in a situation with $i < \bar{i}$ and a high activity state. Haavelmo labels $\bar{i}$ as the *critical level* of the interest rate (see Panel 1a) since an interest rate lower than this is required to sustain a high level of activity. At any interest rate higher than this (e.g. i_2) investment will drop to its minimum level and the economy enters a recession.

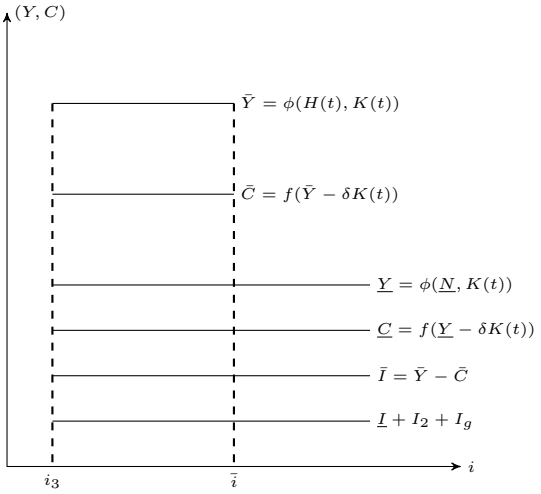
Consider now the case where the interest rate initially is i_1. Whether the high or low activity state will be reached depends on where we started out from (i.e. the initial values of K and H). If the marginal productivity of capital is at a level exceeding $f(i)$ – corresponding to point like a in Figure 1a – investment activity will be at its maximum and the economy in its high activity state. If on the other hand the marginal return is below $f(i)$ – such as in point b – the economy is characterized by low activity. Two central conclusions may now be drawn: If the economy is initially characterized by the

[13] In the words of our discussion from Section 3 – the strategies A, B and C have been defined appropriately.

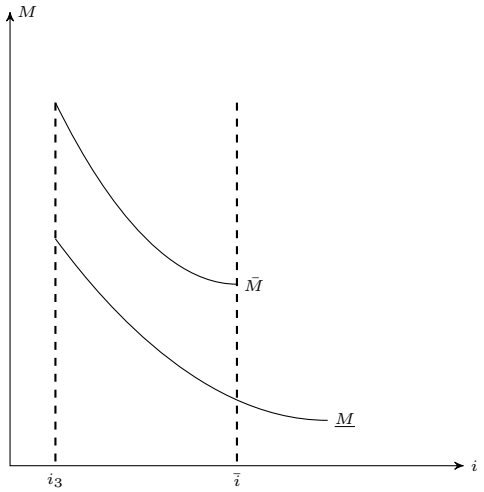
high activity state, then any interest rate below $\bar{i}$ will sustain high activity. However, if the economy is in the low activity state, then any interest rate exceeding i_3 will keep the economy depressed.



(a) Interest Rate



(b) Activity Levels



(c) Money

Figure 1: Alternative regimes – confer Figures (26.12)-(26.14) in SMT

4.1.3 Liquidity trap

Note that there might well be a big difference between the interest rate level required to push the economy out of the low activity state and the interest rate that moves the economy from the high activity state to the low activity state.[14] The implication of this is that it might in a sense be easier to use the interest rate to dampen activity than it is to use monetary stimulus to stimulate recovery, at least according to this model.

In this spirit, Haavelmo provides an alternative explanation of the Keynesian liquidity trap. His point is that it might happen that, as is the case in Figure 2, the actual return to capital in the low activity state is below the required return for *any* money market interest rate. An activistic monetary policy will by itself not be sufficient to move the economy out of recession. As Haavelmo puts it in SMT:[15]

> "J.M Keynes and other macroeconomists have highlighted that an economy might end up in a situation where no positive interest rate level is low enough to move the economy out of a low activity state".

Even though the prescribed cure is the same as that proposed by Keynes and others, namely supplementing monetary policy by a fiscal expansion, the mechanism is quite different. Consider the case where no investments are carried out by existing firms because the return to capital is less than what follows from the law of indifference for any money market interest rate (the lower line in Figure 2). Monetary stimulus is not sufficient to stimulate recovery. However, assume that the government increases public investments by an amount ΔI_g. What will happen? The fiscal expansion will reduce unemployment, leading to an increase in the marginal productivity of capital due to technical complementarities in production. This is illustrated by shifting upwards the lower line in Figure 2. If the interest rate is kept low enough, the combination of expansionary fiscal and monetary policy may be sufficient to move the economy into the high activity state.

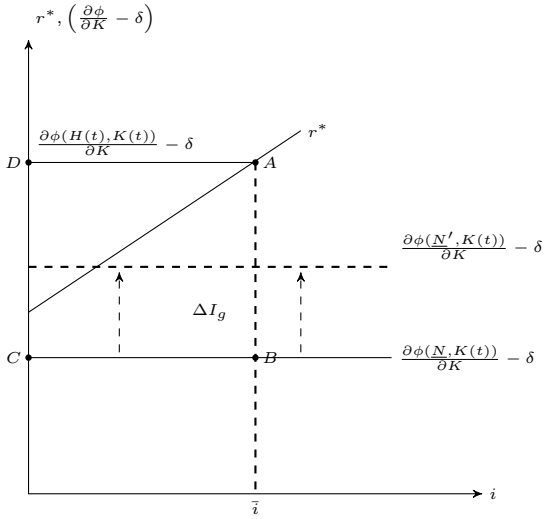


Figure 2: No effect of the interest rate – confer Figure (26.15) in SMT

[14] The same point is stressed in Haavelmo (1968), where a similar model is very briefly discussed.
[15] Haavelmo (1969, p.145), the authors' translation

4.2 Endogenous cycles

In the previous section we presented how the model operates *at every instant*, and we saw that two possible regimes can prevail. We now want to investigate the implications of the model as time elapses. We will see that one feature inherent to the model is that it switches between the two regimes, creating *endogenous cycles*.

In a dynamic context we need, in addition to (9)-(20), equations governing how the stocks of labor and capital evolve over time. We therefore define:

$$\dot{K}(t) = I(t) - \delta K(t) \tag{21}$$

$$\dot{H}(t) = \text{Some function of time} \tag{22}$$

It is implicitly assumed that the exogenous variables C_g, $\hat{I}$, etc.. are such that $\dot{K}(t) > 0$ under regime A and $\dot{K}(t) < 0$ under regime B.

As we saw in the description of the alternative regimes, a central "variable" is the marginal productivity of capital. When capital and the population evolve over time, so will the marginal productivity of capital do. The exact expression for its derivative with respect to time will depend on which regime prevails:

$$\frac{d}{dt}\frac{\partial \phi}{\partial K} = \begin{cases} \dfrac{\partial^2 \phi(H(t), K(t))}{\partial K^2}\dot{K}(t) + \dfrac{\partial^2 \phi(H(t), K(t))}{\partial K \partial N}\dot{H}(t), & \text{under regime A (23a)} \\ \dfrac{\partial^2 \phi(\underline{N}, K(t))}{\partial K^2}\dot{K}(t), & \text{under regime B (23b)} \end{cases}$$

where, as mentioned earlier, we assume the aggregate production function to be strictly increasing and concave in both inputs and that the marginal productivity of capital is increasing in the labor input.

Consider first what happens in regime A. The sign of the expression in (23a) is ambiguous – it depends on whether the capital-to-labor ratio is increasing or decreasing. For small values of growth in the labor stock the marginal productivity will decrease over time as the capital stock increases. Alternatively, if population growth is high then we might have an increasing marginal productivity if investments are insufficient to stop the capital intensity from decreasing. Figure 3 illustrates two alternative paths; "Low" $\dot{H}$ and "High" $\dot{H}$.

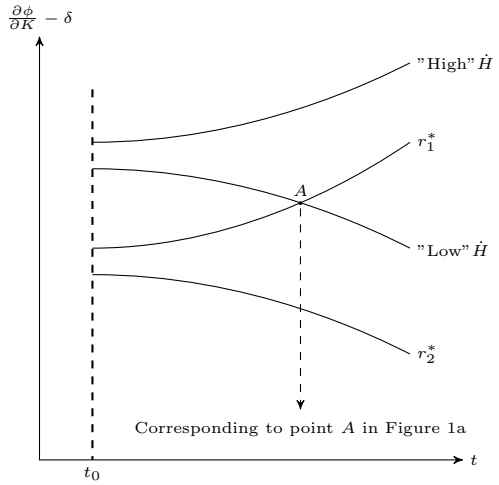
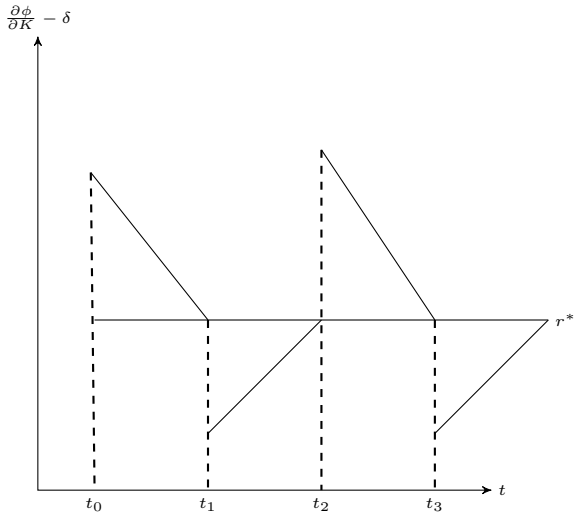


Figure 3: MPK dynamics under regime A – confer Figure (27.11) in SMT

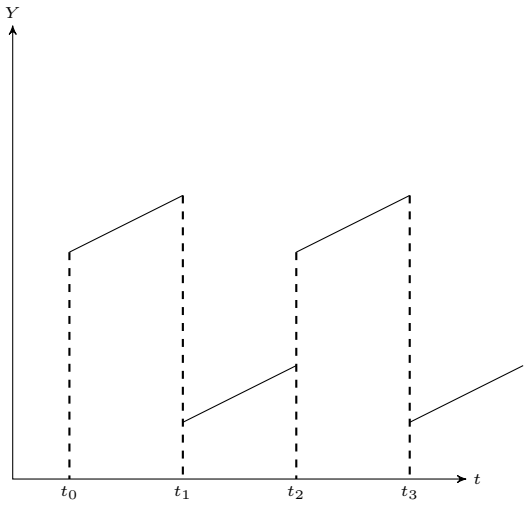
The intriguing point is that what matters is really not the exact time-profiles, but how they match the path of r^*, the required rate of interest. The law of indifference on the capital markets implies a relationship like (8), such that any given path of $i(t)$ – exogenously determined by the authorities – uniquely determines the path of $r^*(t)$. In Figure 3 two possible paths are drawn. If the relevant development for $\frac{\partial \phi}{\partial K} - \delta$ is that of "High" $\dot{H}$, we see that the economy is on a sustainable path (at least within the horizon depicted in the figure). However, if we consider the case where population growth is low, an interest rate policy giving a path such as r_1^* will not sustain high activity forever. As soon as point A is reached, the interest rate on capital goods exceeds the return to capital – we will shift to regime B. Haavelmo refers to point A as the "point of catastrophe".

How will the marginal return to capital develop under regime B? From (23b) it is clear that it will increase steadily as the stock of capital is depreciated. Hence, sooner or later, it will reach r^*, making the economy switch to regime A.

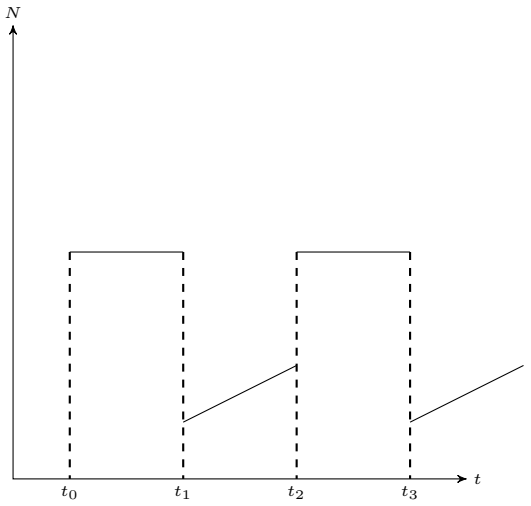
Bringing it all back home, we can now tell a full business cycle story. Assume for simplicity that the interest rate is constant and $\dot{H} = 0$. Say we start out in regime A at some point in time, t_0. Firms are investing as much as they are able to, implying full employment and high activity in the economy. However, as capital is accumulated the marginal productivity of capital will decrease – this is illustrated in panel (a) of Figure 4. At t_1 it has fallen to a level equal to r^*, and as soon as it falls marginally below we will switch to regime B (corresponding to point A in Figure 3). Firms stop investing, leading to a sudden drop in output and an increase in unemployment. Further, since the stock of capital is unchanged but employment has fallen, the marginal product of capital jumps down to a level *far below* r^*. These shifts are depicted in the three panels of Figure 4. After the sudden drop, the marginal product of capital recovers as the stock of capital is slowly worn out. When we reach t_2, it has returned to the level r^*, and as soon as it is marginally above we switch back to regime A. Firms start to invest again, leading to a jump in production and employment. Due to this the marginal productivity of capital jumps up, and a new cycle starts.



(a) MPK



(b) Output



(c) Employment

Figure 4: Haavelmo's Business Cycle Model – confer Figure (28.1) in SMT

4.3 The open economy

In the final part of SMT, Haavelmo discusses how the conclusions we have presented above are affected by considering the case of, what we say today, *the small open economy*. The additional assumptions he introduces are free trade and perfect mobility of capital. Assume also for simplicity that the price-levels domestically and abroad are given, and that the exchange rate is fixed. Let us comment briefly on some conclusions that follows.

First, there is no room for an interest rate policy that departs from the interest rate set by the foreign monetary authorities. The logical reason is (again) arbitrage and the *Law of Indifference*. Further, Haavelmo argues that the *Law of indifference* also implies that the return to capital at home and abroad needs to be equated. This model is therefore fundamentally overdetermined – given a capital stock $K(t)$ it is just as little reason to expect the marginal return to capital to equal the foreign capital rate, r_f, as it was to expect it to equal r^* in the closed economy.

In an open economy the possibility of imports allows the capital stock to adjust (almost) immediately *upwards*, while the export possibility makes domestic production independent of domestic demand. This has a direct bearing on the issue of endogenous business cycles. Now, sharp investment fluctuations are no longer generic in the model. The explanation is that in the case when the rate of interest exceeds the marginal productivity of capital (for example because the international interest rate has been increased), the domestic producers will continue to behave according to profit maximization since they can be sure to sell their outputs on the unbounded world market. Hence, unlike the closed economy analysis, although the investment level will drop dramatically, full employment and maximum production is attained. The access to a large world market also affects the analysis of the case when the marginal product of capital is high relative to the interest rate. The domestic demand for new capital is small relative to the world capacity for producing capital goods, implying that any interest rate inequality arising in the high profitability direction will be annihilated rather quickly.

The bottom line of this discussion is that the logical possibility of domestically driven endogenous business cycle is removed from the small open economy version of the model. This does not mean that business cycles are removed from the model, but that they will have to be of the imported type. Intuitively, if the domestic firms begin to fear that they may not be able to sell all their output abroad, for example because of a recession in foreign economies, then we will be back to the case where they will not want to invest, and we are back to the same business cycle mechanism as above.

Haavelmo based this conclusion on an assumption about a fixed exchange rate regime, but as we discuss in the Appendix, the extended version of the *Law of Indifference* holds for the case of a floating exchange rate regime as well. To see why, let us think through why we still have a fundamental overdeterminacy in the open economy. One reason is that the exchange rate is fixed, i.e. the monetary authorities are using one degree on freedom – it is really irrelevant (for the overdeterminacy) whether they fix the exchange rate or the domestic interest rate. But there is also another reason, although Haavelmo does not focus on this himself, namely that the *foreign* interest rates are given exogenously without any conditions securing that the law of indifference holds in the foreign capital market. Hence there might be global imbalances when the foreign capital return differs from r_f. In the Appendix a model such as that from Section 2 is extended to fit an open

economy to illustrate this point.

5 Relevance and influence

In the previous section we presented Haavelmo's 1969 macroeconomic model more or less as a translation of his work. We have included very few remarks about how this model relates to his earlier work, the macroeconomics of his day or about how it affected macroeconomic thinking and policy in Norway. In this section we address several of these issues.

5.1 Theorizing by relevant simplifications

The dramatic regime switching and the distinct boom-recession-boom cycle of Haavelmo's model are the results of two main thesis that Haavelmo returned to again and again in his macro theoretical offerings. First, he replaced the notion of a mathematically well behaved ('smooth') investment function with the idea about arbitrage-based investment strategies. Second, he showed that, in a portfolio model that includes the market for real capital as one of the assets that speculators can hold, the money market interest rate cannot be autonomously controlled by the central bank. If the central bank nevertheless decides to set the interest rate (use it as a policy instrument), Haavelmo's logical scheme implies that imbalances between supply and demand for capital and assets may occur. When applied jointly, in a macroeconomic model, the two principles implies disequilibrium macrodynamics with endogenous switching between low activity and full employment regimes. Taken at face value, Haavelmo rejected the *Neo Classical Synthesis* macro model which was the standard approach up to the stagflation period that followed in wake of the two OPEC oil price shocks in the 1970's.

As a business cycle theory, Haavelmos model improved upon the pre-existing offerings of the time. In particular Haavelmo paid attention to Goodwin (1951) which he characterized as weakly founded because it "lacked proper behavioral theory for the producers", Haavelmo (1969, p 156). Haavelmo found it unsatisfactory that Goodwin's model rested on an assumed upper and lower level of desired capital stocks (that corresponded to full employment and to the low activity level respectively) without any reference to profitability considerations. As we have seen above, Haavelmo improved on this, and he succeeded in modeling the joint dependence between the desired capital stock and the activity level.

The first principle, concerning the treatment of investment in a macroeconomic model, is partly a consequence of Haavelmo's theorizing about the determinants of net demand for capital, and partly a logical consequence of his insight that finite investment flows are not well modeled by regarding investments as a continuous function of the interest rate. From a modern perspective, it is not difficult to accept the hypothesis that net demand for real capital is affected by its own return as well as by the return on other financial and real assets. It is of course far from certain that this 'rates of return' based model of capital demand is sufficient to make the model realistic when confronted with data. Without becoming too speculative at this point, it seems clear that Haavelmo's motive was to specify a model that included the mechanisms that he regarded as fundamental for the solution of the theoretical modeling task that he had set himself, that is, the

mechanisms he would include also in an extended version of the model that could be taken to the data.

Haavelmo adhered to the principle known as *Occam's Razor*. His theoretical macro model, (which he often referred as a 'skeleton 'or 'ribbed to the bone 'model) should include only the essential mechanisms that would survive also in extended versions of the model that would (potentially) bridge the gap between theory and the real world—but no other elements. The following quotation is rather typical:

> "It is worth reminding the reader that the above conclusions do not represent statements about the development of the real world, rather they are statements that strictly speaking are valid only within the logic of the model. That said, we would also make clear that the model has not been presented just for the purpose of doing some mathematical deductions and analysis. We have of course tried to formulate a model that represent certain salient features of the real world economic systems that we find in many countries, Norway included."[16]

5.2 A supply-oriented theory

Haavelmo never undertook a systematic testing of his hypothesis about investment behavior. Later researchers may have found the investment theory too specific to follow it up closely, and it remains to be seen whether an empirically congruent version of his model can be formulated without watering out the core theoretical ideas too much.

One way to increase the relevance from the theoretical side is to embed the main idea in a model with two or more sectors. In fact Haavelmo did consider a two sector model in Chapter 31 of Haavelmo (1960). In this model the level of investment is determined by the relationship between the price of the pre-determined capital (stock), factor costs, and the technology in the production of new capital. As pointed out by Moene and Rødseth (1991), investments are determined from the supply side of the economy, and the implication is that investments are less volatile than in the classical model (i.e., as properly understood). Haavelmo does not study the effects of overdeterminacy in his two sector model, but doing so could be an interesting path for future research. This could also set the scene for analyzing fascinating price dynamics.[17]

Moene and Rødseth also point out an interesting parallel to Tobin's q-theory of investment, see Tobin (1969). The difference is that while Tobin's theory needed rationalization in the form of increasing firm adjustment costs to obtain 'smooth' investments, as in Hayashi (1982), Haavelmo in his two-sector model obtained a logically sound solution for the investment level with reference to the productive capacity of the macro economy itself. Hence, because of the way investments are determined Haavelmo's theory can be said to be supply side oriented in both the two sector version, and in the 'cruder' form presented above, where private firms 'get' what is left of GDP after consumption has chopped off its share.

[16] Haavelmo (1969, p 155), our translation.

[17] Haavelmo discusses to some extent the issue of price dynamics both in Chapter 31 of Haavelmo (1960) and in Chapter 24 of Haavelmo (1969).

5.3 Disequilibrium and regime switching

In formulating a full-fledged macroeconomic model with endogenous switching between a regime with classical and smooth growth, and another regime with Keynesian unemployment, Haavelmo preceded the disequilibrium or fix-price macroeconomic models of the 1970s and 1980s; see e.g., Barro and Grossman (1976), Malinvaud (1977), Bénassy (1986, 2002).[18] It is interesting to observe that whereas these models first abstracted from investments and capital markets, the main, underlying idea of Haavelmo's model is that states of disequilibria arise in the interface between asset markets and the real economy.[19] The profession seems to a large extent to have lost interest in disequilibrium macroeconomic models around 1990, even though we find exceptions. It will never be known whether or not the perspective adopted by Haaavelmo in SMT could have provided a powerful guideline and a different development.

5.4 An application that never was: The Great Depression

In a wider interpretation, one hypothesis emerging from Haavelmo's theory is that periods where the interest rate has been used as an instrument to achieve very tightly specified nominal targets, for example nominal exchange rate stability, may lead to a build-up of macroeconomic imbalances (see Kajtaz (2010)). To test this implication systematically one would probably need to investigate long historical data series from many countries. Less ambitiously, the model can be tested informally by its ability to explain the past. Retrodictive ability is a non-trivial property of any theory since hypotheses about the past can be falsified, see Elster (2009). One such test would be to evaluate how well the model does in explaining the main aspects of big macroeconomic events, such as the Great Depression in USA from 1929 to 1933, which seems to fit well into this framework given the conflicting role of monetary policy as a source of internal stabilization (the domestic capital markets) and external stabilization (defending the gold peg) at that time.

Although, we will not go very far here, it is striking that when the recession started in the late 1920's it was made worse by the strictures of high interest rates that the authorities in many countries felt were necessary to retain scarce gold reserves and avoid devaluation. In USA in particular, late in 1931, when the downturn in real activity had become visible on both sides of the Atlantic, the Federal Reserve raised interest rates sharply to show the country's commitment to the gold standard. It is not very controversial that the monetary policy of the Federal Reserve was one of the factors prolonging the Great Depression but it also fits well with the predictions of Haavelmo's model.

Closely after Britain decided to abandon the Gold Standard in September 1931, the Fed increased the discount rate from 1.5 to 2.5 percent in an attempt to defend the gold peg of the dollar. Just a week later, it was increased an additional 0.75 percentage points (Friedman and Schwartz, 1963, pp.380-384). The unprecedented increase in the discount rate, which is the highest increase seen in the history of the Fed in such a short time

[18] In Weintraub (1979), Haavelmo's impact on subsequent disequilibrium modeling, is fully recognized; see p.84. Some preliminary thoughts on how to analyze issues outside equilibrium were written, in Norwegian, and published in a "Festschrift" to Frederik Zeuthen in 1958, called "What can static equilibrium models tell us?" (Haavelmo, 1958). This note was published in English in Haavelmo (1974).

[19] Investment and dynamic disequilibrium issues were later analyzed by Malinvaud (1980).

span, resulted in a mismatch between the real rate of return on physical capital and the returns demanded by investors.

In Haavelmo's model, this would be the case of a movement from a situation with high investment in real capital (resulting in increased employment and income generation) to one where it is negligible, or even worse, dries up completely. According to the model such a situation is made worse by reduced inflation, which is exactly what happened.

Finally, the model predicts that after the depression became a reality, a lowering of the interest rate level that would have stimulated the economy early in the recession, would loose its force, and without external fiscal stimulus low activity in the economy would prevail for a long period of time. It is a widely held (but not universally agreed) view that low interest rates, made possible by massive open market operations by the Federal Reserve (i.e. the central bank holding a large portion of government debt) together with the increase in real demand created by the war effort, fed the boom in stock prices. Once again, this is exactly as retrodicted by Haavelmo's model.

5.5 Impression on Norwegian macroeconomic policy

A returning message in Haavelmo's macroeconomic models is that asset markets and the real economy cannot be analyzed in isolation: Instead of regarding the determination of the activity level of the real economy as separate from the asset and loans market, Haavelmo's point seems to have been that the real economy is deeply conditioned by the nature of equilibria or disequilibria in these markets, and vise versa.

For several years after his return to Norway, Haavelmo acted formally and informally as an advisor for the government. On one occasion he was asked by Trygve Bratteli (Minister of Finance) to give a scientifically sound rationale for fixing the interest rate at a low level for a long period of time in the late 1950s.[20] Haavelmo answered that one would be hard pressed to find any scientific argument, which should not surprise us after studying his macroeconomic theory, and that a regime with low and fixed interest rate could only be motivated politically, see Lie and Venneslan (2010, p 78). Of course, with reference to his model, we could add that such a policy would require a battery of regulations to have any hope of being an operational success.

Haavelmo referred to his macro model when lecturing "On the role of monetary policy in a deregulated credit market" in Norges Bank in 1987 (Haavelmo, 1987). This was in the middle of a very trying period for those responsible for Norwegian fiscal and monetary policy, as the historical documentation in Lie and Venneslan (2010) shows. Haavelmo's main message in the lecture was that the monetary regime, where the interest rate was used as an instrument to keep the exchange rate fixed, added to the problems by creating imbalances in the capital markets. Haavelmo did not get the response he may had hoped for.[21] When the Norwegian banking sector later collapsed completely, see for example (Reinhardt and Rogoff, 2009, p 377) and unemployment also rose to a level unheard of

[20] See Lie and Venneslan (2010, p 349)

[21] It was not only the economists in the central bank (Norges Bank) who were unimpressed. The same was true for the economic experts and elite bureaucrats in the government offices (Finansdepartementet). This is shown by the conspicuous *absence* of any reference to Haavelmo's line of thought (let alone to his macroeconomc model) in the more than 150 pages in Lie and Venneslan (2010) that covers the period from 1981-1992.

since the 1930s, one could say that the predictions of his model came true.

This excursion into Haavelmo's engagement in Norway's macroeconomic crisis in the late 1980s and early 1990s, shows that although he was always the scholar, he saw his theoretical framework as relevant for practical policy thinking. Not at the level of daily operation though, but definitively as a guideline for the choice of monetary and fiscal policy system. His conceptual framework and model seems, with the benefit of hindsight, as a highly relevant backdrop for a venture into practical inflation targeting.[22] The main insight is again that the system becomes over determined in the mathematical sense if the short term interest rate is fixed exogenously by the central bank, see Bårdsen and Nymoen (2001). This can be translated to "not in equilibrium"- or "outside equilibrium "-situations, which economists associate with some degree of "chaos" and low predictability. We then have our paradox, namely that any attempt to use the interest rate as an instrument for controlling for example the nominal exchange rate, or inflation, or in order to minimize business cycle fluctuations, may lead to a loss of ability to forecast the macro economy. Clearly, this is the exact opposite conclusion of the macro models that are actually used to guide inflation targeting.

This is a different perspective than the view offered by the macro models that have become dominant as guides for inflation targeting central banks. In these models, inflation is predictable and depends functionally on the interest rate, see Svensson (1997). Inflation targeting thus seems to be a manageable regime that will perform more or less as expected from theory. In the light of Haavelmo's macroeconomic scheme, inflation targeting would seem to be a more daunting task, and that there would be some risks for reacting too slowly to imbalances outside the realm of the inflation rate and the output gap.

Haavelmo had been the university teacher of almost all the leading economists in the central bank and in the government, but Haavelmo's analysis of the macroeconomy never came to play a role in the formative process that led to Norway's new monetary policy regime for the area with deregulated financial markets. Specifically, the central bank sought a new conceptual framework to aid monetary policy in the positions and practice of foreign central banks and in modern academic theories that seemed to be closer to their operational needs.

If it had been possible to ask for Haavelmo's advise, the answer would probably have the same double connotation as his answer to Bratteli's plea for scientific argument for the low interest rate policy many decades earlier. He would probably have endorsed the principle of modern inflation targeting theory that several markets should be analyzed jointly, but he would have been sceptical to the use of equilibrium models as an aid for political advise in a regime that has the autonomous fixing of the interest rate as its defining characteristic. Specifically, it is plausible that Haavelmo would have advised a broad perspective and would have warned against the imbalances in the markets for financial and real assets, and how price setting and product markets are going to be affected by such disequilibria.

For the same reason Haavelmo would probably had said something like: "But don't become too optimistic about the accuracy of your forecasts or about how strong and reliable the causation is from interest rate to inflation. Economic analysis of this regime will

[22]Again, it is interesting to note that there is so few (in fact none?) references to this perspective in the premises for adopting inflation targeting, see for example the contributions in Christiansen and Qvigstad (1997).

require careful thinking about disequilibrium constellations in financial markets, capital markets and product markets".

6 Final Remarks

As pointed out in the introduction, we feel that the macroeconomic paradigm of today has a too short retrospective view when it comes to the literature produced by the old masters, for instance Trygve Haavelmo. Our paper is an attempt to turn the tide, and to re-appreciate some of Haavelmo's macro theoretical insights.

This year we mark the centennial of Haavelmo's birth. A nice way to celebrate this event is to present to an international audience some macrodynamic ideas outlined by him during his long career. Internationally his name is closely (and perhaps only) associated with the development of modern econometrics, as documented by his "Probability Approach" from 1944.[23] However, at the national arena Haavelmo was both a teacher, advisor and "the professors' professor" for a period of over 40 years, and left an intellectual heritage much richer than what is known to the international audience. We are convinced that the international economics community might benefit from learning more about his macrodynamic heritage. Even though Trygve Haavelmo was strongly influenced by the Swedish economist Knut Wicksell (1851 - 1926), he was in a position to frame and develop Wicksell's ideas into a more readable mathematical language compatible with contemporary economics.

In this paper we have presented our interpretation of the core aspects of Haavelmo's monetary theory of investment and business cycles. A central issue in understanding how a market economy with decentralized portfolio decisions will operate is the problem of overdeterminacy related to *the law of indifference in the capital markets*. This relationship has strong implications for the effectiveness of monetary policy in controlling, say inflation or the exchange rate. Even though issues related to "the law of indifference" were publicly known as early as in Haavelmo (1960), the fully dynamic implications of this law were not completed or elaborated thoroughly until SMT was first published in 1966. In this treatise he presented a conventional, yet original, macrodynamic (disequilibrium) model with endogenous business cycles, where the activity level, due to sound economic principles, switched between a full capacity-regime and a low demand-regime. We have also taken the opportunity to discuss the relevance, scope and influence of his way of building macroeconomic models and their implications for the management of a capitalistic market economy.

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A Overdeterminacy in an Open Economy

For completeness, this Appendix shows how to extend the model from Section 2 by including the open-economy portfolio setup from Rødseth (2000, Chapters 1-3).

A.1 Bonds instead of loans

At first, keep the economy closed, but substitute the loans in the economy with bonds. Doing this does not really add any complexity to our model, but is convenient in the open-economy extension as it feels more natural that foreign bonds, and not direct foreign loans, are traded. Let B_g be the government's net holdings of bonds and B_p be that of the private sector. The government issues money (M) and borrows/lends the amount B_g through the bond market. The private sector faces the choice of holding money, bonds (B_p), or capital (K). Money earns no interest, but there's an interest rate i on bonds and r on renting out capital. $\bar{K}$ is the existing stock of capital. In an equilibrium we need the markets for bonds and capital to clear. The full overview of the assets and corresponding equilibrium conditions are given in the following table.

Table 1: Assets in the closed economy

	Balances			Rates of return
	Gov.	Private	*Sum*	(kroner)
Money	$-M$	M	0	0
Bonds	B_g	B_p	0	i
Domestic capital	0	pK	$p\bar{K}$	r
Sum	0	W		

We continue to assume that the private sector's preferences over different portfolio combinations $(\frac{M}{p}, \frac{B_p}{p}, K)$ is a well-defined function. First assume that preferences are separable in money versus other assets, such that we can write money demand as some simple function

$$\frac{M}{p} = m(i, Y) \tag{24}$$

If the private sector now invests optimally the remaining wealth in bonds and capital subject to their budget constraint (see the table) for some initial level of wealth $W = p\bar{K}$, we get a demand equation for capital

$$K^* = h(\frac{W}{p}, r, i, Y) \tag{25}$$

while demand for bonds follow as $W - p[h(\frac{W}{p}, r, i, Y) + m(i, Y)]$.

Combining private sector behavior with the equilibrium conditions we get, since $K^* = \bar{K}$,

$$\bar{K} = h(\bar{K}, r, i, Y) \tag{26}$$

which defines the equilibrium relationship $r^* = F(i; K, Y)$. This is the result from Section 2. For any rate of interest on bonds, there is a corresponding equilibrium rate of return

on capital. Correspondingly, for some rate of return on capital there's a unique interest rate on bonds that gives equilibrium in all asset markets. Fixing one interest rate will therefore give a fundamental overdeterminacy.

A.2 Open economy

In an open economy model we get one extra sector – call it "Foreign". As before, it is possible to invest in domestic bonds and capital, but now it is also possible to invest in *foreign* bonds and capital. We assume for simplicity that foreigners are uninterested in domestic money, and we keep the assumption that the domestic government only invests in bonds, not capital.

Holding one unit of capital earns you a rate of return r domestically and $r^* + e_e$ overseas, while bonds pay a rate of return i domestically and $i^* + e_e$ abroad (e_e is the expected rate of depreciation, E is the exchange rate). Letting subscript $*$ indicate the foreign sector's holdings of assets and F_i be sector i's amount of foreign bonds, we can summarize all assets and equilibrium conditions in the following table.

Table 2: Assets in the open economy

	Balances				Rates of return
	Gov.	Private	Foreign	*Sum*	(kroner)
Money	$-M$	M	0	0	0
Domestic bonds	B_g	B_p	B_*	0	i
Domestic capital	0	pK_p	pK_*	$p\bar{K}$	r
Foreign bonds	EF_g	EF_p	EF_*	0	$i^* + e_e$
Foreign capital	0	Ep^*K_{p*}	Ep^*K_{**}	$Ep^*\bar{K}_*$	$r^* + e_e$
Sum	0	W	W_*		

For simplicity, assume uncovered interest parity (UIP) in the foreign exchange market such that

$$i = i^* + e_e \tag{27}$$

must hold, and assume that exchange rate expectations are formed according to

$$e_e = e_e(E) \tag{28}$$

A consequence of UIP is that it is not possible to derive separate demand equations for foreign and domestic bonds. We must therefore view the total stock of bonds as *one asset*, $Q_i = B_i + EF_i$ being held by sector i. Using (27) and (28) we see that for given interest rate differences, the foreign exchange market pins down the equilibrium exchange rate.

Subject to an initial level of wealth W[24], the private sector chooses an optimal combination of $(\frac{Q_p}{p}, \frac{Ep^*K_{p*}}{p}, K_p)$. Money demand is still assumed to be given as (24). We will

[24]Note that W and W_* are not exogenous variables since exchange rate fluctuations can change the value of initial holdings.

get demand equations for the two types of capital:

$$K_p = k(r, r^* + e_e, i, \frac{W}{p}) \tag{29}$$

$$\frac{Ep^* K_{p*}}{p} = k_*(r, r^* + e_e, i, \frac{W}{p}) \tag{30}$$

while the total stock of privately held bonds follows.

For the foreign sector find similar demand equations given an initial level of wealth W_*:

$$\frac{pK_*}{Ep^*} = f(r - e_e, r^*, i^*, \frac{W_*}{Ep^*}) \tag{31}$$

$$K_{**} = f_*(r - e_e, r^*, i^*, \frac{W_*}{Ep^*}) \tag{32}$$

while the amount of bonds held follows.

Parallel to the closed economy model, let us combine private and foreign sector behavior with the equilibrium conditions. Use also that UIP implies $e_e = i - i^*$ and that because of our foreign exchange market assumption implies $E = e_e^{-1}(i - i^*) = n(i - i^*)$. Since $W + W_* = p\bar{K} + Ep^*\bar{K}_*$, we write $W = \alpha p\bar{K} + \beta Ep^*\bar{K}_*$ and $W_* = (1-\alpha)p\bar{K} + (1-\beta)Ep^*\bar{K}_*$ for appropriate values of α and β. Equilibrium in the two markets for capital requires

$$\begin{aligned}\bar{K} =& k(r, r^* + i - i^*, i, \alpha\bar{K} + \beta q(i - i^*)\bar{K}_*) \\ &+ pq(i - i^*) f(r - i + i^*, r^*, i^*, (1-\alpha)\frac{\bar{K}}{q(i - i^*)} + (1-\beta)\bar{K}_*)\end{aligned} \tag{33}$$

$$\begin{aligned}\bar{K}_* =& \frac{1}{p} k_*(r, r^* + i - i^*, i, \alpha\bar{K} + \beta q(i - i^*)\bar{K}_*) \\ &+ f_*(r - i + i^*, r^*, i^*, (1-\alpha)\frac{\bar{K}}{q(i - i^*)} + (1-\beta)\bar{K}_*)\end{aligned} \tag{34}$$

$$\tag{35}$$

where $q(i - i^*) = n(i - i^*)p^*/p$ is the real exchange rate. We observe that for any pair (i, i^*), these conditions return the necessary rates of return in the capital markets in order to create equilibrium. Hence in the open economy case, it is not only fixing i that will cause over-determinacy – fixing i^* will do so as well. This is the natural extension of Haavelmo's law of indifference on the capital markets.