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Evolutionary Macroeconomics: A synthesis between neo-Schumpeterian and post-Keynesian lines of thought

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Abstract

This paper presents an evolutionary simulation model of the Dutch economy. The model is available in the form of a computer programme, and can be used to simulate growth paths for the Dutch economy under different scenarios. The model is aimed at providing a starting point for the building of practical policy simulation models using ideas from evolutionary economics. Part of the theory builds on post-Keynesian economics, and neo-Schumpeterian economics.

Keywords: Evolutionary economic models, Policy models, Dutch economy, Dynamic input-output model
JEL: O40, O52, E17, C67

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1. Introduction

Most of what many economists would judge to be 'economic theory' is still based on the concept of the perfectly rational agent: the infamous *homo economicus* whose behaviour can be reduced to (mathematically) maximizing a profit or utility function. While this is already a rather far-reaching notion, when applied to the study of macroeconomics, one has to live with an additional restrictive concept, namely that of the representative agent. This notion assumes that aggregate economic behaviour can somehow be analyzed in terms of a microeconomic model based on maximization applied to aggregate data.

Obviously, such an approach provides a rather limiting perspective for the analysis of long-run economic dynamics. What matters for the long run are inherently uncertain phenomena, of which radical technological changes are a major ingredient. The direction of technological change and the outcome of the R&D process are impossible to predict in an accurate way, and hence the perfect foresight or rational expectations assumptions associated with full rationality models are hard to maintain.

Just how difficult it is to think of fully rational agents in connection to long-run technological trends becomes clear from a quotation from Katz and Philips provided by Freeman and Soete (1990, p. 172): "The general view prior to 1950 was that there was no commercial demand for computers. Thomas J. Watson Senior [the executive of IBM] (…) felt that that the one SSEC machine which was on display at IBM's New York offices 'could solve all the scientific problems in the world involving scientific calculations'. He saw no commercial possibilities". In 2001, it would of course be easy to ridicule this prediction.

Although one cannot prove the point with anecdotes as the above one, it is clear that 'bounded rationality' in the sense of Simon (1986) is a much more realistic concept for the basis of long-run economic models than the representative and fully rational agent. This has given rise to a class of economic models that is often referred to as 'evolutionary', or 'neo-Schumpeterian' (e.g., Nelson and Winter, 1982). Key concepts in these models are indeed bounded rationality, heterogeneity (of agents' technological capabilities) and disequilibrium dynamics. Contrary to the full rationality assumption in neoclassical models, this approach leaves room for different mental models and, thus, different actions and outcomes between agents dealing with a similar environment and similar goals.[1]

The way in which most evolutionary economists have proceeded is to borrow from mathematical biology, by adopting population dynamics, or evolutionary models (hence the name evolutionary economics). In this approach, the economy is modeled as a collection of heterogeneous agents that can be characterized by a competitiveness function. This function maps their behavioral patterns (e.g., R&D intensities, or costs functions) to competitiveness. Then, a so-called replicator equation is used to model market share dynamics (see below, and Silverberg, 1988).

A large part of evolutionary economics focuses on developing theory around the fitness functions, i.e., asking questions such as what determines the competitiveness of firms, and what is the role of technology in this. A number of authors have attempted to develop macroeconomic growth models on the basis of such theory (see Silverberg and Verspagen, 1998, for a survey). However, generally, these macro-evolutionary models apply some rather strong assumptions on the macroeconomic structure, which makes it hard to implement such models empirically.[2] So far, evolutionary macroeconomic models are restricted to pure theory, without applications to real economies.

This paper is an attempt to provide a macroeconomic context in which evolutionary models can be applied to real world macroeconomic problems. It should be clear from the above discussion that one main advantage of such an approach is that a 'better' or 'more realistic' microeconomic foundation can be added to practical macro-models. But this does not yet imply that more useful empirical results will result from evolutionary macro-models. This is why the current paper can only be seen as a first step in a longer process of trying to evolutionary economics established as an empirical macroeconomic sub-discipline. Because of the relative infancy of applied evolutionary macroeconomic models, it is probably too early to evaluate the usefulness of the approach with more established practical modeling traditions by means of a comparison of the results from the present models with those of existing models (not based on an evolutionary approach). This is something that might be attempted in a few years from now. What then, at the current stage of development of evolutionary models, is the outlook for the benefits from such models (apart from the above mentioned 'more realistic micro foundations')?

In the first place, evolutionary models provide important advantages in dealing with the phenomenon of technological change. In the established practical macroeconomic modeling traditions up to the late 1980s, technology is not taken into account in any other way than by some exogenous trend of productivity (e.g., see the overview in Den Butter, 1987). With the event of the so-called endogenous growth models in the early 1990s (e.g., Romer, 1990), neo-classical growth theory finally came to grips with technological change, but practical implementation of these ideas into empirical macroeconomic models obviously lags behind.

Jones (1995a,b) has illustrated some of the inherent empirical difficulties with endogenous growth models, but nevertheless at the end of the 1990s macroeconomic policy models began to include technological change as an explicit (although still not very 'endogenous') factor. Nahuis (2000) provides a short overview of these attempts and also adds a model of his own. At such an early stage of the development of these models, however, it seems useful to think about the possible contributions of evolutionary economics, which is arguably a tradition with a much longer history of endogenizing technology. The argument that technology is largely considered as an exogenous factor also holds for most practical approaches to macroeconomic modeling in the Keynesian tradition. For example, this was exactly the point that Fagerberg (1988) raised against Thirlwall's (1979) concept of balance of payments restricted growth.

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[1] This paper does not aim to elaborate on the discussion between neoclassicals and evolutionists. More on this debate can be found in Silverberg and Verspagen (1998).

[2] For example, Silverberg and Verspagen (1994) assume that all profits are invested, and that output is always equal to capacity output.

Second, as the present model shows, the evolutionary approach based on replicator equations is, as a result of its relative simple mathematical structure, able to achieve a great detail of sectoral detail without greatly enlarging the number of equations in the model. Models of more than 5000 equations are not uncommon in this tradition (Den Butter, 1987). In terms of the number of equations, the present model is more similar to the early models by Tinbergen and Klein, while achieving a degree of sectoral detail greater than most state-of-the art models. This is an obvious advantage even in times when computer power is exploding.

In addition to these two arguments, which basically say that other than evolutionary economics approaches may learn from the development of an evolutionary macroeconomic model, the present paper is also intended to further develop the existing evolutionary economic modeling tradition. My proposition here is that evolutionary economics so far by and large lacks a clear theory of other economic phenomena than technological change, e.g., the interaction between trade and growth, or the theory of labour- or financial markets. In order to fill this gap, I will borrow from the (post-)Keynesian tradition, which, as I will argue below, is particularly easy to complement with evolutionary models.

The backbone of the model that is proposed here is an input-output model with post-Keynesian characteristics. Market share dynamics based on replicator equations (the evolutionary content of the model) can be added to this backbone in a relatively easy way. An application of this for the Dutch economy in the 21st century will be described and is available in the form of an easy-to-use computer program.[3] This model can be considered as an evolutionary counterpart of so-called computable general equilibrium models (CGE-models).

The post-Keynesian and evolutionary foundations of the model will be discussed in broad terms in Section 2. Section 3 describes the technicalities of the input-output model, which solves for the short-run variables in the model. The rest of the paper is devoted to the application to the Dutch economy. This application is done in the form of scenario simulations. These scenarios will be described in Section 4. Section 5 discusses the empirical results. Section 6 concludes and discusses options for further research.

2. Theoretical background

The analysis will draw heavily on post-Keynesian theory. The reason for this is that post-Keynesian theory provides a coherent set of macroeconomic theories, which are not based on full rationality models. Moreover, many of the theoretical arguments underlying post-Keynesian theory are quite similar to the arguments used in evolutionary theory. For example, the notion of cumulative causation (e.g., Kaldor, 1970) is very close to the notion of positive feedback-effects and path dependency in evolutionary models.

McCombie and Thirlwall (1994) discuss the notion of balance of payments restricted growth as one of two main ideas in post-Keynesian theory of growth in open economies. This

[3] Available at http://www.tm.tue.nl/ecis/bart

is essentially a demand-side approach, which argues that supply-factors such as capital accumulation and technological change cannot be taken as exogenous (as is done, for example, in growth accounting or the Solow growth model). What is ultimately exogenous, so the theory argues, is foreign demand (exports).

Thus, if a country faces a long-run balance of payments constraint (i.e., its stock of foreign currency is limited and it cannot accumulate debt for ever, nor does it want to accumulate foreign reserves for ever), the domestic economy can only grow as rapidly as the balance of payments allows. McCombie and Thirlwall assume that the income and price elasticities of exports and imports are fixed, and differ between countries. They then derive a model in which the growth rate of a country relative to the growth rate of the world economy depends on the elasticities of exports and imports.

Fagerberg (1988) argued that explicit modeling of the elasticities could refine this approach. He proposed to use innovation and R&D as explanatory factors. The model here also takes this road, by setting up a detailed sectoral description of the economy, which yields the elasticities originally used by McCombie and Thirlwall.

These elasticities result from market share (replicator) dynamics at various levels in the economy. The general form of the replicator equation is as follows:

$$s_{it} - s_{it-1} = f s_{it-1} (\frac{E_{it}}{\overline{E}_t} - 1), \overline{E}_t = \sum_j s_{jt-1} E_{jt},$$

where s_{it} is the population share of item i in period t, ϕ is an adjustment parameter, and E_i is competitiveness (or fitness) of item i. In the mathematical biology literature, this equation is used to model population dynamics, or evolutionary processes. In the economic terms of this paper, it is proposed to use s as a market share variable. More precisely, in the application to the Dutch economy that will be given below, three different market share variables are introduced. The first is the market share on the Dutch domestic market for products of a given sector. The market parties in this market are Dutch producers and foreign producers. The second market share is for the world market for exports (seen from a Dutch perspective). Market parties are the same as in the previous case. The third and final ‘market’ share is the share of a sector in total spending (i.e., household consumption, investment, or exports). In this case, sectors are considered as ‘market parties’.

The competitiveness variable E in the replicator equation is modeled here as completely exogenous. The values of E can be specified by the user of the computer program representing the application to the Dutch economy that will be discussed below. A more satisfying approach would be to make E dependent on decision variables such as R&D expenditures or wages. An example of such an approach in the context of international trade and growth, together with an empirical application, is in Verspagen and Wakelin (1997). To incorporate this into the present model is left for future research.

The three different interpretations of the replicator equation run as follows. First, we define a variable $\tilde{z}_{it}$ as the share of imports in total Dutch domestic sales of goods of sector i in period t. If we introduce a ratio of competitiveness levels between Dutch and foreign producers, denoted by e_i, the following replicator equation can be specified for $\tilde{z}_{it}$

$$\frac{\tilde{z}_{it} - \tilde{z}_{it-1}}{\tilde{z}_{it-1}} = f_i\left(\frac{1}{\tilde{z}_{it-1} + (1-\tilde{z}_{it-1})e_i} - 1\right). \qquad (1)$$

Given an initial value for $\tilde{z}_{it}$, and values for e_i and f_i, this difference equation specifies a time path for $\tilde{z}_i$.

Second, denote by p_i the share of a sector i in total spending (either domestic consumption, domestic investment, or exports). Now 'competitiveness' of the sector is to be interpreted as 'attractiveness', i.e., in the case of consumption demand some function of tastes (income and price elasticities), or, in the case of investment, some function of technology. Note that it would be desirable to specify the 'attractiveness' functions explicitly, but (see below) this is not implemented here. Assume therefore that the 'attractiveness' of a sector can be specified, so that one may set up the following replicator equation

$$\frac{p_{it} - p_{it-1}}{p_{it-1}} = j_i\left(\frac{E_i}{\overline{E}} - 1\right), \overline{E} = \sum_j p_{it-1} E_i. \qquad (2)$$

Given initial values for p, this leads to a time path for that variable.

Third, for Dutch exports, a combination of the two above replicators is used. For the total (i.e., aggregated over sectors) export market, the sectoral share version (2) of the replicator is used. For the Dutch market share in sectoral export markets, a replicator analogous to (1) is used. Then, the growth rate of Dutch exports in a sector is equal to the sum of the growth rate of that sector in sectoral shares, the growth rate of the Dutch market share in that sector, and the growth rate of total spending on the export market (the latter is specified exogenously).

In the short run, i.e., on a yearly basis, the values for all these market shares are given. The values of the market shares can thus be used to solve a short-run model of the economy. This short-run model is an input-output model that is solved using a mechanism of endogenous investment demand, and balance of payments equilibrium (as in post-Keynesian theory outlined above). As is well-known, input-output models usually take final demand (consumption, investment, exports and imports) as exogenous, and then solve for the level of (sectoral) gross output and GDP. The present model is slightly more sophisticated in the sense that it determines the levels of final demand as endogenous. Exports and imports are determined by the market share dynamics associated with the replicator equation introduced above, together with the balance of payments constraint (which says that total exports must equal total imports). Total investment demand is modeled using an accelerator mechanism, i.e., firms have a desired capital stock given gross output, and invest just enough to achieve this level of the capital stock (taking into account exogenous depreciation). The sectoral division of investment demand is given by the replicator introduced above.

This leaves total final consumption demand to be determined. For this, the balance of payments restriction is used. Given the shares of sectors in final consumption demand, there is only one level of total consumption demand that is consistent with balance of payments equilibrium. The procedure is to solve for this level of final consumption demand, and calculate the associated GDP level. The details of this procedure will be outlined in the next section.

3. Short-run determination of output

This section specifies the short-run input-output model (essentially based on Leontief and Duchin, 1986) that is used to solve for the level of GDP given market shares. Suppose we have an input-output system with n sectors:

$$\mathbf{q} = \mathbf{Aq} + \mathbf{f} + \mathbf{in} + \mathbf{x} - \mathbf{m}, \qquad (3)$$

where

$\mathbf{q}$ is the (nx1)-vector of gross output,
$\mathbf{A}$ is the (nxn)-matrix of technical coefficients,
$\mathbf{f}$ is the (nx1)-vector of final consumption demand,
$\mathbf{in}$ is the (nx1)-vector of investment demand,
$\mathbf{x}$ is the (nx1)-vector of export demand,
$\mathbf{m}$ is the (nx1)-vector of imports (note all other variables include imported goods).

Bold capitals point to matrices, bold lowercase letters to vectors. Lowercase letters in italics point to scalars, unless they appear with one or more indices. In the latter case, they refer to an element of a vector or matrix, which is referred to with the corresponding letter (i.e., a_{ij} is the element in row i and column j of $\mathbf{A}$). A hat above a bold capital will refer to a 'diagonal' matrix, i.e., $\hat{\mathbf{A}}$ will refer to a matrix with elements of vector $\mathbf{a}$ on the main diagonal, and zeros elsewhere.

Now define a vector $\mathbf{z}$ with elements equal to $z_i \equiv \frac{\tilde{z}_i}{1-\tilde{z}_i}$, where

$$\tilde{z}_i = \frac{m_i}{q_i + m_i - x_i}.$$

$\tilde{z}_i$ will be referred to as the 'import penetration' (or market share of foreign producers) in sector i, and was already introduced in the previous section when discussing replicator equations. Now one may write:

$$\mathbf{m} = \hat{\mathbf{Z}}(\mathbf{q} - \mathbf{x}). \qquad (4)$$

It is assumed that, in the short run, each sector has a fixed (exogenous) capital output ratio c, defined as:

$$\frac{k_i}{q_i} = c_i,$$

where k is the capital stock. The capital stock evolves according to

$$k_i = (1-\mathbf{d})k_{i,t-1} + r_i,$$

where the subscript t-1 points to a value in period t-1 (wherever such a time subscript is absent, the variable refers to period t), $\mathbf{d}$ is the vector of capital depreciation rates and r is an element of the vector $\mathbf{r}$ which denotes investment demand by demanding (contrary to producing) sector. It is assumed that firms are able to realize investment plans that match exactly to the exogenous capital-output ratios. This means that they realize the following investments:

$$\mathbf{r} = \hat{\mathbf{C}}\mathbf{q} - (1 - \mathbf{d})\mathbf{k}, \qquad (5)$$

where $\hat{\mathbf{C}}$ is the matrix of capital coefficients c. Capital goods are assumed to be heterogeneous goods. The exogenous matrix **S** is assumed to describe the fractions of capital goods demand by i that can be supplied by j. Then one may write

$$\mathbf{in} = \mathbf{Sr}. \qquad (6)$$

Substituting (5) into (6), the result, as well as (4) into (3), one arrives at

$$\mathbf{q} = \mathbf{Aq} + \mathbf{f} + \mathbf{S}\hat{\mathbf{C}}\mathbf{q} - \mathbf{S}(\mathbf{1} - \mathbf{d})\mathbf{k} + \mathbf{x} - \hat{\mathbf{Z}}(\mathbf{q} - \mathbf{x}).$$

This expression can be solved for **q** as follows (**I** is the identity matrix):

$$\mathbf{q} = (\mathbf{I} - \mathbf{A} - \mathbf{S}\hat{\mathbf{C}} + \hat{\mathbf{Z}})^{-1}(\mathbf{f} - \mathbf{S}(\mathbf{1} - \mathbf{d})\mathbf{k} + \mathbf{x} + \hat{\mathbf{Z}}\mathbf{x}). \qquad (7)$$

Define

$$\mathbf{L} \equiv (\mathbf{I} - \mathbf{A} - \mathbf{S}\hat{\mathbf{C}} + \hat{\mathbf{Z}})^{-1}.$$

The trade balance (current account) of the economy can be written as

$$\mathbf{x} - \mathbf{m} = \mathbf{x} - \hat{\mathbf{Z}}\mathbf{q} + \hat{\mathbf{Z}}\mathbf{x} = \mathbf{x} + \hat{\mathbf{Z}}\mathbf{x} - \hat{\mathbf{Z}}\mathbf{L}(\mathbf{f} - \mathbf{S}(\mathbf{1} - \mathbf{d})\mathbf{k} + \mathbf{x} + \hat{\mathbf{Z}}\mathbf{x}). \qquad (8)$$

Taking all other variables on the right hand side of (8) as exogenous, we may solve for a vector **f** that yields balanced trade. To do so, first assume that the shares of sectors in final consumption demand are given exogenously, i.e.,

$$\mathbf{f} = y\mathbf{p}, \qquad (9)$$

where y is total consumption spending, and **p** gives the sectoral shares in total expenditures. Balanced trade is required at the macro level, i.e., individual sectors may show a trade surplus or shortage, as long as these sum to zero. Using (8) and (9), this may be expressed as follows:

$$\mathbf{i}(\mathbf{x} - \mathbf{m}) = \mathbf{i}[\mathbf{x} + \hat{\mathbf{Z}}\mathbf{x} - \hat{\mathbf{Z}}\mathbf{L}(y\mathbf{p} - \mathbf{S}(\mathbf{1} - \mathbf{d})\mathbf{k} + \mathbf{x} + \hat{\mathbf{Z}}\mathbf{x})] = \mathbf{0}, \qquad (10)$$

where **i** is a row-vector with all ones.

Expression (10) is in fact a single equation that may be solved for y. Define

$$\mathbf{i}[\mathbf{x} + \hat{\mathbf{Z}}\mathbf{x} - \hat{\mathbf{Z}}\mathbf{L}(\mathbf{x} - \mathbf{S}(\mathbf{1} - \mathbf{d})\mathbf{k} + \hat{\mathbf{Z}}\mathbf{x})] \equiv \Gamma,$$

$$\mathbf{i}\hat{\mathbf{Z}}\mathbf{L}\mathbf{p} \equiv \Lambda.$$

Now equation (10) can be solved as

$$\Lambda y = \Gamma \Rightarrow y^* = \frac{\Gamma}{\Lambda},$$

where y^* is the value of total consumption expenditures consistent with balance of payments equilibrium.

With this model, one may easily solve for GDP associated with y^*, given the values for **A, S, x, p,** $\hat{\mathbf{Z}}, \hat{\mathbf{C}}$). All of these variables are given by the long-run equations explained in the previous section or the next section (which deals with assumptions about technological change). Specifically, $\hat{\mathbf{Z}}$ and **x** are given by replicator equation (1) and **p** is given by replicator equation (2). The variables **A**, **S** and $\hat{\mathbf{C}}$ are related with the direction and rate of technological change and will be dealt with in the next section.

4. Setting up scenarios

The variables for which scenarios have to be specified can be divided into three groups: technological change (productivity), competitiveness (export and imports), and sectoral composition of demand. For each of these three groups, individual scenarios will be set up and discussed below. These scenarios will also be combined into so-called 'meta-scenarios', which combine scenarios from each of the three groups.

4.1. Technological change (productivity) scenarios

In order to introduce technological change into the system, we will introduce labour productivity in the model. So far, we have not had any need to introduce labour in the analysis, because labour demand results endogenously from the short-run output level that has been derived in section 3. We will denote labour productivity by l. In line with a good deal of the evolutionary economic literature on technological change, we will represent technological change by a change in labour productivity (e.g., Silverberg, 1984). We will also assume, however, that the productivity of other factors (i.e., capital and intermediate use) will change over time.

Specifically, we follow the input-output tradition and assume no short-run substitution between production factors. This implies that the factor-output rates depend on the level of technology only. In the long run, however, the proportion of the various factors may change due to a bias in technological change. The formal implementation of this bias is as follows. Define the rate of technological progress in a sector as the rate of growth labour productivity, i.e., $(dl/dt)/(1/l)$. It is assumed that there is a fixed ratio between the rate of growth of labour productivity and the rate of growth of the other factor-output ratios. This fixed ratio is called the technological bias. In formal notation, this looks as follows:

$$\frac{da_j}{dt}\frac{1}{a_j} = \frac{dl_j}{dt}\frac{1}{l_j}\alpha_j, \qquad \text{(11a)}$$

$$\frac{dc_j}{dt}\frac{1}{c_j} = \frac{dl_j}{dt}\frac{1}{l_j}\beta_j, \qquad \text{(11b)}$$

where α and β are the bias for intermediate use and capital, respectively, and the subscript j denotes, as before, a sector. Equation (11a) specifies the time path of the matrix **A** (technical coefficients). In order to derive a time path for $\hat{\mathbf{C}}$, we need, in addition to equation (11b), a specification for the time path of the matrix **S** (which describes the distribution of the demand for capital goods over sectors). Unfortunately, the empirical data for the Dutch economy do not allow us to specify this matrix. We will therefore assume that this matrix consists of identical rows, each of which is equal to the vector of capital coefficients that results from equation (11b).

Thus, for each sector, three values have to be specified: the rate of technological progress $[(dl/dt)/(1/l)]$, the capital bias (β) and the intermediate use bias (α). Note that we assume that the shares of sectors in total intermediate use are fixed, i.e., that technical coefficients in a column of the input-output table all change at the same rate (this assumption can, of course, easily be replaced by a more realistic one, but this requires more parameters).

Table 1. Base scenario for technological progress

Sector	$\frac{dl_j}{dt}\frac{1}{l_j}$	β	α
Agriculture & fishery	0.039	-0.157	0.137
Mining	0.043	-0.488	0.250
Food, drinks, tobacco	0.037	-0.544	-0.005
Textiles, clothing, leather	0.026	-1.000	0.034
Wood and products	0.019	-1.000	0.168
Paper	0.036	-0.792	-0.040
Printing & publishing	0.029	-0.688	-0.053
Refined oil	0.000	0.000	0.000
Chemicals	0.042	0.605	0.216
Rubber & plastic products	0.039	-0.232	-0.100
Stone, clay, glass	0.029	-0.733	0.062
Basic metals	0.009	-0.423	-0.100
Metal products	0.035	-0.230	-0.100
Machinery (incl. computers)	0.024	-0.413	0.250
Electrical machinery	0.042	-0.297	-0.100
Motor vehicles	0.014	-1.000	0.250
Other transport equipment	0.032	-0.306	-0.073
Other manufacturing	0.019	-1.000	0.250
Gas, water, electricity	0.028	-0.026	-0.100
Construction	0.023	-1.000	0.000
Trade, hotels, bars, repairshops	0.026	0.298	0.000
Transport & communication	0.021	-0.153	-0.092
Finance & insurance	0.023	1.000	0.250
Real estate & business services	0.013	1.000	0.000
Other (incl. government, education)	0.015	1.000	-0.070

Source: OLS estimations on input-tables from Statistics Netherlands, 1971-1992.

The base scenario for technological change assumes the values in Table 1. These values are obtained from the empirical values for the period 1971-1992, with some modifications. The modifications are fourfold. First, capital biases with an absolute value larger than one were set to plus or minus one accordingly. Second, intermediate use biases larger than 0.25 were set to 0.25, and values smaller than 0.1 were set to 0.1. Third, the rate of technological progress for oil refining was set to zero (it was negative in the actual data). Fourth, the intermediate use biases for construction, trade etc., and real estate etc. were set to zero.[4] These changes are necessary to keep the dynamic path of the model within reasonable bounds.

In addition to this base scenario, three other scenarios are available: a scenario without any technological progress (setting the rates to zero), a scenario with slow technological progress

[4] Especially the last change has an important impact on the results. Without it, the growth rate becomes negative in the long run. In the sectors mentioned, changes of the intermediate use to output ratios do not correspond in a very intuitive way to technological change, which is why setting the bias to zero seems reasonable.

(dividing al rates by two), and a scenario with rapid technological progress (multiplying all rates by 1.5). Other scenarios can easily be specified by the user of the software, which allows each of the values in Table 1 to be modified individually.[5]

4.2. Composition of demand scenarios

The scenarios for the composition of demand are specified in terms of the sectors with an above or below average value for competitiveness. The relevant equation is (2) above, where values for E_i and φ need to be specified. The latter is set to 0.1. Further, note that as long as one sector has a value for competitiveness (*E*) that is different from others, all sectors will have their shares changing over time. Empirically, changes of –40 to +30% seem to be normal for the percentual changes of the shares of consumption demand over a fifteen-year period. Thus, competitiveness levels will be set up in a way to ensure that this order of magnitude is not exceeded. For simplicity, the scenarios for the three categories of demand (consumption, exports, investment) will be assumed to be equal.

Table 2 gives two scenarios that are supplied with the software, labeled 'environment friendly through electronics' and 'service economy'. For each scenario, the table gives the assumed values for *E* in equation (2) above for each sector, and the resulting percentual change of the share over 1997-2010 for each of the three categories of final demand. In addition, a scenario where sectoral shares do not change is supplied with the software.[6]

In the environment friendly scenario, the sectors mining; refined oil; chemicals; stone, clay and glass; motor vehicles; gas, water and electricity; and transport and communication are modeled as 'less attractive'. This scenario also assumes that electronic equipment will enable most of the environment saving technologies, hence the sector electrical machinery increases in share at a relatively rapid rate. The table gives the percentual changes of the shares of each of the sectors (note that the sectors with *E* equal to one also increase their share, because they have above average attractiveness).

In the service economy scenario, some of the basic necessities of life (food, drinks, tobacco; textiles, clothing, leather) and the basic manufacturing sectors (basic metals; metal products) decline relatively rapidly. The services sectors (trade, hotels, bars, repairshops; transport and communication; finance and insurance; real estate and business services) increase their share rapidly, as do printing and publishing (a manufacturing sector with a large services content) and electrical machinery (which is assumed to supply the electronic equipment that drives much technological progress in services).

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[5] The technological change scenarios are available in the software under the filenames base.stp, low.stp, high.stp and zero.stp.

[6] The files are named envfr.scd, service.scd and nochange.scd.

Table 2. Scenarios for changes in the composition of demand

Sector	Environment friendly through electronics				Service economy			
	% change* of **p** for expenditure category				% change* of **p** for expenditure category			
	E	**f**	**in**	**x**	*E*	**f**	**in**	**x**
Agriculture & fishery	1.0	2.9	1.7	6.9	1.0	-9.9	-5.9	-3.0
Mining	0.8	-21.3	-22.0	-18.8	1.0	-9.9	-5.9	-3.0
Food, drinks, tobacco	1.0	2.9	1.7	6.9	0.9	-20.1	-17.0	-14.7
Textiles, clothing, leather	1.0	2.9	1.7	6.9	0.9	-20.1	-17.0	-14.7
Wood and products	1.0	2.9	1.7	6.9	1.0	-9.9	-5.9	-3.0
Paper	1.0	2.9	1.7	6.9	1.0	-9.9	-5.9	-3.0
Printing & publishing	1.0	2.9	1.7	6.9	1.2	14.5	20.5	24.8
Refined oil	0.8	-21.3	-22.0	-18.8	1.0	-9.9	-5.9	-3.0
Chemicals	0.8	-21.3	-22.0	-18.8	1.0	-9.9	-5.9	-3.0
Rubber & plastic products	1.0	2.9	1.7	6.9	1.0	-9.9	-5.9	-3.0
Stone, clay, glass	0.8	-21.3	-22.0	-18.8	1.0	-9.9	-5.9	-3.0
Basic metals	1.0	2.9	1.7	6.9	0.9	-20.1	-17.0	-14.7
Metal products	1.0	2.9	1.7	6.9	0.9	-20.1	-17.0	-14.7
Machinery (incl. computers)	1.0	2.9	1.7	6.9	1.0	-9.9	-5.9	-3.0
Electrical machinery	1.1	17.4	16.0	22.4	1.2	14.5	20.5	24.8
Motor vehicles	0.8	-21.3	-22.0	-18.8	1.0	-9.9	-5.9	-3.0
Other transport equipment	1.0	2.9	1.7	6.9	1.0	-9.9	-5.9	-3.0
Other manufacturing	1.0	2.9	1.7	6.9	1.0	-9.9	-5.9	-3.0
Gas, water, electricity	0.8	-21.3	-22.0	-18.8	1.0	-9.9	-5.9	-3.0
Construction	1.0	2.9	1.7	6.9	1.0	-9.9	-5.9	-3.0
Trade, hotels, bars, repairshops	1.0	2.9	1.7	6.9	1.2	14.5	20.5	24.8
Transport & communication	0.8	-21.3	-22.0	-18.8	1.2	14.5	20.5	24.8
Finance & insurance	1.0	2.9	0.0	6.9	1.2	14.5	20.5	24.8
Real estate & business services	1.0	2.9	1.7	6.9	1.2	14.5	20.5	24.8
Other (incl. gov., education)	1.0	2.9	1.7	6.9	1.0	-9.9	-5.9	-3.0

* change over 1997-2010.

4.3. Competitiveness scenarios

For the competitiveness scenarios, equation (1) is used, where a ratio between Dutch and foreign competitiveness (e) and an adjustment parameter (ϕ) value needs to be specified. The adjustment parameter is again fixed at 0.1 for all sectors. Identical replicator equations, and competitiveness ratios, will be used for import and export markets. In addition to the 'no change' scenario (all competitiveness ratios equal to one), three scenarios will be used. These are documented in Table 3.

The first scenario, labeled 'service scenario' assumes that Dutch producers have above average competitiveness in the services sectors (trade, hotels, bars, repairshops; transport and communication; finance and insurance; real estate and business services). Below average competitiveness is assumed for all primary and manufacturing services, while for the other sectors (construction; gas, water, electricity; other) no differences in competitiveness are assumed. Note that the assumption of below average competitiveness in the primary and manufacturing sectors is not connected to services a priori. This assumption is made to provide some contrast into the competitiveness assumptions.

Table 3. Scenarios for relative Dutch competitiveness

Sector	**Service scenario (ICTs)**		**Agro-technology scenario (biotechnology)**		**Heavy industry scenario (low wages)**	
	e	**% change Dutch share***	*e*	**% change Dutch share***	*e*	**% change Dutch share***
Agriculture & fishery	0.95	-5.7	1.20	25.0	0.80	-21.5
Mining	0.95	-6.1	0.95	-6.1	1.20	27.5
Food, drinks, tobacco	0.95	-5.6	1.20	24.4	0.80	-21.3
Textiles, clothing, leather	0.95	-6.2	0.95	-6.2	0.80	-22.8
Wood and products	0.95	-6.2	0.95	-6.2	0.80	-22.8
Paper	0.95	-6.1	0.95	-6.1	0.80	-22.5
Printing & publishing	0.95	-6.0	0.95	-6.0	0.80	-22.4
Refined oil	0.95	-5.8	0.95	-5.8	1.20	25.7
Chemicals	0.95	-5.6	1.10	11.8	1.20	24.3
Rubber & plastic products	0.95	-6.1	0.95	-6.1	0.80	-22.5
Stone, clay, glass	0.95	-6.1	0.95	-6.1	0.80	-22.6
Basic metals	0.95	-6.1	0.95	-6.1	1.20	27.4
Metal products	0.95	-6.1	0.95	-6.1	1.20	27.6
Machinery (incl. computers)	0.95	-6.1	1.10	13.1	1.10	13.1
Electrical machinery	0.95	-6.1	0.95	-6.1	1.20	28.1
Motor vehicles	0.95	-6.2	0.95	-6.2	1.20	28.4
Other transport equipment	0.95	-6.2	0.95	-6.2	1.20	28.5
Other manufacturing	0.95	-6.1	0.95	-6.1	1.20	27.8
Gas, water, electricity	1.00	0.0	1.00	0.0	1.00	0.00
Construction	1.00	0.0	1.00	0.0	1.00	0.00
Trade, hotels, bars, repairshops	1.20	24.1	1.00	0.0	1.00	0.00
Transport & communication	1.20	25.8	1.10	12.4	1.10	12.4
Finance & insurance	1.20	28.4	0.95	-6.2	0.80	-22.8
Real estate & business services	1.20	28.5	0.95	-6.2	0.80	-22.8
Other (incl. gov., education)	1.00	0.0	1.00	0.0	1.00	0.00

* Change over 1997-2010.

The second scenario is labeled 'agro-technology scenario'. This is broadly interpreted as a scenario in which Dutch producers are above average competitive in developing and applying biotechnology and genetic engineering. Above average competitiveness is found in agriculture and fishery, and in the related sectors foods, drinks, tobacco; chemicals; machinery, and transport and communication. The latter two are assumed to show above average competitiveness because they supply goods (machines) or services (transport) to the agriculture, food and chemicals sector.

The third scenario is labeled 'heavy industry scenario'. Here the metaphor is the one of being competitive on the basis of low wages in a number of industries where the scale of production and the price of the goods is relatively important (and technological competitiveness supposedly plays a smaller role). The sectors with above average competitiveness are now mining; refined oil; chemicals; basic metals; metal products; machinery; electrical machinery; transport equipment; other manufacturing, and transport and communication. All other sectors are assumed to have below average competitiveness, except gas, water, electricity; construction; trade, hotels, bars and repairshops, and other. These are assumed to have equal competitiveness between foreign and Dutch producers.

Table 3 shows the resulting changes in market shares over the period 1997-2010. Note that for the last scenario, the absolute value of these changes is relatively large as compared to the other two scenarios.[7]

5. Simulation results

The Dutch economy is one with relatively high total factor productivity, which could be interpreted as corresponding to a relatively high level of technological achievement. Nevertheless, R&D intensity is relatively low compared to some of the leading OECD countries. Business R&D depends heavily on a few large firms (Philips, Akzo Nobel, Unilever, Shell, DSM). This has raised worries with some policy makers about the long-run technological competitiveness of the Dutch economy. A factor that enhanced competitiveness in the 1990s has been the modest growth of wages, based on consensus between labour unions and employers.

With regard to sectoral structure, services play an important role in the Dutch economy. Transport and trade, but more recently also finance, are important traditional strongholds of Dutch economic activity. Within manufacturing, the above-mentioned large firms determine to a large extent the type of activities, which implies (bulk) chemicals, electrical and food products play a large role. The food-processing industry traditionally has strong interactions with agriculture. Also, an important part of the Dutch science and technology infrastructure is aimed at the agro-food cluster. Overall, the impression is that the agro-food cluster is one of the technological specializations of the Dutch economy.

These specific characteristics of the Dutch economy were a major source of inspiration when choosing the scenarios that were explained above and will be used below.

5.1. Varying the rate of technological progress (productivity growth)

This section will look at the impact of variations of the rate of technological progress on the growth path of the Dutch economy. In theoretical terms, technology has an impact on all three types of scenario variables. In the competitiveness domain, technology determines relative competitiveness of Dutch producers compared to foreign producers. Technology and R&D are ways to increase competitiveness and gain market share. In the sectoral composition of demand domain, technology, through product innovation, may lead to shifting shares. As has been stressed above, these interactions are not yet fully represented in the current version of the model.

This section only takes into account variations in the rate of productivity growth, comparing the cases of high and low technological progress to the base values (as introduced in the discussion of Table 1 above). Sectoral shares in demand and market shares do not change (i.e., all competitiveness scenarios have been set to ‘no change’). Thus, the experiments here do not provide a full picture of the impact of technology, as will become evident from the results. One could say the experiments here only look at the process innovation side of the story. Figure 1 shows the results of the experiments. The figures show results relative to the base scenario for technological progress, i.e., a value above (below) one points to a higher (lower) rate than in the base scenario.

The figure shows that a higher rate of technological progress first leads to higher growth, but in the long run, growth is lower than for the ‘normal’ rate. The opposite result (first lower growth, then higher growth) is found for the low rate. Interestingly, the periods that split above and below base results differ greatly between the two cases. For low technological progress, growth turns from low to high around 2025. For the high rate, the turning point between high and low lies at 2010, i.e., 15 years earlier.

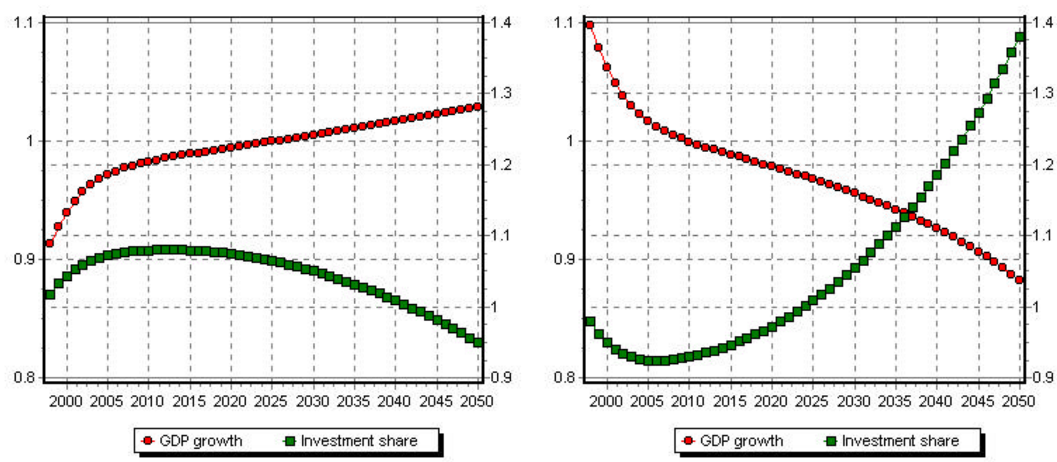

Figure 1. The impact of variations in the rate of technological progress: low (left panel) and high (right panel) technological progress relative to the base scenario (left axis shows GDP growth, right axis Investment share)

The main reason why a higher rate of technological progress does not lead to higher long-run growth is the absence of increased (foreign) demand. Although, due to the specific values assume for the technology bias of capital, investment demand increases with higher technological progress, this is not enough to compensate for the more efficient use of other factors (labour, intermediate demand). Undocumented experiments with biases of technological change (e.g., setting all biases to zero) yield a positive long-run effect of higher technological progress on growth. However, a more satisfactory avenue for modeling the full effects of technological change is to change variables in the other two variable sets.

[7] The files for these scenarios in the computer model are called service.sco, agro.sco, heavy.sco and nochange.sco.

5.2. Varying the composition of demand

This section illustrates the impact of changes in the composition of demand. The two scenarios presented in Table 2 will be compared to a scenario in which there is no change in the composition of demand. The rate of technological progress is set to the base scenario for all runs in this section, and the 'no change' scenario is assumed for competitiveness.

Figure 2 shows that the environment friendly scenario has a negative impact on both long-run growth and investment demand as a share of GDP. This impact is relatively small: in the very long run about 10% lower growth (i.e., compared to 2.5% growth in the base run, 2.25% in the environment friendly scenario). A service economy yields higher growth: the long-run growth rate is 1.2 times as large as in the base scenario. This is accompanied by higher investment demand. These differences reflect the notion that some sectors provide a higher growth potential than others, and they seem to confirm, at least for the Netherlands, that environment saving goes at the expense of growth, but that this effect is rather small.

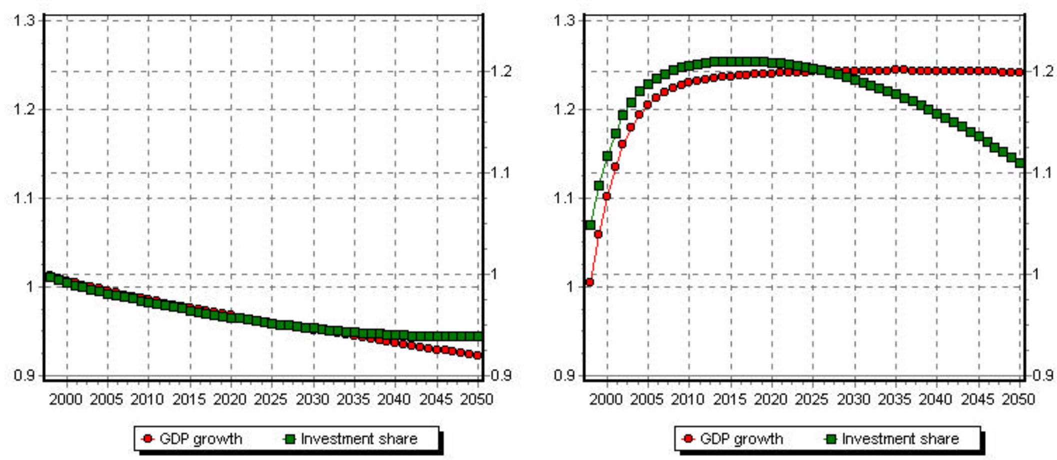

Figure 2. The impact of composition of demand: 'environment friendly through electronics' (left panel) and 'service economy' (right panel) scenarios relative to the 'no change' scenario (left axis shows GDP growth, right axis Investment share)

5.3. Varying the competitiveness levels

This section presents three experiments with different scenarios for competitiveness levels of Dutch producers relative to foreign producers. The three scenarios presented in Table 3 will be compared to the 'no change' scenario. The base scenario for the rate of technological progress will be assumed, and the 'no change' scenario will be assumed for changes in the composition of demand. Figure 3 gives the results for the three scenarios.

Note that all three scenarios assume that the Netherlands is above average competitive in at least a subset of all sectors. Therefore, all three scenarios show higher long-run growth than in the base scenario, where market shares remain constant throughout the run. One interesting difference between the runs is that for the heavy industry scenario, the short-run impact is negative, but in the long run the effect on growth and investment demand of this scenario is positive. In the other two cases, the impact is always positive.

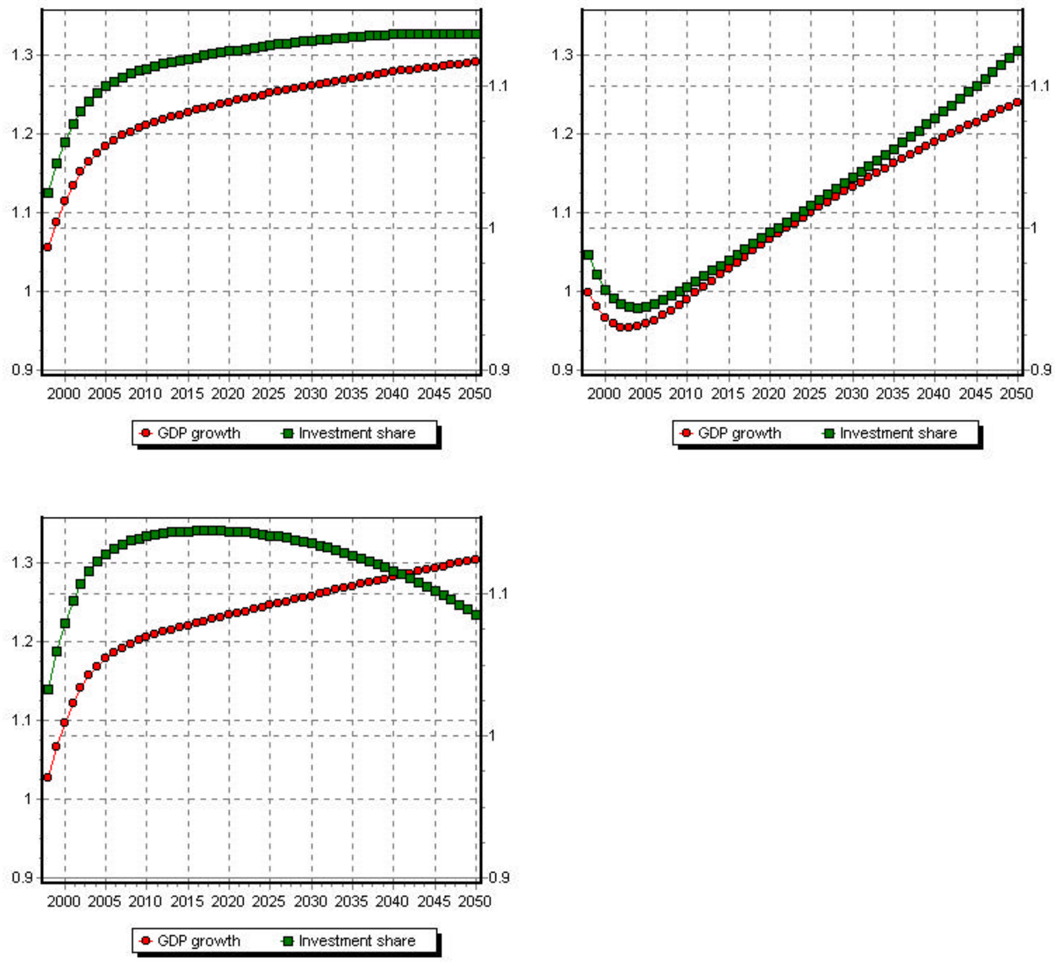

Figure 3. The impact of competitiveness levels: 'agro-technology scenario' (top left panel), and 'heavy industry scenario' (top right panel) and 'service scenario' (bottom panel) relative to the 'no change' scenario (left axis shows GDP growth, right axis Investment share)

Together, these scenarios show that above average competitiveness is a powerful way of creating economic growth. It is hard to compare the impact of the three scenarios to each other, because the variations in competitiveness levels have not been picked in such a way that their aggregate impact is of a comparable order of magnitude. However, it is clear that being competitive in a sector, even if it is one that does not have high growth impact will have a positive impact on growth. More experiments would be necessary to generate insight into which sectors can be considered as 'strategic', in the sense that they generate more growth than others for a given increase in competitiveness.

5.4. Mixing scenarios

The final set of simulation experiments that will be presented here combines scenarios from each of the three subsets. Although many different combinations are possible, four runs will be compared in the form of two pairs. All four runs will assume the base scenario for the rate of technological progress. The first pair of runs to be discussed is in Figure 4, which assumes the service scenario for the composition of demand. This is combined with one case (left panel) where competitiveness is in a different set of sectors than the ones for which the share in demand is on the rise (i.e., services). This is the case where competitiveness follows the agro-technology scenario. The other case (right panel) is one where the demand and supply side match to a high degree: the Dutch producers are highly competitive in those sectors where demand shares are on the rise (services).

Not surprisingly, economic growth is highest in the latter case. In the very long run, growth is almost twice as high in this case as compared to the base run (which is the same as in Sections 5.2 and 5.3). Investment as a fraction of GDP is also higher as compared to the base run, but this effect peaks around 2030, whereas the relative growth rate keeps increasing until the end of the simulation period.

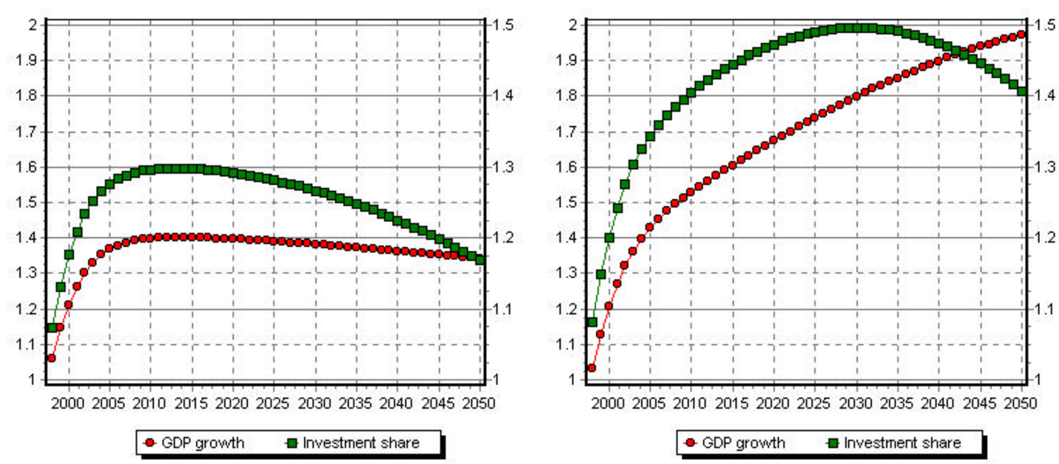

Figure 4. Mixed scenarios: 'service scenario' for composition of demand combined with 'agro-technology scenario' for competitiveness (left panel) and 'service economy scenario' for competitiveness (right panel) relative to the base runs of Sections 5.2 and 5.3 (left axis shows GDP growth, right axis Investment share)

Despite the non-match between competitiveness and the changing composition of demand, growth in the left panel of Figure 4 is also relatively high. Now the relative growth rate peaks at a value of 1.4 around 2010, and declines afterwards (but stays clearly above one for the whole period).

Thus, these two scenarios show how the match between developments on the demand side of the economy and competitiveness (a supply-side phenomenon) may enhance economic growth in the long run. being specialized in the 'right' sectors is seen to pay off in terms of higher growth. Note however, that from a policy point of view, it is not easy to determine which sectors are the right ones (see, e.g., Dalum et al., 1999).

Figure 5 shows a case where the degree of matching between supply-side factors and demand-side factors leads to a distinction between above and below average growth. Here the demand composition scenario is the environment friendly one. The left panel shows the agro-technology competitiveness scenario, and the right panel shows the heavy industry scenario.

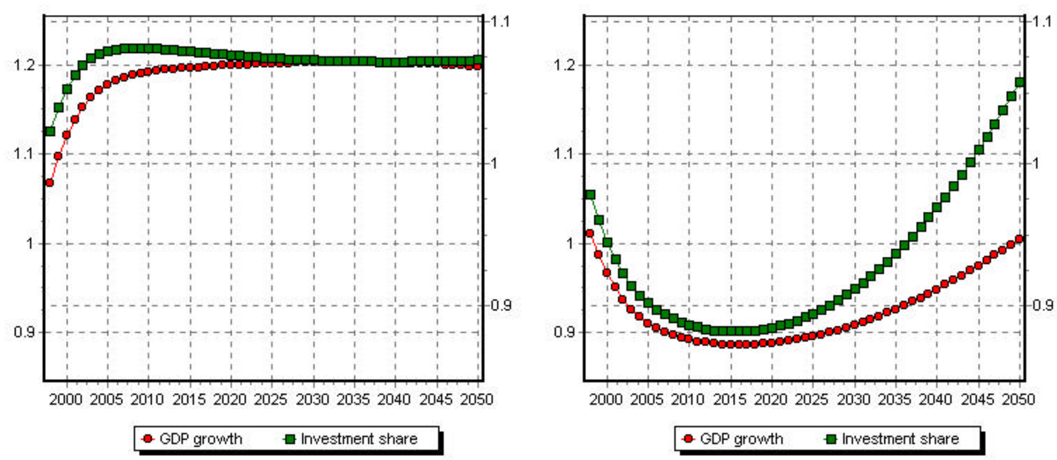

Figure 5. Mixed scenarios: 'environment friendly scenario' for composition of demand combined with 'agro-technology scenario' for competitiveness (left panel) and 'heavy industry scenario' for competitiveness (right panel) relative to the base runs of Sections 5.2 and 5.3 (left axis shows GDP growth, right axis Investment share)

The first of these (agro-technology) shows growth above the base run, leveling off at a value of 1.2. The right panel (heavy industry) shows growth below that of the base run for the complete period, although the curve is U-shaped, and returns to a value of one towards the end of the simulation period.

6. Conclusions, discussion and directions for future research

This paper has presented a macroeconomic modeling framework that combines insights from post-Keynesian theory with evolutionary economics. This leads to a tool that enables the researcher to apply insights from evolutionary economic models to a real world macroeconomic case. An accompanying computer program that implements the model for the Dutch economy is available.

The proposed model is by no means a completed piece of theory. Due to simplifying assumptions, at least two major problems with the model remain. The first of these was already mentioned above: the sources of evolutionary change in the model are only specified as exogenous parameters that can be set by the user. Ideally, these variables should be modeled in an endogenous way. A possible way of implementing this has already been proposed in Verspagen and Wakelin (1997).

The second theoretical problem is that relative prices play no role in the model so far. All dynamics in terms of changing shares of sectors have been implemented in terms of volume changes only, and the impact of (relative) prices has been assumed away. Theoretical extensions of the model will be necessary to deal with prices in a more adequate way. An example of a related model that takes into account prices in a more adequate way is in Los (1999).

Nevertheless, the model shows that evolutionary macroeconomics is feasible. The results generated in the simulation runs show that differences in terms of competitiveness, the rate of productivity change as a result of technological progress, and changes in terms of the sectoral shares of demand may have a significant impact on the rate of growth of the Dutch economy over the long run.

Such differences in growth paths should not be taken as predictions, however. They are illustrations of possible outcomes under different scenarios, and the differences between them. As such, they point to an order of magnitude of possible effects, rather than to precise predictions of the growth path of the Dutch economy. In fact, whereas standard macroeconomic theory is often applied in models to predict future economic growth, evolutionary theory would find such predictions much more difficult from a conceptual point of view. There are several reasons for this. First, evolutionary economics is primarily about the long run (e.g., the period considered in the present implementation for the Dutch economy is much longer than the standard period applied in macroeconomic predictions). The longer the period one looks ahead, the larger uncertainty, and this means that there is considerable uncertainty with respect to the growth paths generated by any evolutionary model.

Second, and perhaps more fundamentally, evolutionary dynamics have an inherently large level of uncertainty with respect to their outcome. Normally, fully developed theoretical evolutionary models underline a complex interaction between 'chance and necessity' (Monod, 1970, for a discussion in the context of evolutionary models of economic growth see Silverberg and Verspagen, 1998). Although the exact mix between random factors (chance) and deterministic factors (necessity) is still a matter of debate between evolutionists, it is clear than in every evolutionary process, there is a considerable degree of randomness. Contingencies may direct biological evolution into completely unanticipated directions, and this phenomenon may have its counterparts in economic evolution.

The current model is completely deterministic, and assumes no stochastic processes. Other evolutionary models of economic growth (see Silverberg and Verspagen, 1998, for an overview) assume that technological change is a stochastic process. In the context of the present model, this could mean that the endogenization of the scenario variables would have some stochastic properties. Further developments along these lines would increase the evolutionary content of the model considerably, and this is envisaged for the future. This could, for example, lead to results that point out a reasonable range of outcomes of the growth process, and how this range varies with changes in exogenous variables. Viewed in such a way, predictions from a fully developed evolutionary macro model may be considered as much more realistic than predictions from standard models, because the latter often have difficulties with generating indicators of the reliability of the predictions. In evolutionary models, such indicators of reliability (or the lack of it) are almost naturally a part of the theory.

Before such a model can be implemented, however, much more theoretical work is necessary, for example along the lines sketched above. In the mean time, it is hoped that evolutionary economists will find the proposed modeling framework useful as a macroeconomic skeleton for further development of their field.

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