A Multi-sector Kaleckian-Harrodian Model for Long-run Analysis

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Abstract: This paper presents a step toward a post-Keynesian dynamic model for long-run policy analysis. It is a multi-sector Harrodian-Kaleckian growth model with locally unstable dynamics contained by a Hicksian floor and ceiling. It adopts a model of biased technological change that links productivity growth with the functional income distribution. The model features endogenous wages, prices, labor and capital productivities, capital utilization, employment, and labor participation. At present it lacks government, financial, and foreign sectors, but despite this it exhibits interesting behavior. The model generates asymmetric business cycles, with a long expansion and a short contraction, as well as long waves and changes in the structure of employment.

Keywords: post-Keynesian; Harrodian-Kaleckian; multiplier-accelerator; technological change

JEL classifications: E11, E17, E32

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1 Introduction

Increasing human pressure on the environment, combined with persistent poverty and underdevelopment, has led the countries of the world to adopt an agenda for sustainable development (UN General Assembly 2015). Suggestively titled “Transforming Our World”, UN Agenda 2030 includes action on climate in line with the negotiations under the UN Framework Convention on Climate Change (UNFCCC). Meeting the climate target requires that most of the remaining fossil fuels stay in the ground (Benedikter et al. 2016; McGlade and Ekins 2015); as economic growth goes hand-in-hand with energy consumption (Ayres et al. 2013), shifting the energetic basis of the economy from fossil to renewable resources is likely to require substantial changes in the ways that we produce and consume.

The core of Agenda 2030 is the set of 17 Sustainable Development Goals (SDGs), each with several targets. An essential policy question is how those targets will be met, particularly in combination. In addition to meeting the climate targets under UNFCCC, Agenda 2030 asks countries to “sustain per capita economic growth in accordance with national circumstances” (target 8.1); “achieve higher levels of economic productivity through diversification, technological upgrading and innovation” (target 8.2); “achieve full and productive employment and decent work for all women and men” (target 8.5); “upgrade infrastructure and retrofit industries to make them sustainable” (target 9.4); “achieve the sustainable management and efficient use of natural resources” (target 12.2); and “substantially reduce waste generation through prevention, reduction, recycling and reuse” (target 12.5). Policies in support of Agenda 2030 must thus be crafted to rapidly reduce greenhouse gas emissions and waste while ensuring full employment in decent jobs and encouraging investment and innovation. This is a challenging task, and addressing it has macroeconomic implications (Rezai and Stagl 2016).

Mainstream macroeconomic models have been widely criticized for their lack of realism, particularly features that preclude instabilities observed in real economies (Taylor 2004; Solow 2008; Galbraith 2012). In this paper we present a multi-sector, long-run post-Keynesian model intended as a step toward a macroeconomic model for studying transformation in mature economies. For long-run dynamics, we draw on a growing literature on “Harrodian-Kaleckian” models (Skott 1989; Fazzari et al. 2013; Allain 2015; Lavoie 2016). While that literature has not produced a consensus, it has illuminated the choices facing a modeler, including stable vs. unstable dynamics, an autonomous source of demand, and a dynamic that sets the tempo of economic growth.

In its current state, the model presented in this paper is closed to trade and lacks government, banking and finance, and extractive sectors. These are severe limitations from a policy analysis standpoint, but they facilitate a critical review of the model’s behavior by reference to the literature. We show that the model produces asymmetric business cycles with a long expansion phase and short contraction phase in which some sectors lag others. The model also produces longer-term dynamics, driven by endogenous processes.

2 Model elements

We assume a Kaleckian investment function, which we apply to each sector. Firms adopt target-return pricing, marking up costs of labor and intermediate goods to achieve a desired profit rate. Price adjustment happens after a lag, consistent with observed pricing behavior (Coutts and Norman 2013). Both labor and capital productivity growth are endogenous, through a mechanism first proposed by Hicks (1932), and extended by Duménil and Lévy (1995) and Kemp-Benedict (2017a), in which productivity growth rates of different inputs to production depend on their share in total cost.

Harrodian-Kaleckian models are stabilized with an autonomous source of demand for consumption goods. In our model, autonomous demand derives from two sources: consumption by non-production staff, which does not change over the business cycle (as in Dutt 2016), and "committed" consumption by all households. Using data from the 2005 US Consumer Expenditure Survey (a year chosen to be well inside the "Great Moderation"), we found that three-quarters of expenditure across all households was devoted to housing and related items, transport and related items, healthcare, future income (through education, pensions, and social security), and food at home (a proxy for habitual food expenditure). These expenditures are either for basic needs (food) or committed by earlier choices of where to live and in what kind of dwelling, main mode of transport, whether to attend school, and so on. They can be changed only within a narrow range. The model assumes committed expenditure to be proportional to the wage bill at normal utilization; a more realistic assumption would be for consumption patterns to vary with household size, source of income, and age profile.

We add income-dependent consumption by production staff to autonomous consumption expenditure, in which production employment varies in proportion to capital utilization over the business cycle. Saving out of wages is given by the residual of wage income net of consumption expenditure. Because committed expenditure is assumed to be stable, the model allows for dissaving out of wages. Dissaving is observed in real economies, but a more realistic model would account for spending out of accumulated wealth. In the present model, all profits are assumed to be saved. Together, these assumptions determine total saving and implicitly define a saving function.

Adopting a conflict view of wage setting (Goodwin 1951; Rowthorn 1977; Palley 1996, 185), we assume that employees wish to share in productivity gains; maintain or improve their position within the firm's wage distribution and relative to workers in comparable firms; and at least maintain their purchasing power in the face of inflation. Neither the firm nor its employees can anticipate the precise impact that firm-level decisions have on real wages, so negotiations focus on nominal wages relative to the previous period, with a cost-of-living adjustment based on historical inflation rates. We adopt a Goodwin-type wage-setting formula (Goodwin 1967). At a reference level of employment, nominal wages increase at the same rate as labor productivity. Above that level, wages grow slightly faster than labor productivity, while at lower levels they grow slightly slower.

We introduce a dynamic labor force participation rate, which tracks the employment rate with a delay. This assumption is motivated by the observation that workers leave the labor force after prolonged low employment because they become discouraged or otherwise change their lifestyle (such as shifting from a two-income to a single-income household), while to rejoin the labor force in periods of high employment they must undertake time-consuming activities, such as bringing their skills up to date or changing routines at home to accommodate a two-earner household.

3 Instability and investment

Kaleckian models typically assume the Keynesian stability condition, which states that rising utilization generates a surplus of saving relative to investment, and therefore a negative feedback on demand and utilization. Skott (2012) has argued that empirical data support the Keynesian stability condition in the short run, but not in the long run. We review evidence that it may not hold in the short run, either.

Our model features a multiplier, arising from saving, and an accelerator, arising from utilization-driven investment. Such models can have either stable (damped) or unstable (explosive) equilibria. They exhibit steady cycles only within a narrow range of parameter values, so some mechanism must be invoked to explain why the parameters stay within that range. When the equilibrium is stable, business cycles must be driven by an additional dynamic or by external shocks, as in the model proposed by Frisch (1933). If unstable, there must be some mechanism, or combination of mechanisms, which ensures global stability. Locally unstable models of this sort are, of necessity, nonlinear (Goodwin 1951).

A prominent class of nonlinear models, proposed by Hicks (1950), features explosive linear dynamics near the equilibrium combined with a “floor” and “ceiling” that contain the explosion. The ceiling in Hicks’ model corresponds to full employment, while the floor arises because disinvestment can only happen through depreciation. Further features of Hicks’ model lead to smoothing of the cycle. Following Blatt (1978; 1980), we refer to stable linear models as “Frischian” and unstable nonlinear models as “Hicksian”, but acknowledge that there are damped and exogenously-driven models that look quite unlike Frisch’s original, and nonlinear models that owe little to Hicks (cf. Brock 1991, 311). While econometric tests have appeared to favor Frischian models over Hicksian ones (Hymans 1972), Blatt (1978; 1980) questioned that judgement. He showed that the data series produced by a simple and explosive Hicksian model, when tested using standard methods, gave a false positive result for a Frischian model. He then showed that Frischian models imply symmetric cycles, contrary to evidence. With appropriate tests, Frischian models appear to be consistently rejected when using data for Europe, and less consistently using US data (Teräsvirta and Anderson 1992; Pesaran and Potter 1997; Razzak 2001; Clements and Krolzig 2003; Belaire-Franch and Contreras 2003). The balance of empirical evidence thus leans against a Frischian specification and towards a nonlinear one (cf. Brock 1991, 320).

Following Hicks (1950), we assume total gross investment in each sector to be given by the sum of autonomous investment, γ, and induced investment. Induced investment is positively affected by both utilization, u, and the profit rate at full utilization, r, a standard Kaleckian specification (Bhaduri and Marglin 1990, 380; Blecker 2002). Rising utilization is a signal to the firm that it should expand capacity and to investors that future expansion is likely, while rising profitability indicates available funds for the firm and future profits for investors. In the model, firms are assumed to compare utilization to a normal rate, u^*, and the profit rate to their target r^*. Autonomous investment is the level that obtains if utilization and the profit rate are at their targets; it should be sufficient to cover depreciation plus expansion to match the long-run growth path of the economy. While the normal rate of utilization can be driven by endogenous dynamics (Lavoie 1996; Hein, Lavoie, and van Treeck 2012; Nikiforos 2013), we simplify the present model by assuming firms adopt a fixed value.

In the model, nonlinearity arises from a Hicksian floor and ceiling. The ceiling is set by capacity utilization, as labor supply does not face a hard constraint in the model. We allow utilization factors to exceed 100% for brief periods. Utilization as reported by, for example, the Federal Reserve, is equal to actual output relative to sustainable maximum output (Corrado and Mattey 1997), and output can exceed the sustainable maximum for short times. The model assumes that orders for investment goods are always fulfilled, so forced saving, if it occurs, is experienced by consumers.

Following Hicks (1950), induced investment has a hard floor given by the depreciation rate of capital. In the model, we set the floor equal to the negative of a fraction, f_{disenv}, of the depreciation rate, on the assumption that not all firms in a sector will choose to disinvest in a downturn,

$$g^i = \gamma + \max\left[\alpha\left(u-u^*\right)+\beta\left(r-r^*\right),-f_{\text{disenv}}\delta\right]. \tag{1}$$

Autonomous investment γ adjusts slowly to reflect changing expectations for future growth based on past experienced growth.

Induced investment should average to zero over the long run, as firms and investors absorb long-lasting trends into long-term expectations. Using g^i_{ind} to represent the induced component,

$$g^i_{\text{ind}} \equiv \max\left[\alpha\left(u-u^*\right)+\beta\left(r-r^*\right),-f_{\text{disenv}}\delta\right], \tag{2}$$

we can write investment as

$$g^i = \gamma + g^i_{\text{ind}}. \tag{3}$$

Firms and investors adapt their expectations gradually, so we smooth induced investment,

$$\bar{g}^i_{\text{ind}} = \bar{g}^i_{\text{ind},-1} + \frac{1}{\tau}\left(g^i_{\text{ind}} - \bar{g}^i_{\text{ind},-1}\right), \tag{4}$$

and use the following updating rule,

$$\gamma = \gamma_{-1} + \bar{g}^i_{\text{ind},-1}. \tag{5}$$

4 A multi-sector model for long-run analysis

We now combine the elements introduced above into a multi-sector model with endogenous wages, prices, productivities, capital utilization, and employment. For the multi-sector model with N sectors, we introduce matrix notation, using boldface to indicate matrices and vectors, denoting the transpose with a prime, and adopting the convention that unprimed vectors are column vectors.

4.1 Production

Total sector output $\mathbf{X}$ is related to the inter-industry matrix $\mathbf{A}$, final demand for consumption goods $\mathbf{F}_c$, and investment goods $\mathbf{F}_i$ through the standard Leontief relationship,

$$\mathbf{X} = \mathbf{A} \cdot \mathbf{X} + \mathbf{F}_i + \mathbf{F}_c. \tag{6}$$

We require this relationship to hold in each time period. In particular, we do not include production smoothing through inventories, but do allow for other adjustments as discussed below.

Output is characterized by Leontief production functions. In principle, production can be limited by either labor or capital, but as there is reserve labor that can be brought into the labor force if jobs are available, output X_i is given by a utilization factor u_i, multiplied by potential output X_i^*, which in turn is given by the product of capital productivity κ_i and the capital stock K_i,

$$X_i = u_i X_i^* = u_i \kappa_i K_i. \tag{7}$$

Firms expect to operate near a normal level of utilization u^*, which remains fixed over time.

4.2 Employment, wages, and pricing

Potential employment L_i^* is given by potential output divided by labor productivity λ_i,

$$L_i^* = \frac{X_i^*}{\lambda_i} = \frac{\kappa_i}{\lambda_i} K_i. \tag{8}$$

As discussed earlier, actual employment is given by two types of labor: a flexible pool of production workers who are laid off and rehired proportional to utilization, and a fixed staff of managers, clerical workers, and technical workers whose size is given by the reference utilization multiplied by potential employment. We denote the fraction of flexible workers at reference utilization by φ_i, so

$$L_i^{\text{flex}} = \varphi_i u_i L_i^*, \quad L_i^{\text{fixed}} = \left(1 - \varphi_i\right) u^* L_i^*. \tag{9}$$

4.2.1 Wages

The wage grows at a slower or faster rate than labor productivity, depending on the employment rate, e, relative to a reference employment rate, e_{ref}. With Goodwin (1967), we assume a bias in the relationship, so the wage grows more rapidly when employment rises above the reference rate than it declines when employment falls below the reference. However, we depart from Goodwin by expressing all monetary quantities in nominal terms. Following the earlier discussion, negotiations between employers and employees are assumed to be in real terms relative to the previous times step, followed by a cost-of-living adjustment. As it is easier to raise wages or leave them constant than to decrease them, we assume that the nominal wage is adjusted upwards when inflation is present, but is not adjusted downward in deflationary periods, thus introducing an inflationary bias into wage-setting. Using $\langle \hat{P}_c \rangle$ to represent a smoothed consumer price inflation rate, we write

$$\hat{w}_j = \hat{\lambda}_j \left\{ 1 + \theta_w \left[\left(\frac{e_{-1}}{e_{\text{ref}}} \right)^2 - 1 \right] \right\} + \max\left(\langle \hat{P}_c \rangle, 0 \right), \quad e = \frac{L}{L_{\text{LF}}}, \tag{10}$$

where θ_w is a sensitivity parameter and L_{LF} is the labor force.

To distinguish the working-age population from the full population, we include a demographic model. It has three cohorts – young (age 0-14 years), working age (age 15-64 years), and elderly (65+ years) – with corresponding populations N_{Y}, N_{W}, N_{E}. We denote total population by N. Each cohort has a cohort-specific death rate, while the young population is increased when those of working age have children, with a specified birth rate. The working age population is increased by the young aging into the working age population, and by net immigration. The available pool of labor decreases, and the population of elderly increases, as working-age people retire.

The labor force L_{LF} is given by a participation rate ℓ, applied to the working-age population,

$$L_{\text{LF}} = \ell N_{\text{W}}. \tag{11}$$

As the employment rate changes, we assume that people exit or re-enter the labor pool, so the participation rate changes gradually with the employment rate, without rising above one. We use the following specification,

$$\Delta \ell = \theta_\ell \ell (1 - \ell)^{a_\ell} \left(\frac{e}{e_{\text{ref}}} - 1 \right), \quad 0 < a_\ell \le 1. \tag{12}$$

4.2.2 Prices and inflation

Firms in sector i target a desired profit rate at full utilization r_i^* and set their prices accordingly. We assume a common net profit rate r^*_{net} across sectors, while sector target profit rates are the common net rate plus a sector-specific depreciation rate,

$$r_i^* = \delta_i + r_{\text{net}}^*. \tag{13}$$

Corresponding to desired rates of return are sector-specific profit margins μ_i^* that depend on capital productivity,

$$\mu_i^* = \frac{\kappa_i}{\kappa_i - r_i^*} = \frac{1}{1 - r_i^* / \kappa_i}. \tag{14}$$

Sectors apply the profit margin to unit labor costs **v** and the costs of intermediate inputs. Given previous-period total costs, firms secure their target rate of return when their prices equal the Sraffian “production prices”, or the prices that would obtain in the long run if costs and profit margins remain the same. Using a tilde over a vector to denote a diagonal matrix constructed by placing the vector entries along the diagonal, the vector of production prices $\mathbf{p}^*$ is

$$\mathbf{p}^* = \tilde{\boldsymbol{\mu}}^* \cdot \left(\mathbf{v}_{-1} + \mathbf{A}' \cdot \mathbf{p}_{-1} \right). \tag{15}$$

In general, production prices will differ from the prevailing price in the previous period. Firms within the sector update their prices to close the gap, but not necessarily all at the same time. In the model, sector prices are set as a linear combination of the previous-period price and the production price. We further assume that at lower levels of utilization it is more difficult for firms to raise prices because they are more likely to invite competitors (Rowthorn 1977). We define a "price-setting power" ξ_i for sector *i*, where

$$\xi_i = \begin{cases} \min\left(u_{i,-1}/u_{\text{ref}}, 1\right) & , p_i^* > p_{i,-1}, \\ 1 & , p_i^* \leq p_{i,-1}. \end{cases} \tag{16}$$

Prices are then given by

$$p_i = \left(1 - \xi_i \theta_p\right) p_{i,-1} + \xi_i \theta_p p_i^*. \tag{17}$$

This gives a recurrence relationship that "chases" production prices, which are driven by changes in unit costs. As shown by Kemp-Benedict (2017b), as long as the production prices are well-defined, this is a stable process.

Total nominal GDP, *PY*, is given by the product of the GDP price level, *P*, and real GDP, *Y*. In matrix notation, it can be calculated as the sum of sector value added **V**, which can be written in matrix form as

$$PY = \mathbf{p}' \cdot \mathbf{V} = \mathbf{p}' \cdot \left(\mathbf{1} - \mathbf{A}\right) \cdot \mathbf{X}. \tag{18}$$

To distinguish nominal from real GDP, we calculate a Laspeyeres index,

$$\hat{P} \equiv \sum_{i=1}^{N} \frac{p_i V_i}{PY} \hat{p}_i. \tag{19}$$

Similarly, the consumer price index P_c is a Laspeyeres index of the price of consumption goods,

$$\hat{P}_c \equiv \sum_{i=1}^{N} \frac{p_i F_{c,i}}{\sum_{j=1}^{N} p_j F_{c,j}} \hat{p}_i. \tag{20}$$

This is the price index that appears in the wage-setting equation (10).

4.3 Productivity change

Factor productivity responds to changes in the associated cost shares (Hicks 1932; Duménil and Lévy 1995; Foley 2003, 42 ff.). We hold inter-industry coefficients constant over time, so the only factors affected are capital and labor. Using the model developed by Kemp-Benedict (2017a), labor and capital productivities are related to wage and profit shares through the following relationships,

$$\frac{\partial \hat{\lambda}_i}{\partial \pi_i} = \frac{\partial \hat{\kappa}_i}{\partial \omega_i} = -\frac{\pi_i}{\omega_i} \frac{\partial \hat{\kappa}_i}{\partial \pi_i} = -\frac{\omega_i}{\pi_i} \frac{\partial \hat{\lambda}_i}{\partial \omega_i}. \tag{21}$$

These equations do not fully determine the relationships between productivity growth rates and cost shares. We adopt a particular solution given by

$$\hat{\lambda}_i = c_i - b_i \frac{\pi_i}{\omega_i}, \quad \hat{\kappa}_i = d_i + b_i \ln \frac{\pi_i}{\omega_i}. \tag{22}$$

At constant capital productivity, the equilibrium ratio of the profit share to the wage share equals

$$\left(\frac{\pi_i}{\omega_i}\right)^* = e^{-d_i/b_i}. \tag{23}$$

The corresponding labor productivity growth rate is then

$$\hat{\lambda}_i^* = c_i - b_i\left(\frac{\pi_i}{\omega_i}\right)^* = c_i - b_i e^{-d_i/b_i}. \tag{24}$$

We can now express productivity growth in terms of three parameters: the labor productivity growth rate, the ratio of the profit share to the wage share at constant capital productivity, and a "responsiveness" parameter b_i,

$$\hat{\lambda}_i = \hat{\lambda}_i^* - b_i\left[\frac{\pi_i}{\omega_i} - \left(\frac{\pi_i}{\omega_i}\right)^*\right], \quad \hat{\kappa}_i = b_i\left[\ln\frac{\pi_i}{\omega_i} - \ln\left(\frac{\pi_i}{\omega_i}\right)^*\right]. \tag{25}$$

In the model, the responsiveness parameter is taken to be the same across sectors, $b_i = b$.

4.4 Demand for investment goods

Demand for investment goods in the current period is determined by investment plans made in previous periods. Those plans are assumed to always be honored, so if capacity is constrained then the production of consumption goods, and not investment goods, is curtailed. We assume that production of investment goods takes time and they are paid for as they are produced, so the amount of investment goods I produced and purchased in a given time period is partly in response to orders placed several time periods ago and partly from the current time period. In the national accounts, investment costs include, not only the cost of the capital good itself, but also the associated services and construction costs. Accordingly, we assume, for a given level of investment goods production I, a corresponding demand for manufacturing, services, and construction output $\boldsymbol{\sigma} I$, where $\boldsymbol{\sigma}$ is a vector of sector output per unit of investment demand. With this notation,

$$\mathbf{F}_i = \boldsymbol{\sigma} I. \tag{26}$$

Investment orders are computed using the investment function in equation (1), but applied to each sector,

$$g_i = \gamma_i + \max\left[\alpha\left(u_i - u^*\right) + \beta\left(r_i - r^*\right), -f_{\text{disenv}}\delta_i\right]. \tag{27}$$

New orders contribute to a backlog, while a fixed fraction of outstanding orders is filled in each time period.

In principle, the parameters α and β can differ by sector, but lacking the data to estimate sector-specific parameters, we assume they are the same across sectors. The term γ_i is autonomous gross investment, while the other terms constitute induced investment

Growth of the capital stock is net of sector-specific depreciation,

$$\hat{K}_i = g_i - \delta_i. \tag{28}$$

We assume that autonomous investment adjusts in response to realized investment rates in each sector following the updating rule in equation (5).

4.5 Consumption and saving out of wages

Consumption is made up of fixed and variable components. We start with committed consumption $\mathbf{F}_{c0}$. We set it proportional to the real wage bill at normal utilization, W_{norm},

$$\mathbf{F}_{c0} = \mathbf{f}_{c0} \frac{W_{\mathrm{norm}}}{P_c}. \tag{29}$$

Beyond this, people spend out of actual wage and salary income, which varies with the realized utilization rate. They would like to spend at a marginal rate $\mathbf{f}_{c1}$ proportional to any real wage income beyond that required to pay for committed consumption, but if productive capacity is insufficient, then households' desire to consume is frustrated, leading to forced saving. We therefore identify desired consumption $\mathbf{F}_c^*$,

$$\mathbf{F}_c^* = \frac{W_{\mathrm{norm}}}{P_c}\mathbf{f}_{c0} + \frac{1}{P_c}\left(W - \frac{W_{\mathrm{norm}}}{P_c}\mathbf{p}' \cdot \mathbf{f}_{c0}\right)\mathbf{f}_{c1} = \left(\mathbf{1} - \mathbf{f}_{c1}\frac{\mathbf{p}'}{P_c}\right) \cdot \mathbf{f}_{c0}\frac{W_{\mathrm{norm}}}{P_c} + \mathbf{f}_{c1}\frac{W}{P_c}. \tag{30}$$

Next, we calculate total wages using the expressions for fixed and flexible labor from (9),

$$W = \sum_{i=1}^{N} w_i \left[\varphi_i u_i + (1-\varphi_i)u^*\right] L_i^* = \sum_{i=1}^{N} \varphi_i w_i u_i L_i^* + u^* \sum_{i=1}^{N} (1-\varphi_i) w_i L_i^*. \tag{31}$$

We define the last term as the fixed contribution to the wage bill, W_{fix},

$$W_{\mathrm{fix}} = u^* \sum_{i=1}^{N} (1-\varphi_i) w_i L_i^*. \tag{32}$$

We further define the potential flexible contribution to the wage bill for each sector, $W_{\mathrm{flex},i}$, as

$$W_{\mathrm{flex},i} = \varphi_i w_i L_i^*. \tag{33}$$

With these definitions, we can write equation (31) in matrix form as

$$W = \mathbf{W}'_{\mathrm{flex}} \cdot \mathbf{u} + W_{\mathrm{fix}}. \tag{34}$$

Substituting into equation (30), we then have

$$\mathbf{F}_c^* = \frac{W_{\mathrm{norm}}}{P_c}\left(\mathbf{1} - \mathbf{f}_{c1}\frac{\mathbf{p}'}{P_c}\right) \cdot \mathbf{f}_{c0} + \frac{W_{\mathrm{fix}} + \mathbf{W}'_{\mathrm{flex}} \cdot \mathbf{u}}{P_c}\mathbf{f}_{c1}. \tag{35}$$

Actual consumption may be less than this. We accommodate the possibility by writing

$$\mathbf{F}_c = \mathbf{F}_c^* - z\Delta_z \mathbf{F}_c, \tag{36}$$

where z lies between zero and one and $\Delta_z\mathbf{F}_c$ is a vector representing the way in which households preferentially curtail consumption when faced with production constraints. We set a maximum deviation vector $\mathbf{d}$ for goods from each sector, relative to consumption at normal utilization. That is,

$$\left(\Delta_z \mathbf{F}_c\right)_i = d_i F_{c,i}^*, \quad u_j = u^* \ \forall j. \tag{37}$$

With this expression, when there are production constraints, consumers reduce their consumption more readily from some sectors (such as construction) than others (such as agriculture) relative to their preferred level of consumption. That difference is reflected in a larger value of d_i for construction than for agriculture.

Utilization may be greater than one in some sectors when z is equal to one. As discussed earlier, full utilization represents operation at maximum sustainable production levels, and we allow for brief periods of production in excess of the sustainable maximum.

4.6 Model closure

The model is closed by solving for utilization in each sector. Conceptually, this is a straightforward procedure. Both demand and supply depend linearly on utilization, with mixing between sectors due to inter-industry relationships. There is also a component of demand that does not depend on utilization. Setting demand equal to supply gives a linear equation for the utilization vector **u**, which can be solved using standard matrix operations. This comparatively straightforward procedure is complicated by the possibility of supply constraints. The complication requires us to find a value of z in equation (36) such that utilization does not rise much above one while maintaining consumption close to the desired level.

We now translate this procedure into mathematical form. First, we express the relationship between potential and realized production into matrix form,

$$X_j = u_j X_j^* \quad \Leftrightarrow \quad \mathbf{X} = \tilde{\mathbf{X}}^* \cdot \mathbf{u}. \tag{38}$$

Then, from the input-output equations (6), we have

$$\left(\mathbf{1} - \mathbf{A}\right) \cdot \mathbf{X} = \left(\mathbf{1} - \mathbf{A}\right) \cdot \tilde{\mathbf{X}}^* \cdot \mathbf{u} = \mathbf{F}_i + \mathbf{F}_c. \tag{39}$$

We next substitute from equation (26), for investment demand, and equation (35), for consumption demand, to give

$$\left[\left(\mathbf{1} - \mathbf{A}\right) \cdot \tilde{\mathbf{X}}^* - \frac{1}{P_c}\mathbf{f}_{c1}\mathbf{W}'_{\text{flex}}\right] \cdot \mathbf{u} = \boldsymbol{\sigma} I_{-1} + \frac{W_{\text{norm}}}{P_c}\left(\mathbf{1} - \mathbf{f}_{c1}\frac{\mathbf{p}'}{P_c}\right) \cdot \mathbf{f}_{c0} + \frac{W_{\text{fix}}}{P_c}\mathbf{f}_{c1} - z\Delta_z \mathbf{F}_c. \tag{40}$$

The vector of utilization factors, **u**, can then be calculated from this expression using standard matrix operations,

$$\mathbf{u} = \left[\left(\mathbf{1} - \mathbf{A}\right) \cdot \tilde{\mathbf{X}}^* - \frac{1}{P_c}\mathbf{f}_{c1}\mathbf{W}'_{\text{flex}}\right]^{-1} \cdot \left[\boldsymbol{\sigma} I_{-1} + \frac{W_{\text{norm}}}{P_c}\left(\mathbf{1} - \mathbf{f}_{c1}\frac{\mathbf{p}'}{P_c}\right) \cdot \mathbf{f}_{c0} + \frac{W_{\text{fix}}}{P_c}\mathbf{f}_{c1} - z\Delta_z \mathbf{F}_c\right]. \tag{41}$$

Because z is not known, **u** is not yet fully determined. We calculate it in a sequence of steps. First, we set z equal to zero and compute an initial utilization vector $\mathbf{u}_0$. We then define a utilization adjustment vector $\Delta_z\mathbf{u}$,

$$\Delta_z \mathbf{u} \equiv \left[\left(\mathbf{1} - \mathbf{A}\right) \cdot \tilde{\mathbf{X}}^* - \frac{1}{P_c}\mathbf{f}_{c1}\mathbf{W}'_{\text{flex}}\right]^{-1} \cdot \Delta_z \mathbf{F}_c. \tag{42}$$

With these definitions, the utilization vector **u** can be written as a linear function in *z*,

$$\mathbf{u} = \mathbf{u}_0 - z\Delta_z\mathbf{u}. \tag{43}$$

Because *z* is constrained to lie between zero and one, we compute the value of *z* as

$$z = \min\left[1, \max_{i\in[1,N]} \frac{\max(u_{0,i} - 1, 0)}{\Delta_z u_i}\right]. \tag{44}$$

From this we see that if $\mathbf{u}_0 < 1$, then $z = 0$. Otherwise, it is the value of *z* that brings utilization below one in all sectors by curtailing consumption or, if that is not possible, $z = 1$.

5 Simulation results

The model has been implemented in the Vensim DSS system dynamics modeling software,[1] running the model at a quarterly time step. The model was populated in part from US data, but in its current form it is closed to trade and has no government or financial sector, so it does not represent the US economy. Rather, we used US data to provide plausible values for most parameters, and assigned reasonable values to other parameters – see the Appendix for parameter values. Consistent with an economy lacking government stabilizers, inventory dynamics, and consumption smoothing through household saving, the simulated economy is considerably more volatile than the actual US economy.

A symmetric 5-sector input-output table was constructed from the Bureau of Economic Analysis (BEA) 2014 15-sector make and use tables by first aggregating and then applying the industry-technology assumption (ITA) approach described in Guo et al. (2002). The five sectors are services, construction, manufacturing, agriculture, and mining. We identified the construction, manufacturing, and mining sectors with the corresponding BEA categories, and agriculture with “Agriculture, forestry, fishing, and hunting”. The services sector is calculated as a residual. As we do not represent the financial sector, we subtracted the finance, insurance, and real estate (FIRE) sector, as well as government, and BEA’s “Used” and “Other” categories.

Wage and occupational data are drawn from the Bureau of Labor Statistics (BLS) Occupational Employment Statistics (OES) database, while the UN Population Division’s World Population Prospects database was used to compute demographic parameters. We then computed capital stocks based on an assumed rate of return, adjusted demand to fit the closed-economy assumption, set the reference employment and utilization rates (at 90% and 85%, respectively), and calculated the initial labor participation rate. Investment and depreciation rates were calculated at replacement cost using BEA estimates for capital stocks and flows by sector. The most recent capital stock estimates were from 2001, so the levels were not applicable to our 2014 data set, but we assumed the rates were applicable.

Results from the model baseline run are shown in Figure 1. As seen in the figure, this Kaleckian-Harrodian model exhibits asymmetric business cycles. In the graph, those cycles last 13 quarters, or 39 months. This is just over one-half the 69 months of the average

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[1] http://www.vensim.com/.

postwar US business cycle,[2] but the cycle lengthens later in the simulation, to over fifty months. The expansion covers 77% of the cycle and the contraction 23% of the cycle, comparing favorably to the average of around 80% for the observed expansion phase in postwar US business cycles. Most sectors move together across the cycle, but construction lags by three quarters. This is a realistic feature, which arises because most demand for construction is for fixed capital investment, and we assume delays between orders for investment goods and delivery.

At the start of a cycle, utilization is below the target, so induced investment rises, driving investment and, as a consequence, greater utilization. Employment of production staff rises, further increasing consumption. This continues until capacity constraints mean that desired consumption cannot be satisfied. Consumption contracts, leading to a contraction in utilization, which is then compounded by a fall in investment and employment. The result is a business cycle characterized by sharp and deep troughs and comparatively smooth and shallow peaks. These features have been observed in US business cycles (Sichel 1993; McQueen and Thorley 1993). The modeled business cycles also feature steeper recessions than expansions, which is not observed in US data; the difference may be due to dynamics omitted in the model, such as consumption smoothing and government stabilizers.

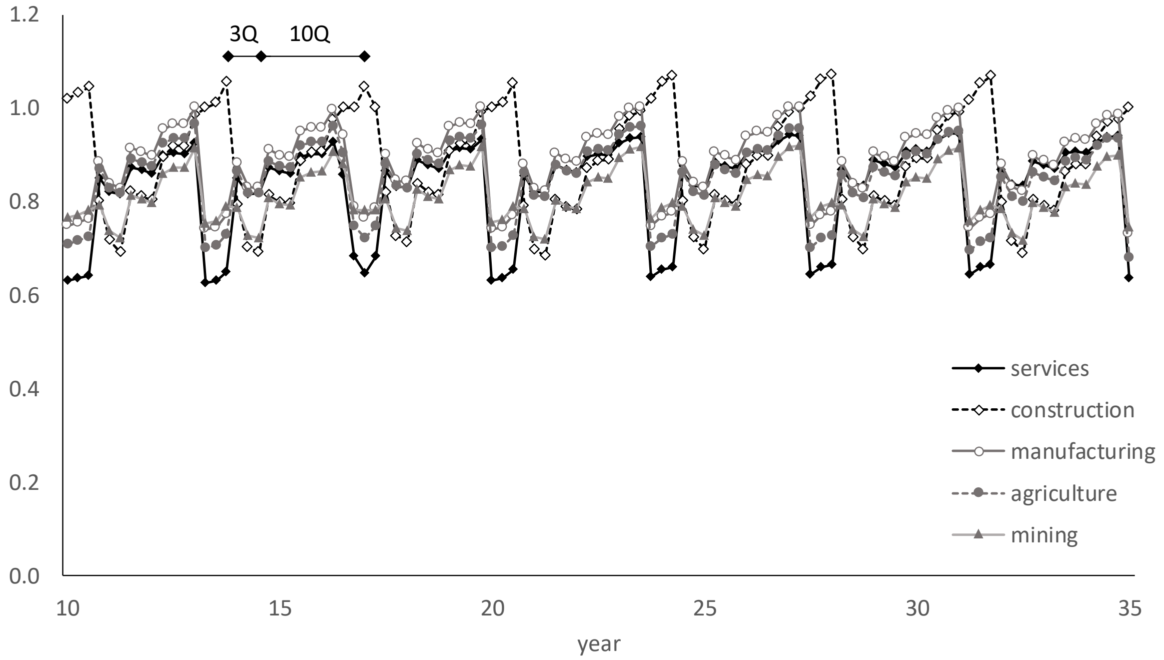

Figure 1: Utilization in the model baseline

As seen in Figure 2, the abrupt fall in utilization at the start of the downturn leads to a delayed fall in employment. Even as utilization starts to recover, employment continues to fall due to delays between orders and production for investment goods and between employment and subsequent consumption. Over the course of a cycle, employment and utilization move in a mainly clockwise direction, as observed in US data (Zipperer and Skott

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[2] http://www.nber.org/cycles/cyclesmain.html

2011). The wage-setting behavior assumed in the model leads to faster wage increases when employment is high, and slower increases when employment falls. This leads to Goodwin-like wage and employment cycles (see Figure 3). Goodwin's model yielded clockwise cycles in the wage-employment plane, while we observe a counter-clockwise cycle; both clockwise and counter-clockwise cycles have been observed in US data (Grossman 1974).

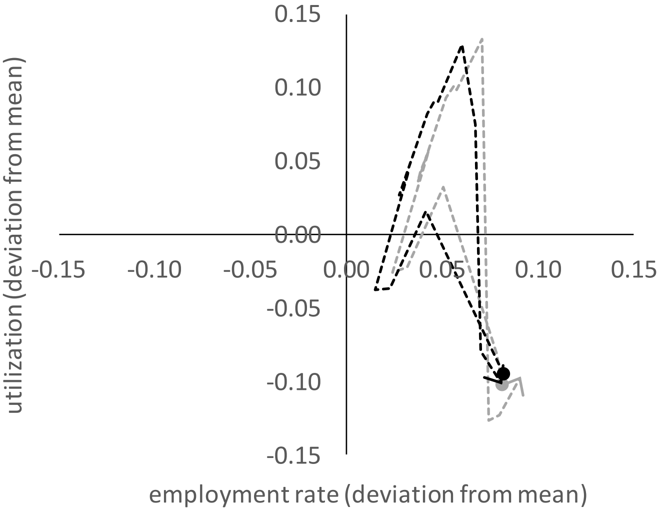

Figure 2: Two sequential cycles in the employment-utilization plane

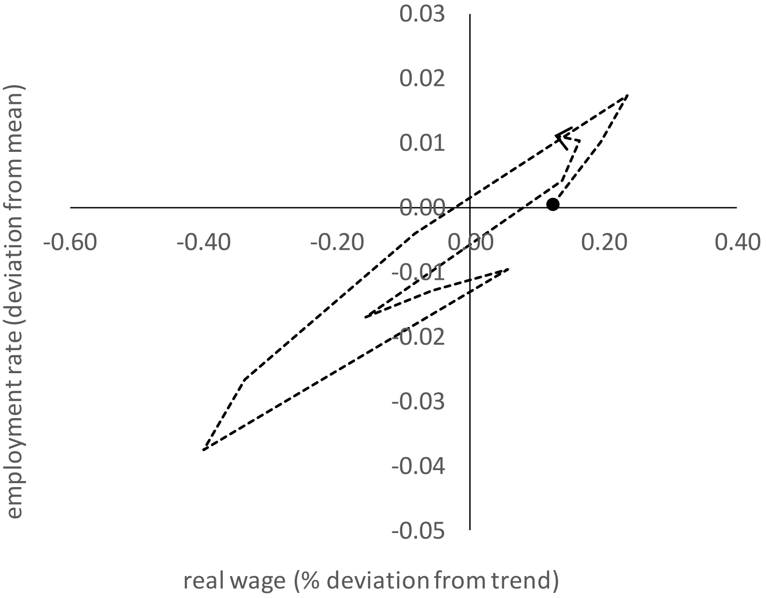

Figure 3: Goodwin-type cycle

Real GDP is shown on a log scale in Figure 4. While annualized quarterly GDP growth is much more volatile than in the actual US economy, the 50-year average growth rate has a plausible mean of 2.0%/year, driven mainly by population growth of 0.4%/year and labor productivity growth in services, at 1.5%/year. Not shown in the figure are changes in economic structure. The distribution of value added across sectors as a share of GDP remains comparatively stable through the scenario, while sectoral employment shifts away from manufacturing and towards services as manufacturing productivity rises.

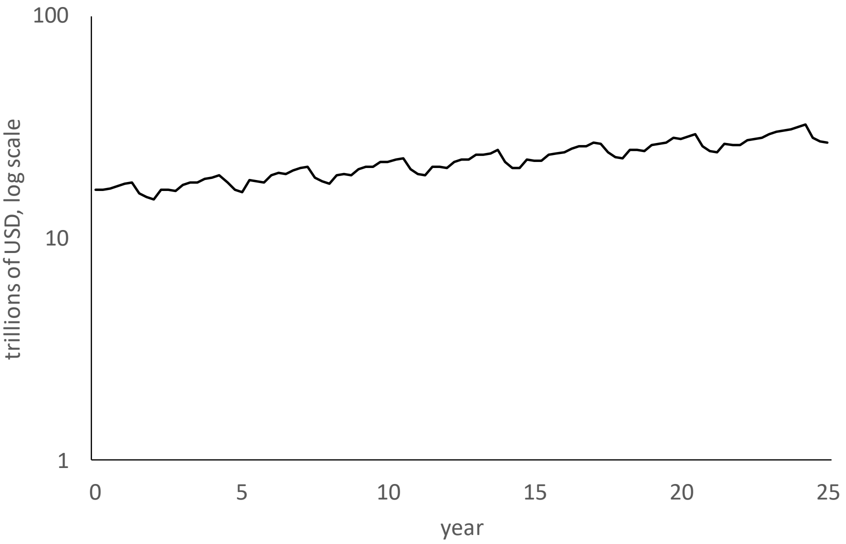

Figure 4: Real GDP

Running the model over 100 years it is possible to see a transition caused by productivity-driven shifts in employment and demographic changes. The model run starts with employment at the reference level, so there is no pressure on wages. However, consumption is rising, which pushes up investment after a lag. Rising output drives demand for labor, which pushes up the participation rate, wages, and prices. Increasing labor costs push labor productivity growth higher, partly counteracting the trend toward higher employment.

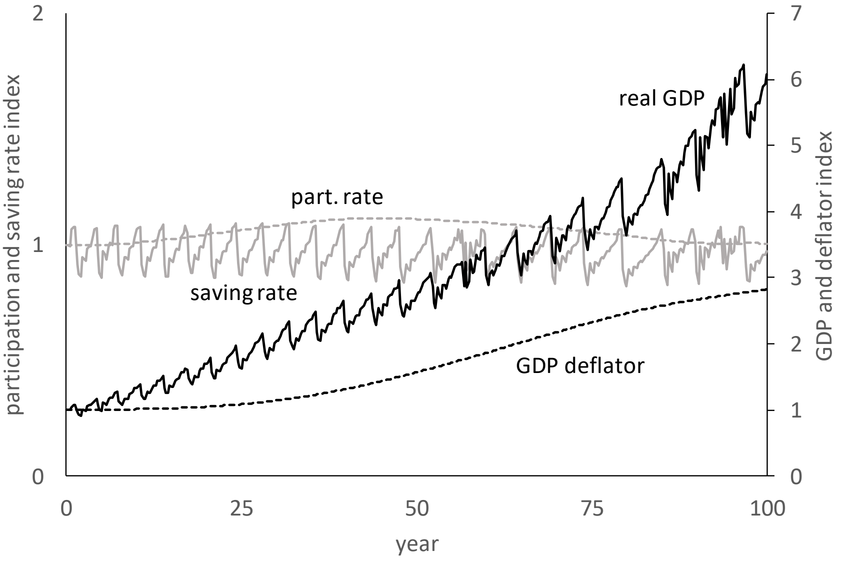

Figure 5: Real GDP, GDP deflator, participation rate and saving rate

Eventually, this leads to slowing labor demand growth, lower pressure on wages, and a declining participation rate. This can be seen in Figure 5, which shows effectively no inflation for the first 25 years of the model run, followed by accelerating and then slowing inflation as demand for labor rises and falls. Such a pattern of low or zero inflation punctuated by inflationary periods has been observed repeatedly in historical data, and is called a “price revolution” by historians (Fischer 1996).

Running the model over an even longer time (not shown) reveals inflationary cycles about a century in length, accompanied by cycles in GDP growth rates and capital and labor productivity. As in Figure 5, inflation is driven by rising labor costs as demand outpaces labor supply. Rising labor costs drive an increase in labor productivity growth rates, and a fall in capital productivity growth rates, which sometimes turn negative. Target-return pricing then leads firms to increase their profit margins to compensate for falling capital productivity. This shifts income away from wages, thereby reducing consumption and modestly dampening GDP growth. High labor productivity growth, stimulated by rising labor costs, counteracts those rising costs, thereby slowing inflation. This stabilizes real consumption and sets the stage for a new cycle. In this way, “secular stagnation” appears periodically in the model as a feature of long waves.

6 Discussion

We have presented a post-Keynesian model for studying the macroeconomic implications of transformational change in high-income capitalist economies. The model exhibits asymmetrical business cycles and transitional dynamics driven by changing technology and demography. It combines elements of Kaleckian-Harrodian growth models with a Sraffian price system. It has some novel features, but the core of the model is a multiplier-accelerator model of the type described by Hicks over half a century ago (Hicks 1950). Multiplier-accelerator models have been out of favor because empirical studies seemed to show that utilization dynamics are stable, but Blatt (1978; 1980) argued the empirical tests were flawed. Subsequent analysis has shown considerable, although not entirely definitive, evidence for Hicksian instability.

Business cycles in the model have a long expansion phase and a short and sharp contraction phase, as observed in real economies. This is very encouraging. However, in its present form the model has several limitations that must be overcome before it can be tested against real data. At present the simulated economy is closed to trade and has no government, banking, or financial sectors. The model assumes that all sectors behave fundamentally the same, which is not realistic. To take one example, while the model includes a fossil sector, it does not address the particular features of markets for raw materials, nor the costs of raw materials in firm pricing decisions. To take another, it does not consider the special features of the construction sector aside from its lagging other activity over the business cycle. A more complete model would include the role of rental markets in the provision of service sector and residential buildings. As a further extension, in the current version of the model demographic parameters are independent of the state of the economy. To a first approximation this may be reasonable for birth and death rates in high-income countries, but there is some evidence of second-order influences (Jiang 2014), while immigration rates are very likely to be influenced by economic trends.

Consumption behavior can also be made more realistic. A few high-cost items, particularly on housing, transport, and education, commit households to ongoing expenditure. While committed expenditure is reflected in the current model, its dependence on the demographic structure of households is not. Also, not all ongoing expenditure is equivalent, with some needs more pressing than others (Lavoie 1994). Expenditure on basic needs – for food, energy, and water – can constrain other household expenditure (Kemp-Benedict 2013). Many households maintain stocks of assets, which they use to buffer fluctuations in income and cover expenditure after retirement. These dynamics can be represented in a model with banking, finance, and real estate. A model with a government sector can include government expenditure, government employment, unemployment benefits, and public pensions. Finally, the assumption that supply constraints limit household consumption can be questioned; a model with inventory dynamics would be more realistic.

As discussed in the Introduction, one purpose for building the model is to study policies in support of the sustainability agenda agreed by the UN member states (UN General Assembly 2015). This agenda, which includes urgent action on climate change, raises questions about employment and macroeconomic stability. The dominant policy models today assume rapid adjustment to new information and at most temporary departures from a long-run equilibrium trajectory. In contrast, post-Keynesian theory allows for path dependency and fundamental uncertainty. Post-Keynesian theory makes heavy use of the Kaleckian model as it has evolved over time (Blecker 2002), including its recent extension to include Harrodian elements (Allain 2015). The model described in this paper is in this tradition.

7 Conclusion

Policy-relevant models of transformational dynamics are needed to inform efforts to meet the global sustainability agenda. In this paper we present a model for longer-term analysis. It is post-Keynesian in its underlying assumptions and theoretical orientation, drawing on a growing literature on Kaleckian-Harrodian models (e.g., Allain 2015). It is a multi-sector model, with a Sraffian pricing dynamic that is consistent with post-Keynesian pricing theory (Coutts and Norman 2013).

While at present the model lacks realistic features that prevent a true test, we used US data to construct a plausible baseline. The model features asymmetric business cycles with a long expansion and a short contraction. It yields endogenous transitions driven by technological change and demographic shifts. These are promising results that warrant further development of the model.

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Appendix: Parameter values

Table 1: Scalar parameters

	Unit	Value
Employment and wages		
reference employment rate		0.90
wage employment sensitivity		1.00
initial labor participation rate		0.81
participation rate adjustment factor		0.10
participation rate exponent		0.25
COLA smoothing	years	3.00
COLA weight		1.00
profit to wage share ratio scale factor		1.50
Investment, capital, and utilization		
reference utilization		0.85
target (net) rate of return	1/year	0.02
investment utilization sensitivity	1/year	0.25
investment return sensitivity		1.00
investment delay	years	0.38
autonomous net investment rate adjustment time	years	30.00
Productivity		
productivity responsiveness	1/year	0.05
Prices		
price adjustment rate		1.00
minimum profit margin		1.05

Table 2: Demographic parameters

	Unit	Young	Working age	Elderly
initial population	million	60.98	213.22	47.58
death rate	per 1000	0.55	3.14	43.36
birth rate	per 1000		18.88	
advancement	per person	0.07		
retirement	per person		0.02	
net immigration	per 1000		4.75	

Table 3: Sector parameters

		services	construction	manufacturing	agriculture	mining
Employment and wages						
flexible employment fraction		0.10	0.67	0.61	0.87	0.60
initial wage	USD/worker	58,551.88	65,959.23	78,866.54	127,470.58	122,803.86
initial labor productivity	USD/worker	127,630.40	181,610.24	485,426.38	1,131,541.91	744,514.43
Investment, capital, and utilization						
initial capital stock	billion USD	24,980.33	3,417.68	19,726.86	4,425.00	11,088.63
initial capital productivity	1/year	0.71	0.68	0.55	0.18	0.15
depreciation rate	1/year	0.11	0.12	0.08	0.04	0.06
initial base net investment rate	1/year	0.04	0.02	0.02	0.02	0.04
sectoral allocation of investment		0.36	0.28	0.31	0.00	0.05
Consumption						
committed consumption per wage		0.58	0.00	0.16	0.01	0.00
flexible consumption per wage		0.58	0.00	0.16	0.01	0.00
Productivity						
init eqm labor productivity growth	1/year	0.02	0.02	0.03	0.02	0.03
Interindustry matrix						
services		0.25	0.18	0.18	0.12	0.12
construction		0.01	0.00	0.00	0.01	0.01
manufacturing		0.10	0.23	0.34	0.19	0.09
agriculture		0.00	0.00	0.05	0.22	0.00
fossil		0.01	0.01	0.09	0.01	0.10