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Structural change, Engel's consumption cycles and Kaldor's facts of economic growth ☆

Reto Foellmi [a,*], Josef Zweimüller [b,1]

[a] Department of Economics, University of Berne, Schanzeneckstrasse 1, CH-3001 Bern, Switzerland
[b] Institute for Empirical Research in Economics, University of Zurich, Bluemlisalpstrasse 10, CH-8006 Zürich, Switzerland

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ABSTRACT

Non-linear Engel-curves for consumer goods cause continuous structural change. Goods are sequentially introduced starting out as a luxury with high income elasticity and ending up as a necessity with low income elasticity. Although this leads to rising and falling sectoral employment shares, the model exhibits a steady growth path along which the Kaldor facts are satisfied. Extending the basic model to the case of endogenous product innovations shows that complementarities between aggregate and sectoral growth may give rise to multiple equilibria.

1. Introduction

The process of economic development is characterized by fundamental changes in the structure of production and employment. In historical perspective, the emergence of new and the decline of old industries has led to a dramatic reallocation of resources between sectors of production.[2] Despite these huge structural changes, the long-term growth

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* Corresponding author. Tel.: +41 31 631 55 98; fax: +41 31 631 39 92.
E-mail addresses: reto.foellmi@vwi.unibe.ch (R. Foellmi), zweim@iew.uzh.ch (J. Zweimüller).
[1] Josef Zweimüller is also associated with CEPR, IZA and CESifo.

[2] Maddison (1987) documents the huge reallocation of labor in six major industrialized countries (France, Germany, Japan, Netherlands, U.K. and U.S.). His data show that the average employment share in agriculture was as high as 46.0% in 1870 and has decreased to 5.5% by 1984. During the same period the average employment share in the service sector has increased from 26.4% to 62.2%.

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process has been remarkably stable in the aggregate. As mentioned by Kaldor (1961) in his famous stylized facts, a situation where the growth rate, interest rate, capital output ratio, and labor share are constant over time is a reasonable approximation of the long-run growth experience of a modern economy.

Changes in the structure of production and employment result either from sectoral differences in productivity growth or from sectoral differences in income elasticities of demand. This paper focuses on the *demand* side. In this case, the structural transformation is driven by changes in consumer demand as households get richer. In a poor society, the overwhelming part of income is spent on basic goods, predominantly food. Consequently, the larger part of the population is working in the agricultural sector. As the society gets richer, consumers devote their expenditures to cover less basic needs which is associated with the creation of employment opportunities in the manufacturing sector. In the mature society consumers direct their expenditures increasingly towards the satisfaction of more advanced wants covered predominantly (though not exclusively) by services.

The importance of the demand-based approach to structural change lies in the close relationship between the dynamics of sectoral employment and the composition of aggregate consumer demand. A strong case for such a relationship can be made for the agricultural sector. Historically, increasing per-capita incomes were not only associated with a strong decline in the employment share in agriculture but also with a strongly declining budget share for food, the latter relationship being known as "Engel's law". According to Houthakker (1987), "of all the empirical regularities observed in economic data, Engel's law is probably the best established."[3] In the U.S., for instance, the budget share for food has been strongly decreasing from 28% in 1950 to 14% in 2000 whereas service expenditures have been steadily increasing during the same period, from 21.8% in 1950 to 43.9% in 2000. Over the same period, the budget share for non-food manufactures (clothing, durables, other non-durables) decreased from 38.9 to 27.8. Moreover, the familiar sectoral trichotomy—agriculture, manufacturing, services—obscures a lot of heterogeneity within these sectors. For instance, further disaggregation shows that within the service sector, purchases of medical services rose disproportionately, similarly, purchases of clothing among non-food manufactures declined very strongly. This suggests that there is substantial structural change not only between but also within broad sectors which underlines the relevance to allow for heterogeneity in industries within these broad sectors.

Modern growth theory has been surprisingly silent on the issue of how to reconcile the huge structural changes with the Kaldor facts of economic growth. The first paper that has explicitly addressed the issue is Kongsamut et al. (2001). They study a three-sector model where consumers have Stone–Geary preferences over an agricultural good (a necessity), a manufactured good (with an income elasticity near unity), and services (a luxury). They find that a "generalized balanced growth path" along which the Kaldor facts are satisfied is only possible if preference and technology parameters jointly satisfy a knife-edge condition. Just like in Kongsamut et al. (2001), in our model structural change is driven by sectoral differences in income elasticities. Unlike Kongsamut et al. (2001), however, our model studies a situation where new goods are continuously introduced, leading to the expansion of new and the decline of old industries. This creates a non-linear relationship between manufacturing employment and the level of development that does not show up in the Kongsamut et al. (2001) model.

To the best of our knowledge, other papers rationalizing structural change and steady growth in a unified framework have focused exclusively on technological differences across sectors. In Ngai and Pissarides (2007) sectors experience different total factor productivity growth rates (but have identical capital intensities). They show that the aggregate growth process satisfies the Kaldor facts if the intertemporal utility function is logarithmic in the consumption composite; and the consumption composite is non-logarithmic (yet homothetic) across goods. Another recent paper by Acemoglu and Guerrieri (2008) does not only allow for different rates of technical progress but also for differences in capital intensities across sectors. In a two-sector growth model with constant elasticity of substitution preferences and Cobb–Douglas production technologies they show that, provided the elasticity of substitution is less than one, convergence to the limiting equilibrium may be slow and along the transition path (when the sectoral structure changes) the capital share and the interest rate vary only by relatively small amounts hence reconciling structural change with the Kaldor facts.[4]

In contrast to these technology-based approaches, our model is based on the assumption of hierarchic preferences. New goods are continuously introduced and each of these new goods starts out as a luxury with a high income elasticity and ends up as a necessity with a low income elasticity. These non-linearities in Engel-curves generate consumption cycles that

[3] Engel (1857) concluded explicitly from his empirical analysis that needs have a hierarchic structure—an idea which goes back at least to Plato and has played an important role in the thinking of classical economists: "*Nunmehr* (*ist*) *gleichsam eine Scala der Bedürfnisse des Lebens zu Tage gefördert* (p. 27)." The idea that, in the age of mass consumption, the very concept of necessities and luxuries has changed, has been stressed by Katona (1964). See also the discussion on Engel-curves in Pasinetti (1981, Chapter IV).

[4] Starting with Baumol (1967) an important strand of the literature views structural change as a *supply* phenomenon. Sectors with low technical progress suffer from the "cost disease", i.e. rising relative costs and prices. When relative output levels of stagnant and dynamic sectors remain roughly constant (due to limited substitutability between products), the Kaldor facts are necessarily violated. Other models study the transition of agricultural to industrial societies without aiming at explaining the Kaldor facts as they focus on longer time periods. In these models the relative productivity between the agricultural and the manufacturing sectors determine patterns of the structural transformation, see Hansen and Prescott (2002), Parente and Prescott (2005). See also the endogenous growth models by Young (1993a, b) where changes in the structure of production arising from sector-specific learning-by-doing and/or complementarities among old and new technologies; by Chari and Hopenhayn (1991) where asymmetries arise from lags in the diffusion of new technologies; and by Thompson (2001) where quality uncertainty in connection with rising product variety leads to a non-degenerate firm size distribution. In these models, the demand-side plays a passive role as preferences between the various goods are assumed to be symmetric.

account for structural change. To highlight the demand-channel and to keep things as simple as possible the analysis abstracts from technological differences across sectors. However, a separate section discusses how various dimensions of technological heterogeneity can be incorporated in our model without substantially changing our main message.

Our analysis leads to the following results. First, non-linear Engel-curves for the various products can be consistently embedded into a growth model that features Kaldor's facts of economic growth. While previous papers have studied models featuring Engel's consumption cycles (e.g. Matsuyama, 2002), a main contribution of the present paper is to show that this framework is consistent with balanced growth.[5] Prima facie reconciling non-linear Engel-curves and the Kaldor facts seems to be non-trivial. However, just as a constant elasticity of intertemporal substitution is required for steady growth in a one-good economy, a constant intertemporal substitution elasticity of *total consumption expenditures* is required in our framework where there are many goods. Along the balanced growth path total consumption expenditures grow at the same rate as total output. However, along this path the level of demand for a *particular product* does not grow at the economy-wide growth rate. New goods experience a higher increase in demand than old goods involving a transfer of labor resources from old to new industries. By featuring a steady growth path our analysis provides a natural extension of the one-sector growth model to a multi-sector set-up in which preferences over the various goods have a hierarchical structure.

Second, while the main purpose of the paper is theoretical, an illustrative numerical exercise makes the qualitative features of our model transparent. Our model may be interpreted in the context of the sectoral trichotomy (agriculture, manufacturing, services) by assuming that the most urgent wants are satisfied by agricultural goods, the less urgent ones by manufactures and the most luxurious ones by services. The model leads to monotonically decreasing (increasing) employment sharesin the agricultural (service) sector whereas employment in the manufacturing sector increases in early stages of development and decreases in later stages. Hence our model generates quite naturally the hump-shaped evolution of the manufacturing employment share observed in the data. This feature is hard to generate in supply-based approaches.

Third, when consumption evolves along a hierarchy of wants consumers get increasingly satiated with existing products, new goods have to be continuously introduced to ensure that demand keeps pace with technical progress. To highlight the importance of product innovations for sustaining growth our basic growth model is extended to endogenous product innovations. In that case an interesting two-way causality between growth and structural change arises. On the one hand, innovation activities depend on the speed of structural change as innovation incentives are determined by the expansion of demand in new industries. On the other hand, the speed of structural change is itself determined by the aggregate growth rate. To highlight this interdependence our model is presented as a standard endogenous growth framework à la Romer (1990) and Grossman and Helpman (1992). The complementarities between sectoral and aggregate growth may give rise to multiple equilibria: when innovators expect a disproportionate increase in demand for new products, incentives to innovate are strong and vice versa. Expectations are self-fulfilling as high sectoral growth requires high aggregate growth which can only be sustained in an innovative environment.

The paper is organized as follows. Section 2 discusses our assumptions on hierarchic preferences and characterizes the equilibrium allocation of consumption expenditures. In Section 3 the implications of hierarchic preferences in an otherwise standard neoclassical growth model are explored. In particular, it is shown that a balanced growth path exists along which the sectoral composition changes continuously. Section 4 extends our model to the case of endogenous growth due to product innovations. Section 5 discusses the robustness of our main results with respect to several crucial assumptions. Section 6 concludes.

2. The static equilibrium

In this section, we introduce the hierarchic preferences and describe the equilibrium composition of demand across the different sectors.

Preferences and consumer demand: Consider a representative agent economy with infinitely many potentially producible goods and services ranked by an index i. You may think of low-i items as "agricultural goods", medium-i items as "manufactures", and high-i items as "services". Consumer preferences are given by

$$u(\{c(i)\}) = \int_0^\infty \xi(i)v(c(i))\,\mathrm{d}i, \tag{1}$$

where $v(c(i))$ is an indicator for the utility derived from consuming good i in quantity c. The baseline utility $v(c(i))$ satisfies the usual assumptions $v'>0$ and $v''<0$; and the "hierarchy" function $\xi(i)$ is monotonically decreasing in i, $\xi'(i)<0$, hence low-i goods get a higher weight than high-i goods.[6]

[5] Further papers studying the implications of non-homothetic preferences and non-linear Engel-curves for structural change include Echevarria (1997), Laitner (2000), Caselli and Coleman (2001), Gollin et al. (2002, 2007), Greenwood and Vysal (2005). For an overview on further recent theories of structural change see Matsuyama (2008).

[6] Hierarchic preferences with a continuum of (indivisible) goods have been first studied by Murphy et al. (1989) in a static framework. Our formulation allows for divisible goods and a more general specification of the weighting function. For other applications, see Zweimüller (2000) and Matsuyama (2002).

A meaningful specification of hierarchic preferences has to take account of the fact that some goods may not be consumed because the consumer cannot afford them. This implies that preferences must be such that the non-negativity constraints may become binding and Engel-curves for the various goods are non-linear. Formally, binding non-negativity constraints require that the marginal utility of consuming good i in quantity zero, $\xi(i)v'(0)$ is finite for all $i>0$. If marginal utility at quantity zero were infinitely large, it would always be optimal to consume a (small) positive amount even when prices are very high or income is very low.[7]

To keep the analysis tractable two assumptions concerning the functional forms of the hierarchy function $\xi(i)$ and the baseline utility $v(c(i))$ are made. *First*, the weighting function is a power function $\xi(i)=i^{-\gamma}$ with $\gamma\in(0,1)$. This first assumption is essential for a dynamic equilibrium featuring the Kaldor facts. It turns out that this assumption is equivalent to the assumption of CRRA utility in the one-good growth model. Just as the CRRA-form is required to generate balanced growth in the one-good growth model, the weighting function $\xi(i)=i^{-\gamma}$ is required for steady growth with many, hierarchically ordered goods. *Second*, it is assumed that the baseline utility is quadratic, $v(c(i))=(1/2)[s^2-(s-c(i))^2]$. This specification allows for binding non-negativity constraints as marginal utility at quantity zero is finite, $\xi(i)v'(0)=i^{-\gamma}s<\infty$, for all goods $i>0$. This second assumption, while keeping the analysis tractable, is not essential. While the quadratic subutility function allows for explicit solutions (and binding non-negativity constraints), it can be shown that our analysis holds for other subutility functions (see Foellmi, 2005). In Section 5 these conditions are discussed in more detail.[8]

Let us now specify the objective function of the consumer's static maximization problem. Assume that all goods i are available on the market. Then the objective function is[9]

$$u(\{c(i)\})=\int_0^\infty i^{-\gamma}\tfrac{1}{2}[s^2-(s-c(i))^2]\,\mathrm{d}i \tag{2}$$

which will be maximized subject to the budget constraint $\int_0^\infty p(i)c(i)\,\mathrm{d}i=E$ and the non-negativity constraints $c(i)\geqslant 0$, for all i. The optimality conditions require that the above constraints and the first order conditions

$$\begin{aligned}&c(i)[i^{-\gamma}(s-c(i))-\lambda p(i)]=0\quad\forall i,\\&i^{-\gamma}(s-c(i))-\lambda p(i)\leqslant 0\quad\forall i\end{aligned} \tag{3}$$

be satisfied where λ denotes the Lagrangian multiplier, equal to the marginal utility of income.

Equilibrium composition of demand: The composition of demand in the static equilibrium, given the representative agent's budget E and the measure of consumed goods N has the following properties. The measure N is finite, since consumers choose not to consume all goods, i.e. non-negativity constraints become binding for goods of low priority.

The optimal level of consumption of good i, when supplied at the marginal cost price, equals $c(i)=s-i^{\gamma}\lambda$ as can be seen from (3). This quantity is decreasing in i meaning that low-priority goods are consumed in smaller quantity. It turns out convenient to express λ in terms of the quantity of the last good that is consumed N. By continuity, $c(N)=0$. From (3) it is straightforward to express the marginal utility of income as $\lambda=s/N^{\gamma}$. The equilibrium composition of demand can now be expressed as

$$c(i)=s\left[1-\left(\frac{i}{N}\right)^{\gamma}\right],\quad i\in[0,N]. \tag{4}$$

Eq. (4) reveals that quantities depend on the *relative position* of a particular good in the hierarchy of needs, i/N. At a lower position in the hierarchy, with relatively higher priority, good is *ceteris paribus* consumed in higher quantity ($c(i)$ decreases in i). Furthermore, the steeper the hierarchy (the higher is γ) the stronger the effect of the relative position on equilibrium quantities.

From (4) one can already infer a relationship between the level of consumption of a particular good in the course of economic development. N increases over time as the economy gets richer and consumers demand more and more consumption goods. When N equals i the good is just introduced and consumed in quantity 0. Increases in N initially lead to a strong expansion of the market, followed by decreasing growth rates and finally stagnating demand in the long term once consumption approaches the saturation level s. The path of the demand for some good i in dependency of N is shown in Fig. 1.

[7] Non-negativity constraints never become binding in the standard monopolistic competition model (Dixit and Stiglitz, 1977) that dominates the macroeconomic literature. In that model $v(c(i))=(1/\alpha)c(i)^{\alpha}$, $\alpha<1$, and $v'(0)=\infty$. Thus in the standard monopolistic competition model all available goods are consumed in positive amounts.

[8] In this sense, our formulation of preferences provides a natural extension of the one-sector framework to a framework with hierarchic preferences.

[9] $v(c(i))=(1/2)[s^2-(s-c(i))^2]$ has been normalized such that $v(0)=0$. This normalization is necessary to prevent divergence of the utility integral because the consumer's preferences are defined over an *infinite* number of goods. Since only goods in the interval $i\in[0,N]$ are consumed in positive amounts the consumer's objective can be written as $u(\{c\})=\int_0^N i^{-\gamma}(1/2)[s^2-(s-c(i))^2]\,\mathrm{d}i+\int_N^\infty i^{-\gamma}(1/2)[s^2-s^2]\,\mathrm{d}i$. To prevent divergence of the first integral we must have $\gamma<1$. By the normalization of $v(\cdot)$ the second integral is zero and does not diverge. We can then restrict our attention to the utility function $u(\{c\})=\int_0^N i^{-\gamma}(1/2)[s^2-(s-c(i))^2]\,\mathrm{d}i$.

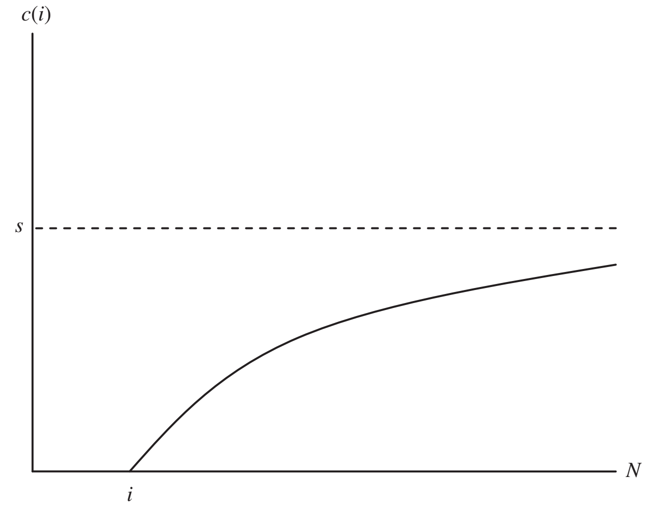

Fig. 1. The consumption quantity of good i as a function of the total number of goods consumed N.

3. Balanced growth equilibrium

Before discussing the general equilibrium of the model the assumptions on technology need to be specified.

Technology: Output is produced using capital and labor. For simplicity, assume that capital is homogenous. Capital and consumption goods are produced with the same constant-returns-to-scale technology $F[K(i,t), A(t)L(i,t)]$. To economize notation, output is measured net of depreciation. The inputs $K(i,t)$ and $L(i,t)$ denote, respectively, the amounts of physical capital and labor employed in sector i at date t. $A(t)$ is the stock of (labor-augmenting) technical knowledge which increases at exogenous rate g . Given the linear homogeneity of the production function one can write $f(k(i,t)) = F[K(i,t)/(A(t)L(i,t)), 1]$ with $k(i,t) \equiv K(i,t)/(A(t)L(i,t))$ as capital per efficiency unit of labor and $f(k(i,t))$ as the intensive-form production function. In equilibrium, each firm produces with the same capital labor ratio, hence marginal costs are equalized across firms and sectors. Marginal costs and hence the prices of output goods are normalized to unity.

Optimal savings and capital accumulation: Consider the optimal intertemporal allocation of consumption expenditures of the representative consumer. Assuming that an agent maximizes utility over an infinite horizon, the objective function is given by

$$U(t) = \int_t^\infty \frac{u(\tau)^{1-\sigma}}{1-\sigma} \mathrm{e}^{-\rho(\tau-t)} \, \mathrm{d}\tau, \tag{5}$$

where $u(\tau) \equiv (1/2)\int_0^\infty i^{-\gamma}[s^2 - (s - c(i,\tau))^2] \, \mathrm{d}i$ is the consumption aggregator for the various goods. The parameter σ measures the willingness to shift the composite $u(\tau)$ across time and ρ is the subjective rate of time preference. The above objective function is maximized subject to the intertemporal budget constraint

$$\int_t^\infty E(\tau)\mathrm{e}^{-R(\tau,t)} \, \mathrm{d}\tau \leqslant \int_t^\infty w(\tau)\mathrm{e}^{-R(\tau,t)} \, \mathrm{d}\tau + V(t), \tag{6}$$

where $R(\tau,t) = \int_t^\tau r(s) \, \mathrm{d}s$ is the cumulative interest rate, $E(\tau) \equiv \int_0^{N(\tau)} p(i,\tau)c(i,\tau) \, \mathrm{d}i$ is the level of consumption expenditures at date τ, and $V(t)$ is the value of assets owned by the consumer at date t. Setting up the Lagrangian and taking derivatives with respect to $c(i,\tau)$ yields the first order condition

$$u(\tau)^{-\sigma} i^{-\gamma}(s - c(i,\tau))\mathrm{e}^{-\rho(\tau-t)} = \mu \mathrm{e}^{-R(\tau,t)}, \tag{7}$$

where μ is the Lagrangian multiplier. This first order condition (and the intertemporal budget constraint) determines the optimal consumption levels for each good at each date. Condition (7) must hold for all i and τ. Setting $i = N(\tau)$ in (7), taking logs and the derivative with respect to time τ yields

$$-\sigma \frac{\dot{u}(\tau)}{u(\tau)} - \gamma \frac{\dot{N}(\tau)}{N(\tau)} - \rho = -r(\tau). \tag{8}$$

Using (4) it is easy to show that expenditures $E(\tau)$ are proportional to the number of goods consumed $N(\tau)$.

Lemma 1. (a) *In the steady state equilibrium, expenditures are proportional to range of goods*; $E(\tau) = N(\tau)s\gamma/(1+\gamma)$.

(b) *The maximized instantaneous utility at date* τ, $\hat{u}(\tau)$, *can be written as* $\hat{u}(\tau) = E(\tau)^{1-\gamma}/(1-\gamma) \cdot \Phi(s,\gamma)$.

Proof. Part (a): Using (4), yields $E(\tau) = s\int_0^{N(\tau)}[1-(i/N(\tau))^{\gamma}]\,\mathrm{d}i = N(\tau)s\gamma/(1+\gamma)$. Part (b): See Appendix 1 in supplemental material section. □

Part a of Lemma 1 implies that the optimal consumption path features a situation where $N(\tau)$ and $E(\tau)$ grow at the same rate and where the consumption level $c(\omega N(\tau),\tau)$ does not change over time—so that the consumption at a given relative position $\omega = i/N$ in the consumption hierarchy is the same at all dates. Consumption of good i increases over time but at a decreasing rate and approaches the saturation level as the relative position in the consumption hierarchy approaches 0. Using the above properties, Eq. (8) simplifies considerably. Parts (a) and (b) of Lemma 1 imply $\dot{u}/u = (1-\gamma)\dot{E}/E$. Define expenditures in efficiency units as $e \equiv E/A$ and therefore $\dot{e}/e = \dot{E}/E - g$. Rewrite (8) to get the Euler equation

$$\frac{\dot{e}}{e} = \frac{f'(k)-\rho}{\sigma(1-\gamma)+\gamma} - g, \tag{9}$$

where $r = f'(k)$ in the capital market equilibrium. Note that the symmetric case ($\gamma \to 0$) yields the familiar equation $\dot{e}/e = (r-\rho)/\sigma - g$.

Capital is accumulated according to $\dot{K} = Y - E$. Hence, the capital accumulation equation in efficiency units (where $k \equiv K/A$ and $f(k) \equiv Y/A$) reads

$$\dot{k} = f(k) - e - gk. \tag{10}$$

The differential equations (9) and (10) are isomorphic to those of the standard neoclassical growth model. The only difference is that the hierarchy parameter γ changes the relevant intertemporal elasticity of substitution in (9). Therefore, it is straightforward to see that a unique expenditure level $e(0)$ exists, given an initial level of capital $k(0)$.

The Kaldor facts and sectoral employment dynamics: It is easy to check that the Kaldor facts are satisfied along the balanced growth path. In steady state, e and k are constant, hence $f(k)$ is constant as well, this implies that output Y and consumption E grow at the same rate. As k is constant, the interest rate $f'(k)$ is constant and the wage rate per efficiency unit of labor $f(k) - f'(k)k$ is also constant. The wage rate grows pari passu with productivity $A(t) = N(t)$ and the capital output ratio $f(k)/k$ is constant.

Along the balanced growth path the composition of demand across sectors changes as a result of different income elasticities of the various products. From (4) it is straightforward to calculate the income elasticity of a particular product as $\gamma \cdot (i/N(t))^{\gamma}/[1-(i/N(t))^{\gamma}]$.[10] When a new good is introduced, i.e. when $i = N(t)$, the income elasticity of demand is infinity and when $i/N(t)$ becomes small, the income elasticity approaches zero. In this sense each good starts out as a luxury with a high income elasticity and ends up as a necessity with a low income elasticity. While the income elasticity of demand of each existing product is monotonically decreasing over time, the income elasticity of aggregate consumption stays constant (and is equal to unity) because new goods are continuously introduced. Hence our model highlights the importance of the rise and stagnation of individual products as an underlying force of structural change. It points to the fact that compositional changes do not only take place between but also within broadly defined sectors.

Our results are summarized in the following:

Proposition 1. (a) *Along the balanced growth path the Kaldor facts are satisfied.* (b) *Structural change occurs because of income elasticities of demand that are different across sectors. The income elasticity of demand for some good i is given by* $\gamma \cdot (i/N(t))^{\gamma}/[1-(i/N(t))^{\gamma}]$, *i.e. starts out with infinity and eventually approaches zero.*

Let us now discuss the qualitative implications of our model for the evolution of sectoral employment shares. The employment share in agriculture (in the services sector) has been strongly decreasing (increasing) in all countries, whereas the evolution of the manufacturing employment share follows and inverse *U* in all countries (except Japan). Our theoretical framework can be used to study this issue by mapping each good into one of the three sectors. As the consumption hierarchy ranks the most urgent needs first and products satisfying less urgent needs later, think of low-i items as agricultural goods, medium-i items as manufacturing goods and high-i items as services. Fig. 2 shows the resulting employment shares.[11] This simple exercise reveals that the model is capable of generating realistic movements of labor out of agriculture and into services. In particular, the model predicts a hump shape in the evolution of the manufacturing share, a period of increasing manufacturing employment is followed by a period of de-industrialization. This is interesting because such a qualitative pattern is observed in most industrialized countries but such a pattern is typically difficult to generate in technology-based models of structural change.

4. Structural change with R&D-based growth

When consumption evolves along a hierarchy of wants and consumers get increasingly satiated with existing products, new goods have to be continuously introduced to ensure that demand keeps pace with technical progress. In the past

[10] To calculate this elasticity we note that the balanced growth path features a constant savings rate and that, by Lemma 1, the consumption expenditures E and the product range N grow pari passu. The elasticity of $c(i)$ with respect to N is then identical to the income elasticity of demand.

[11] In the figure, to make our suggestive exercise as simple as possible, we assume that goods $i \in [0,1)$ are taken as agricultural products, goods $i \in [1,4)$ are manufacturing goods, and goods $i \geqslant 4$ are services. The other parameter values are given in the figure.

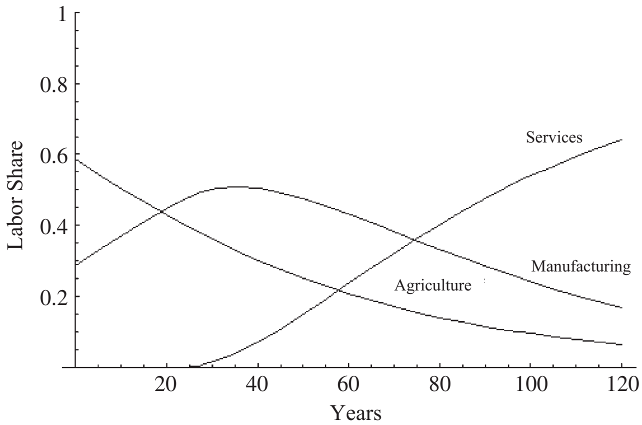

Fig. 2. Structural change—the reallocation of employment across sectors. The figure displays the dynamic evolution of employment shares in the three sectors agriculture, manufacturing, and services. The parameter values are $\alpha = 0.33$, $\rho = 0.02$, $\alpha = 4$, $s = 3$, $\gamma = 0.77$, and a productivity growth rate of $g = 2.1\%$. Note that the labor shares do not sum up to one because a constant share of $gk/y = 12.5\%$ is working in the capital goods sector and neither counted as manufacturing or service employees.

sections, the focus was on the simple case where the introduction of new products is costless. This section extends our basic model to endogenous R&D to highlight the importance of product innovations for sustaining growth. This yields interesting new insights. First, the R&D-based growth model features monopolistic firms: hierarchic preferences generate heterogenous mark-ups across firms and, for a given firm, changing mark-ups over time. Second, the effect of aggregate growth on the incentive to innovate becomes ambiguous. Besides the familiar negative effect of higher growth (which raises the interest rate and thus discounts future profits at a higher rate), hierarchic preferences lead to a second effect that stimulates the incentive to innovate. Higher growth implies that the market expands more quickly and leads to a faster growth of profits. This latter effect is not present in the standard R&D-based model. It will be shown that the resulting demand externalities may give rise to multiple equilibria.[12]

To study structural change and growth in a R&D-based framework the previous set-up is changed in two ways. *First*, to simplify the analysis it is assumed that labor is the only productive input. To invent a new good a fixed cost of $F(t)$ units of labor is necessary and to produce final output $b(t)$ units of labor are required. In line with previous R&D-based approaches, the aggregate knowledge stock $A(t)$ increases pari passu with innovative activities and that the labor coefficients are inversely related to the knowledge stock, so $A(t) = N(t)$, $b(t) = b/N(t)$, and $F(t) = F/N(t)$ where b and F are positive constants.[13] In equilibrium resources are fully utilized. The economy's total supply of labor is normalized to 1 and labor demand comes either from firms producing final output or from firms conducting R&D. Employment in the R&D sector is $\dot{N}(t) \cdot F/N(t)$ and employment in the production of some good i is $c(i,t) \cdot b/N(t)$. The economy's resource constraint is

$$1 = \frac{\dot{N}(t)}{N(t)}F + \frac{b}{N(t)}\int_0^{N(t)} c(i,t)\,\mathrm{d}i. \tag{11}$$

Second, a firm that invents a new good acquires a temporary monopoly position by a patent with duration Δ. After that period, other firms can enter and the market becomes competitive. In steady state, a constant fraction a of all products are supplied by monopolistic producers (innovators still protected by patents) and the remaining fraction $1 - a$ is supplied on competitive markets. Fraction a is endogenously determined in the model and given by $a = 1 - \exp(-g\Delta)$. As innovations follow the consumption hierarchy monopolistic firms produce goods $i \in (aN(t), N(t)]$ and competitive firms produce goods $i \in [0, aN(t)]$. This implies that old (low-i) goods are supplied on competitive markets whereas new (high-i) goods are supplied by innovators still protected by patents.

[12] Notice that also other models that are based on hierarchic preferences may generate multiple equilibria. In Matsuyama (2002), there are multiple steady states. In his model it is determined by *initial conditions* (e.g. by the extent of inequality in the income distribution) in which particular steady state the economic finally will end up. Unlike in Matsuyama (2002), in our model *expectations* about the economy's aggregate growth rate select the equilibrium. When these expectations are optimistic the economy will end up in the good (high-growth) equilibrium and vice versa.

[13] Note that our assumption on knowledge spillovers differs from the standard "love-for-variety" model (Grossman and Helpman, 1992). In that model productivity grows only in research but not in production. In the hierarchical model instead there has to be technical progress otherwise innovations come to a halt because consumers are not willing to reduce consumption on high-priority goods if new goods come along. Hence without technical progress in production, sooner or later the whole labor force will be employed to satisfy the demand of consumers on the already existing goods. Our assumption could be justified, e.g. using the argument of Young (1993a): if the invention of a new good i leads as a by-product to the discovery of a new intermediate input and if the final goods are produced by combining these inputs using a constant returns to scale CES technology, the productivity of the output sector rises linearly in the number of these inputs.

Sectoral prices and quantities: Competitively supplied goods $i \in [0, aN(t)]$ are taken as the numéraire which implies that marginal production costs are $w(t)b(t) = 1$.[14] Determining the prices for the monopolistically supplied goods $i \in (aN(t), N(t)]$ is straightforward. To set up the innovator's profit function use the market demand function (3) to calculate prices and quantities on monopolistic markets. Prices and quantities on competitive market are given by setting $p(i,t) = 1$ in the household's optimality conditions (3). The evolution of prices and quantities of the various goods is then fully determined. The solution is summarized in the following:

Proposition 2. *Denote by p the price of good N(t). Price and quantity of some good i at date t is given by*

$$p(i,t) = \begin{cases} 1, & i \in [0, aN(t)], \\ \dfrac{1}{2}\left[1 + \left(\dfrac{i}{N(t)}\right)^{-\gamma}(2p-1)\right], & i \in (aN(t), N(t)] \end{cases} \tag{12}$$

and

$$c(i,t) = \begin{cases} s\left[1 - \left(\dfrac{i}{N(t)}\right)^{\gamma}\dfrac{1}{2p-1}\right], & i \in [0, aN(t)], \\ \dfrac{s}{2}\left[1 - \left(\dfrac{i}{N(t)}\right)^{\gamma}\dfrac{1}{2p-1}\right], & i \in (aN(t), N(t)]. \end{cases} \tag{13}$$

Proof. Appendix 2 in supplemental material section. □

The proposition shows how prices and quantities vary over time and across products along the balanced growth path. Eqs. (12) and (13) express these prices and quantities in terms of p, the price of the most recent innovator and in terms of a, the fraction of monopolistic sectors. Both p and a are constant (though endogenously determined) on the balanced growth path. From (12) one can infer how the price of some good i evolves over time. At the date when good i is introduced $i = N(t)$ which means that $p(N(t), t) = p$. After that date the price increases because $N(t)$ grows. The reason is that the consumers' higher income shifts out the monopolistic producer's demand curve resulting in a higher monopoly price (and a higher quantity). The price increases smoothly until the patent expires, when $i = aN(t)$. Notice also that prices attached to a particular relative position in the consumption hierarchy $\omega = i/N$ are constant along the balanced growth. This stationarity of prices implies that the same Euler equation as in the simple model with exogenous technical progress prevails. (This is shown in Appendix 3 in the supplemental material section.)

The innovation process: Innovations occur because consumers demand new products as they get richer. The costs of an innovation are $w(t)F(t) = F/b$ and constant over time. The (private) value of an innovation at date t, denoted by $\Pi(t)$, equals the present value of the profit flow accruing to the innovating firm. Denote the flow profit at date τ to the date-t innovator by $\pi(N(t), \tau) = [p(N(t), \tau) - 1]\, c(N(t), \tau)$. The date-$t$ innovator gets a patent of duration Δ yielding positive profits during the interval $[t, t + \Delta]$. The flow profit between these dates increases due to growing incomes of consumers which generate a higher level of demand and an increasing monopoly price for the particular product.

Assuming free access to the research sector, there is entry as long as innovation costs fall short of the value of an innovation. Hence in equilibrium where all profit opportunities are exploited, it must be $F/b \geqslant \Pi(t)$, with equality whenever innovations take place. The zero-profit condition can be stated as

$$F/b = \int_t^{t+\Delta} [p(N(t), \tau) - 1]c(N(t), \tau)e^{-R(\tau,t)}\, d\tau. \tag{14}$$

General equilibrium: It is straightforward to solve the above model. Express the resource constraint (11) and the entry-condition (14) in terms of the endogenous growth rate g, and the price of the most recent innovator's product p. The resulting conditions, the resource constraint or labor market equilibrium (L-curve) and the R&D entry-condition (Z-curve) allow us to analyze the equilibrium graphically. The following proposition summarizes the conditions under which a unique general equilibrium with positive growth exists.

Proposition 3. *Define by* $p_Z = 1 + ([1 + bs(1 - e^{-\Delta\rho})/(\rho F)]^{1/2} - 1)^{-1}$ *the intercept of the R&D entry-condition and by* $p_L = (1/2)[1 + bs/(1+\gamma)(bs - 1)]$ *the intercept of the resource constraint.* (a) *A unique balanced growth equilibrium exists if* $p_Z < p_L$ *or if* $bs \leqslant 1$. (b) *Sufficient for a unique equilibrium is* $bs \leqslant 1$ *and* $\gamma \leqslant \sigma(p_Z - 1)/(1 + \sigma(p_Z - 1))$ *(flat hierarchy).*

Proof. Appendix 4 in supplemental material section. □

Fig. 3 studies the equilibrium graphically. The Z-curve has an ambiguous slope. This ambiguity arises because of hierarchic preferences. In standard R&D-based growth models, the aggregate growth rate affects the incentive to innovate only via the interest rate. Higher growth means higher discounting of future profits and depresses the value of an innovation. With our assumption of hierarchic preferences, there is an additional counteracting effect. Because rising incomes generate an increasing flow profit for the innovator the incentive to innovate increases in the aggregate growth

[14] This implies that wages grow with productivity $N(t)$. Using $b(t) = b/N(t)$ the choice of the numéraire implies that $w(t) = N(t)/b$.

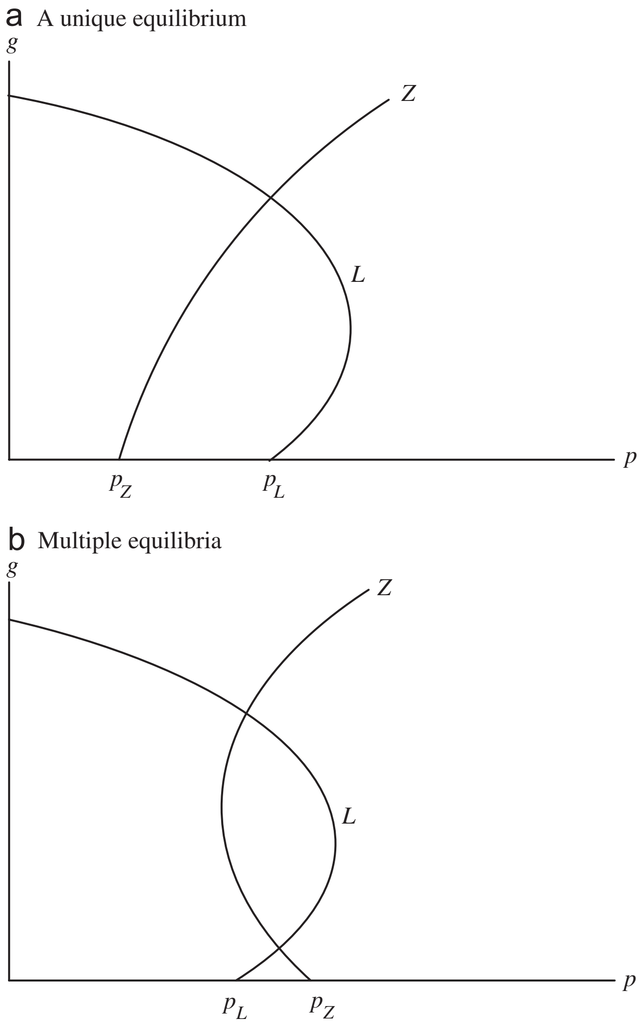

Fig. 3. The general equilibrium of the endogenous growth model is determined by the zero profit constraint curve Z and the resource constraint schedule L. (a) shows a situation with a unique equilibrium for the growth rate g and the entry price p. (b) there are multiple equilibria.

rate. With $\gamma \leqslant \sigma(p_Z - 1)/(1 + \sigma(p_Z - 1))$ (flat hierarchy), the former effect always dominates the latter and the Z-curve is positively sloped. The slope of the L-curve is negative for high growth rates but is ambiguous for low growth rates. Higher growth requires a larger research sector, hence more resources are needed to generate a higher g. However, higher growth is also associated with a larger fraction of monopolistic sectors and a lower fraction of competitive sectors. Due to this composition effect higher growth is associated with lower demand for production labor. (This is because, ceteris paribus, monopolistic firms have a lower equilibrium output than competitive firms.) This composition effect arises due to finite patent duration (see Laussel and Nyssen, 1999). At low growth rates, the negative effect of g on employment in the production sector may dominate the positive effect of g on employment in the R&D sector. Finally, a higher entry price p is associated with higher equilibrium consumption levels for all goods (see Eq. (13)) and thus fewer resources available for R&D. Taken together, the L-curve may have a positive slope at low growth rates but a negative slope at higher growth rates. Panel (a) of Fig. 3 shows a unique equilibrium in which the conditions stated in Proposition 3 are satisfied.

If the conditions in Proposition 4 are violated either a stagnation equilibrium or multiple equilibria may arise. This is summarized in the next proposition.

Proposition 4. *If $p_Z \geqslant p_L$, either a stagnation equilibrium or multiple equilibria may arise. To generate multiple equilibria the consumption hierarchy has to be sufficiently steep, $\gamma > \sigma(p_Z - 1)/(1 + \sigma(p_Z - 1))$.*

Panel (b) of Fig. 3 shows a situation with multiple equilibria. Multiple equilibria arise when the Z-curve is sufficiently strongly backward bending. The proposition says that this requires a large value of γ, i.e. a sufficiently steep consumption hierarchy. The higher γ, the stronger the impact of aggregate growth on an innovator's price and quantity making multiple intersections of the L-curve and Z-curve more likely.[15]

The economic intuition generating multiple balanced growth equilibria is a demand externality. If innovators expect high aggregate growth they expect that the demand for their products and hence their profits expand more quickly. Thus, optimistic expectations about economy-wide growth stimulate the incentive to innovate. If innovators expect low growth, profit expectations and the resulting incentives to innovate are correspondingly low. Low growth rates are sustained by pessimistic expectations.[16]

5. Discussion

Our analysis has made a number of strong assumptions. In particular, hierarchic preferences were specified in a very stylized way, abstracting from technological asymmetries across sectors and assuming that all sectors participate equally from technical progress. This section provides a discussion of the robustness of these results if we deviate from these assumptions.

Assumptions on preferences: Generating a balanced growth path hinges upon the following crucial assumptions: (i) a felicity function that is additively separable across the various products, (ii) a quadratic subutility function, and (iii) a consumption hierarchy that weights the products with a power function. The assumption of additive separability is made for tractability.[17]

The functional form of the subutility function $v(c)$ is not essential. As shown by Foellmi (2005) any form of $v(\cdot)$ that satisfies the usual assumptions $v'(c)>0$ and $v''(c)<0$ would do. Only a small set of regularity conditions are needed: the normalization $v(0)=0$ is required to guarantee that the utility integral is well defined; the condition $v'(0)<\infty$ must hold to allow for an equilibrium with binding non-negativity constraints (which also implies that utility is non-homothetic). The quadratic form of $v(\cdot)$ has been chosen to obtain closed-form solutions. Moreover, its saturation point captures a basic idea of any model of hierarchic consumption in a very stylized way: consumers move to goods with less priority, once they have saturated their basic needs.[18]

The restriction of the weighting function to take the power form $i^{-\gamma}$ is essential. It implies that demand functions (and monopoly prices) only depend on the relative (rather than the absolute) position of the product in the hierarchy. As a result, the maximized static utility function can be expressed as a function of total (current) expenditure levels, the function taking the constant elasticity form with parameter γ. In other words, in intertemporal problems with a continuum of goods, assuming additive separability and weighting by a power function is the *equivalent* of assuming a CRRA-felicity function in the one-good growth model.[19] In either case, these functional forms guarantee a constant rate of consumption growth when rates of interest are constant over time.

Sectoral differences in productivity levels and productivity growth: The second important assumption relied on identical supply conditions across sectors. These assumptions were made to keep the analysis tractable. Nevertheless, sectoral differences in productivity levels and/or scopes for productivity growth can be integrated in our model.

The case is straightforward when only *productivity levels* (but not rates of technical progress) *differ across sectors*. Consider the simplest case, when labor is the only production factor. (The arguments extend in a straightforward way to the case of more general production functions.) Assume that the labor coefficient in product line i is given by $b(i)=b+\varepsilon(i)$ with $\varepsilon(i)$ being the deviation of sector i from average productivity. Assume that the distribution of ε has the properties $E\varepsilon(i)=0$, $E\varepsilon(i)^2=\sigma^2$, and $E\varepsilon(i)\varepsilon(j)=0$ for $j\neq i$. The latter assumption implies that there are no *systematic* differences in productivity level between high- and low-priority goods. Absent such differences, there is no mechanism that would lead to violation of the Kaldor facts. Note, however, that patterns of structural change may be affected. Allowing for random differences in technology across sectors may reverse the order in which new goods and services are introduced. When $b(i)\gg b(j)$ so that productivity in sector i is much lower than in j, then good j may be introduced earlier even if i has higher priority, so that $i<j$. Even though good j yields lower utility than good i, the lower prices may induce consumers to purchase them earlier.

The situation becomes slightly more tricky when there are *sectoral differences in technical progress*. Assume, there is uncertainty with respect to technical progress at the date when a new product is introduced. Each good starts out with the "state-of-the-art" technology. With probability β a new sector is "dynamic" (costs fall with the number of previous innovations $N(t)$, just like before) and "stagnant" with probability $1-\beta$ (no change in costs of production). This implies

[15] In a stagnation equilibrium, the value of an innovation is *smaller* than the costs of an innovation at all values of g. In that case no research will be undertaken.

[16] As shown by Laussel and Nyssen (1999) multiple equilibria may also arise due to a finite patent length. However, in the present model, multiple equilibria may occur even if patent length is infinite, provided that γ is sufficiently large.

[17] The assumption of separability implies that "Pigou's law", proportionality of income and price elasticities, holds in our model. Clements and Selvanathan (1994), in an empirical study based on aggregate cross-country consumption data, find empirical evidence in favor of Pigou's law.

[18] For instance, it is not necessary to have a utility function with a saturation level. In an earlier version of this paper (Foellmi and Zweimüller, 2003) we have used the felicity function $v(c)=\ln(c+q)$ with q as a positive constant. This yields qualitatively similar results (and explicit solutions) except that the demand elasticity for a given product remains strictly above unity.

[19] More precisely, Foellmi and Zweimüller (2003) have shown that a felicity function of the form $u(\{c(i)\})=\int_0^\infty i^{-\gamma}v(c(i))\,\mathrm{d}i$ is CRRA in expenditure levels if the price of good i can be expressed as a function of its relative position i/N only. This clearly holds true in the preset model.

that, at each date, there co-exist dynamic sectors with "state-of-the-art" productivity levels $b/N(t)$ and stagnant sectors with $b/N(s)$ where s denotes the period when the product is introduced. (The latter assumption says that *all* new sectors start out with state-of-the-art productivity but only dynamic sectors experience productivity growth.) Assume that β is uncorrelated with i, so that sectoral differences are "random" in the sense that low- and high-priority goods have the same scope for technical progress. Products that experience technical progress will experience unchanged marginal costs. Products that experience no technical progress will suffer from the "cost disease". Unlike in the Baumol model, stagnant products will disappear from the market because sooner or later costs will become larger than the prohibitive price. The steady-state growth path is characterized by a constant fraction of output and employment in stagnant sectors, though the composition of these sectors changes over time as new goods enter and old goods disappear. Hence, our framework can capture, by way of a natural extension, also the fact that goods and services disappear over time.

A further dimension of technological heterogeneity across sectors involves the scope for *technological spillovers*. Suppose there are differences across sectors in the contribution of innovation i to the aggregate stock of knowledge. With a probability α, the by-product of a new innovation is additional knowledge that makes factors more productive in all other sectors, and with probability $1-\alpha$, there are no such knowledge spillovers. As a result, the aggregate stock of knowledge is given by $A(t) = \alpha N(t)$ and productivity levels are only α times as high as in the basic model, the equilibrium outcome remains otherwise unchanged.

A final point concerns differences in technologies between investment and consumption goods. Our analysis has shown that the consumption sector can be aggregated nicely, the model could be extended to a two-sector framework à la Rebelo (1991). It is well known that a balanced growth path exists within that model even though consumption and investment goods are produced with different technologies and experience different productivity growth. Such a framework would account for the empirical evidence in Greenwood et al. (1997).

The above discussion has highlighted conditions on technological asymmetries that are compatible with the Kaldor facts. The absence of a correlation between the relevant technology parameters and the hierarchy index i is essential. It is straightforward to see how the long-run growth path is affected when these conditions are violated. If there are systematic correlations over extended intervals along the consumption hierarchy growth rates will no longer be constant. Hence our framework can generate *growth cycles*, periods of productivity slowdowns and productivity revivals.

6. Conclusions

Two dominant features of the long-run growth process were reconciled in this paper: the dramatic changes in the structure of production and employment; and the Kaldor facts of economic growth. Our model has focused on the demand-explanation of structural change which is based on the idea that households expand their consumption along a hierarchy of needs. In such a context structural change results from differences in income elasticities across sectors. The paper proposed a specification of hierarchic preferences featuring realistic patterns of structural change while also generating an equilibrium growth path that is consistent with the Kaldor facts. Furthermore, a simple numerical example showed that our model can capture realistic patterns of structural change. In particular, the model predicts not only monotonically decreasing (increasing) employment in agriculture (services) but also a manufacturing share that first increases and then decreases in the course of economic development.

In contrast to previous approaches that try to explain the Kaldor facts together with changes in the structural composition of output, our approach has studied the non-homothetic nature of preferences together with a situation where new goods are sequentially introduced. In our model, new goods start out as luxuries with a high income elasticity and finally become necessities with a low income elasticity. In this sense, our paper presents a model of rising and stagnating products and highlights the importance of structural changes also within broadly defined sectors.

While our basic model was presented in the context of exogenous technical progress where new goods are introduced without any costs, our analysis was extended to study endogenous growth. In such a framework, it was shown that hierarchic preferences highlight interesting interactions between structural change and long-run growth. On the one hand, the aggregate growth rate depends on structural change because innovation incentives are crucially determined by the growth rates in the new industries. On the other hand, the speed of structural change is itself determined by aggregate growth. The resulting complementarities between sectoral and aggregate growth open up the possibility for multiple equilibria. Hence our model is not only capable of yielding insights into the process of growth and structural change, but sheds also light on the question why some countries experience high long-term growth and many industries take off, while in other countries there is neither a change in the production structure nor increases in aggregate productivity.

Our model can be extended in several directions. Two extensions are most promising. First, while our analysis has focused on a representative consumer, the introduction of consumer heterogeneity is potentially interesting. As preferences are non-homothetic, rich and poor households will consume different consumption bundles which opens up a new channel by which income inequality could affect growth and structural change (Foellmi and Zweimüller, 2006). Second, hierarchic preferences in a world economy with rich and poor countries would imply interesting patterns of growth and the international division of labor. Our model provides a natural way of modelling the Linder-hypothesis (Linder, 1961) and/or the product-cycle hypothesis (Vernon, 1966). A rich country faces high home-demand and hence will innovate early. The poor country will first import new goods, but later on start to imitate. Hence rich countries will produce new goods with a high income elasticity and poor countries will produce old goods with a low elasticity. Our set-up may also be useful to understand the mixed empirical evidence concerning the Prebisch/Singer-hypothesis (Prebisch, 1950; Singer, 1950) according to which the terms of trade for the poor countries deteriorate as their exports are concentrated on goods with low income elasticities.[20]

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at 10.1016/j.jmoneco.2008.09.001.

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[20] For a static model along these lines, see Matsuyama (2000).