Impacts of Intermediate Trade on Structural Change

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by

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Abstract

Traditional structural change theories study the dynamics of inter-sector labour-reallocation in autarky models. We analyse how model-results change if open economy setting is assumed, where we focus on the impacts of intermediate trade in a multi-sector growth model with capital accumulation. We show that, when controlling for specialisation-effects, open economy features a relatively high employment share of capital/manufacturing sector and a relatively low rate of labour-reallocation across consumption industries in comparison to autarky. The process of tertiarisation (transition to a services economy) is relatively slow in the intermediate trade model in comparison to the autarky model.

Keywords: *structural change, factor reallocation, labour, multi-sector growth modelling, neoclassical growth theory, trade, intermediates, offshoring.*

JEL Classification Numbers: F16, F43, O14, O41

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1. Introduction

Structural change, i.e. inter-sector labour-reallocation, is one of the most evident stylized facts of the development process. In early stages of development the greatest share of labour is employed in the agricultural sector. This agricultural stage is followed by a period of industrialization – where labour is reallocated to the manufacturing (and services) sector – and a period of tertiarisation – where labour is reallocated to the services sector –, such that in advanced economies the services sector employs the largest share of labour-force. Nevertheless, structural change in advanced societies does not come to a halt; it is simply shifted to another level, i.e. it takes place within the services sector, where e.g. information and communication services become increasingly important over time. For evidence see Section 2.2.1.

Traditional structural change theories study structural change in autarky models (cf. Section 2.2). An essential question is how their results change if open economy setting is assumed; cf. Matsuyama (2009). We analyse this topic in our paper, where we focus on the impacts of trade in *intermediate* products; for an overview of literature on *final* goods trade and structural change see Section 2.3.

Although intermediate trade is often perceived as a modern phenomenon, where e.g. some complex machine-parts are provided by foreign suppliers, it is nothing new. In fact, the first goods which were "traded" – e.g. gold, silver, spices and cloth/silk – were intermediates.[1] Moreover, the importance of intermediate trade is emphasised by the fact that technological progress and political integration of the world allow for increasing international fragmentation of production processes; for evidence see e.g. Hummels et al. (2001). For example, the latest wave of globalization – trade in intermediate services – is related to innovations in information and communication technology, which has been discussed extensively in theory

[1] Rather than being consumed directly, these goods were/are used to produce final goods: gold is used to produce jewellery or coins, spices are used to cook meals and silk is used to produce clothes.

and policy under the headlines "offshoring" and "the next industrial revolution" in the last years; see e.g. Blinder (2006) and Mankiw and Swagel (2006). For an overview of intermediate-trade literature see Section 2.1.

All in all, we analyse the impacts of intermediate imports on the structural change dynamics in the domestic economy. The analysis of this topic requires integrating intermediate trade into a multi-sector growth model. As discussed in Section 2.2.1, there are various structural change models. Our model is based on the "new structural change school" and, in particular, on the Ngai-Pissarides-(2007)-model, since their approach of analysis allows for analytical study of structural change dynamics by analysing dynamic equilibriums of "auxiliary systems". For a detailed discussion/comparison see Section 2.2.2.

In addition, our paper is related to the papers by Uzawa (1964), Baumol (1967), Echevarria (1995), Matsuyama (2009), Rodriguez-Clare (2010) and Yi and Zhang (2011). These papers are discussed and integrated into a broader literature overview in the next section.

The most obvious difference between autarky and open economy is the fact that trade-specialisation determines the sector structure of open economy: open economy specialises in the production of some goods; thus, the sectors which produce these goods feature a relatively great employment share in open economy in comparison to autarky. This specialisation-related structural change is, in general, country-specific. We focus on structural change which is independent of country-specific factors.

The starting point of our analysis is the fact that economies which import intermediates feature relatively high productivity growth in comparison to autarkic economies; for empirical evidence see, e.g., Amiti and Konings (2007), Kasahara and Rodrigue (2008), Amit and Wei (2009) and Goldberg et al. (2010). There are several "microfoundations" of this fact in the literature; for example, the availability of foreign intermediates accelerates (intermediate) product innovation; cf. Goldberg et al. (2010). We choose the simplest microfoundation by assuming that sectoral productivity growth rates differ across trading countries. The productivity growth impacts of intermediate trade imply structural changes: A high (intermediate) productivity growth rate is associated with a high rate of capital-accumulation. Thus, the share of employment devoted to the capital (consumption) sector is relatively great (small) in open economy in comparison to autarky. This effect implies that consumption-demand-patterns are less relevant for domestic labour-allocation in open economy; thus, structural change is relatively slow in open economy in comparison to autarky, where changes in consumption-demand are a key driver of structural change.

These effects have important implications. They imply that employment share of manufacturing sector is relatively great and process of tertiarisation is relatively slow in open economy in comparison to autarky. Thus, empirical analyses of structural change should take account of changes in the global environment (which allow for new ways of intermediate trade) and cross-country differences in intermediate imports; see also Section 6.2.

The paper is set up as follows: In the next section we discuss the relevant literature. In Section 3 we present our models of autarkic and open economy. We compare the structural change dynamics of these two models in Section 4. Section 5 is devoted to the discussion of our results. Section 6 concludes the discussion and provides some topics for further research.

2. Literature

2.1 Literature on Intermediate Trade

There is a lot of trade literature which is related to intermediate trade. Recent examples of this literature include: Jones and Kierzkowski (2001), Bhagwati et al. (2004), Samuelson (2004), Grossman and Helpman (2005), Markusen et al. (2005), Antràs et al. (2006), Choi (2007), Grossman and Rossi-Hansberg (2008) and Rodriguez-Clare (2010).

The focus of these papers is different from ours: they study specialisation patterns, terms-of-trade-development and factor-price-changes associated with intermediate trade. In contrast, we are interested in structural change dynamics. Nevertheless, among this literature the paper by Rodriguez-Clare (2010) is the one which's framework (a *dynamic* Ricardian model) shares the most similarities with ours. Rodriguez-Clare (2010) does not incorporate capital into analysis; capital accumulation is essential for all our results.

2.2 Literature on Structural Change

2.2.1 Theoretical Literature and Evidence

We distinguish here between two types of structural change: a) factor reallocation across consumption sector and capital sector and b) factor reallocation across heterogeneous consumption industries:

a) Uzawa (1964) and Boldrin (1988) present growth models where capital and consumption goods are produced in different sectors. Furthermore, there are some newer models of structural change which feature endogenous capital accumulation, e.g. the models by Echevarria (1997, 2000), Kongsamut et al. (2001), Ngai and Pissarides (2007), Acemoglu and Guerrieri (2008) and Stijepic and Wagner (2012a,b). Although these papers do not focus on consumption-capital-structural change, most of them, and especially Ngai and Pissarides (2007), discuss the impact of capital accumulation on factor allocation.

b) In general, changes in consumption structure are modelled by assuming non-homothetic preferences and/or cross-sector technology-variation. This literature has long tradition in economics. An overview of early empirical and anecdotal structural change literature is provided by Kongsamut et al. (2001), Schettkat and Yocarini (2006) and Krueger (2008). Theoretical models of factor reallocation across consumption sectors are presented by, e.g., Baumol (1967), Gundlach (1994), Echevarria (1997, 2000), Kongsamut et al. (2001), Meckl (2002), Steger (2006), Sasaki (2007), Ngai and Pissarides (2007, 2008), Acemoglu and Guerrieri (2008), Foellmi and Zweimüller (2008) and Stijepic and Wagner (2012a,b). For overview see Stijepic (2011), Chapter IV.

For evidence of structural change see, e.g., Robinson (1971), Baumol et al. (1985), Maddison (1987), Dowrick and Gemmel (1991), Bernard and Jones (1996), Broadberry (1997,1998), Foster et al. (1998), Berthélmy and Soederling (1999), Poirson (2000), Caselli and Coleman (2001), Temple (2001), Disney et al. (2003), Peneder (2003), Broadberry and Irwin (2006), Schettkat and Yocarini (2006), UN (2006), Nordhaus (2008), Restuccia et al. (2008), Duarte and Restuccia (2010) and McMillan and Rodrik (2011).

Discussion of structural change within the services sector in advanced economies is provided by, e.g., Peneder et al. (2001) and Kapur (2012).

2.2.2 New Structural Change School and the Relation to our Model

Our results cannot be derived in models without capital accumulation. Furthermore, the analysis of structural change in models with capital accumulation tends to be complicated due to the unbalanced nature of structural change; cf. Kongsamut et al. (2001). Some newer structural change models – especially the models by Kongsamut et al. (2001), Ngai and Pissarides (2007) and Stijepic and Wagner (2012a) – seem to be predestined for our purposes: they feature capital accumulation; furthermore, their focus on "auxiliary/aggregate balanced growth paths" simplifies the analysis of structural change considerably. Among these models, the Ngai-Pissarides-(2007)-model is most simple/elegant and satisfies all our requirements. Ngai and Pissarides (2007) show that, if CES-utility and Cobb-Douglas production functions are assumed, aggregate balanced growth paths exist. We use this idea, i.e. we assume CES-utility and Cobb-Douglas production functions. However, in contrast/comparison to Ngai and Pissarides (2007), our model features intermediate trade and a different sector structure.

2.3 Literature on Trade and Structural Change

Some newer essays focus on merging trade theory with structural change theory. This literature deals with final goods trade, not intermediate trade. Nevertheless, it supports our opinion that the effects of globalization on structural change should be analysed. Examples of this literature are: Echevarria (1995), Rowthorn and Ramaswamy (1999), Fagerberg (2000), Hsieh and Klenow (2007), Matsuyama (2009) and Yi and Zhang (2011). For detailed literature-overview see Yi and Zhang (2011).

Among these essays, the models by Echevarria (1995) and Yi and Zhang (2011) share the most similarities with our model: Like Echevarria (1995), we assume an open economy structural change model with capital accumulation and abstract from international factor mobility. In contrast to Echevarria (1995), we analyse the impacts of intermediate trade (not final goods trade); our model setting, analytical approach and focus of analysis (results) are different in comparison to Echevarria (1995). Yi and Zhang (2011) base their analysis on the Ngai-Pissarides-(2007)-model, like us. However, in contrast to us, Yi and Zhang (2011) focus on final goods trade (not intermediate trade) and on reproducing some stylized facts of structural change ("hump-shaped" pattern of manufacturing employment). Their model-extensions include capital or intermediates, however, not at the same time; thus, none of our results is discussed in their paper.

3. Models of Open and Autarkic Economy

In this section we present two versions of the multi-sector Ramsey-Cass-Koopmans model: an autarkic model and a model with intermediate trade.

3.1 Assumptions

Households

Assume that there is an autarkic economy and an open economy. Let index $j = \text{A,O}$ denote the type of economy: "A" is for autarky (economy A) and "O" is for open economy (economy O). The marginalistic representative household in economy j seeks to maximize its life-time utility (U^j) by consuming three types of goods ($i = 1,2,3$); $j = \mathrm{A,O}$. We assume the CES-type utility-function suggested by Ngai and Pissarides (2007):

(1) $$\max_{C_{1t},C_{2t},C_{3t}} U^j = \int_0^{\infty} \ln(C_t^j)\exp(-\rho t)dt \qquad j = \mathrm{A,O}$$

where

(2) $$C_t^j := \left(\sum_{i=1}^{3} \omega_i (C_{it}^j)^{(\varepsilon-1)/\varepsilon} \right)^{\varepsilon/(\varepsilon-1)} \qquad j = \mathrm{A,O}$$

(3) $$0 < \varepsilon < 1; \quad \rho, \omega_i > 0 \quad i = 1,2,3$$

(4) $$\sum_{i=1}^{3} \omega_i = 1$$

where: t is the time-index. C_{it}^j is consumption of good i at time t in economy j; $j = \mathrm{A,O}$. ρ is the time preference rate. We assume that elasticity of substitution $\varepsilon < 1$, since only this parameter-setting generates structural change patterns which are consistent with empirical evidence; see Ngai and Pissarides (2007) for details.

The budget constraint of the representative household in economy j is given by:

(5) $$\dot{W}_t^j = w_t^j L_t^j + R_t^j W_t^j - \sum_{i=1}^{3} p_{it}^j C_{it}^j \qquad j = \mathrm{A,O}$$

where W_t^j is the wealth of the household at time t in economy j, w_t^j is the wage-rate at time t in economy j, R_t^j is the interest rate at time t in economy j, p_{it}^j is the price of consumption-good i at time t in economy j, L_t^j is labour supply at time t in economy j; $j = \mathrm{A,O}$. W_t^j at time $t = 0$ is given by W_0^j, which is exogenous; $j = \mathrm{A,O}$. We assume that labour-supply in both economies is equal and grows at exogenous rate γ_L:

(6) $$L_t^{\mathrm{A}} = L_t^{\mathrm{O}} = L_t, \quad \dot{L}_t = \gamma_L L_t$$

The representative household in economy j maximizes U^j subject to (1)-(6); $j = \mathrm{A,O}$.

Production structures

The entrepreneurs in economy *j* produce consumption goods (C_{it}^{j}), capital (K_t^{j}) and domestic intermediates D (D_t^{j}); $j = \mathrm{A,O}$. There is a further type of domestic intermediates: intermediates H. Autarky-entrepreneurs produce domestic intermediates H (H_t^{A}). Open-economy-entrepreneurs do not produce intermediates H (but import a substitute, as we will see later). Open-economy entrepreneurs produce export goods (E_t^{O}). Each of these goods is produced in a corresponding sector, i.e. the consumption good *i* is produced in "consumption-sector i", capital is produced in "sector K", intermediates D are produced in "sector D", intermediates H are produced in "sector H" and export goods are produced in "sector E":

(7) $C_{it}^{j} = Y_{it}^{j}, \quad i = 1,2,3 \quad j = \mathrm{A,O}$

(8) $\dot{K}_t^{j} + \delta K_t^{j} = Y_{\mathrm{K}t}^{j} \qquad j = \mathrm{A,O}$

(9) $D_t^{j} = Y_{\mathrm{D}t}^{j} \qquad j = \mathrm{A,O}$

(10a) $H_t^{\mathrm{A}} = Y_{\mathrm{H}t}^{\mathrm{A}}$

(10b) $E_t^{\mathrm{O}} = Y_{\mathrm{E}t}^{\mathrm{O}}$

where: Y_{it}^{j}, $Y_{\mathrm{K}t}^{j}$ and $Y_{\mathrm{D}t}^{j}$ denote respectively output of consumption-sector i ($i = 1,2,3$), output of sector K and output of sector D at time *t* in economy j; $j = \mathrm{A,O}$. $Y_{\mathrm{H}t}^{\mathrm{A}}$ and $Y_{\mathrm{E}t}^{\mathrm{O}}$ denote respectively output of sector H in economy A and output of sector E in economy O at time *t*. K_t^{j} and D_t^{j} denote respectively the aggregate amount of capital and intermediates D available in economy j at time *t*; $j = \mathrm{A,O}$. E_t^{O} denotes the aggregate amount of export goods available in economy O at time *t*. H_t^{A} denotes the aggregate amount of intermediates H available in economy A at time *t*. δ is the depreciation rate on capital.

The entrepreneurs in economy j use labour (L_t^{j}), capital (K_t^{j}) and intermediates D (D_t^{j}) as inputs; $j = \mathrm{A,O}$. Furthermore, economy-O-entrepreneurs use foreign intermediates F (F_t^{O})

and economy-A-entrepreneurs use intermediates H as inputs; i.e. foreign intermediates F and domestic intermediates H are substitutes. We assume Cobb-Douglas production functions:

(11a) $Y_{it}^{A} = B_{it}(l_{it}^{A}L_{t})^{\alpha_L}(k_{it}^{A}K_{t}^{A})^{\alpha_K}(d_{it}^{A}D_{t}^{A})^{\alpha_D}(h_{it}^{A}H_{t}^{A})^{\alpha_H}, \quad i = 1,2,3,K,D,H$

(11b) $Y_{it}^{O} = B_{it}(l_{it}^{O}L_{t})^{\alpha_L}(k_{it}^{O}K_{t}^{O})^{\alpha_K}(d_{it}^{O}D_{t}^{O})^{\alpha_D}(f_{it}^{O}F_{t}^{O})^{\alpha_H}, \quad i = 1,2,3,K,D,E$

$$\alpha_L, \alpha_K, \alpha_D, \alpha_H > 0, \qquad \alpha_L + \alpha_K + \alpha_D + \alpha_H = 1$$

where: F_t^{O} is the aggregate amount of intermediates F available in economy O at time *t*. l_{it}^{j} is the share of L_t^{j} devoted to sector *i* at time *t* in economy *j*, k_{it}^{j} is the share of K_t^{j} devoted to sector *i* at time *t* in economy *j* and d_{it}^{j} is the share of D_t^{j} devoted to sector *i* at time *t* in economy *j*; $j = A,O$. h_{it}^{A} is the share of H_t^{A} devoted to sector *i* in economy A and f_{it}^{O} is the share of F_t^{O} devoted to sector *i* in economy O at time *t*. B_{it} is the productivity parameter of sector *i* at time *t*; it grows at exogenous rate γ_i:

(12) $\dot{B}_{it} = \gamma_i B_{it}, \quad i = 1,2,3,K,D,H,E$

These assumptions have some important implications/background:

a) Equations (11) and (12) imply that growth rate of total-factor-productivity (TFP) differs across sectors. This is an important source of structural change, as discussed later.

b) TFP-growth rates of consumption sectors, capital sector and domestic intermediate sector D do not differ between autarky and open economy. We make this assumption for simplicity; it does not reduce the validity of our key results.

c) In reality, some intermediates are non-tradable and some tradable intermediates may not be imported due to high transportation costs and/or low (high) quality (price) of foreign intermediates. Thus, open economy uses foreign *and* domestic intermediates; cf. eq. (11b).

d) It makes sense to assume that tradable and non-tradable intermediates are essential and substitutable to some extent; see also e.g. Desai et al. (2005) and Hanson et al. (2003). Thus, we use Cobb-Douglas-type linkage between D_t^{O} and F_t^{O} in equation (11b).

e) Equation (11) implies that output-elasticity of intermediates F is the same as output-elasticity of intermediates H (α_H); i.e. F and H are perfect substitutes; see Section 5.3.

We assume that there is perfect factor mobility across and within sectors and that each sector is polypolistic. Thus, a representative marginalistic producer in sector i in economy j maximizes its profit Π_{it}^{j} as follows ($j = \mathrm{A,O}$):

(13a) $$\max_{l_{it}^{\mathrm{A}},k_{it}^{\mathrm{A}},d_{it}^{\mathrm{A}},h_{it}^{\mathrm{A}}} \Pi_{it}^{\mathrm{A}} = p_{it}^{\mathrm{A}}Y_{it}^{\mathrm{A}} - (r_t^{\mathrm{A}} + \delta)p_{\mathrm{K}t}^{\mathrm{A}}k_{it}^{\mathrm{A}}K_t^{\mathrm{A}} - w_t^{\mathrm{A}}l_{it}^{\mathrm{A}}L_t - p_{\mathrm{D}t}^{\mathrm{A}}d_{it}^{\mathrm{A}}D_t^{\mathrm{A}} - p_{\mathrm{H}t}^{\mathrm{A}}h_{it}^{\mathrm{A}}H_t^{\mathrm{A}}$$

$i = 1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}$

(13b) $$\max_{l_{it}^{\mathrm{O}},k_{it}^{\mathrm{O}},d_{it}^{\mathrm{O}},f_{it}^{\mathrm{O}}} \Pi_{it}^{\mathrm{O}} = p_{it}^{\mathrm{O}}Y_{it}^{\mathrm{O}} - (r_t^{\mathrm{O}} + \delta)p_{\mathrm{K}t}^{\mathrm{O}}k_{it}^{\mathrm{O}}K_t^{\mathrm{O}} - w_t^{\mathrm{O}}l_{it}^{\mathrm{O}}L_t - p_{\mathrm{D}t}^{\mathrm{O}}d_{it}^{\mathrm{O}}D_t^{\mathrm{O}} - p_{\mathrm{F}t}^{\mathrm{O}}f_{it}^{\mathrm{O}}F_t^{\mathrm{O}}$$

$i = 1,2,3,\mathrm{K},\mathrm{D},\mathrm{E}$

where: r_t^j is the rental rate of capital at time t in economy j; $j = \mathrm{A,O}$. $p_{\mathrm{K}t}^{j}$ and $p_{\mathrm{D}t}^{j}$ denote respectively the prices of capital and intermediates D at time t in economy j; $j = \mathrm{A,O}$. $p_{\mathrm{H}t}^{\mathrm{A}}$ is the price of intermediates H at time t in economy A. $p_{\mathrm{E}t}^{\mathrm{O}}$ and $p_{\mathrm{F}t}^{\mathrm{O}}$ denote respectively the prices of export goods and intermediates F at time t in economy j; $j = \mathrm{A,O}$.

Trade structures

The autarkic economy does not trade. To isolate the impacts of intermediate trade in open economy we abstract from any trade or financial flows not associated with intermediate trade in open economy. Especially, we do not allow for investment into foreign assets or accumulation of foreign debt. Thus, domestic wealth is invested in domestic capital only:

(14) $W_t^j = p_{\mathrm{K}t}^{j}K_t^j$ and $R_t^j = r_t^j$ for $j = \mathrm{A,O}$.

We assume that $p_{\mathrm{F}t}^{\mathrm{O}}$ is the "effective price" of foreign intermediates, i.e. it includes transportation costs, losses due to low quality, etc. The growth rate of $p_{\mathrm{F}t}^{\mathrm{O}}$ is exogenous:

(15) $\dot{p}_{\mathrm{F}t}^{\mathrm{O}} = \gamma_F p_{\mathrm{F}t}^{\mathrm{O}}$

Since we abstract from any balance-of-payments imbalances, intermediate imports (F_t^{O}) must be “paid by” exports (E_t^{O}). Thus:

(16) $p_{\mathrm{F}t}^{\mathrm{O}} F_t^{\mathrm{O}} = p_{\mathrm{E}t}^{\mathrm{O}} E_t^{\mathrm{O}}$.

Market clearing

By now we have implicitly assumed clearing of several markets, in particular, domestic goods and intermediates markets (cf. eq. 7-10), financial market (cf. eq. 14) and international relations (cf. eq. 16). The following assumptions, which imply factor-market clearing, complete the set of market clearing conditions:

(17a) $\sum_{i=1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}} l_{it}^{\mathrm{A}} = 1$

(17b) $\sum_{i=1,2,3,\mathrm{K},\mathrm{D},\mathrm{E}} l_{\mathrm{it}}^{\mathrm{O}} = 1$

(18a) $\sum_{i=1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}} k_{it}^{\mathrm{A}} = 1$

(18b) $\sum_{i=1,2,3,\mathrm{K},\mathrm{D},\mathrm{E}} k_{it}^{\mathrm{O}} = 1$

(19a) $\sum_{i=1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}} d_{it}^{\mathrm{A}} = 1$

(19b) $\sum_{i=1,2,3,\mathrm{K},\mathrm{D},\mathrm{E}} d_{it}^{\mathrm{O}} = 1$

(20a) $\sum_{i=1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}} h_{it}^{\mathrm{A}} = 1$

(20b) $\sum_{i=1,2,3,\mathrm{K},\mathrm{D},\mathrm{E}} f_{it}^{\mathrm{O}} = 1$

These assumptions, which imply that all factors available in economy *j* are used in production in economy *j*, are similar to those made in a lot of newer structural change literature, e.g. Kongsamut et al. (2001) and Ngai and Pissarides (2007).

Numéraire

Capital is numéraire, i.e.

(21) $p_{Kt}^{j} = 1, \quad \forall t, \quad j = \mathrm{A,O}$

Thus, all prices, including p_{Ft}^{O}, are expressed in "units of capital".

3.2 Optimum, Equilibrium and Dynamic Equilibrium

Lemma 1: *The solution of household's utility-maximization problem (eq. 1-6) implies the following necessary and sufficient optimality conditions:*

(22) $p_{it}^{j} / p_{zt}^{j} = u_{it}^{j} / u_{zt}^{j} \qquad i,z = 1,2,3 \qquad j = \mathrm{A,O}$

(23) $-\dot{u}_{it}^{j} / u_{it}^{j} + \dot{p}_{it}^{j} / p_{it}^{j} = R_t^{j} - \rho \qquad i = 1,2,3 \qquad j = \mathrm{A,O}$

and equation (5), where $u_{it}^{j} := (\partial \ln C_t^{j})/(\partial C_{it}^{j})$ *and* $\dot{u}_{it}^{j} := (\partial u_{it}^{j})/(\partial t)$.

Proof: Prices ($p_{it}^{j}, w_t^{j}, R_t^{j}$) are exogenous to the representative households, since households are marginalistic. Thus, the maximization problem is standard. It can be solved by using the Hamiltonian. The Hamiltonian is concave; thus, the necessary conditions are sufficient. The transversality condition is given by $\lim_{t\to\infty} W_t^{j} \exp(-\rho t) = 0$. We omit here explicit proofs. ■

Lemma 2: *The solution of entrepreneur's profit-maximization problem (eq. 11-13) implies the following necessary and sufficient optimality conditions:*

(24a) $$\frac{\partial Y_{it}^{A}}{\partial (l_{it}^{A} L_t)} - \frac{w_t^{A}}{p_{it}^{A}} = \frac{\partial Y_{it}^{A}}{\partial (k_{it}^{A} K_t^{A})} - (r_t^{A} + \delta)\frac{p_{Kt}^{A}}{p_{it}^{A}} = \frac{\partial Y_{it}^{A}}{\partial (d_{it}^{A} D_t^{A})} - \frac{p_{Dt}^{A}}{p_{it}^{A}} = \frac{\partial Y_{it}^{A}}{\partial (h_{it}^{A} H_t^{A})} - \frac{p_{Ht}^{A}}{p_{it}^{A}} = 0$$

$i = 1,2,3,\mathrm{K,D,H}$.

(24b) $$\frac{\partial Y_{it}^{O}}{\partial (l_{it}^{O} L_t^{O})} - \frac{w_t^{O}}{p_{it}^{O}} = \frac{\partial Y_{it}^{O}}{\partial (k_{it}^{O} K_t^{O})} - (r_t^{O} + \delta)\frac{p_{Kt}^{O}}{p_{it}^{O}} = \frac{\partial Y_{it}^{O}}{\partial (d_{it}^{O} D_t^{O})} - \frac{p_{Dt}^{O}}{p_{it}^{O}} = \frac{\partial Y_{it}^{O}}{\partial (f_{it}^{O} F_t^{O})} - \frac{p_{Ft}^{O}}{p_{it}^{O}} = 0$$

$i = 1,2,3,\mathrm{K,D,E}$.

Proof: Prices (p_{it}^j, w_t^j, r_t^j) are exogenous to the representative entrepreneurs, since entrepreneurs are marginalistic. The rest of the proof is obvious, since standard. ■

Remark 1: Now we have to use the equations from Section 3.1 to transform the optimality conditions (Lemma 1 and 2) into dynamic equations describing our "variables of interest" (sectoral employment shares). As we will see, the dynamics of our variables of interest are determined by exogenous parameters and by some variables which we name "auxiliary variables". Thus, in the following we approach as follows: First, we define an "auxiliary system" and we derive the differential equation system which describes its dynamics. We are not interested in the interpretation of this system (due to space restrictions); we simply show that a globally stable dynamic equilibrium of this system exists. Then we show that the dynamics of our "variables of interest" are determined by the dynamics of the "auxiliary system". In the dynamic equilibrium of our "auxiliary system" the dynamics of the "variables of interest" are very easy to study. This approach is nothing new. It has been used by Kongsamut et al. (2001) and Ngai and Pissarides (2007) in structural change modelling. However, in contrast to us, those authors are interested in the interpretation of their "auxiliary system"; thus, in fact their "auxiliary system" is not auxiliary but of interest.

Definition 1: *The "auxiliary system of economy j" ($\overline{C}_t^j, K_t^j, s_t^j$) is defined by* $\overline{C}_t^j := C_t^j \Phi_t$ *and*

$$s_t^j := \alpha_L + \alpha_K - \overline{C}_t^j / \left(\Psi_t^j L_t^{\overline{\alpha}} (K_t^j)^{1-\overline{\alpha}} \right), \quad \textit{where} \quad \Phi_t := B_{\mathrm{K}t} \left(\sum_{i=1}^{3} \omega_i^{\varepsilon} B_{it}^{\varepsilon - 1} \right)^{1/(1-\varepsilon)}, \quad \overline{\alpha} := \alpha_L / (\alpha_L + \alpha_K),$$

$$\Psi_t^{\mathrm{A}} := \left[\alpha_D^{\alpha_D} \alpha_H^{\alpha_H} B_{\mathrm{K}t} \left(\frac{B_{\mathrm{D}t}}{B_{\mathrm{K}t}} \right)^{\alpha_D} \left(\frac{B_{\mathrm{H}t}}{B_{\mathrm{K}t}} \right)^{\alpha_H} \right]^{\frac{1}{\alpha_L + \alpha_K}} \quad \textit{and} \quad \Psi_t^{\mathrm{O}} := \left[\alpha_D^{\alpha_D} \alpha_H^{\alpha_H} B_{\mathrm{K}t} \left(\frac{B_{\mathrm{D}t}}{B_{\mathrm{K}t}} \right)^{\alpha_D} p_{\mathrm{F}t}^{-\alpha_H} \right]^{\frac{1}{\alpha_L + \alpha_K}}$$

are functions of exogenous parameters; $j = \mathrm{A}, \mathrm{O}$.

Remark 2: As we will see later s_t^j is the savings rate.

Lemma 3: *The dynamics of the "auxiliary system of economy j" (cf. Definition 1) are determined by the following differential equation system:*

(25) $\dot{K}_t^j = (\alpha_L + \alpha_K)\Psi_t^j L_t^{\overline{\alpha}} (K_t^j)^{1-\overline{\alpha}} - \overline{C}_t^j - \delta K_t^j$

(26) $\dot{\overline{C}}_t^j / \overline{C}_t^j = \alpha_K \Psi_t^j L_t^{\overline{\alpha}} (K_t^j)^{-\overline{\alpha}} - \delta - \rho$

where $s_t^j := \alpha_L + \alpha_K - \overline{C}_t^j / \left(\Psi_t^j L_t^{\overline{\alpha}} (K_t^j)^{1-\overline{\alpha}}\right)$ *as defined in Definition 1;* $j = \mathrm{A,O}$.

Proof: Optimality conditions (5) and (22)-(24) can be transformed into equations (25)/(26) by using the equations from the previous section. For explicit proof see APPENDIX A. ■

Lemma 4: a) *The auxiliary system of economy j features a globally stable dynamic equilibrium in which variables* $\overline{C}_t^j$ *and* K_t^j *grow at the constant rate* γ^{j*}, $j = \mathrm{A,O}$, *where*

(27a) $\gamma^{\mathrm{A}*} := \gamma_L + [\gamma_{\mathrm{K}} + \alpha_D(\gamma_{\mathrm{D}} - \gamma_{\mathrm{K}}) + \alpha_H(\gamma_{\mathrm{H}} - \gamma_{\mathrm{K}})] / \alpha_L$

(27b) $\gamma^{\mathrm{O}*} := \gamma_L + [\gamma_{\mathrm{K}} + \alpha_D(\gamma_{\mathrm{D}} - \gamma_{\mathrm{K}}) - \alpha_H \gamma_{\mathrm{F}}] / \alpha_L$

b) *In dynamic equilibrium,* s_t^j *is given by*

(28) $s^{j*} = \alpha_K(\gamma^{j*} + \delta)/(\gamma^{j*} + \delta + \rho) \qquad j = \mathrm{A,O}$.

c) *If* $K_0^j = \left[\alpha_K \Psi_0^j L_0^{\overline{\alpha}} / (\gamma^{j*} + \delta + \rho)\right]^{1/\overline{\alpha}}$, *the economy j is in dynamic equilibrium;* $j = \mathrm{A,O}$. *Otherwise it converges to the dynamic equilibrium (transition phase).*

Proof: The system (25)-(26) is formally nearly identical to the differential equation system of the textbook Ramsey-model. Furthermore, the interpretation of the variables is similar to the interpretation of the Ramsey-model-variables: K_t^j is an index of capital and $\overline{C}_t^j$ is an index of utility from consumption (cf. eq. 1 and 2 and Definition 1). Thus, the proof of existence and stability of the dynamic equilibrium (part a of Lemma 4) is identical to the corresponding proof in the Ramsey-model; the latter is discussed in detail by e.g. Barro and Sala-i-Martin (2004). Use Lemma 3 and Lemma 4a to prove Lemmas 4b and c. ■

Definition 2: *We name the dynamic equilibrium (Lemma 4) "partially balanced growth path" (abbreviated "PBGP").*

Lemma 5: *Sectoral factor-input-shares and prices in market clearing optimum are given by:*

(29) $l_{it}^{j} = (\alpha_L + \alpha_K - s_t^j) B_{it}^{\varepsilon-1} \omega_i^{\varepsilon} / \left(\sum_{x=1}^{3} \omega_x^{\varepsilon} B_{xt}^{\varepsilon-1} \right) \qquad i = 1,2,3 \quad j = \mathrm{A,O}$

(30) $l_{\mathrm{K}t}^{j} = s_t^j \qquad j = \mathrm{A,O}$

(31) $l_{\mathrm{D}t}^{j} = \alpha_D \qquad j = \mathrm{A,O}$

(32a) $l_{\mathrm{H}t}^{\mathrm{A}} = \alpha_H$

(32b) $l_{\mathrm{E}t}^{\mathrm{O}} = \alpha_H$

(33a) $l_{it}^{\mathrm{A}} = k_{it}^{\mathrm{A}} = d_{it}^{\mathrm{A}} = h_{it}^{\mathrm{A}} \qquad i = 1,2,3,\mathrm{K,D,H}$

(33b) $l_{it}^{\mathrm{O}} = k_{it}^{\mathrm{O}} = d_{it}^{\mathrm{O}} = f_{it}^{\mathrm{O}} \qquad i = 1,2,3,\mathrm{K,D,E}$

(34a) $p_{it}^{\mathrm{A}} = B_{\mathrm{K}t} / B_{it}, \qquad i = 1,2,3,\mathrm{K,D,H}$

(34b) $p_{it}^{\mathrm{O}} = B_{\mathrm{K}t} / B_{it} \qquad i = 1,2,3,\mathrm{K,D,E}.$

Proof: The optimality conditions (5) and (22)-(24) can be transformed into these equations by using the equations from the previous section. For explicit proof see APPENDIX A. ■

Remark 3: a) We can see that sectoral factor-input-shares are functions of exogenous parameters and of our auxiliary system. Therefore, we have studied first the dynamics of the auxiliary system, which will help us later to study the dynamics of factor-inputs. **b)** The interpretation of equations (29) and (30) is discussed extensively in the remaining part of this section. **c)** Equations (31) and (32a) seem to be plausible: the higher the economy-wide output-elasticity of domestic intermediates (α_D, α_H), the more domestic intermediates are used in optimum and, thus, the more labour is employed in domestic intermediates production. **d)** The interpretation of equation (32b) is similar: the higher the output-elasticity of foreign intermediates (α_H), the more foreign intermediates are used in the economy and, thus, the more labour must be employed in export sector in order to produce export goods which are used to "pay" for foreign intermediates. **e)** Equation (33) implies that the dynamics of capital-shares, domestic intermediates-shares and foreign intermediate-shares are the same as the dynamics of employment shares. Thus, in the following discussion we can focus on employment shares. **f)** Equation (34) implies that relative prices (expressed in capital-units) are determined by sectoral TFP's. This result has been derived by Ngai and Pissarides (2007) as well. In fact, it is obvious: due to inter-sector factor-mobility, all sectors have the same factor-prices; thus, sectors with high level of TFP are able to set lower prices in comparison to sectors with low TFP and they do so because of perfect competition within sectors. **g)** Note that equations (31)-(34) are relatively simple because of the assumption of Cobb-Douglas-production functions and absence of inter-sector differences in output-elasticities of inputs. As discussed in Section 6.3, these simplifying assumptions do not affect the validity of our key results.

Definition 3: a) $l_{\mathrm{C}t}^j := l_{1t}^j + l_{2t}^j + l_{3t}^j$ *is the employment share of consumption sector in economy j;* $j = \mathrm{A,O}$. ***b)*** *Consumption-capital labour allocation (abbr. "C-K-allocation") in economy j is given by* $(l_{\mathrm{K}t}^j, l_{\mathrm{C}t}^j)$*;* $j = \mathrm{A,O}$. ***c)*** *Labour-allocation in consumption sector (abbr. "C-allocation") in economy j is given by* $(l_{1t}^j / l_{\mathrm{C}t}^j, l_{2t}^j / l_{\mathrm{C}t}^j, l_{3t}^j / l_{\mathrm{C}t}^j)$*;* $j = \mathrm{A,O}$. ***d)*** *"Change of the consumption-capital labour-allocation" (abbr. "C-K-structural change") in economy j means* $\dot{l}_{\mathrm{K}t}^j / l_{\mathrm{K}t}^j \neq \dot{l}_{\mathrm{C}t}^j / l_{\mathrm{C}t}^j$*;* $j = \mathrm{A,O}$. ***e)*** *"Structural change in consumption sector" (abbr. "C-structural change") in economy j means* $\dot{l}_{1t}^j / l_{1t}^j \neq \dot{l}_{2t}^j / l_{2t}^j \neq \dot{l}_{3t}^j / l_{3t}^j$*;* $j = \mathrm{A,O}$.

Remark 4: a) Since $(l_{it}^{j}L_t)/(l_{Ct}^{j}L_t)=l_{it}^{j}/l_{Ct}^{j}$, C-allocation indicates how labour devoted to consumption sector ($l_{Ct}^{j}L_t$) is allocated across consumption sectors *i, i*=1,2,3. **b)** If C-structural change takes place, some consumption sectors become more important (in terms of employment) in comparison to other consumption sectors over time. **c)** Since l_{Dt}^{O}, l_{Dt}^{A}, l_{Ht}^{A} and l_{Et}^{O} are constant (cf. eq. 31, 32), C-K-structural change is associated with reallocation of labour from consumption sector to capital sector or vice versa (cf. eq. 17).

Definition 4: *The savings rate in autarkic economy is given by* $(\dot{K}_t^{\mathrm{A}}+\delta K_t^{\mathrm{A}})/\sum_{i=1,2,3,\mathrm{K,D,H}} p_{it}^{\mathrm{A}}Y_{it}^{\mathrm{A}}$. *The savings rate in open economy is given by* $(\dot{K}_t^{\mathrm{O}}+\delta K_t^{\mathrm{O}})/\sum_{i=1,2,3,\mathrm{K,D,E}} p_{it}^{\mathrm{O}}Y_{it}^{\mathrm{O}}$.

Remark 5: Since all savings have to be invested in capital in our model, savings correspond to capital investment. We relate these savings to gross output (denominator). Note that nominator and denominator are expressed in capital-units (cf. eq. 21). Furthermore, it is more or less irrelevant for the discussion in our paper whether we use net output (i.e. output without intermediates) instead of gross output.

Lemma 6: *The savings-rate in economy j (cf. Definition 4) is equal to* s_t^{j}*;* $j=\mathrm{A,O}$.

Proof: Equation (24) and Definition 1 imply after some algebra $\sum_{i=1,2,3,\mathrm{K,D,E}} p_{it}^{\mathrm{O}}Y_{it}^{\mathrm{O}}=\Psi_t^{\mathrm{O}}L_t^{\overline{\alpha}}(K_t^{\mathrm{O}})^{1-\overline{\alpha}}$ and $\sum_{i=1,2,3,\mathrm{K,D,H}} p_{it}^{\mathrm{A}}Y_{it}^{\mathrm{A}}=\Psi_t^{\mathrm{A}}L_t^{\overline{\alpha}}(K_t^{\mathrm{A}})^{1-\overline{\alpha}}$. This fact, Lemma 3 and Definition 4 can be used derive Lemma 6. See APPENDIX A for explicit proof. ■

Lemma 7: a) *C-structural change takes place if and only if TFP-growth rates differ across consumption sectors* ($\gamma_1\neq\gamma_2\neq\gamma_3$). ***b)*** *C-K-structural change is driven by changes in the* *savings-rate (s_t^j): (i) if $\dot{s}_t^j = 0$, $\dot{l}_{Kt}^j = \dot{l}_{Ct}^j = 0$; (ii) if $\dot{s}_t^j > 0$, $\dot{l}_{Ct}^j < 0$ and $\dot{l}_{Kt}^j > 0$; (iii) if $\dot{s}_t^j < 0$, $\dot{l}_{Ct}^j > 0$ and $\dot{l}_{Kt}^j < 0$; $j = \text{A,O}$.*

Proof: Equations (12) and (29) imply that $\dot{l}_{1t}^j / l_{1t}^j \neq \dot{l}_{2t}^j / l_{2t}^j \neq \dot{l}_{3t}^j / l_{3t}^j$, if and only if $\gamma_1 \neq \gamma_2 \neq \gamma_3$, $j = \text{A,O}$. This fact proves part a of the lemma. Equation (29) and Definition 3a imply

(35) $\quad l_{Ct}^j = \alpha_L + \alpha_K - s_t^j \qquad j = \text{A,O}$

This equation and equation (30) imply part b of Lemma 7. ■

Remark 6: a) In fact, Lemma 7 is a standard result of structural change literature: part a of the lemma has been shown in other form, in particular in autarkic economy, by Baumol (1967) and Ngai and Pissarides (2007). Part b is not explicitly shown but implied by a lot of autarkic economy models, e.g. Uzawa (1964), Kongsamut et al. (2001), Ngai and Pissarides (2007) and Stijepic and Wagner (2012,a,b). **b)** Lemma 7a seems to make sense: cross-sector-differences in TFP-growth are reflected by cross-sector differences in price-growth (cf. Remark 3f), which implies cross-sector differences in demand, thus, output and, thus, employment. **c)** Lemma 7b makes sense as well: the higher the savings rate, the more capital is produced and, thus, the more labour is employed in the capital producing sector; this labour is withdrawn from the consumption sector (cf. Remark 4c). Thus, increasing savings rate is associated with reallocation of labour from consumption sector to capital sector (case ii); the explanation of cases (i) and (iii) is analogous.

***Lemma 8: a)** C-structural change takes place along the PBGP and during the transition phase. **b)** C-K-structural change takes place during the transition phase; C-K-allocation is constant along the PBGP, i.e. $\dot{l}_{Kt}^j = \dot{l}_{Ct}^j = 0$ along the PBGP of economy j; $j = A,O$.*

Proof: This lemma is implied by Definition 3 and Lemmas 4b and 7b. ■

Remark 7: This lemma is more or less obvious: **a)** Changes in relative prices occur always, since they are driven by (exogenous) TFP-growth. Thus, labour is always reallocated across consumption sectors (cf. Remark 6b). **b)** Like in the standard Ramsey-model, the savings rate changes only during the transition period and is stable in dynamic equilibrium. Hence, the employment share of capital-sector changes only during the transition period (cf. Remark 6c).

4. Impact of Intermediate Trade on Structural Change

Now we compare the structural change dynamics in autarky to the structural change dynamics in open economy. To save space we discuss in the following only the case $\dot{p}^{\mathrm{O}}_{\mathrm{F}t} / p^{\mathrm{O}}_{\mathrm{F}t} < \dot{p}^{\mathrm{A}}_{\mathrm{H}t} / p^{\mathrm{A}}_{\mathrm{H}t}$. In this case entrepreneurs have an incentive to import intermediates; see Section 5.1. For a discussion of the other case, $\dot{p}^{\mathrm{O}}_{\mathrm{F}t} / p^{\mathrm{O}}_{\mathrm{F}t} > \dot{p}^{\mathrm{A}}_{\mathrm{H}t} / p^{\mathrm{A}}_{\mathrm{H}t}$, see as well Section 5.1.

Theorem 1 (Impact of Intermediate Trade on C-K-allocation): a) *If $\dot{p}^{\mathrm{O}}_{\mathrm{F}t} / p^{\mathrm{O}}_{\mathrm{F}t} < \dot{p}^{\mathrm{A}}_{\mathrm{H}t} / p^{\mathrm{A}}_{\mathrm{H}t}$, the PBGP-savings rate in open economy is higher than the PBGP-savings rate in autarky, i.e. $s^{\mathrm{O}*} > s^{\mathrm{A}*}$.* ***b)*** *If $\dot{p}^{\mathrm{O}}_{\mathrm{F}t} / p^{\mathrm{O}}_{\mathrm{F}t} < \dot{p}^{\mathrm{A}}_{\mathrm{H}t} / p^{\mathrm{A}}_{\mathrm{H}t}$, the PBGP-rate of capital accumulation in open economy is higher than the PBGP-rate of capital accumulation in autarky, i.e. $\dot{K}^{\mathrm{O}*}_t / K^{\mathrm{O}*}_t = \gamma^{\mathrm{O}*} > \dot{K}^{\mathrm{A}*}_t / K^{\mathrm{A}*}_t = \gamma^{\mathrm{A}*}$.* ***c)*** *If $\dot{p}^{\mathrm{O}}_{\mathrm{F}t} / p^{\mathrm{O}}_{\mathrm{F}t} < \dot{p}^{\mathrm{A}}_{\mathrm{H}t} / p^{\mathrm{A}}_{\mathrm{H}t}$, the PBGP-employment share of consumption (capital) sector in open economy is smaller (greater) than the PBGP-employment share of consumption (capital) sector in autarky, i.e. $l^{\mathrm{O}*}_{\mathrm{C}} < l^{\mathrm{A}*}_{\mathrm{C}}$ and $l^{\mathrm{O}*}_{\mathrm{K}} > l^{\mathrm{A}*}_{\mathrm{K}}$.*

Proof: If $\dot{p}^{\mathrm{O}}_{\mathrm{F}t} / p^{\mathrm{O}}_{\mathrm{F}t} < \dot{p}^{\mathrm{A}}_{\mathrm{H}t} / p^{\mathrm{A}}_{\mathrm{H}t}$, $\gamma^{\mathrm{O}*} > \gamma^{\mathrm{A}*}$ (cf. eq. 12, 15, 27 and 34). Thus, Lemma 4a implies part b of Theorem 1 and Lemmas 4b and 6 imply part a of Theorem 1. Equations (30)/(35) and Theorem 1a imply Theorem 1c. ■

Remark 8: **a)** Note that it does not matter that prices are expressed in capital-units (cf. eq. 21), since Theorem 1 refers to the development of the *ratio* p_{Ft}^{O} / p_{Ht}^{A}. **b)** Theorem 1 has a simple interpretation: If the price of foreign intermediates does not grow as fast as the price of domestic intermediates H, foreign intermediates become increasingly cheaper in comparison to domestic intermediates over time, i.e. cost advantages from intermediate trade increase over time. Thus, intermediate trade acts like an increase in productivity growth, which is, like in the standard Ramsey-model, associated with an increase in the savings-rate and in the rate of capital accumulation. Thus, factors are reallocated from consumption sector to capital sector in our model (cf. Lemma 7b and Remark 6c).

Definition 5: ***a)*** *The velocity of structural change in open economy is defined by* $v_t^{O} := 1/2 \sum_{i=1,2,3,K,D,E} \left|\dot{l}_{it}^{O}\right|$. *The velocity of structural change in autarky is defined by* $v_t^{A} := 1/2 \sum_{i=1,2,3,K,D,H} \left|\dot{l}_{it}^{A}\right|$. ***b)*** *The velocity of C-structural change in economy j is defined by* $v_{Ct}^{j} := 1/2 \sum_{i=1,2,3} l_{Ct}^{j} \left|\partial(l_{it}^{j} / l_{Ct}^{j}) / \partial t\right|;\ j = \mathrm{A}, \mathrm{O}$.

Remark 9: **a)** The *velocity of structural change* indicates how many units of labour are reallocated across sectors per unit of time. We multiply the sum of $\left|\dot{l}_{it}^{j}\right|$ with 1/2 to avoid double counting: an increase in labour-share of one sector is always associated with a decrease in labour share of another sector. We use the modulus function, since the sum of $\dot{l}_{it}^{j}$ is equal to zero (cf. eq. 17). **b)** *Velocity of C-structural change* is calculated in similar manner; the key difference is that we use $l_{Ct}^{j} \left|\partial(l_{it}^{j} / l_{Ct}^{j}) / \partial t\right|$ instead of $\left|\dot{l}_{it}^{j}\right|$. The reason is simple: the measure $v_{Ct}^{j}{}' := 1/2 \sum_{i=1,2,3} \left|\dot{l}_{it}^{j}\right|$ is not a good index of velocity of reallocations *within* the consumption sector: even if labour is not reallocated within the consumption sector ($\dot{l}_{1t}^j / l_{1t}^j = \dot{l}_{2t}^j / l_{2t}^j = \dot{l}_{3t}^j / l_{3t}^j$), $v_{Ct}^j{}'$ is different from zero if $\dot{l}_{1t}^j / l_{1t}^j = \dot{l}_{2t}^j / l_{2t}^j = \dot{l}_{3t}^j / l_{3t}^j > 0$. Another important aspect is that we multiply $\left|\partial(l_{it}^j / l_{Ct}^j)/\partial t\right|$ with l_{Ct}^j. We do this, because the measure $v_{Ct}^j{}'' := 1/2 \sum_{i=1,2,3} \left| d(l_{it}^j / l_{Ct}^j)/dt \right|$ is not a good index of labour reallocation within the consumption sector, as implied by the following example. Assume that savings-rate in economy A is lower than savings rate in economy O, ceteris paribus. Thus, $l_{Ct}^{A} > l_{Ct}^{O}$ (cf. eq. 35). Nevertheless, $l_{it}^{A} / l_{Ct}^{A} = l_{it}^{O} / l_{Ct}^{O}$, $i = 1,2,3$ (cf. eq. 29 and Definition 3a), and, thus, $v_{Ct}^{A}{}'' = v_{Ct}^{O}{}''$. That is, the measure $v_{Ct}^j{}''$ indicates that velocity of C-structural change in economy A is the same as in economy O. However, the number of labour-units which are reallocated across consumption sectors per unit of time in autarkic economy is greater than the corresponding number in open economy, since a smaller share of labour is exposed to the consumption-demand dynamics in open economy, as we will see now (cf. Theorem 2 and its corollary).

Theorem 2 (Impact of Intermediate Trade on Velocity of Structural Change): *If $\dot{p}_{Ft}^{O} / p_{Ft}^{O} < \dot{p}_{Ht}^{A} / p_{Ht}^{A}$, the PBGP-velocity of (C-)structural change in open economy is lower than the PBGP-velocity of (C-)structural change in autarky, i.e. $v_t^{O*} < v_t^{A*}$ and $v_{Ct}^{O*} < v_{Ct}^{A*}$.*

Proof: Along the PBGP $\dot{l}_{Ct}^{j*} = \dot{l}_{Kt}^{j*} = \dot{l}_{Dt}^{j} = \dot{l}_{Ht}^{A} = \dot{l}_{Et}^{O} = 0$; $j = \text{A,O}$ (cf. Lemma 8b and eq. 31/32). Thus, $v_t{}^{j*} = v_{Ct}{}^{j*}$; $j = \text{A,O}$; cf. Definition 5. Equations (29) and (35) imply

$$(36) \qquad \dot{l}_{it}{}^{j*} = (1-\varepsilon) l_{Ct}^{j*} \left(\sum_{z=1}^{3} \omega_z{}^{\varepsilon} B_{zt}{}^{\varepsilon-1} \right)^{-2} \omega_i{}^{\varepsilon} B_{it}{}^{\varepsilon-1} \sum_{x=1}^{3} \omega_x{}^{\varepsilon} B_{xt}{}^{\varepsilon-1} (\gamma_x - \gamma_i) \qquad i = 1,2,3 \quad j = \text{A,O}$$

where $l_{Ct}^{j*} = \alpha_L + \alpha_K - s^{j*}$. By using Definition 5 we obtain the velocities along the PBGPs:

$$(37) \qquad v_t^{j*} = (1-\varepsilon) l_{Ct}^{j*} \left(\sum_{z=1}^{3} \omega_z{}^{\varepsilon} B_{zt}{}^{\varepsilon-1} \right)^{-2} \sum_{i=1}^{3} \left| \omega_i{}^{\varepsilon} B_{it}{}^{\varepsilon-1} \sum_{x=1}^{3} \omega_x{}^{\varepsilon} B_{xt}{}^{\varepsilon-1} (\gamma_x - \gamma_i) \right| \qquad j = \text{A,O}$$

Thus, Theorem 1c implies $v_t^{\mathrm{O}*} < v_t^{\mathrm{A}*}$. Thus, since $v_t^{j*} = v_{\mathrm{C}t}^{j*}$, $v_{\mathrm{C}t}^{\mathrm{O}*} < v_{\mathrm{C}t}^{\mathrm{A}*}$. ■

Corollary of Theorem 2 (Impact Channels): *The relatively low velocity of (C-)structural change in open economy in comparison to autarky (Theorem 2) results from the fact that savings-rate is relatively high (* $s^{\mathrm{O}*} > s^{\mathrm{A}*}$ *) and, thus, the employment share of consumption sector is relatively small (* $l_{\mathrm{C}t}^{\mathrm{O}*} < l_{\mathrm{C}t}^{\mathrm{A}*}$ *) in open economy in comparison to autarkic economy.*

Remark 10: Equation (37) implies that the difference between $v_t^{\mathrm{O}*}$ and $v_t^{\mathrm{A}*}$ comes from the difference between $l_{\mathrm{C}t}^{\mathrm{O}*}$ and $l_{\mathrm{C}t}^{\mathrm{A}*}$. Equation (35) implies that the difference between $l_{\mathrm{C}t}^{\mathrm{O}*}$ and $l_{\mathrm{C}t}^{\mathrm{A}*}$ comes from the difference between $s^{\mathrm{O}*}$ and $s^{\mathrm{A}*}$.

Remark 11 (Summary: Chain of Impacts of Intermediate Trade on Structural Change): If $\dot{p}_{\mathrm{F}t}^{\mathrm{O}} / p_{\mathrm{F}t}^{\mathrm{O}} < \dot{p}_{\mathrm{H}t}^{\mathrm{A}} / p_{\mathrm{H}t}^{\mathrm{A}}$, intermediate import is increasingly cheaper in comparison to home production and, hence, productivity-growth-enhancing. Thus, open economy has a higher savings-rate and, thus, greater capital demand in comparison to autarkic economy. Hence, open economy allocates a greater share of labour to the capital sector and a smaller share of labour to the consumption sector (cf. Theorem 1 and Remark 8b). This implies that, in open economy, a smaller share of labour-force is subject to the consumption-demand dynamics which are driven by changing prices (cf. Lemma 7a, Remark 6b). Thus, fewer units of labour are reallocated over time (along the PBGP), i.e. velocity of structural change is relatively low in open economy in comparison to autarkic economy (cf. Theorem 2 and its Corollary).

5. Discussion and Extensions

5.1 Absence of Negative Impacts of Intermediate Trade

We assumed in Section 4 that the following parameter restriction is satisfied:

(40) $\dot{p}^{\mathrm{O}}_{\mathrm{F}t} / p^{\mathrm{O}}_{\mathrm{F}t} < \dot{p}^{\mathrm{A}}_{\mathrm{H}t} / p^{\mathrm{A}}_{\mathrm{H}t}$

This parameter restriction implies that foreign intermediates are cheaper than domestic intermediates H (in the limit). Thus, entrepreneurs' profit is higher when using foreign intermediates instead of domestic intermediates H (cf. eq. 13) – remember that $p^{\mathrm{O}}_{\mathrm{F}t}$ includes transportation costs, quality losses, etc. Thus, entrepreneurs prefer foreign intermediates over domestic intermediates, i.e. intermediate trade takes place.

In the other case ($\dot{p}^{\mathrm{O}}_{\mathrm{F}t} / p^{\mathrm{O}}_{\mathrm{F}t} > \dot{p}^{\mathrm{A}}_{\mathrm{H}t} / p^{\mathrm{A}}_{\mathrm{H}t}$) intermediate imports are more expensive than domestic intermediates. Thus, entrepreneurs prefer autarky. Therefore, intermediate trade does *not* take place in this case. If it took place, its effects would be negative: profits would be lower, savings rate would be lower and (C-)structural change would be faster in comparison to autarky. (All proofs are analogous to the proofs of the previous section.)

Overall, negative impacts of intermediate trade cannot arise in our framework: if intermediate trade is inefficient, the country remains in autarky and negative impacts do not arise.

5.2 Focus on PBGP and Transitional Dynamics

Most of our analysis focused on the dynamics along PBGPs. Lemma 4 shows that the economy always converges to the PBGP. Thus, since we analyse long-run structural change dynamics, our focus on PBGP-effects seems to be justified.

A related topic is the discussion of transitional dynamics in open economy. Such dynamics may arise if, e.g., an autarkic economy opens for trade. Although such opening should be analysed in more appropriate models (where e.g. labour-reallocation frictions exist), we discuss the transitional dynamics for the sake of completeness. In fact, we already have discussed the transitional dynamics implicitly: The savings-rate changes and C-K-structural change takes place during the transition period but not along the PBGP (cf. Lemmas 4b and 8b). The savings rate of our model is a monotonous and smooth function of time during the transition period like the savings-rate of the textbook Ramsey-model with Cobb-Douglas production functions (cf. Lemma 3, Proof of Lemma 4 and Barro and Sala-i-Martin, 2004, p.106ff). Furthermore, l_{Ct}^{j} and l_{Kt}^{j} are smooth and monotonous functions of the savings rate (cf. eq. 30 and 35). Thus, during the transition period l_{Ct}^{j} and l_{Kt}^{j} converge smoothly and monotonously to their PBGP-values (cf. Lemmas 4 and 7b). Whether savings rate and, thus, l_{Ct}^{j} and l_{Kt}^{j} are increasing or decreasing during the transition period depends on the parameter setting (cf. Barro and Sala-i-Martin, 2004, p. 109).

5.3 Impact of Intermediate Trade on Output-Elasticity of Intermediates

By now, we compared open and autarkic economy by assuming that output-elasticity of foreign intermediates F is equal to the output elasticity of their domestic substitutes H (α_H), i.e. F and H are perfect substitutes; cf. eq. (11). The question is what happens if $\alpha_F \neq \alpha_H$, where α_F is the output-elasticity of foreign inputs F. The answer is straight forward: the smaller the output-elasticity of foreign inputs (α_F), the weaker the impacts of intermediate trade. Thus, the impacts of $\alpha_F < \alpha_H$ can be approximated by assuming a higher γ_F. Thus, the discussion of changes in output-elasticities is little fruitful.

We should, however, keep in mind that output-elasticities may differ between autarky and open economy, since e.g. the quality/type of foreign and domestic intermediates is not the same. Thus, in general, the advantageousness of intermediate trade does not only depend on price-relation (40) but also on elasticity-relation (α_F, α_H).

5.4 Interpretation of Sectors and Assignment of Capital and Export Sectors

We named our consumption sectors “1”, “2” and “3”. It makes sense to interpret and rename these sectors depending on the development stage of the country being analysed.

When analysing the historic development of today’s industrialized countries or the dynamics of developing and emerging countries, sectors 1, 2 and 3 may be named “agriculture”, “manufacturing” and “services”. Sector K should be assigned to manufacturing sector, since empirical evidence implies that manufacturing sector produces most capital goods; cf. e.g. Valentinyi and Herrendorf (2008). It is, then, straight-forward to show that our model’s qualitative structural change predictions are consistent with empirical evidence under reasonable parameterisation. This sector-interpretation and the necessary parameterisation have been discussed extensively by Ngai and Pissarides (2007).

An alternative way to interpret the sectors is based on the recent discussion about trade in (impersonal) intermediate services; cf. e.g. Blinder (2005,2006,2007). Sectors 1, 2 and 3 may be named “manufacturing”, “personal services” (or: “non-tradable services”) and “impersonal services” (or: “tradable services”). Intermediate sector D may be assigned to personal services sector and intermediate sector H may be assigned to impersonal services sector. Sector K can be assigned to manufacturing sector again. This sector-naming is appropriate for discussing today’s and future development in industrialized countries, since structural change and trade within services sector is increasingly important in industrialized countries; cf. Section 1. See Stijepic (2011), Chapter V, Part II, for discussion of this model interpretation.

When analysing North-South trade, where industrialized countries import some intermediates from emerging or developing countries, export sector E may be assigned to sector K (manufacturing sector) and/or to some consumption sector. Empirical evidence implies that industrialized countries are major exporters of capital; cf. e.g. Eaton and Kortum (2001).

6. Summary, Implications, Discussion and Topics for Further Research

6.1 Summary of the Effects

Intermediate trade acts like an increase in intermediate productivity growth. This productivity-growth-effect is associated with a relatively high savings-rate and a relatively high rate of capital accumulation in open economy in comparison to autarky. Thus, the employment share of capital sector (consumption sector) is relatively great (small) in open economy – Effect 1. As a result, a smaller share of labour is exposed to consumption demand patterns. Thus, velocity of labour-reallocation across consumption industries (and velocity of overall-structural change along the PBGP) is relatively low in open economy – Effect 2.

6.2 Implications

(I) Since, in general, capital sector is part of manufacturing sector (see Section 5.4), open economy features a relatively strong manufacturing sector in comparison to autarky, because of Effect 1.

(II) Our results imply differences between autarky and open economy regarding *long-run* structural change (Effect 2). These differences go beyond the (transitory) specialisation-related restructuring implied by standard trade theories: in all discussion we assumed that specialisation-related structural change – i.e. structural change which arises after opening of the economy due to specialisation – is already accomplished, since we compared autarky to (already) open economy. The specialisation-related restructuring is quite standard in our model; see Stijepic (2011), Chapter V, Part II.

(III) As discussed in Section 5.4, our model can be interpreted in two ways: it may depict structural change in traditional economies – where labour is reallocated across agriculture, manufacturing and services – or in advanced economies – where labour is reallocated across manufacturing, personal and impersonal services and the latter are traded among others. In any case, open economy features relatively slow structural change in comparison to autarky. Thus, e.g., tertiarisation (cf. Section 1) is relatively slow in open (traditional) economy in comparison to autarky, because of Effect 2.

(IV) All in all, intermediate trade has an impact on the *long-run* rate of structural change (Effect 2). Thus, our results imply that theorists who are interested in long-run dynamics of labour-reallocation should look carefully for significant changes in global environment (e.g. emergence of new countries in the global market or significant progress in information, communication and transport technologies) which enable new forms of intermediate trade or new cost-savings from intermediate trade. Our model implies that such global changes can have an impact on the long-run rate of structural change. Identifying such changes in the global environment (e.g. end of cold war, European integration) and empirically testing their impacts on long-run dynamics of structural change seems to be an interesting question for further research.

6.3 Discussion of Assumptions and Extensions

(1) The question is, whether our results persist in an endogenous terms-of-trade setting. Our results require that condition (40) is satisfied. This condition can be satisfied if there are differences in growth rates of relative prices across trade-partner countries. These differences exist if there are differences in sectoral/intermediate productivity-growth-rates across countries. In the light of large cross-country differences in natural resource endowments, cross-country differences in intermediate productivity growth rates seem to be “always” warranted (cf. WTO p.74 ff.). Furthermore, we used condition (40) for simplicity, cf. Section 1: our results require that intermediate trade has positive impacts on productivity growth. Such impacts may be alternatively microfounded by endogenous growth theory; cf. Section 1. Anyway empirical evidence implies that such impacts exist; cf. Section 1.

(2) The analysis in our paper is based on the notion of dynamic equilibrium (PBGP). As discussed in Section 5.2, our focus on PBGP-effects seems to be justified, since the economy converges to the PBGP in the long run. In fact, the only transitional effect in our model is consumption-capital-structural change (cf. Lemma 8). Anyway, we regard the PBGP simply as a mathematical concept which is aimed to simplify the mathematical analysis, i.e. help to distinguish between different impact channels.

(3) Our key results remain valid if we use more general/complex utility- and production-functions and/or include additional structural change determinants; cf. APPENDIX B1. Nevertheless, it may be interesting albeit difficult to use more complicated assumptions, alternative auxiliary systems and alternative PBGP-concepts to isolate additional impact channels of intermediate trade. See Stijepic and Wagner (2012a) on the existence of PBGPs in more complicated models.

(4) Condition (40) implies that our results can arise even if terms-of-trade are constant or worsening; cf. APPENDIX B2. If there is a structural break in terms-of-trade development, i.e. a change in γ_F, transitional effects may arise, especially consumption-capital-structural change. Nevertheless, our key results remain valid; cf. APPENDIX B3.

(5) We assumed that elasticity of substitution between consumption goods $\varepsilon < 1$, since the model is consistent with the data only in this case. Our key results are not dependent on this assumption: if $\varepsilon > 1$, Effects 1 and 2 (cf. Section 6.1) remain valid.

(6) Factors are not mobile across countries in our model. Cross-country *labour mobility* barriers are obvious. Regarding *capital mobility*: our results arise if at least some of the capital goods are produced at home. Most countries produce a significant share of capital goods at home. This is true, especially, when analysing North-South trade relations: industrialized countries, which import intermediates from emerging or developing countries, produce and export a great share of capital-goods; cf. e.g. Eaton and Kortum (2001).

6.4 Topics for Further Research

Structural change has impacts on GDP-growth (via, e.g., "Baumol's cost disease"). Thus, our results imply that intermediate trade has impacts on GDP-growth via structural change. We will discuss these impacts in a separate paper; for a preview see Stijepic (2011), Chapter V, Part II.

Technological breakthroughs open new ways for intermediate trade. An important question is: Which structural changes are induced by such a breakthrough? We discussed the structural change induced by a breakthrough in Section 5.2 briefly. Stijepic (2011) discusses this structural change more extensively and shows that there is a "turbulent phase" and a "smooth phase"; see there Chapter V, Part II. However, models which are more suitable for analysing this question could be created.

These topics are left for further research.

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APPENDIX A: Proof of Lemmas 3, 5 and 6

In the following we prove the Lemmas for the case of autarky. The proofs for open economy are analogous.

Equation (24) implies

(A.1) $$\frac{p_{it}^A \frac{\partial Y_{it}^A}{\partial (l_{it}^A L_t)}}{p_{xt}^A \frac{\partial Y_{xt}^A}{\partial (l_{xt}^A L_t)}} = \frac{p_{it}^A \frac{\partial Y_{it}^A}{\partial (k_{it}^A K_t^A)}}{p_{xt}^A \frac{\partial Y_{xt}^A}{\partial (k_{xt}^A K_t^A)}} = \frac{p_{it}^A \frac{\partial Y_{it}^A}{\partial (d_{it}^A D_t^A)}}{p_{xt}^A \frac{\partial Y_{xt}^A}{\partial (d_{xt}^A D_t^A)}} = \frac{p_{it}^A \frac{\partial Y_{it}^A}{\partial (h_{it}^A H_t^A)}}{p_{xt}^A \frac{\partial Y_{xt}^A}{\partial (h_{xt}^A H_t^A)}} \quad i,x = 1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}$$

which can be transformed into the following term by using (11):

(A.2) $l_{xt}^A / l_{it}^A = k_{xt}^A / k_{it}^A = d_{xt}^A / d_{it}^A = h_{xt}^A / h_{it}^A \quad i,x = 1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}$

This equation can be transformed into (33) by using (17)-(20) as follows: (A.2) implies $l_{it}^A = l_{xt}^A / k_{xt}^A k_{it}^A$; $i,x = 1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}$. Thus, (17) and (18) imply

$$\sum_{i=1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}} l_{it}^A = l_{xt}^A / k_{xt}^A \sum_{i=1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}} k_{it}^A = l_{xt}^A / k_{xt}^A = 1 \Leftrightarrow l_{xt}^A = k_{xt}^A;\ x = 1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}.$$

It can be shown analogously that $l_{it}^A = d_{it}^A = h_{it}^A$; $i = 1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}$. **This fact completes the proof of equation (33), Lemma 5.**

Equation (24) implies $p_{it}^A / p_{Kt}^A = \{(\partial Y_{Kt}^A)/[\partial(l_{Kt}^A L_t)]\}/\{(\partial Y_{it}^A)/[\partial(l_{it}^A L_t)]\}$; $i = 1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}$. This equation can be transformed into **equation (34) (Lemma 5)** by using (11), (21) and (33). **q.e.d.**

Equation (24) implies $(\partial Y_{Dt}^A)/[\partial(d_{Dt}^A D_t^A)] = 1$; furthermore, (9)/(11) imply $(\partial Y_{Dt}^A)/[\partial(d_{Dt}^A D_t^A)]$ $= \alpha_D / d_{Dt}^A$. Thus, $d_{Dt}^A = \alpha_D$ and, thus, $l_{Dt}^A = \alpha_D$; cf. (33). **This fact proves equation (31), Lemma 5. Proof of equation (32a) (Lemma 5) is analogous.**

Equation (11) implies $(\partial Y_{Et}^O)/[\partial(f_{Et}^O F_t^O)] = \alpha_H Y_{Et}^O /(f_{Et}^O F_t^O)$; furthermore, (24b) implies $(\partial Y_{Et}^O)/[\partial(f_{Et}^O F_t^O)] = p_{Ft}^O / p_{Et}^O$. Thus, $\alpha_H p_{Et}^O Y_{Et}^O /(p_{Ft}^O F_t^O) = f_{Et}^O$. Thus, $\alpha_H = f_{Et}^O$; cf. (10b)/(16). Thus, $\alpha_H = l_{Et}^O$; cf. (33). **This fact proves equation (32b), Lemma 5.**

Equations (9), (11), (31) and (33) imply

(A.3) $D_t^A = \alpha_D B_{Dt}^A (L_t)^{\alpha_L} (K_t^A)^{\alpha_K} (D_t^A)^{\alpha_D} (H_t^A)^{\alpha_H}$

Equations (10a), (11), (32a) and (33) imply

(A.4) $H_t^A = \alpha_H B_{Ht}^A (L_t)^{\alpha_L} (K_t^A)^{\alpha_K} (D_t^A)^{\alpha_D} (H_t^A)^{\alpha_H}$

Dividing (A.3) by (A.4) implies

(A.5) $D_t^A = H_t^A \alpha_D B_{Dt}^A / \left(\alpha_H B_{Ht}^A\right)$

Equations (A.4) and (A.5) imply

(A.6) $H_t^A = \left\{ \alpha_H B_{Ht}^A \left(L_t\right)^{\alpha_L} \left(K_t^A\right)^{\alpha_K} \left[\alpha_D B_{Dt}^A / \left(\alpha_H B_{Ht}^A\right)\right]^{\alpha_D} \right\}^{1/(\alpha_L+\alpha_K)}$

Equations (11), (17), (33) and (34) imply

(A.7) $\sum_{i=1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}} p_{it}^A Y_{it}^A = B_{Kt}^A (L_t)^{\alpha_L} (K_t^A)^{\alpha_K} (D_t^A)^{\alpha_D} (H_t^A)^{\alpha_H}$

Equations (A.5), (A.6), (A.7) and Definition 1 imply

(A.8) $\sum_{i=1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}} p_{it}^A Y_{it}^A = B_{Kt}^A (L_t)^{\alpha_L} (K_t^A)^{\alpha_K} (D_t^A)^{\alpha_D} (H_t^A)^{\alpha_H} = \Psi_t^A (L_t)^{\overline{\alpha}} (K_t^A)^{1-\overline{\alpha}}$

Equation (24) implies $w_t^A = p_{it}^A (\partial Y_{it}^A) / \left[\partial (l_{it}^A L_t)\right]$; $i = 1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}$. This equation can be transformed into the following equation by using (11), (33), (34) and (A.8):

(A.9) $w_t^A = \alpha_L \Psi_t^A (L_t)^{\overline{\alpha}-1} (K_t^A)^{1-\overline{\alpha}}$

Equations (21) and (24) imply $r_t^A = p_{it}^A (\partial Y_{it}^A) / \left[\partial (k_{it}^A K_t^A)\right] - \delta$; $i = 1,2,3,\mathrm{K},\mathrm{D},\mathrm{H}$. This equation can be transformed into the following equation by using (11), (33), (34) and (A.8):

(A.10) $r_t^A = \alpha_K \Psi_t^A (L_t)^{\overline{\alpha}} (K_t^A)^{-\overline{\alpha}} - \delta$

Equations (2), (21), (22), and (34) imply

(A.11) $C_{it}^A = C_{xt}^A \left(B_{xt}\omega_x\right)^{-\varepsilon} \left(B_{it}\omega_i\right)^{\varepsilon} \qquad i, x = 1, 2, 3$

Equations (2), (A.11) and Definition 1 imply

(A.12) $C_t^A = C_{it}^A \left(B_{Kt}\right)^{\varepsilon} \left(B_{it}\omega_i\right)^{-\varepsilon} \left(\Phi_t\right)^{-\varepsilon} \qquad i = 1, 2, 3$

Equations (2), (A.12), (34) and Definition 1 imply

(A.13) $u_{it}^A \equiv \left[\partial (\ln C_t^A)\right] / (\partial C_{it}^A) = p_{it}^A / \overline{C}_t^A \qquad i = 1, 2, 3$

Equations (34), (A.12) and Definition 1 imply

(A.14) $\sum_{i=1}^{3} p_{it}^A C_{it}^A = \overline{C}_t^A$

Equation (5), (14) and (21) imply $\dot{K}_t^A = w_t^A L_t + r_t^A K_t^A - \sum_{i=1}^{3} p_{it}^A C_{it}^A$. This equation can be transformed into **equation (25) (Lemma 3)** by using (A.9), (A.10) and (A.14). **q.e.d.**

Equations (14), (23), (A.10) and (A.13) imply **equation (26) (Lemma 3). q.e.d.**

Equations (25), (A.8) and Definitions 1 and 4 imply **Lemma 6. q.e.d.**

Equation (8), (11), and (33) imply $\dot{K}_t^A + \delta K_t^A = l_{Kt}^A B_{Kt}^A (L_t)^{\alpha_L} (K_t^A)^{\alpha_K} (D_t^A)^{\alpha_D} (H_t^A)^{\alpha_H}$. This equation can be transformed into **equation (30) (Lemma 5)** by using (A.8), (25) and Definition 1. **q.e.d.**

Equations (7), (11) and (33) imply $C_{it}^A = l_{it}^A B_{it}^A (L_t)^{\alpha_L} (K_t^A)^{\alpha_K} (D_t^A)^{\alpha_D} (H_t^A)^{\alpha_H}$. This equation can be transformed into **equation (29) (Lemma 5)** by using (A.8), (A.12) and Definition 1. **q.e.d.**

APPENDIX B: DISCUSSION

B1 Further Sources of Structural Change

In our model, structural change is driven by two "structural change determinants": changes in the savings rate and cross-sector differences in TFP-growth. In this respect our model resembles the autarky model presented by Ngai and Pissarides (2007).

We focused on these structural change determinants, since they are relatively easy to model. However, there are two other structural change determinants studied in the literature (cf. Section 2.2.1): (1) e.g. Kongsamut et al. (2001) show that consumption demand patterns associated with *non-homothetic preferences* can cause structural change; (2) Acemoglu and Guerrieri (2008) show that *inter-sector differences regarding output-elasticity of capital* can induce structural change by affecting relative prices and, thus, consumer demand structure. Thus, both structural change determinants generate structural change by changing the consumption demand structure. Thus, our results imply that the velocity of structural change caused by structural change determinants (1) and (2) is reduced by intermediate trade: intermediate trade reduces the relevance of consumption-demand-dynamics for structural change, where it does not matter what drives the consumption-demand-dynamics. All in all, the effects discussed in our paper arise when structural change patterns are caused by non-homothetic preferences or cross-sector differences regarding capital-elasticities.

Stijepic and Wagner (2012a) integrate all four structural change determinants (TFP-growth differences, changes in savings-rate, non-homothetic preferences and capital-elasticity differences) into a model. They show that stable PBGPs exist in this model and that structural change patterns are qualitatively similar to the structural change patterns of the Ngai and Pissarides (2007) model. However, the analysis becomes very complicated.

Overall, it is possible to generalize/complicate our model assumptions. The resulting model would not reduce the validity of our results. However, the analysis would become considerably complicated, lengthy and less clear.

B2 Results in Case of Terms-of-Trade Worsening

An index of terms-of-trade in our model is given by $p_{\mathrm{F}t}^{\mathrm{O}} / p_{\mathrm{E}t}^{\mathrm{O}}$ or $(p_{\mathrm{F}t}^{\mathrm{O}} F_t^{\mathrm{O}})/(p_{\mathrm{E}t}^{\mathrm{O}} E_t^{\mathrm{O}})$ or, simply, $p_{\mathrm{F}t}^{\mathrm{O}}$, since $p_{\mathrm{F}t}^{\mathrm{O}}$ is the price of foreign intermediates in terms of domestic capital. Interestingly, our model-results do not rely on a certain dynamic pattern of terms-of-trade development. In fact, our results can arise even if terms-of-trade are constant or worsening over time. What counts for the impacts of intermediate trade is the comparison to the autarky: if in autarky $p_{\mathrm{H}t}^{\mathrm{A}}$

increases over time, intermediate trade can be productivity-enhancing even if the terms-of-trade worsen over time ($\dot{p}^{\mathrm{O}}_{\mathrm{F}t} > 0$). The only requirement for our results in this case is that $p^{\mathrm{O}}_{\mathrm{F}t}$ does not increase as fast as $p^{\mathrm{A}}_{\mathrm{H}t}$ in autarky would do, i.e. $\dot{p}^{\mathrm{O}}_{\mathrm{F}t} / p^{\mathrm{O}}_{\mathrm{F}t} < \dot{p}^{\mathrm{A}}_{\mathrm{H}t} / p^{\mathrm{A}}_{\mathrm{H}t}$ (cf. Section 5.1). A simple example for this argument is: The fact that mineral oil prices are increasing does not imply that using oil-based technology (and thus importing oil-based intermediates) is productivity-reducing. We have to compare the profits of entrepreneurs in oil-based economy to the profits of entrepreneurs in economy with state-of-art alternative (or: oil-independent) technology. Only if profits in the economy which uses alternative technology are higher than profits in oil-based economy, ceteris paribus, oil-imports are not advantageous.

B3 Structural Breaks in Terms-of-Trade Development

We assumed that terms-of-trade (whether increasing, decreasing or constant) evolve smoothly (cf. eq. 15) for analytical convenience. Some empirical evidence implies that there are structural breaks or changes in the trend of north-south terms-of-trade development, see e.g. Powell (1991) and Bleaney and Greenaway (1993). Although $p^{\mathrm{O}}_{\mathrm{F}t}$ is not comparable to terms-of-trade in reality – $p^{\mathrm{O}}_{\mathrm{F}t}$ is an index of terms-of-trade in intermediate trade, whereas terms-of-trade in reality include final-goods trade – structural breaks in $p^{\mathrm{O}}_{\mathrm{F}t}$-dynamics may arise. Assume a worst case scenario: the growth rate of $p^{\mathrm{O}}_{\mathrm{F}t}$ (γ_{F}) is negative and then unexpectedly becomes positive. Two outcomes are possible:

a) If condition (40) is violated after the increase in γ_{F}, the North may return to autarky, i.e. stop using the technology which relies on South’s intermediates (cf. Section 5.1).

b) If condition (40) is still satisfied, the change in γ_{F} induces a departure from the (old) PBGP and convergence to a new PBGP (cf. Lemma 4c). During the transition period, labour is reallocated from the capital sector to the consumption sector (which is a corollary of Theorem 1). Along the new PBGP, profits are lower, velocity of C-structural change is higher and more labour is allocated to the consumption sector in comparison to the situation along the old PBGP. Nevertheless, open economy is better off than autarkic economy. Note that in reality, where inter-sector labour reallocation is associated with unemployment due to inter-sector labour-mobility barriers, (additional) unemployment arises during the transition to the new PBGP, because of C-K-structural change. Furthermore, the unemployment rate along the new PBGP may be higher than the unemployment rate along the old PBGP, because of relatively high velocity of C-structural change along the new PBGP.