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The real exchange rate and the structure of aggregate production

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Abstract This paper proposes a new, production theory approach to the determination of the real exchange rate, which is defined as the relative price of traded to nontraded goods as is common in the international trade literature. Using a Translog real GDI function that describes the aggregate technology of an open economy as a starting point, the real exchange rate can be formally derived as a function of domestic excess savings, the terms of trade, relative factor endowments and technological progress. Empirical results for Switzerland suggest that the main drivers of the real exchange rate are the terms of trade, followed by relative factor endowments. Contrary to conventional wisdom, the Balassa-Samuelson effect does not seem to play a significant role in explaining the long-term real appreciation of the Swiss franc.

Keywords Real exchange rate · Technological change · Terms of trade · Factor intensity · Middle products · Nontraded goods

JEL Classification F11 · O47 · C43 · D33

1 Introduction

Switzerland's currency is known to have appreciated considerably in real terms over the past several decades. From 1980 to 2007, for instance, the price of traded goods has fallen by over 25 % relative to the price of nontraded goods. This movement is not without causing some concern, among business people and policy makers alike, and economists are often at a loss when trying to explain this phenomenon. One hypothesis that is frequently aired in Switzerland, though, is that the appreciation might be due to a Balassa-Samuelson effect.[1] Thus, if technological progress favors the production of traded rather than nontraded goods, domestic factor mobility will result in the price of nontraded goods rising faster than the price of traded goods. An increase in the price of nontraded goods relative to the price of traded goods is tantamount to a real appreciation of the domestic currency. This view, which is consistent with the so-called *Australian model* of international trade, provides a convenient starting point for our analysis.[2] One purpose of this paper is to investigate whether the secular real appreciation of the franc can be explained by a Balassa-Samuelson effect, or whether there are other forces at work.[3]

A second reference mark for our analysis is the recognition that most international trade is in *middle products*, i.e.,

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[1] See Balassa (1964) and Samuelson (1964). The view that the long-run real appreciation of the Swiss franc can be explained by a Balassa-Samuelson effect has been put forward by the Swiss State Secretariat for the Economy, among others; see Seco (2008).

[2] See Salter (1959) and Corden (1992), for instance. This model is also known as the *dependent economy model*; see Dornbusch (1980), Turnovsky (1997).

[3] The Balassa-Samuelson hypothesis has received much empirical support, for the United States, Canada, Japan, and Germany among others; see Asea and Mendoza (1994) and De Gregorio et al. (1994). Sax and Weder (2009), on the other hand, reject the hypothesis for Switzerland.

intermediate goods and services.[4] Thus, nearly all imports (exports), including almost all so-called "finished" products, must still transit through the domestic (foreign) production sector and go through a number of changes—such as unloading, transporting, storing, assembling, testing, cleaning, financing, insuring, marketing, wholesaling and retailing—before reaching final demand. During this process, traded products are combined with local factor services, with the consequence that the cost to the end-user is typically well in excess of the price charged at the border, the difference being accounted for by local value added. Hence, production theory, rather than consumer theory, provides the natural setting for international trade analysis,[5] all the more so that most import and export decisions are made by firms, not by households. Imbedding trade decisions in production theory also suggests that relative factor endowments might play a role in explaining the real exchange rate. Thus, if traded goods are relatively capital intensive at the margin, an increase in aggregate capital intensity will favor their production and will tend to lead to a decrease in their relative price.[6] Another logical, and indeed major consequence of our approach is that if all traded goods are middle products, then all end-products, i.e., the products intended for domestic use, must be nontraded.[7] This view greatly facilitates the empirical work. If one fails to make this fundamental distinction between middle products and end-products, the decomposition of output between tradables and nontradables is rather tricky, and it requires often a large number of quite arbitrary decisions as to the classification and even the definition of various sectors and industries.[8] This is not so with our approach, for national accounts data can then readily be used: imports and exports are tradables, whereas the domestic GDP components (consumption, investment and government purchases) are nontradables. In fact, our approach, which is fully compatible with joint production, does not even require that individual sectors and activities be identified, much less be classified.

Another question that arises is whether the movements in the real exchange rate can be associated with changes in the terms of trade. Indeed, Switzerland's terms of trade have improved by about 20 % between 1980 and 2007. Many models of international economics are not well equipped to deal with this question, for they often allow for two goods only, in which case there can be only one price ratio. Thus, the Heckscher-Ohlin-Samuelson model and the specific factors model cannot explain the possible link between the terms of trade and the real exchange rate, for the real exchange rate does not even show up in these models. There are other models—such as the Mundell-Fleming model—that make no distinction between the terms of trade and the real exchange rate, so that the two terms are often used interchangeably in practice, even though they refer to two fundamentally different concepts. In the standard version of the Australian model, it is the terms of trade that do not appear (they are implicitly assumed to be constant in order to justify the Hicksian aggregation of imports and exports into a composite traded good). Fortunately, the Australian model can easily be extended to distinguish between importables and exportables.[9] By allowing for three goods (a nontraded good, an import and an export), it is possible to draw a meaningful distinction between the real exchange rate and the terms of trade. This is precisely the setting of the analysis that follows. We will, however, generalize the Australian model in two further important respects, namely, as already suggested, by recognizing that all trade is in middle products and by refraining from imposing any nonjointness restrictions on the form of the technology.

This paper thus innovates by showing how, starting from a general representation of the technology of a small open economy, the real exchange rate can be formally derived as a function of domestic relative factor endowments, excess savings, the terms of trade, and the passage of time, which captures the changes in total factor productivity (TFP). The model is then applied to Swiss data as an illustration. The results suggest that the terms of trade and relative factor endowments are the main drivers of the real exchange rate. Moreover, technological progress seems to have little or no

[4] The term *middle product* has been coined by Sanyal and Jones (1982).

[5] This view, long advocated by Burgess (1974), Kohli (1978, 1991, 2004), Woodland (1982) and Diewert and Morrison (1986), among others, has been gaining in recognition lately: see Harrigan (1997) and Feenstra (2004), for instance.

[6] See Bergstrand (1991), for instance.

[7] Of course, the converse is not necessarily true: not all nontraded products are end-products, since there may well be nontraded intermediate goods and services. However, these net out in the aggregate.

[8] Another difficulty with the standard approach to testing the Balassa-Samuelson hypothesis has to do with the measurement of technological progress. Typically, it taken to be the change in output per unit of labor in the two sectors. This is problematic, since average labor productivity can increase as a result of either an increase in total factor productivity (TFP) or an increase in capital intensity. Since capital intensity may increase more rapidly in the traded good sector than in the nontraded good sector, a faster increase in average labor productivity may be mistakenly be interpreted as a higher rate of technological progress. This difficulty is avoided in our treatment since it is the relative impact of TFP on the two outputs that is being estimated.

[9] See Corden (1984), for instance.

role to play, which contradicts the commonly held view that it is a Balassa-Samuelson effect that is responsible for the long-run real appreciation of the Swiss franc.

The paper proceeds as follows. The basic Australian model is reviewed in the next section. The extended theoretical model is presented in Sect. 3. The empirical implementation of the model is discussed in Sect. 4, and our empirical results are reported in Sects. 5 and 6. Section 7 concludes.

2 The basic Australian model

In its most basic form, the Australian model assumes that the country produces two endproducts, a traded good (*T*) and a nontraded good (*N*). The production possibilities frontier is depicted in Fig. 1 in output space for given domestic factor endowments and a given technology. A pair of social indifference curves is also shown. Quantities produced are indicated by q_i's and quantities consumed by c_i's ($i = T, N$). Assume that trade is initially balanced. In that case, production and consumption must take place at the same point, point Q_0, or, equivalently, C_0. Production (and consumption) of the traded and the nontraded goods is given by q_{T0} (=c_{T0}) and q_{N0} (=c_{N0}), respectively. The real exchange rate (ε), defined as the price relative of traded to nontraded goods, is given by the marginal rate of transformation (equivalently, the marginal rate of substitution) between traded and nontraded goods; in absolute value, it is equal to the slope of line labelled $-\varepsilon_0$.

Consider now an exogenous increase in domestic absorption. The demand for both goods tends to go up, but, whereas the increased demand for traded goods can be satisfied if needed through imports, this is not so for nontraded goods. The domestic output mix must therefore shift towards nontraded goods. This requires an increase in their relative price. Production moves to Q_1 (q_{T1},q_{N1}), whereas consumption moves to C_1 (c_{T1}, c_{N1}). One notes that

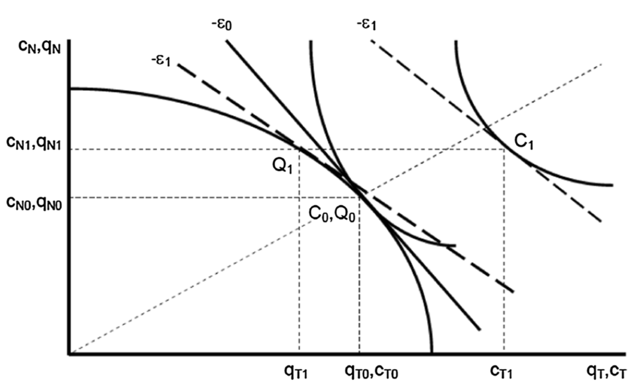

Fig. 1 The basic Australian model under balanced trade (state 0) and a trade deficit (state 1)

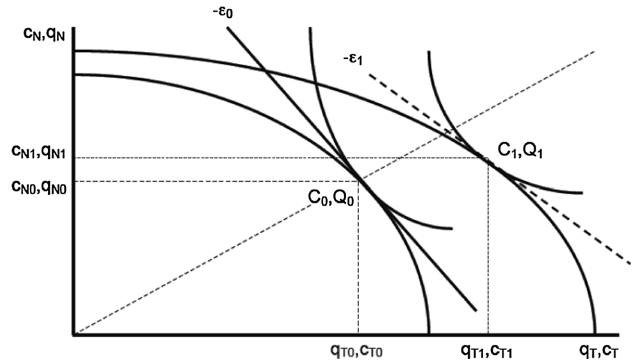

Fig. 2 The basic Australian model: Impact of a technological progress or of an increase in factor endowments favoring the production of traded goods

$q_{N1} = c_{N1}$, but $q_{T1} < c_{T1}$. The difference between c_{T1} and q_{T1} indicates the trade deficit (negative excess savings). The real exchange rate is now ε_1, i.e., the marginal rate of transformation at Q_1 (the marginal rate of substitution at C_1). Clearly $\varepsilon_1 < \varepsilon_0$: the reduction in domestic excess savings has thus led to a drop in the real exchange rate, i.e., an appreciation of the domestic currency.

Shifts in the production possibilities frontier are likely to affect the real exchange rate as well. A technological change, for instance, will shift the production possibilities frontier outwards. If it favours the production of traded goods (the Balassa-Samuelson hypothesis), the frontier will tend to twist anti-clockwise as shown in Fig. 2. Assuming that trade remains balanced (zero excess savings), production (and consumption) will move from Q_0 (C_0) to Q_1 (C_1). For homothetic preferences, the marginal rate of substitution (and hence the marginal rate of transformation) will fall, thus indicating an appreciation of the domestic currency. A change in factor endowments can be analysed in the same way. Thus, the shift in the production possibilities frontier depicted in Fig. 2 could just as well be due to an increase in the endowment of the factor used relatively intensively in the production of the traded good.[10]

[10] If production is joint, it is the marginal factor requirements that matter since the sectors are not defined; see Kohli (1991). If production is nonjoint in input quantities, an increase in the endowment of one factor will, for given output prices, lead to an increase in the supply of the good that uses that factor relatively intensively and to an absolute decrease in the supply of the other output; the Rybczynski (1955) Theorem. This need not be the case under nonjoint production: the supply of both outputs might increase, although the production of the good that uses the factor relatively intensively at the margin will be favored.

As already suggested, we will extend the Australian model is several directions. First, we will allow for two types of traded goods, importables and exportables; this will enable us to take changes in the terms of trade into account. Changes in the terms of trade are likely to influence the position of the equilibrium point on the production possibilities frontier (which will now be a surface in a three-dimensional space), and thus to influence the real exchange rate. Second, we will assume that all traded goods are middle products. As argued earlier, this is consistent with the fact that most traded goods must still transit through the production sector before they are ready to meet final demand. Third, we will not assume, as it is done implicitly in the Australian model, that production is nonjoint. This is much less restrictive and it allows for a larger range of cross price and quantity effects.

3 The extended model

In what follows, we assume that the country uses two domestic factors (labor, L, and capital, K) and imports (M) to produce two goods, one intended for foreign markets (exports, X) and one intended for domestic absorption (N, an aggregate of consumption, investment and government purchases).

Let $p_{i,t}$ and $q_{i,t}$ be the price and the quantity of GDP component i ($i = N, X, M$), and $w_{j,t}$ and $x_{j,t}$ the price and quantity of domestic factor service j ($j = K, L$) at time t. Let Π_t be nominal gross domestic product (GDP)—or, equivalently, nominal gross domestic income (GDI). It is given by:

$$\Pi_t \equiv p_{N,t}q_{N,t} + p_{X,t}q_{X,t} - p_{M,t}q_{M,t}. \tag{1}$$

The aggregate technology can be represented by the following *nominal* GDP/GDI function:

$$\Pi(p_{N,t}, p_{X,t}, p_{M,t}, x_{K,t}, x_{L,t}, t) \equiv \max_{q_N, q_X, q_M} \left\{ \begin{matrix} p_{N,t}q_N + p_{X,t}q_X - p_{M,t}q_M : \\ \phi(q_N, q_X, q_M, x_{K,t}, x_{L,t}, t) = 0 \end{matrix} \right\}. \tag{2}$$

where $\phi(\cdot)$ is the economy's transformation function. We assume a convex technology, constant returns to scale, and free disposals. No additional restrictions are placed on the technology. In particular, unlike the standard Australian model, we do not assume that production is nonjoint.[11] Note that the transformation function is allowed to shift over time in order to capture changes in TFP.

It is well known that the profit-maximising output supply and import demand functions can be obtained by differentiation[12]:

$$q_{i,t} = \pm \frac{\partial \Pi(\cdot)}{\partial p_{i,t}} = q_i(p_{N,t}, p_{X,t}, p_{M,t}, x_{K,t}, x_{L,t}, t), \quad i \in \{N, X, M\}, \tag{3}$$

where the minus sign applies to imports, which are treated as a negative output. Moreover, assuming that the domestic factors are mobile between firms, the derivatives with respect to the fixed input quantities yields the competitive domestic factor rental prices:

$$w_{j,t} = \frac{\partial \Pi(\cdot)}{\partial x_{j,t}} = w_j(p_{N,t}, p_{X,t}, p_{M,t}, x_{K,t}, x_{L,t}, t), \quad j \in \{K, L\}. \tag{4}$$

As for *real* GDI ($q_{Z,t}$), it is obtained by deflating nominal GDI by the price of domestic absorption:

$$q_{Z,t} \equiv \frac{\Pi_t}{p_{N,t}} = q_{N,t} + \frac{p_{X,t}}{p_{N,t}} q_{X,t} - \frac{p_{M,t}}{p_{N,t}} q_{M,t}. \tag{5}$$

Note the difference between real GDI so defined and the common definition of real GDP, where nominal GDP (or nominal GDI) is deflated by an index of the prices of nontraded goods (consumption, investment, government purchases), exports, and imports. The difference between the GDI and the GDP deflators, i.e., the contributions of import and export prices, is known as the trading gains. An improvement in the terms of trade will have little impact on real GDP (as nominal GDP and the GDP price deflator will tend to increase in the same proportions), whereas real GDI will unambiguously increase. Similarly, a real appreciation of the domestic currency would have little impact on real GDP, but it would tend to increase (decrease) real GDI if the trade account is in a deficit (surplus) position.[13]

We now need a number of additional definitions. The price of traded goods ($p_{T,t}$) is defined as the geometric mean of the prices of exports and imports[14]:

[11] The Australian model typically assumes that production is either nonjoint in input quantities or almost nonjoint in input prices and quantities; see Kohli (1983, 1993).

[12] See Diewert (1974), Kohli (1978, 1991) and Woodland (1982).

[13] See Kohli (2007, 2008) for details.

[14] The United Nations' 1993 SNA considers the arithmetic average of import and export prices as a measure of the price of traded goods. This recommendation is made in the context of the Laspeyres aggregation, however. In the Törnqvist context, a geometric average makes more sense.

$$p_{T,t} \equiv p_{X,t}^{1/2} p_{M,t}^{1/2}. \quad (6)$$

The real exchange rate (ε_t, also known as the Salter ratio) is defined as the relative price of traded to nontraded goods:

$$\varepsilon_t \equiv \frac{p_{T,t}}{p_{N,t}}. \quad (7)$$

Note that an increase in ε_t means a real depreciation of the home currency. This definition of the real exchange rate is commonly used in the international trade literature.[15] Note, though, that it differs from another common definition of the real exchange rate (sometimes called the *PPP real exchange rate*), namely the nominal exchange rate adjusted for price level differentials.[16] To see this, let $p_{N,t}^*$ be the price of foreign absorption (expressed in foreign currency) and let E_t be the nominal exchange rate (the price of foreign exchange). The PPP *nominal* exchange rate (π_t) can then be defined as:

$$\pi_t \equiv \frac{p_{N,t}}{p_{N,t}^*}, \quad (8)$$

whereas the PPP *real* exchange rate (e_t) can be written as:

$$e_t \equiv \frac{E_t p_{N,t}^*}{p_{N,t}} = \frac{E_t}{\pi_t}. \quad (9)$$

Comparing (7) with (9), the difference between ε_t and e_t is clear: the former refers to the domestic prices of traded and nontraded goods, whereas the latter makes an international comparison between the prices of nontraded goods. As we shall see below, neither π_t nor e_t are relevant for domestic production decisions.[17]

Finally, we define the country's terms of trade (τ_t) as the price of exports relative to the price of imports:

$$\tau_t \equiv \frac{p_{X,t}}{p_{M,t}}. \quad (10)$$

Note that, in view of definitions (6), (7) and (10), real GDI can also be written as:

$$q_{Z,t} = q_{N,t} + \varepsilon_t \tau_t^{1/2} q_{X,t} - \varepsilon_t \tau_t^{-1/2} q_{M,t}. \quad (11)$$

This implies that, in lieu of (2), the aggregate technology can just as well be represented by the following *real* GDI function[18]:

$$\begin{aligned} q_{Z,t} &= z(\tau_t, \varepsilon_t, x_{K,t}, x_{L,t}, t) \\ &\equiv \max_{q_N, q_X, q_M} \left\{ \begin{array}{c} q_N + \varepsilon_t \tau_t^{1/2} q_X - \varepsilon_t \tau_t^{-1/2} q_M : \\ \phi(q_N, q_X, q_M, x_{K,t}, x_{L,t}, t) = 0 \end{array} \right\}. \end{aligned} \quad (12)$$

Let s_t be the domestic excess savings rate, i.e., one minus the ratio of domestic absorption to GDI[19]:

$$s_t \equiv \frac{\Pi_t - p_{N,t} q_{N,t}}{\Pi_t} = \frac{q_{Z,t} - q_{N,t}}{q_{Z,t}} = 1 - \frac{q_{N,t}}{q_{Z,t}}. \quad (13)$$

As shown by Kohli (2007), s_t can be obtained as the partial elasticity of the real GDI function with respect to the real exchange rate:

$$s_t = \frac{\partial \ln z(\tau_t, \varepsilon_t, x_{K,t}, x_{L,t}, t)}{\partial \ln \varepsilon_t} \equiv \sigma(\tau_t, \varepsilon_t, x_{K,t}, x_{L,t}, t). \quad (14)$$

Moreover, given the assumption of constant returns to scale, $\sigma(\cdot)$ is homogeneous of degree zero in $x_{K,t}$ and $x_{L,t}$. We can therefore write:

$$s_t = s(\tau_t, \varepsilon_t, k_t, t), \quad (15)$$

where k_t is capital/labor ratio for the entire economy:

$$k_t \equiv \frac{x_{K,t}}{x_{L,t}}. \quad (16)$$

Consider Eq. (15,). It is customary in international trade theory to take domestic factor endowment as given: k_t can therefore be taken as predetermined. In the small open economy, the terms of trade can be viewed as given as well. The time index is obviously exogenous too. The real exchange rate, i.e., the price of traded versus nontraded goods, on the other hand, will generally be endogenous, since it reflects domestic demand conditions. These demand conditions are reflected by the domestic excess savings ratio, which can be viewed as exogenous to production decisions, even though it is not exogenous in the statistical sense of the term. As we will see below, concavity of the production possibilities frontier implies that $s(\cdot)$ is a monotonically increasing function of ε_t. It can therefore be solved for the real exchange rate as a function of the savings rate, the terms of trade, capital intensity, and time:

$$\varepsilon_t = \varepsilon(s_t, \tau_t, k_t, t). \quad (17)$$

Eq. (17) will provide the basis for our empirical investigation.

[15] See Helpman (1977), Dornbusch (1980), Jones and Neary (1984), Edwards (1989), Caves et al. (1990), and Corden (1992), for instance.

[16] See Edwards (1989) for a review of competing definitions of the real exchange rate.

[17] In the absence of transportation costs and of any barriers to trade, one might expect the law of one price to hold: $p_{T,t} = E_t p_{T,t}^*$, $p_{T,t}^*$ being the world price of traded goods. In that case, the PPP real exchange rate can also be expressed as $e_t = \varepsilon_t / \varepsilon_t^*$, where $\varepsilon_t^* \equiv p_{T,t}^* / p_{N,t}^*$ is the foreign Salter ratio; ε_t^* plays no role in our analysis.

[18] For further explanations, see Kohli (2007, 2008).

[19] Note that s is also equal to the trade balance relative to nominal GDP.

4 Empirical implementation

We now need a functional form that is general enough not to impose any prior restrictions on the form of the 2-input, 3-output technology. The Translog functional form is ideally suited to our needs. It is flexible functional form, i.e., it provides a second-order approximation to an arbitrary technology and it therefore incorporates none of the nonjointness restrictions that are usually imposed on the Australian model. As a nominal GDP/GDI function, it is as follows[20]:

$$\begin{aligned}\ln \Pi_t = {} & \ln x_{L,t} + \alpha_0 + \sum_i \alpha_i \ln p_{i,t} + \beta_K \ln k_t + \beta_T t \\ & + \frac{1}{2}\sum_i \sum_h \gamma_{ih} \ln p_{i,t} \ln p_{h,t} \\ & + \frac{1}{2}\varphi_{KK} \ln k_t^2 + \varphi_{KT} \ln k_t t + \frac{1}{2}\varphi_{TT} t^2 \\ & + \sum_i \delta_{iK} \ln p_{it} \ln k_t + \sum_i \delta_{iT} \ln p_{i,t} t \end{aligned} \tag{18}$$

for $i, h \in \{N, X, M\}, j, k \in \{K, L\}$, with $\sum_i \alpha_i = 1$, $\gamma_{ih} = \gamma_{hi}$, $\sum \gamma_{ih} = 0$, $\sum_i \delta_{iK} = 0$, and $\sum_i \delta_{iT} = 0$.

One notes that this function is flexible with respect to all its arguments, including with respect to time. It is thus TP flexible, to use the terminology of Diewert and Wales (1992). TFP is thus modeled as a quadratic function of time, where time also interacts with output prices and factor endowments:

$$\ln TFP_t = \beta_T t + \varphi_{KT} \ln k_t t + \sum_i \delta_{iT} \ln p_{i,t} t + \frac{1}{2}\varphi_{TT} t^2. \tag{19}$$

Since production is not assumed to be nonjoint, it is not possible to talk about technological change in one sector rather than in another. However, for given output (including import) prices and given factor endowments, technological progress, as captured by the passage of time, can lead to any change in the output mix and in factor rental prices. These changes are captured by the $\delta_{i,T}$'s and by φ_{KT}. In particular, δ_{NT}, δ_{XT}, and δ_{MT} indicate how technological change affects the composition of output.[21] A positive parameter indicates that technological change, other things equal (including output prices), leads to an increase in the GDP share of the corresponding good. If all three parameters are zero, technological change is neutral relative to outputs (technological change might still be pro-capital or pro-labor biased, depending on the sign of φ_{KT}). If, on the other hand, δ_{NT} is negative technological change is anti-nontraded goods biased, which is the Balassa-Samuelson hypothesis. This provides for a simple test of that hypothesis. Similarly, an increase in relative capital intensity would be biased against the production of nontraded goods if δ_{NK} is negative.

As shown by Kohli (2007), using nominal GDP/GDI function (18) as a starting point, the corresponding real GDI function is also Translog, and it is as follows:

$$\begin{aligned}\ln q_{Z,t} = {} & \ln x_{L,t} + \alpha_0 + \alpha_\tau \ln \tau_t + \alpha_\varepsilon \ln \varepsilon_t + \beta_K \ln k_t + \beta_T t \\ & + \frac{1}{2}\gamma_{\tau\tau} \ln \tau_t^2 + \gamma_{\tau\varepsilon} \ln \tau_t \ln \varepsilon_t + \frac{1}{2}\gamma_{\varepsilon\varepsilon} \ln \varepsilon_t^2 \\ & + \frac{1}{2}\varphi_{KK} \ln k_t^2 + \varphi_{KT} \ln k_t t + \frac{1}{2}\varphi_{TT} t^2 \\ & + \delta_{\tau K} \ln \tau_t \ln k_t + \delta_{\varepsilon K} \ln \varepsilon_t \ln k_t + \delta_{\tau T} \ln \tau_t t \\ & + \delta_{\varepsilon T} \ln \varepsilon_t t \end{aligned} \tag{20}$$

where $\alpha_\tau = \frac{1}{2}(\alpha_X - \alpha_M)$, $\alpha_\varepsilon = \alpha_X + \alpha_M = 1 - \alpha_N$, $\gamma_{\tau\tau} = \frac{1}{4}(\gamma_{XX} + \gamma_{MM} - 2\gamma_{MX})$, $\gamma_{\varepsilon\varepsilon} = \gamma_{XX} + \gamma_{MM} + 2\gamma_{MX} = \gamma_{NN}$, $\gamma_{\tau\varepsilon} = \frac{1}{2}(\gamma_{XX} - \gamma_{MM})$, $\delta_{\tau K} = \frac{1}{2}(\delta_{XK} - \delta_{MK})$, $\delta_{\varepsilon K} = \delta_{XK} + \delta_{MK} = -\delta_{NK}$, $\delta_{\tau T} = \frac{1}{2}(\delta_{XT} - \delta_{MT})$, $\delta_{\varepsilon T} = \delta_{XT} + \delta_{MT} = -\delta_{NT}$.

Logarithmic differentiation of (20) with respect to the real exchange rate yields:

$$s_t = \alpha_\varepsilon + \gamma_{\tau\varepsilon} \ln \tau_t + \gamma_{\varepsilon\varepsilon} \ln \varepsilon_t + \delta_{\varepsilon K} \ln k_t + \delta_{\varepsilon T} t. \tag{21}$$

Convexity of the GDP function with respect to prices (concave production possibilities frontier) requires $\partial \ln q_N / \partial \ln p_N \geq 0$. This in turn requires $\gamma_{NN} = \gamma_{\varepsilon\varepsilon} \geq s_N - s_N^2$, where $s_N = 1 - s$ is the share of nontraded goods in GDP.[22] As Switzerland has had a trade surplus for the entire sample period, we can conclude that $\gamma_{\varepsilon\varepsilon}$ must be strictly positive for convexity to be satisfied.[23] We can thus solve (21) for the real exchange rate. This gives:

$$\begin{aligned}\ln \varepsilon_t & = -\frac{\alpha_\varepsilon}{\gamma_{\varepsilon\varepsilon}} + \frac{1}{\gamma_{\varepsilon\varepsilon}} s_t - \frac{\gamma_{\tau\varepsilon}}{\gamma_{\varepsilon\varepsilon}} \ln \tau_t - \frac{\delta_{\varepsilon K}}{\gamma_{\varepsilon\varepsilon}} \ln k_t - \frac{\delta_{\varepsilon T}}{\gamma_{\varepsilon\varepsilon}} t \\ & = a_0 + a_1 s_t + a_2 \ln \tau_t + a_3 \ln k_t + a_4 t \end{aligned} \tag{22}$$

Thus, the (logarithm of the) real exchange rate is a function of time, the (logarithm of the) terms of trade, the (logarithm of the) capital/labor ratio, and the domestic excess savings ratio. Eq. (22) has a strong theoretical underpinning and it provides a convenient starting point for an

[20] See Kohli (1978, 1991).

[21] By Young's Theorem, $\delta_{iT} = \partial\mu/\partial \ln p_i = \partial s_i/\partial t$ where $\mu = \partial \ln \Pi/\partial t = \partial \ln TFP/\partial t$ is the instantaneous rate of growth of GDP (for given output prices and factor endowments) and s_i is the GDP share of output i.

[22] See Kohli (1978, 1991).

[23] The value of s_N varied between 0.9074 and 0.9948 over the entire sample; the sample mean value is 0.9569.

empirical investigation of the real exchange rate. It makes it possible, in particular, to identify the contribution of technological change (as captured by a_4). It further suggests that the terms of trade, aggregate factor intensity, and excess domestic savings too may play a role in the determination of the real exchange rate.

As argued earlier, $\gamma_{\varepsilon\varepsilon}$ must be strictly positive for convexity to be satisfied: a_1 ($a_1 \equiv 1/\gamma_{\varepsilon\varepsilon}$) must therefore be positive as well. In other words, an increase in excess savings (a drop in domestic absorption) must be met by a real depreciation of the currency.

It has often been contended in Switzerland that the main reason why the Swiss franc has tended to strengthen over time in real terms is due to a Balassa-Samuelson effect.[24] Thus, it is argued, technological progress tends to favor the production of traded rather than nontraded goods, thereby leading to a progressive decrease in the price of traded goods relative to the price of nontraded goods. If that is the case, i.e., if technological change is biased against the production of nontraded goods, we would expect $\delta_{\varepsilon,T} = -\delta_{N,T}$ to be positive; that is, a_4 ($a_4 \equiv -\delta_{\varepsilon T}/\gamma_{\varepsilon\varepsilon}$) should be negative.

The impact of a change in relative factor endowments on the real exchange rate could be of either sign. This is purely an empirical matter. However, there is some evidence that an increase in relative capital abundance tends to favor the production of exports and the derived demand for imports over the output of nontraded goods.[25] In other words, the production of nontraded goods may be relatively labor intensive at the margin. The tendency for the output of nontraded goods to fall in relative terms ($\delta_{NK} < 0$) can be offset by an increase in their relative price, i.e., an appreciation of the currency. This would suggest that a_3 ($a_3 \equiv -\delta_{\varepsilon K}/\gamma_{\varepsilon\varepsilon} = \delta_{NK}/\gamma_{\varepsilon\varepsilon}$) be less than zero.

An improvement in the terms of trade, finally, will favor the supply of exports and increase the derived demand for imports. Unless the marginal import requirements of nontraded goods happen to be unusually large, the shift in resources towards the production of exports should tend to a decline in the output of nontraded goods. To offset this tendency, the price of nontraded goods needs to increase, i.e., the currency needs to appreciate in real terms. We should thus expect a_2 to be negative as well. Note that this effect is distinct from the Harberger-Laursen-Metzler effect that focuses on the impact of terms of trade changes on real income, savings, and the trade account.[26] This effect relates to consumer behavior, which is exogenous to production decisions.

Before proceeding with the empirical application, we should stress that this model does not pretend to offer a general equilibrium approach to the modeling of a small open economy. In particular, we take the supply of labor, the stock of capital, and the savings rate as given at any point in time (but, of course, they are variable though time). Thus, we do not model the capital accumulation process or the labor supply decision. Neither do we model the final demand for nontraded goods, which is captured by the savings ratio. Of course, this is common in most empirical work, since it is hardly possible to model everything simultaneously. In particular, this is standard practice in most studies dealing with the estimation of production functions or structures. Our main purpose thus is to show that the relative price of traded to nontraded goods is akin to a marginal rate of transformation, and thus it can be explained by referring to production theory exclusively. We should also recognize that the model assumes that the economy is in a long-run equilibrium, that markets are competitive, and that exchange-rate pass through is complete. In the short run, some of these assumptions are unlikely to be met, but it is beyond the scope of this paper to model adjustment costs or deviations from competitive behavior. For this reason, therefore, our results should be viewed as tentative.

5 Cointegration analysis

Since the estimation of Eq. (22) requires an approach that recognizes the potential simultaneity of s_t and ε_t as well as the non stationarity of the variables in level, a VECM[27] is estimated on Swiss annual data for the period 1980–2007[28]. Admittedly, our sample is rather short, and thus our results should be viewed as tentative. Our empirical application should mostly be viewed as serving an illustrative purpose. The model to be estimated is as follows:

$$\Gamma(L)\Delta Y_t = \delta_0 + \alpha\mu T + \alpha\beta' Y_{t-1} + \upsilon_t \tag{23}$$

where $\Gamma(L)$ is a matrix polynomial lag operator of order one, T is a deterministic vector of time trends, $\mathbf{Y}_t$ is a vector of time series comprising the four endogenous

[24] See Aebersold and Brunetti (1998), for instance.

[25] Thus, Kohli (1992) reports a set of Rybczynski elasticities for Switzerland that show that a 1 % increase in the endowment of capital would increase the demand for imports by 0.5 %, the supply of exports by 1.0 %, and the supply of consumption goods by 0.1 %, while reducing the supply of investment goods by 0.1 % (1988 estimates).

[26] See Svensson and Razin (1983), for instance.

[27] See Johansen (1996).

[28] A description of the data is given in Appendix 1.

Table 1 Regression results, long-run estimates

Coefficients	VECM	DOLS	Bootstrap 95 % CI	Bootstrap 80 % CI
a_1	0.478**	0.261	[− 0.649 1.845]	[− 0.191 1.259]
	(0.201)	(0.482)		
a_2	−0.698***	−0.665***	[− 0.949 −0.475]	[− 0.849 −0.571]
	(0.039)	(0.088)		
a_3	−0.237***	−0.262*	[− 0.651 0.208]	[− 0.432 −0.033]
	(0.074)	(0.138)		
a_4	−0.002	−0.001	[−0.010 0.005]	[−0.006 0.001]
	(0.001)	(0.003)		

Standard deviation in parenthesis; * 10 %, ** 5 %, 1*** significance level

variables ($\ln \varepsilon_t$,s_t,$\ln \tau_t$,$\ln k_t$), υ_t is a vector of residuals such that $\upsilon_t \sim N(0, \Omega)$ and $\beta'$is a $(k \times n)$ matrix of parameters with k the number of cointegrating vectors and n the number of endogenous variables in the system.

Cointegration analysis tends to suggest that the VECM has one cointegrating vector so that β' is a (1×4) row vector of parameters. Various tests for the cointegration rank show that we can reject the null hypothesis of no cointegration, but that we cannot reject the null hypothesis of one cointegrating relationship against alternatives at 10 and 5 % significance levels. This result confirms prior analysis of the residuals from regressing Eq. (22) in level using OLS and seems to be robust to various alternative specifications of exogenous processes, trend or constant (see tables in Appendices 2 and 3).

6 Estimation results

To give a fair assessment of the reliability of our results, we adopt a diversified estimation strategy. First, we run a reduced rank regression estimation of the four equations VECM restricted to have one cointegrating vector. Second, we estimate the long run real exchange rate relationship in level using the single equation DOLS approach [see Eq. (24) below]. An analysis of the residuals confirms that introducing one lead and one lag of first differenced right hand side variables is enough to deal with potential bias due to the endogeneity of the regressors in levels:

$$\begin{aligned}\ln \varepsilon_t = a_0 + a_1 s_t + a_2 \ln \tau_t + a_3 \ln k_t + a_4 t \\ + b_1 \Delta s_{t+1} + b_2 \Delta s_{t-1} + c_1 \Delta \ln \tau_{t+1} + c_2 \Delta \ln \tau_{t-1} \\ + d_1 \Delta \ln k_{t+1} + d_2 \Delta \ln k_{t-1} + \vartheta_t \end{aligned} \quad (24)$$

This dual approach is justified given that VECM and DOLS estimators are asymptotically equivalent, but may differ in finite samples.[29] Third, although our sample spans 25 years of data, small sample bias may be a legitimate concern. To check the robustness of our asymptotic analysis, we then compute the small sample (25 annual observations) distribution of the parameters of interest based on a non-parametric bootstrap simulation of the VECM.[30] Plots of the small sample distribution of the parameters of interest are reported in Appendix 5 and compared to their asymptotic counterparts.

In Table 1 below we report estimates of the long run equation of the real exchange rate [Eq. (22)] using DOLS[31] and VECM. We also report 80 and 95 % confidence intervals of the parameters based on 20,000 bootstrap replications.[32]

The estimates in Table 1 suggest that the terms of trade are the main driver of the real exchange rate in Switzerland, followed by relative factor endowments. It also appears that the Balassa-Samuelson effect and domestic excess savings do not play a significant role in explaining long-run variations of the real exchange rate.[33]

All coefficients have the expected sign[34] and point estimates are remarkably close in VECM and DOLS.[35] An

[29] See Stock and Watson (1993).

[30] See Horowitz (2001).

[31] See Appendix 4 for a detailed report of DOLS estimates.

[32] This is done using Anders Warne's econometric package SVAR running on MATLAB.

[33] This confirms the results of Sax and Weder (2009), although their approach is quite different: they define the tradable good sector as the industrial sector and the nontradable good sector as the rest of the economy; they use changes in average labor productivity as a measure of technological progress.

[34] We verified that $1/a_1 \geq s_N - s_N^2$ for all observations as required by convexity of the technology.

[35] Bootstrapped small sample distributions of the parameters (see Appendix 5) tend to show the absence of small sample bias in VECM coefficient estimates based on Maximum Likelihood. The value of the maximum likelihood estimator of parameters α_1 to α_4 is exactly on top of the mean, mode and median of the small sample distribution. Yet, the variance of bootstrap-based coefficient estimates tends to be much larger than its asymptotic counterpart, meaning that statistical tests based on asymptotic distributions may be oversized.

improvement in the terms of trade (parameter a_2), an increase in capital intensity (parameter a_3), and technological progress (parameter a_4) all lead to a real appreciation of the Swiss franc, while an increase in domestic excess savings (parameter a_1) leads to a real depreciation.[36]

Note however that only parameters a_3 and a_2 are significant in both VECM and DOLS. While the terms of trade parameter is significant at the 1 % level in VECM and DOLS estimations and is also clearly negative in the small sample analysis, the empirical evidence is less clear cut regarding the role of the capital intensity in explaining the long run level of the real exchange rate. The parameter a_3 is significant at the 1 % level in VECM but only at the 10 % level in DOLS. Moreover, the small sample bootstrap exercise shows that it is significantly different from zero at the 20 % level only.

Before turning to the conclusion, we may examine our model's implications for the long-term evolution of the real value of the Swiss franc. Since the beginning of the seventies, the Swiss franc real exchange rate has been on a continuous appreciating trend that seems to have come to an end in 2003. Since then, the Swiss franc has started to depreciate progressively, stimulating heated discussions on the potential factors behind this change of fortune. Is it a new fundamental trend? If yes, what are the main factors behind it? Are they the same as the ones behind the 30 years trend appreciation? Or is it only a persistent, but essentially temporary, deviation from the previous appreciating tendency?

Although it is probably too early to reach definite conclusions, we think that there are valuable insights to be gained from our empirical analysis. Relying on the VECM long-term cointegration relationship reported in Table 1, we first compute the model-implied fitted value of the real exchange rate, i.e., the value of the real exchange rate that is implied by the level of the explanatory variables in the cointegrating vector, and compare it to the actual value of the real exchange rate. The first graph in the "Appendix 6" displays the actual behaviour of the real exchange rate (bold solid line), the model fitted value (bold dashed line) and the gap in percent between the two curves (thin solid line, left scale). Despite periods of persistent and quite significant discrepancies between actual and fitted real exchange rate, the model tracks the long run evolution of the Swiss franc strikingly well. Concerning the last 4 years, our exchange rate equation seems to indicate that, indeed, there has been a change in trend and that the available data, if anything, tend to *under*estimate it.

The second graph in the "Appendix 6" shows the contribution[37] of each variable to the long-term appreciation of the real exchange rate and to the recent depreciation between 2003 and 2007. The decomposition tends to confirm the dominant role played by changes in the terms of trade. Continuous improvements in the terms of trade have contributed for 60 % to the trend-like appreciation of the real exchange rate until 2003, but their deterioration since 2003 explains more than 90 % of the recent depreciation. The secular increase in the domestic capital intensity also seems to be an important factor behind the trend-like appreciation of the Swiss franc, with a contribution of almost 40 %. It has played virtually no role, however, in the recent depreciation.

7 Conclusions

The realization that in the small open economy the real exchange rate can be associated with the relative price of traded to nontraded products, together with the recognition that nearly all trade is in middle products has far reaching consequences for understanding real exchange rates. Thus, production theory is the natural setting for analyzing real exchange rates, and production parameters—such as domestic factor endowments, technological change, and the terms of trade—are liable to play a role in determining the marginal rate of transformation between traded and nontraded products. Moreover, any empirical application is greatly facilitated by the fact that national accounts data can readily be used. There is no need therefore to make any heroic decisions as to what goods and services are traded rather than nontraded.

Starting from a fully flexible representation of the country's technology by way of a Translog real GDI function, we were able to formally derive a real exchange rate equation that depends on four key variables: domestic factor intensity, the terms of trade, domestic excess savings, and a time index that captures the impact of changes in TFP. The results for Switzerland suggest that the real appreciation of the franc that has taken place over the past several decades is mostly due to the improvement in Switzerland's terms of trade. The increase in domestic capital intensity has also played a part, whereas demand conditions and technological change seem to have played a minor and statistically insignificant role. This last result invalidates a widely held view, namely that it is a Balassa-Samuelson effect that is mostly responsible for the secular real appreciation of the Swiss franc.

[36] See footnote 25.

[37] The contribution of factor X is computed as $a\Delta X/\Delta \ln RER$.

In recent years, the strengthening trend of the Swiss franc seems to have come to an abrupt halt. In fact, from 2003 to 2007, the price of traded goods has increased by 2.5 % against the price of nontraded goods. The jury is still out as to decide whether this movement is a temporary deviation or whether it signals a break from the past. Naturally, exchange rates are known to be very volatile, and random deviations of this magnitude have been experienced in the past. Some observers have suggested, however, that this turnaround might be due to a reversal of the Balassa-Samuelson effect, with efforts directed at invigorating the Swiss internal market being successful and resulting in a decrease in the relative price of non-traded goods. Our results suggest on the contrary that the explanation rather lies in the worldwide increase in energy, commodity, and food prices. Thus, from 2003 to 2007, Switzerland's terms of trade have worsened by over 6 %. This has not only taken a direct toll of Switzerland's real GDI, but it has also contributed to the real depreciation of the currency. Unfortunately, there is no way of telling whether this development is transitory or permanent, but the real weakening of the franc during that period does not seem to be an aberration.

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Appendix 1: Description of the data

All data are annual for the period 1981–2007. Prices and quantities of the five GDP components (consumption, investment, government purchases, exports and imports) are drawn from the Swiss national accounts. The price of nontraded goods is obtained as a Törnqvist chained index of the prices of consumption, investment and government purchases, and the corresponding quantity index is obtained by deflation. The quantity series for capital and labour (hours worked) inputs are obtained from the Swiss National Bank.

In what follows, the following notation is used: LNRER = ln(ε), SB = s, LNKL = ln(k), LNTOT = ln(τ).

Appendix 2: Cointegration tests 10 % significance level

Included observations: 26
Series: LNRER SB LNKL LNTOT
Lags interval: 1–1

Selected (0.1 level*) Number of Cointegrating Relations by Model

Data trend:	None	None	Linear	Linear	Quadratic
Test type	No intercept	Intercept	Intercept	Intercept	Intercept
	No trend	No trend	No trend	Trend	Trend
Trace	1	1	1	1	1
Max-Eig	1	1	1	1	1

* Critical values based on MacKinnon-Haug-Michelis (1999)

Included observations: 26 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: LNRER LNKL LNTOT SB
Lags interval (in first differences): 1–1

Unrestricted cointegration rank test (Trace)

Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	0.1 Critical value	Prob.**
None*	0.719434	60.54543	60.08629	0.0923
At most 1	0.402851	28.77179	39.75526	0.5757
At most 2	0.314176	15.88208	23.34234	0.5020
At most 3	0.227520	6.453716	10.66637	0.4050

Trace test indicates 1 cointegrating eqn(s) at the 0.1 level
* denotes rejection of the hypothesis at the 0.1 level
** MacKinnon-Haug-Michelis (1999) *p*-values

Unrestricted cointegration rank test (Maximum Eigenvalue)

Hypothesized no. of CE(s)	Eigenvalue	Max-Eigen statistic	0.1 Critical value	Prob.**
None *	0.719434	31.77364	29.54003	0.0550
At most 1	0.402851	12.88971	23.44089	0.8119
At most 2	0.314176	9.428360	17.23410	0.6798
At most 3	0.227520	6.453716	10.66637	0.4050

Maximum Eigenvale test indicates 1 cointegrating eqn(s) at the 0.1 level
* denotes rejection of the hypothesis at the 0.1 level
** MacKinnon-Haug-Michelis (1999) *p*-values

Appendix 3: Cointegration tests 5 % significance level

Included observations: 26
Series: LNRER LNTOT LNKL SB
Lags interval: 1–1

Data trend:	None	None	Linear	Linear	Quadratic
Rank or no. of CEs	No intercept	Intercept	Intercept	Intercept	Intercept
	No trend	No trend	No trend	Trend	Trend
Selected (5 % level) Number of Cointegrating Relations by Model (columns)					
Trace	1	1	1	0	0
Max-Eig	1	1	1	1	0

Included observations: 26 after adjusting endpoints
Trend assumption: Linear deterministic trend (restricted)
Series: LNRER LNTOT LNKL SB
Lags interval (in first differences): 1–1

Unrestricted cointegration rank test

Hypothesized no. of CE(s)	Eigenvalue	Trace statistic	5 % Critical value	1 % Critical value
None	0.719434	60.54543	62.99	70.05
At most 1	0.402851	28.77179	42.44	48.45
At most 2	0.314176	15.88208	25.32	30.45
At most 3	0.227520	6.453716	12.25	16.26

*(**) denotes rejection of the hypothesis at the 5 (1 %) level
Trace test indicates no cointegration at both 5 and 1 % levels

Hypothesized no. of CE(s)	Eigenvalue	Max-Eigen statistic	5 % Critical value	1 % Critical value
None *	0.719434	31.77364	31.46	36.65
At most 1	0.402851	12.88971	25.54	30.34
At most 2	0.314176	9.428360	18.96	23.65
At most 3	0.227520	6.453716	12.25	16.26

*(**) denotes rejection of the hypothesis at the 5 (1 %) level
Max-eigenvalue test indicates 1 cointegrating equation(s) at the 5 % level
Max-eigenvalue test indicates no cointegration at the 1 % level

Appendix 4: Detailed estimation results

a) VECM model
Vector Error Correction Estimates
Included observations: 26 after adjusting endpoints
Standard errors in () and t-statistics in []

Cointegrating Eq:	CointEq1
LNRER(−1)	1.000000
LNTOT(−1)	0.698647
	(0.03920)
	[17.8247]
LNKL(−1)	0.236969
	(0.07414)
	[3.19623]
SB(−1)	−0.478380
	(0.20142)
	[− 2.37502]
@TREND(80)	0.001848
	(0.00127)
	[1.45406]

Error correction:	D(LNRER)	D(LNTOT)	D(LNKL)	D(SB)
CointEq1	−0.566299	−0.518410	−0.114205	−0.337472
	(0.66330)	(0.87414)	(0.25406)	(0.23968)
	[−0.85375]	[−0.59305]	[−0.44952]	[−1.40801]
D(LNRER(−1))	−0.071221	0.210206	−0.176405	−0.083183
	(0.43671)	(0.57552)	(0.16727)	(0.15780)
	[−0.16309]	[0.36524]	[−1.05462]	[−0.52714]
D(LNTOT(−1))	−0.165611	0.247309	0.024163	−0.106184
	(0.32592)	(0.42952)	(0.12483)	(0.11777)
	[−0.50813]	[0.57578]	[0.19356]	[−0.90163]
D(LNKL(−1))	0.037188	0.138452	0.562151	−0.109251
	(0.45988)	(0.60606)	(0.17614)	(0.16617)
	[0.08086]	[0.22845]	[3.19142]	[−0.65745]
D(SB(−1))	−0.604804	0.395990	−0.238984	−0.252135
	(0.82053)	(1.08134)	(0.31428)	(0.29649)
	[−0.73709]	[0.36620]	[−0.76042]	[−0.85040]
C	−0.007748	0.002068	0.004931	0.005468
	(0.00968)	(0.01275)	(0.00371)	(0.00350)
	[−0.80070]	[0.16220]	[1.33038]	[1.56399]
R-squared	0.086037	0.107134	0.561225	0.216295
Adj. R-squared	−0.154480	−0.127831	0.445757	0.010056

b) DOLS model
Dependent Variable: LNRER
Method: Least Squares
Sample (adjusted): 1983 2007
Included observations: 25 after adjustments

	Coefficient	Std. error	t-Statistic	Prob.
C	−0.014602	0.027321	−0.534469	0.6047
SB	0.261405	0.482324	0.541970	0.5997
LNKL	−0.262562	0.138011	−1.902477	0.0863
LNTOT	−0.665111	0.088448	−7.519793	0.0000
T	−0.001030	0.002752	−0.374320	0.7160
DSB(1)	−0.274947	0.293261	−0.937549	0.3706
DSB	−1.047944	0.365601	−2.866362	0.0168
DSB(−1)	−0.390271	0.294136	−1.326840	0.2141
DLNKL(1)	−0.276445	0.265688	−1.040490	0.3226
DLNKL	0.077014	0.308049	0.250006	0.8076
DLNKL(−1)	0.307111	0.293204	1.047431	0.3196
DLNTOT(1)	0.001715	0.086510	0.019827	0.9846
DLNTOT	0.060349	0.087737	0.687834	0.5072
DLNTOT(−1)	−0.071894	0.090796	−0.791812	0.4468

Appendix 5

See Fig. 3.

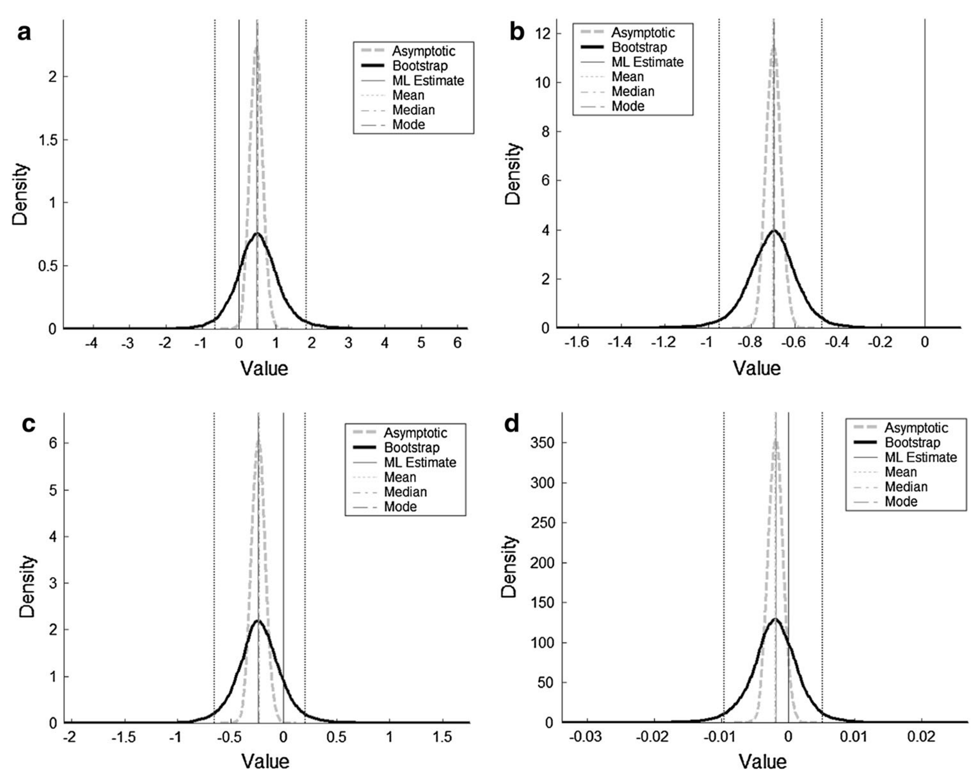

Fig. 3 Appendix 5: VECM bootstrapped parameters distributions. **a** Bootstrapped a_1 with 95 % confidence interval from bootstrapped t-statistic distribution. **b** Bootstrapped a_2 with 95 % confidence interval from bootstrapped t-statistic distribution. **c** Bootstrapped a_3 with 95 % confidence interval from bootstrapped t-statistic distribution. **d** Bootstrapped a_4 with 95 % confidence interval from bootstrapped t-statistic distribution

Appendix 6

See Fig. 4.

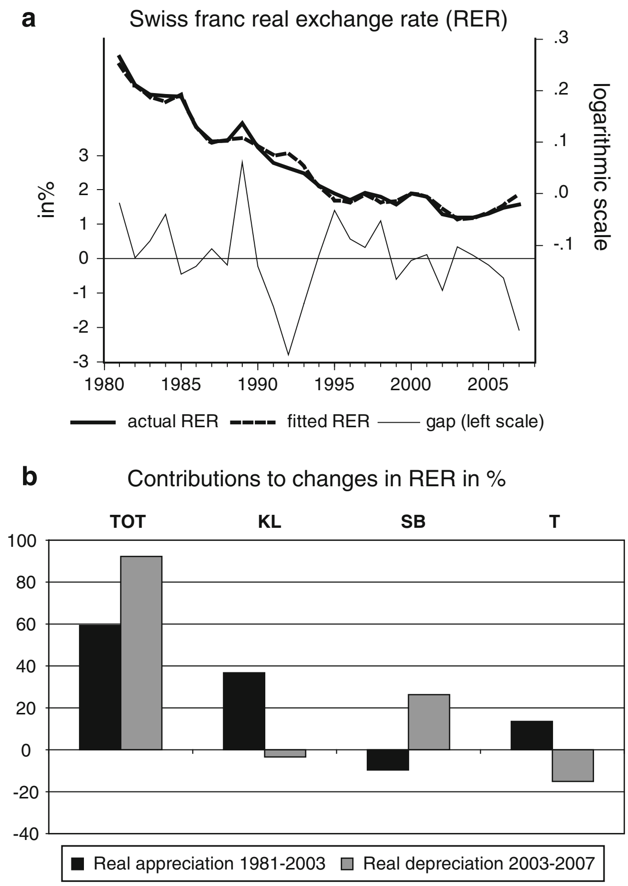

Fig. 4 Appendix 6: VECM implications for RER in Switzerland. **a** Swiss franc real exchange rate (RER). **b** Contributions to changes in RER in %

References

Aebersold C, Brunetti A (1998) Die langfristige reale Aufwertung des Schweizer Frankens gegenüber der D-Mark: nichthandelbare Güter und der Balassa-Samuelson-Effekt. Aussenwirtschaft 53:365–386

Asea PK, Mendoza EG (1994) The Balassa-Samuelson model: a general-equilibrium appraisal. Rev Int Econ 2:244–267

Balassa Bela (1964) The purchasing power doctrine: a reappraisal. J Polit Econ 72:584–596

Bergstrand JH (1991) Structural determinants of real exchange rates and national price levels: some empirical evidence. Am Econ Rev 81:325–334

Burgess DF (1974) Production theory and the derived demand for imports. J Int Econ 4:103–117

Caves RE, Frankel JA, Jones RW (1990) World trade and payments: an introduction, 5th ed. Scott, Foresman/Little, Brown, Glenview

Corden WM (1984) Booming sector and Dutch disease economics: survey and consolidation. Oxf Econ Pap 36:359–380

Corden WM (1992) "Dependent economy model of the balance of payments", New palgrave dictionary of money and finance. Macmillan, London

De Gregorio J, Giovannini A, Wolf HC (1994) International evidence on tradables and nontradables inflation. Eur Econ Rev 38: 1225–1244

Diewert WE, Morrison CJ (1986) Adjusting output and productivity indexes for changes in the terms of trade. Econ J 96:659–679

Diewert WE, Wales TJ (1992) Quadratic spline models for producer's supply and demand functions. Int Econ Rev 33:705–722

Dornbusch R (1980) Open economy macroeconomics. Basic Books, New York

Edwards S (1989) Economic liberalization and the equilibrium real exchange rate in developing countries. In: Calvo G, Findlay R, Kouri P, Braga de Macedo J (eds) Debt, stabilization and development. Blackwell, Oxford

Feenstra RC (2004) Advanced international trade: theory and evidence. Princeton University Press, Princeton

Harrigan J (1997) Technology, factor supplies and international specialization: estimating the neoclassical model. Am Econ Rev 87:475–494

Helpman E (1977) Nontraded goods and macroeconomic policy under a fixed exchange rate. Q J Econ 91:469–480

Horowitz JL (2001) The Bootstrap. In: Heckman JJ, Leamer EE (eds) Handbook of econometrics, vol 5. North-Holland, Amsterdam, pp 3159–3228

Johansen S (1996) Likelihood-Based-Inference in Cointegrated Vector Autoregressive Models (2nd ed.), Oxford University Press

Jones RW, Neary PJ (1984) The positive theory of international trade. In: Jones RW, Kenen PB (eds) Handbook of international economics, vol 1. North-Holland, Amsterdam

Kohli U (1978) A gross national product function and the derived demand for imports and supply of exports. Can J Econ 11:167–182

Kohli U (1983) Non-joint technologies. Rev Econ Stud 50:209–219

Kohli U (1991) Technology, duality, and foreign trade: the GNP function approach to modeling imports and exports. University of Michigan Press, Ann Arbor

Kohli U (1992) Production, foreign trade, and global curvature conditions: Switzerland, 1948–1988. Swiss J Econ Stat 128:3–20

Kohli U (1993) US technology and the specific-factors model. J Int Econ 34:115–136

Kohli U (2004) Real GDP, real domestic income, and terms-of-trade changes. J Int Econ 62:83–106

Kohli Ulrich (2007) Terms-of-trade changes, real GDP, and real value added in the open economy: reassessing Hong Kong's growth performance. Asia-Pac J Account Econ 14:87–109

Kohli U (2008) Globalization, trade in middle products, and relative prices. In: Marjit S, Yu E (eds) Contemporary and emerging issues in trade theory and policy, Macmillan, London

Rybczynski TM (1955) Factor endowment and relative commodity prices. Economica 22:336–341

Salter WEG (1959) Internal and external balance: the role of price and expenditure effects. Econ Rec 35:226–238

Samuelson PA (1964) Theoretical note on trade problems. Rev Econ Stat 23:145–154

Sanyal KK, Jones RW (1982) The theory of trade in middle products. Am Econ Rev 72:16–31

Sax C, Weder R (2009) How to explain the high prices in Switzerland? Swiss J Econ Stat 145:463–483

Seco (2008) Preisinsel Schweiz. Staatsekretariat für Wirtschaft, Berne

Stock JH, Watson MW (1993) A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica 61:783–820

Svensson LEO, Razin A (1983) The terms of trade and the current account: the Harberger-Laursen-Metzler effect. J Polit Econ 91:97–125

Turnovsky SJ (1997) International macroeconomic dynamics. MIT Press, Cambridge

Woodland AD (1982) International trade and resource allocation. North-Holland, Amsterdam