Time-Intesnive R&D and Unbalanced Trade*

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Abstract

This paper highlights a novel mechanism that generates global imbalances. It develops a general equilibrium model with one country having a comparative advantage in a sector, whose production is characterized by (i) rapid, anticipated demand growth and (ii) large upfront R&D costs. International funding of the accruing R&D costs generates capital inflows in the R&D stage, which are balanced by subsequent outflows. Importantly, the sector-level growth does not generate cross-country growth differentials, which are typically regarded as rationales of global imbalances. Also, it is shown that a trade surplus can coincide with appreciations of the real exchange rate. Switzerland's trade surplus, which was driven to record hights during 2010-2014 by pharmaceutical exports, provides an example of this mechanism. A calibration exercise of the model to Swiss trade flows underpins this argument.

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1 Introduction

Trade theory does not require that cross-border trade flows be balanced period by period. Nevertheless, large current account and trade imbalances raise serious concerns. Those concerns arise, since such global imbalances may result in disruptive and potentially painful adjustments.[1]

Harmful, or *bad imbalances* (Blanchard and Milesi-Ferretti (2009)) are typically attributed to the realm of policy misalignments and systemic risks. On the other hand, beneficial, or *good imbalances* can naturally arise due to differentials in economic growth rates, demographic dynamics and other factors that impact national savings and investment opportunities.[2] The correct distinction between good and bad imbalances, being a prerequisite for adequate policy actions, is of obvious relevance.

This paper documents one particular source of *good imbalances*, which previous literature has ignored. It shows that unbalanced trade naturally arises under fast growth of demand for goods of one specific sector, which is characterized by a cost- and time-intensive R&D activity. Countries with a comparative advantage in such a sector will, in anticipation of demand growth for its export goods, scale up their R&D activity. Part of these investments are financed on the international capital market, thus generating capital inflow. By consequence, such countries run trade deficits. Conversely, there are capital outflows in later periods, mirrored by the according trade surpluses.

Importantly, the fast growth of the R&D-intensive sector (spurred by either growing demand or technological progress) does not generate substantial differences in measured GDP growth across countries. Thus, the mechanism does not merely exemplify the well-studied imbalances that are driven by differentials in country-wide productivity growth (Obstfeld and Rogoff 1996). Instead, it highlights that the forces of technological progress can generate imbalances without necessarily surfacing in country-wide growth rates. The underlying reason of this observation is that shifts in factor allocation and countries' specialization patterns transmit the gains from sector-specific productivity growth in one country across borders, thus levelling growth

[1]See, e.g. Roubini and Sester (2005); and Obstfeld and Rogoff (2007), and Lane and Milesi-Ferretti (2014). Obstfeld and Rogoff (2005) see adjustment shocks and possible economic "traumas [for] the United States and foreign economies" as a reasonable scenario.

[2]For recent prominent examples, see Caballero et al (2008) and Mendoza et al (2009).

differentials across countries.[3] Consequently, this type of imbalances that would be classified as *bad* under an conventional assessment based on cross-country growth (and savings) rates must actually be classified as *good*. In these cases, distinguishing good and bad imbalances may thurn out to be even harder than previously thought.[4]

In addition, the model delivers valuable implications regarding the exchange rate dynamics. Specifically, it predicts that a country's trade surplus may coincide with an appreciation of its real exchange rate (defined as the ratio of local over foreign consumer-price adjusted wages). The real exchange rate of the country with the growing, R&D-intensive described above, appreciates over time through a combination of the two following antagonistic forces. First, wages in this country tend to fall relative to foreign wages because of the capital outflows in the second period.[5] Second, wages tend to increase by the home market effect as physical production expands in the second period These effects make the local price index fall, thus increasing real wages. These second forces turn out to be dominant, and the real exchange rate of the country appreciates. In sum, exchange rate appreciations concur with positive net exports.

The theory is framed in the classical two-country trade model à la Krugman (1980), amended in two dimensions. First, countries trade in two periods, which allows for non-trivial international borrowing and lending. Second, goods (or varieties) are produced in two different sectors under unlimited but costly entry. These sectors differ in the nature of setup costs: in one of the them, the sector D, setup costs accrue up-front; in the other sector, there are only per-period fixed costs. Consequently, firms in sector D are set up in the initial period but produce in the second period, while the other firms are set up and produce in each of the periods. I assume that only country 1 can produce in sector D and covers supplies world demand. In the first period, country 1 thus allocates part of its resources to cover setup costs in sector D. International capital markets channel savings to foreign investors to country

[3]Indeed, in absence of trade costs, growth and savings rates are identical across countries.

[4]Blanchard Milesi-Ferretti 2009 write that "assessing whether imbalances were good or bad, and the role of distortions and risks, turns out to be far from obvious in practice, and thus a major source of disagreements."

[5]This first force, labeled the *secondary burden* of international transfers by Keynes, extensively studied. See Keynes (1929), Corsetti et al (2013) and Land and Milesi-Ferretti (2012).

1's D-sector to (partly) cover up-front setup costs. Thus, capital flows to country 1, its position of net foreign asset decreases as it runs a trade deficit. In the second period the firms in sector D produce; their profits are used to service gross returns one investment. Country 1 runs a trade surplus.

It is important to stress that the logic of the argument rests on the assumption that the R&D-intensive sector exhibits fast growth. This growth may be driven by either technological progress (the costs of R&D drops and suddenly becomes profitable) or reflect an increase in demand of the R&D-intensive good (demographic change and per capita income growth change expenditure patterns). In either scenario, the economy is not in steady state and there is not a constant stream of capital outflow that is balanced by a constant stream of capital inflows.

The model is calibrated to Switzerland trade flows, which happen to provide an especially fitting example of the mechanism outlined above. In particular, Swiss net exports were at record heights during the period 2010 to 2014, with the last decades' increase in exports mainly by pharmaceutical trade. The pharmaceutical industry, in turn, is the paradigm of a R&D-intensive sector, with R&D phase that is not only cost-intensive but that extends over particularly long periods of time.[6] Together, these features make the Swiss economy a relative clean example of the situation described by in the theoretical setup.

Calibrated to match the increase of the share of pharmaceutical products in the Swiss export basket, the model predicts the increase of total trade quite well under a wide range of reasonable parameter values. At the same time, the terms of trade (wage ratio domestic over foreign) and the real exchange rate (price adjusted wage ratio) are predicted to remain essentially unchanged. It is also shown that these results – moderate changes of terms of trade and real exchange rates at simultaneously large movements in the trade balance – are generalize to the case when the country considered is relatively large.

The present paper connects to various literatures. First, it relates to the extensive work on the global imbalances and external adjustments, large parts of which are motivated by the US current account deficit (the largest

[6] See Klette (1996), Acemoglu and Linn (2004) and Deutsche Bank (2012).

piece of the global imbalances).[7] Key determinants are the strong reserve accumulation of Asian (in particular, the Chinese) central banks and US fiscal policy and some see them as a major contributor of the financial crisis.[8] Most studies argue that for ultimate rebalancing, substantial depreciations of the USD is needed. The studies with a critical view on global imbalances are summarized by Blanchard Milesi-Ferretti 2009, who state that before 2007, "the large structural deterioration in fiscal accounts was viewed as undesirable." Other studies take comfort in the fact that the US current account deficit can be rationalized as efficient outcomes in general equilibrium. Prominent explanations rely on the *global savings glut* valuation effects or financial development.[9] The current paper adds to this literature by showing that cross-country differences in aggregate growth rates are generally not enough to detect the sources of "good" imbalances, when these are based on sector-specific growth.

The current study also contributes to the analysis of global imbalances through the lens of trade-based models such as Dekle et al (2007) and (2008) and Corsetti et al (2007 and 2013) and those based on Obstfeld and Rogoff (1996).[10] These studies typically build on static trade models and examine the implications and channels of eliminating current account imbalances but do not analyze their causes.[11] The current paper adds to this literature in two dimensions. First, it abandons the static modelling setup that is usually explored and thus allows for the endogenous motives of cross-border capital flows and unbalanced trade.[12] Second, unbundles the sectorial dimension and identifying sectorial growth in specific industries as one particular source of global imbalances. It thus takes on the challenge of Dekle et al (2007)

[7]See Edwards (2005), Obstfeld and Rogoff (2005a, 2007) Lane and Milesi-Ferretti (2014), Corsetti and Konstantinou (2012) and Blanchard et al (2005).

[8]See, in particular, Chinn and Ito (2008) and Roubini and Sester (2005).

[9]See Bernake 2005, McGrattan and Prescott 2010 Gourinchas and Rey 2007, Chakraborty and Dekley 2008 , Caballero et al 2008, Mendoza et al 2009 and Prades and Rabitsch 2012.

[10]See also Boyd et al (2001), Kappler et al (2013) and Chinn and Wei (2013) for discussions of the literature on exchange rates and current account adjustments, which goes back to Ohlin (1929) and Keynes (1929).

[11]Under such an approach, the effects in the short and the long run are usually distinguished by considering perfect or no factor mobility (Deckle et al (2008)), or, alternatively, exogenous and endogenous number of firms (Corsetti et al (2007)).

[12]See Corsetti et al (2013), who present a recent noteworthy exception from the static setup.

who, observing that trade imbalances are still imperfectly understood "defer modeling their determinants for future work."

The current paper relates to the literature on cyclicality of trade flows, which received much attention during the recent trade collapse (as in Alessandria et al. (2010) Domit and Shakir (2010), Crowley and Luo (2011), Engel and Wang (2011) and Bems et al. (2012). Closely related to the current paper in the general idea, Erceg et al. (2008) argue that investment shocks may generate external adjustments and show that these adjustments do not need to come about real exchange rate fluctuations. As for its framework and analytical tools the present paper is closest to Corsetti et al (2007, 2013), who analyze enhanced versions of the Krugman (1980) type of model. While these authors explore the effects of firm entry in tradable and nontradable sectors under largely exogenous adjustments, the present paper cuts goes one step further, endogenizing trade imbalances by assuming differential investment opportunities.

Finally, the general principle of the paper is also reminiscent of the *hysteresis* or *beachhead effect* (see Baldwin (1988), Dixit (1989) Baldwin and Krugman (1986), by which sunk costs that are incurred in the past partly decouple of the trade flows from actual exchange rate fluctuation. Referring to this phenomenon, Baldwin and Krugman (1986) argue that, "[o]nce foreign firms have invested in marketing, R&D, reputation, distribution networks, etc., they will find it profitable to remain in the U. S. market even at a lower exchange rate."

The remainder of this paper is structured as follows. Section 2 presents the theory, section 3 illustrates a calibration exercise to the Swiss economy and, in particular, to its pharmaceutical sector and section 4 concludes.

2 The Model

There are two countries, indexed by $i = 1, 2$, and populated with identical individuals. The world economy deviates from the standard Krugman (1980) setup in two dimensions. First, countries produce and trade in two periods, indexed by $t = 0, 1$. The main implication of this assumption is that trade is balanced on an intertemporal basis, but not necessarily period-by-period. Second, there are two sectors, indexed by $S = C, D$. One of the sectors (sector C) is subject to the standard period-by-period fixed costs; in the other (sector D) setup costs need to be incurred one period in advance of actual production.

2.1 Model Setup

Preferences. The representative consumer in country i derives a sub-utility from the consumed quantities c_{ij} produced in sector C and quantities d_{ij} produced in sector D. This sub-utility is

$$\bar{C}_{i,t} = \left[\int c_{ij,t}^{1-1/\varepsilon} dj + \int d_{ij,t}^{1-1/\varepsilon} dj \right]^{\varepsilon/(\varepsilon-1)} \tag{1}$$

Total utility is

$$U_i = \ln\left(\bar{C}_{i,1}\right) + \delta \ln\left(\bar{C}_{i,2}\right) \tag{2}$$

where δ is the discount factor of individuals.

Denoting wages with $w_{i,t}$, consumers maximize utility (2) subject to the budget constraints

$$\sum_{t=0}^{1} R^{-t} \left\{ \int q_{ij,t}^{D} d_{ij,t} dj + \int q_{ij,t}^{C} c_{ij,t} dj - w_{i,t} \right\} \leq 0 \tag{3}$$

where $q_{j,t}^{S}$ is the consumer price of a variety of sector S produced in country j, charged at time t; R is the gross nominal interest rate between both periods.

Technology. The amount $x_{k,t}$ of sector C-variety k is produced through

$$L_{k,t} = \alpha^{C} + \beta x_{k,t} \tag{4}$$

in Home and Foreign. I assume that only country 1 can produce varieties of sector D according to

$$x_{k,t} = \begin{cases} L_{k,t}/\beta & \text{if } L_{k,t-1} = \alpha^{D} \\ 0 & \text{if } L_{k,t-1} < \alpha^{D} \end{cases} \tag{5}$$

That is, in the D-sector fixed costs are incurred in the period before actual production. In $t = 0$ no firms are active in the D-sector and no D-type varieties can be produced.[13]

[13] Notice that this setup admits interpretations of growth in the D-sector due to technological change (e.g., when α^{D} drops from prohibitive levels in periods $t < 0$) or demand shocks (when a weighting factor in the aggregator (1) increases from zero in periods $t < 0$ to one as specified here).

2.2 Optimization

Product Prices. Factory-gate prices of varieties produced in country i are

$$p_{i,t}^{S} = \frac{\varepsilon}{\varepsilon - 1}\beta w_{i,t} \tag{6}$$

Cross border trade is subject to standard iceberg-type trade costs, captured by $\tau \geq 1$, so that consumer prices equal $p_{i,t}^{S}$ when goods consumed locally and $p_{i,t}^{S}$ times the factor τ when shipped abroad.

Country Bundles. The ideal producer price index of goods produced in country i at time t is denoted by

$$P_{i,t} = \left[\int_{B_{it}} \left(p_{jt}^{S}\right)^{1-\varepsilon} dj\right]^{1/(1-\varepsilon)} = \frac{\varepsilon}{\varepsilon - 1}\beta w_{i,t} n_{it}^{1/(1-\varepsilon)} \tag{7}$$

where B_{it} is the set of varieties produced in country i at time t and n_{it} is its mass. Consumer prices of the corresponding consumption bundles $C_{ij,t}$ are equal to these prices (7) times gross trade costs τ if applicable. The consumption bundle of individuals in country i of goods produced in country j at time t can be written as

$$C_{ij,t} = c_{ij,t} n_{jt} \tag{8}$$

and aggregate consumption $\bar{C}_{i,t}$ from (1) is

$$\bar{C}_{i,t} = \left[C_{i1,t}^{1-1/\varepsilon} + C_{i2,t}^{1-1/\varepsilon}\right]^{\varepsilon/(\varepsilon-1)} \tag{9}$$

Expenditures. Consumer decision involves intertemporal expenditure. Preferences (2) imply that expenditure shares in period t is $\delta^{t}/(1+\delta)$. In period $t = 0$ the net present value of an individual's income is $W_i = w_{i,0} + R^{-1} w_{i,1}$, where R is the gross nominal interest rate. Thus, expenditures of individuals are, when expressed in period 1-dollars

$$e_{1,t} = \frac{(\delta R)^{t}}{1+\delta} w_{1,0}\left(1 + \frac{\Omega}{R}\right) \quad \text{and} \quad e_{2,t} = \frac{(\delta R)^{t}}{1+\delta} w_{1,0}\left(\omega_0 + \frac{\Omega}{R}\omega_1\right) \tag{10}$$

where relative wages

$$\Omega = w_{1,1}/w_{1,0} \quad \text{and} \quad \omega_t = w_{2,t}/w_{1,t} \tag{11}$$

are introduced.

Demand for Bundles. Consumer optimization of (2) under (9) subject to the budget constraint $\sum_t R^t(P_{i,t}C_{ii,t}+\tau P_{j,t}C_{ij,t}) \leq W_i$ (with $j \neq i$) implies

$$\frac{C_{ii,t}}{C_{ij,t}} = \left(\frac{P_{i,t}}{\tau P_{j,t}}\right)^{-\varepsilon} \tag{12}$$

Expenditure on consumption goods in country i at time t is now with (7) (see Appendix)

$$e_{i,t} = \tau P_{j,t}C_{ij,t}\left(\left(\frac{w_{i,t}}{\tau w_{j,t}}\right)^{1-\varepsilon}\frac{n_{it}}{n_{jt}}+1\right) \tag{13}$$

Notice that combining (7), (10) and (13) determines consumption of bundles $C_{ij,t}$ as a function of relative wages Ω and ω_t, and the number of firms $n_{i,t}$. To determine these latter endogenous variables will be aim of the next steps.

Savings and Capital Flows. In period $t = 0$ individual savings in either country equals wage income minus expenditure ($s_{i,0} = (w_{i,0} - e_{i,0})$) or with (10)

$$s_{1,0} = \frac{w_{1,0}}{1+\delta}\left(\delta - \frac{\Omega}{R}\right) \quad \text{and} \quad s_{2,0} = \frac{w_{1,0}}{1+\delta}\left(\delta\omega_0 - \frac{\Omega}{R}\omega_1\right) \tag{14}$$

Since investment in the D-sector is the only form of savings, all savings in country 2 ($S_{2,0} = L_2 s_{2,0}$) are invested in country 1. In period $t = 1$, when returns on investments are collected and country 1's capital outflow is $RS_{2,0}$. Together, country 1's net capital inflows in period t are thus with (14)

$$CF_{1,t} = (-R)^t S_{2,0} = (-R)^t L_2\frac{w_{1,0}}{1+\delta}\left(\delta\omega_0 - \frac{\Omega}{R}\omega_1\right) \tag{15}$$

Investment in the D-Sector. Denote the number of active D-type firms in country 1 in period 1 with n^D so that the total costs of generating blueprints in the D-sector is $\alpha^D n^D w_{1,0}$.[14] This sum must be equal the total value of savings in period 0, which is (use $S_{i,0} = L_i s_{i,0}$ and (14))

$$S_{1,0} + S_{2,0} = L_1\frac{w_{1,0}}{1+\delta}\left(\delta\left[1+\lambda\omega_0\right] - \frac{\Omega}{R}\left[1+\lambda\omega_1\right]\right) \tag{16}$$

[14]The number of D-type firms in country 2 or in period $t = 0$ is zero by construction.

where $\lambda = L_2/L_1$. Together, this yields

$$n^D = \frac{L_1}{\alpha^D}\frac{1}{1+\delta}\left(\delta\left[1+\lambda\omega_0\right] - \frac{\Omega}{R}\left[1+\lambda\omega_1\right]\right) \tag{17}$$

The obvious conditions for an interior solution to prevail are $n^D > 0$ and, by the resource constraint, $\alpha^D n^D < L_1$, or

$$0 < \delta\left[1+\lambda\omega_0\right] - \frac{\Omega}{R}\left[1+\lambda\omega_1\right] < 1+\delta \tag{18}$$

At the firm level, free entry in the D-sector requires that the entry costs $(w_{1,0}\alpha^D)$ are just covered by the present value of future operating profits. The CES aggregator (1) implies that the share of operating profits in firm revenues equals $1/\varepsilon$: This, in turn, implies that the present value of future profits equals $R^{-1}(1/\varepsilon)x_{1,1}^D\beta w_{1,1}$. Equating costs to profits and using (11) implies

$$\alpha^D = (\Omega/R)\,(\beta/\varepsilon)\,x_{1,1}^D$$

In $t = 1$ firm output for the C- and for D-sector firm is identical $(x_{1,1}^C = x_{1,1}^D)$, and, moreover, $\beta/\varepsilon x_{1,1}^C w_{1,1} = \alpha^C w_{1,1}$ holds by free entry in the C-sector. Thus, the equality

$$\Omega/R = \alpha^D/\alpha^C \tag{19}$$

follows. Clearly, in the cases where $\Omega/R < \alpha^D/\alpha^C$, investment costs are not covered and the D-sector is idle.[15] Alternatively, $\Omega/R > \alpha^D/\alpha^C$ cannot be an equilibrium, since more D-type firms would enter the market.

Equation (19) conveniently pins down the wage evolution in country 1 by requiring $\Omega = w_{1,1}/w_{1,0} = R\alpha^D/\alpha^C$. The crucial observation is that in the interior solution in period 1, a worker (or entrepreneur) is indifferent between buying a blueprint of the D-good at the production cost plus interest $Rw_{1,0}\alpha^D$ or paying a worker (or inventor) to set up a C-firm at cost $w_{1,1}\alpha^C$.

[15] That case occurs if α^D is too large to justify investment. It can be excluded, however, when α^D is small enough.

2.3 Equilibrium

The Trade Balance. In period t the value of country 1's net exports is $NE_{1,t} = \tau \left(L_2 P_{1,t} C_{21,t} - L_1 P_{2,t} C_{12,t} \right)$ or, with (10) and (13)

$$NE_{1,t} = \frac{w_{1,0} L_1}{1+\delta} (\delta R)^t \left(\lambda \frac{\omega_0 + \frac{\Omega}{R}\omega_1}{\left(\frac{\omega_t}{\tau}\right)^{1-\varepsilon} \frac{n_{2,t}}{n_{1,t}} + 1} - \frac{1 + \frac{\Omega}{R}}{\left(\frac{1}{\tau\omega_t}\right)^{1-\varepsilon} \frac{n_{1,t}}{n_{2,t}} + 1} \right) \tag{20}$$

Trade must be balanced on an intertemporal basis, which implies $NE_{1,0} + R^{-1} NE_{1,1} = 0$.

A convenient observation is that country 1's trade surplus must correspond to the capital outflows $NE_{1,t} = -CF_{1,t}$ from (15), or

$$\lambda \frac{\omega_0 + \frac{\Omega}{R}\omega_1}{\left(\frac{\omega_0}{\tau}\right)^{1-\varepsilon} \frac{n_{2,0}}{n_{1,0}} + 1} - \frac{1 + \frac{\Omega}{R}}{\left(\frac{1}{\tau\omega_0}\right)^{1-\varepsilon} \frac{n_{1,0}}{n_{2,0}} + 1} = -\lambda \left(\delta\omega_0 - \frac{\Omega}{R}\omega_1 \right) \tag{21}$$

$$\lambda \frac{\omega_0 + \frac{\Omega}{R}\omega_1}{\left(\frac{\omega_1}{\tau}\right)^{1-\varepsilon} \frac{n_{2,1}}{n_{1,1}} + 1} - \frac{1 + \frac{\Omega}{R}}{\left(\frac{1}{\tau\omega_1}\right)^{1-\varepsilon} \frac{n_{1,1}}{n_{2,1}} + 1} = \frac{\lambda}{\delta} \left(\delta\omega_0 - \frac{\Omega}{R}\omega_1 \right) \tag{22}$$

Since Ω/R is determined by (19), this system of equations determines relative wages ω_t as a function of model parameters and the number of firms $n_{i,t}$. These variables will be determined next.

The Number of Firms. Consider first the number of firms in country 2. Recall that a firm's operating profits as share of revenues equals $1/\varepsilon$. Since operating profits just cover a firm's fixed costs $w_{1,t}\alpha^C$ in country 2 on a period-by-period basis, a firm's revenue must be $\varepsilon w_{1,t}\alpha^C$ within each period t. Total revenues of all C-sector firms in country 2 and period t are thus $n_{i,t}\varepsilon w_{i,t}\alpha^C$. This expression must be equal to the aggregate wagebill, $w_2 L_2$, so that

$$n_{2,t} = L_2 / \left(\varepsilon \alpha^C \right) \tag{23}$$

Computing the number of active firms in country 1 is more complicated since entry in the D-sector is not based on period-by-period profits but on the net present value of operating profits. I will restrict the analysis of equilibria with interior solutions, i.e., in which C-varieties will be produced in country 1 in both periods. The relevant conditions will be formulated below.

Letting $L_{1,t}^C$ the amount of labor employed in the C-sector, the same argument as above implies $L_{1,t}^C = \varepsilon\alpha^C n_{1,t}^C$. In period $t=0$, when $\alpha^D n^D$ units of labor are devoted to invention of blueprints in the D-sector in country 1, labor market clearing implies

$$L_1 = \varepsilon\alpha^C n_{1,0}^C + \alpha^D n^D$$

Now observe that a C-firm's labor demand for production excluding setup costs equals its total labor demand $\varepsilon\alpha^C$ minus employment for setup costs α^C. In period $t=1$, a firm's employment for production is thus $(\varepsilon-1)\alpha^C$. This statement holds not only for C- but for D-firms as well, as marginal costs and demand are the same across sectors. Hence, labor market clearing in $t=1$ implies

$$L_1 = \varepsilon\alpha^C n_{1,1}^C + (\varepsilon-1)\alpha^C n^D = \alpha^C\left[\varepsilon n_{1,1}^C + (\varepsilon-1)n^D\right]$$

The two preceding equations can be rewritten as

$$\varepsilon\alpha^C n_{1,0} = L_1 - \alpha^D n^D \tag{24}$$

$$\varepsilon\alpha^C n_{1,1} = L_1 + \alpha^C n^D \tag{25}$$

where $n_{i,t}$ is newly introduced as the total number of firms in country i. Notice that setting up n^D D-type firms in period $t=0$ is equivalent to subtracting $\alpha^D n^D$ units of labor from the labor force in period 0 and adding $\alpha^C n^D$ labor units in period 1.

Using (19) and (23), the two equations above imply

$$\frac{n_{1,0}}{n_{2,0}} + \frac{n_{1,1}}{n_{2,1}}\frac{\Omega}{R} = \frac{1+\Omega/R}{\lambda}$$

Equations (17), (23), (24) and (25) determine the number of firms as a function of relative wages and thus close the model.

With (17), (19) and (23), equations (24) and (25) are

$$\frac{n_{1,0}}{n_{2,0}} = \frac{\lambda^{-1}}{1+\delta}\left(1+\frac{\Omega}{R} - \lambda\left(\delta\omega_0 - \frac{\Omega}{R}\omega_1\right)\right) \tag{26}$$

$$\frac{n_{1,1}}{n_{2,1}} = \frac{\lambda^{-1}}{1+\delta}\left(\frac{\Omega}{R}\right)^{-1}\left(\delta\left(1+\frac{\Omega}{R}\right) + \lambda\left(\delta\omega_0 - \frac{\Omega}{R}\omega_1\right)\right) \tag{27}$$

With these expressions, the system of two equations (21) and (22) can be written in terms of parameters and the two remaining endogenous variables, ω_t.

The resulting system determines ω_t, which then pins down $n_{1,t}$ through (23), (26) and (27) and all other endogenous variables follow.

2.4 Economic Aggregates

Notice that in all equations above the variables Ω and R appear only in combination, namely as the fraction Ω/R. The reason is that in the absence of nominal rigidities, the nominal interest rate is undetermined as long as the level of prices (or wages) are not fixed for all periods. Formally, it is therefore save to set $R = 1$. With this normalization, some key economic aggregates can be computed in the following.

Output. Country 1's share of world GDP in period t is

$$y_{1,t} = \frac{w_{1,t}L_1}{w_{1,t}L_1 + w_{2,t}L_2} = \frac{1}{1+\omega_t\lambda} \tag{28}$$

Exports. Its export shares are with (10) and (13)

$$ex_{1,t} = \frac{\tau L_2 P_{1,t} C_{21,t}}{w_{1,t}L_1} = \lambda\frac{(\delta/\Omega)^t}{1+\delta}\frac{\omega_0+\Omega\omega_1}{(\omega_t/\tau)^{1-\varepsilon}\frac{n_{2t}}{n_{1t}}+1}$$

The size of the D-sector in period 1 is, when measured in sales, with (17) and (25)

$$\frac{n^D}{n_{1,1}} = \varepsilon\frac{1+\lambda\omega_0-\Omega/\delta\left[1+\lambda\omega_1\right]}{\Omega+1+\lambda\left[\omega_0-\Omega/\delta\omega_1\right]}$$

Real Exchange Rate. I follow the convention that the real exchange rate, RER, is defined as the relative price of consumption across border (see Corsetti et al 2013): For country 1 the real exchange rate is thus

$$RER_{1,t} \equiv \frac{w_{1,t}/P_{1,t}}{w_{2,1}/P_{2,t}} = \frac{P_{2,t}/P_{1,t}}{\omega_t}. \tag{29}$$

These economic indicators will be highlighted in the calibration exercise further below.

2.5 The Equilibrium at $\tau = 1$

To build a first intuition, I take a brief look at the world economy with frictionless trade, i.e. under the assumption $\tau = 1$. In this case, the standard Krugman (1980) model features equalization of goods prices and factor prices (i.e., wages) across countries. Building on this knowledge, intuition strongly suggests that the same effects materialize in the current model on a period by period basis. This intuition turns out to be correct: within each period, wages equalize across countries so that the terms of trade and the real exchange rate are constant over time.

To confirm intuition, assume that $\tau = 1$ holds, in which case the system (21) and (22) is solved by $\omega_t = 1$ (see Appendix). Hence, the country 1's share of world GDP (28) equals its share of population and is, in particular, constant over time. At the same time, price indices (7) are a simple function of the mass of firms and are, in particular, equal in both countries. Hence, the real exchange rate (29) is does not change over time. Also, the countries' savings rates are with (14), $s_{1,0}/w_{1,0} = s_{2,0}/w_{1,1} = (\delta - \Omega)/(1+\delta)$. Despite all these equalities, however, country 1's capital inflows (15), and thus net imports are, when normalized by the respective wage bill ($w_{1,t}L_1$)

$$\frac{CF_{1,t}}{w_{1,t}L_1} = \begin{cases} \lambda \dfrac{\delta - \Omega}{1+\delta} & t = 0 \\ -\dfrac{\lambda}{\Omega}\dfrac{\delta - \Omega}{1+\delta} & t = 1 \end{cases}$$

(Notice that conditions (18) imply $\delta > \Omega$, so that, as expected, capital flows from country 1 to country 2 in period 0 and flows are reversed in period 1.) The reason for non-trivial capital flows (and the corresponding net exports) are obvious: individuals in both countries save but only country 1 offers investment opportunities. Hence, capital flows from country 2 to country 1 during R&D periods and reverses during subsequent periods.

This very simple example concisely illustrates one of the model's lesson. In particular, global imbalances arise naturally, i.e., without underlying distortions and inefficiencies, even in the absence of differentials if growth and savings rates.

3 Quantitative simulations of Swiss trade flows

In this section I consider a numerical simulation of the theoretical model developed above.

3.1 Why Switzerland?

In the calibration exercise, country 1 will represent the Swiss economy. The choice of Switzerland as a case study is motivated by two key observations that closely relate it to the assumptions of the model. First, pharmaceutical products are the dominant item of the Swiss export basket. In 2013, Switzerland exported pharmaceutical products worth USD 62.4 billion, making a share of 27.6 percent of the total USD 225.7 billion Swiss exports, up from USD 10.0 (4.4) billion or 12.5 (6.8) percent of total Swiss exports in 2000 (1990).[16]

This first observation is important, since production of pharmaceutical products is paradigmatic for the cost-and time-intensive R&D phase and thus has the key features that characterize the D-sector in the model above. Indeed, the R&D costs for a new drugs or the according compound range between USD 1 and 2 billion according to recent industry estimations. Costs do not only accrue in basic research activity but also due to extensive clinical tests. The total R&D costs amount to 20 to 40 percent of production costs and make the pharmaceutical industry probably the most prominent example of R&D intensive industry, which exemplifies effects of patent protection on the intensity and the direction of innovation.[17]

The second important observation is that the pharmaceutical sector exhibited impressive growth rates of cross border trade and expenditure shares. The World Bank reports that health expenditure in the three largest markets grew at an annual rate of 5.6% in the USA, 4.7% in the European Union and 4.1% in Japan between 1996 and 2012; these growth rates are far above the respective growth rates of per capita GDP during the same period (3.7%, 3.6% and 1.5%). Correspondingly, trade volumes increased substantially over the last decades for both, Switzerland and the rest of the world. Figure 2 plots pharmaceutical exports as shares of total export values for Switzerland

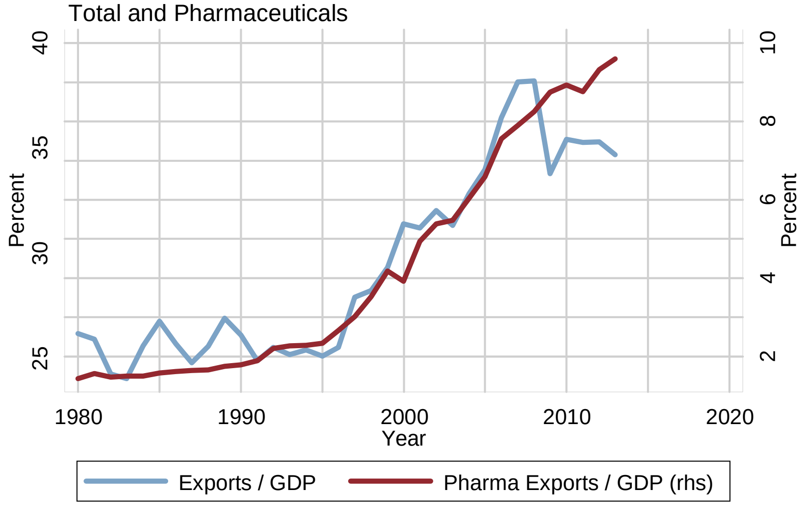
[16] Compare Figure 1. Import growth has been very high as well, but stayed at much lower levels (1.93 billion USD in 1990, 5.13 billion USD in 2000 and 23.9 billion USD in 2013).

[17] See, e.g., Cohen and Klepper (1992), Acemoglu et al (2004).

and for the rest of the world. In Switzerland trade shares of pharmaceutical products has increased by a factor of four between 1990 (6.8%) and 2007 (27.6%); for the rest of the world the increase started from much lower levels but was only slightly less pronounces in terms of growth rates with a factor of 2.6 (from 1.1 to 2.8 percent). Moreover, the rise of pharmaceutical shares in the Swiss and the global trade basked was remarkably parallel. As stressed in the preceding section, the strong increase in trade volumes (be it demand or supply driven) is the second key assumption of the model.

FIGURE 1: SWISS EXPORTS

Total and Pharmaceuticals



Sources: UN Comtrade, BIS

Together, both observations confirm that Switzerland has a quite strong comparative advantage in a sector (the pharmaceutical sector), whose production is characterized, first, by rapid demand growth and second, by large up-front R&D costs. Hence, the two crucial conditions underlying the last section's theoretical model are satisfied and make the Swiss a good case to study the outlined mechanism.[18]

3.2 Parametrization

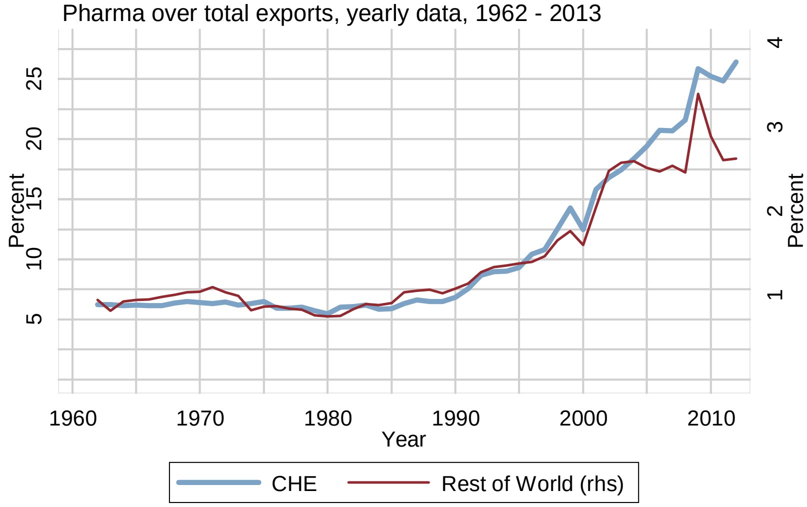
For the quantitative simulation of the model I follow Corsetti et al 2013 in the choice of the key parameters. Accordingly, the elasticity of substitution

[18]See Sauré (2015) for more information about Swiss trade and Switzerland's pharmaceutical sector.

is set to two ($\varepsilon = 2$) and the overall iceberg cost to 20% ($\tau = 1.2$) in the benchmark specification. The relative size of the two countries is chosen so that the D-exporting country (Switzerland) is roughly 0.87 percent of the world economy ($\lambda = 114$).[19] Further, the setup costs in the C-sector is set to unity ($\alpha^C = 1$), the one in D-sector ($\alpha^D = \Omega\alpha^C = \Omega$) is calibrated so that the export basket of the D-exporting country equals 10.2 percent in period $t = 1$, reflecting the increase in the share of Swiss pharmaceutical exports between 2000 and 2013 ($23.1 - 12.9$). The discount factor is set to $\delta = 0.599$, thus applying a yearly discount factor of $\delta_{year} = 0.95$ to a time horizon of a decade. This assumption corresponds to assuming a ten year period of R&D, followed by a ten year period of effective patent protection. I also consider alternative setups with combinations of $\varepsilon = 5$ (as suggested by trade models) $\tau = 1.74$ (as suggested by Anderson and van Wincoop (2004)) and $\delta = 1.04$ (reflecting a 20-year period of effective patent protection, where $\delta = \sum_{k=0}^{9} \delta_{year}^{k} / \sum_{k=10}^{29} \delta_{year}^{k}$).

FIGURE 2: PHARMA EXPORT SHARES - CHE; ROW

Pharma over total exports, yearly data, 1962 - 2013



Source: Comtrade

19 According to the World Development Indicators, Swiss GDP was at 650 billion US$ in 2013, the World output was at 74 910 billion US$.

3.3 Calibration Results

As motivated above, the parameter Ω will be used to calibrate the model to generate an increase in country 1's export share of 10.2 percent in the baseline specification. The variables of key interest from the calibration exercise the are

- $\Delta\omega$ – the change of country 1's wage relative to the one of country 2, which coincides with the standard definition of the (change in) terms of trade. Also, as GDP equals total wage bill, this number also reflects the differential in growth rates.
- ΔRER_1 – the change of country 1's real exchange rate between period 0 and period 1, defined as the (change in) price-adjusted relative wages.
- $NX_{1,t} = CF_{1,t}$ – the GDP-normalized net exports, or capital outflows of country 1 in period t.

The calibration results of the various specifications are displayed in Table 1, with the baseline specification in the first and data in the last two columns. An initial observation is in order before turning to the endogenous variables: the parameter Ω is always smaller than δ (as required by condition (18)) but very close to δ; In particular, Ω never falls short of δ by more than 1/8 of a percent. The reason for this fact lies in the size of country 1 (i.e., Switzerland) Since, in this model, country 1 supplies the world demand of the D-type good in period $t = 1$, it will completely specialize on D-production whenever the D-technology allows for quite efficient production of D-goods (i.e., if $\Omega = \alpha^D/\alpha^C$ is very small). However, since the targeted share of D-type goods in period $t = 1$ is smaller than unity, this condition imposes a rather strict lower bound of the choice of parameter Ω.

The first variable of interest, the countries relative wages (or terms of trade), shows virtually no reaction to trade flows, the expansion of country 1's exports between period 0 and period 1. This result, which may appear natural under very small trade costs, in which case the equilibrium wages should be close to those in Section 2.5 (where $\omega_t = 1$ was shown). However, the result also holds, under sizable trade costs ($\tau = 1.74$). The following two forces that impact the wages almost cancel out. First country 1's relative wage tends to fall, since the capital outflows, through which foreign investors collect the interest on their investments, generate a depreciation of the terms of trade. This effect was labeled by Keynes the *secondary burden* of international transfers (see Corsetti et al 2013). Second, there is the home market effect, which implies that the growth of tradable goods between the first and the second period generates an appreciation of country 1's terms of trade, that counteracts the *secondary burden*. It turns out that both effects almost cancel out so that the change in relative wages is negligible. (It is worth noting, however, that for small λ and for large τ this statement does no longer hold.)

Table 1: Calibration Results wiht D-export share = 10.2

	Model								Data	
	δ=0.599				δ=1.045				1994-2003 to 2004-2013	1994 to 2013
	τ=1.2		τ=1.74		τ=1.2		τ=1.74			
	ε=2	ε=5	ε=2	ε=5	ε=2	ε=5	ε=2	ε=5		
Parameter [%]										
Ω/δ-1	-0.082	-0.033	-0.098	-0.045	-0.104	-0.043	-0.125	-0.057		
Endogenous Variables [%]										
$\Delta\omega$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	9.034	19.832
ΔRER	0.025	0.006	0.066	0.011	0.032	0.008	0.084	0.014	1.724	14.369
NE_{10}/GDP_{10}	-2.928	-1.194	-2.870	-1.175	-4.982	-2.062	-4.856	-2.024	0.356	-2.351
NE_{11}/GDP_{11}	5.323	2.062	5.313	2.054	5.323	2.062	5.313	2.054	3.010	3.934

Note: Key equilibrium equations are (21), (22), (26) and (27). The remaining parameters are λ=114 according to the Swiss economic size and α^C=1 (that last normalization is irrelevant). The parameter Ω is chosen so that the share of D-type exports in period t=1 is 10.2.

Second, country 1's real exchange rate appreciates, yet rather moderately so – by about a quarter of a percent in the set of eight specifications. These effects are due to the expansion of in the set of varieties produced in country 1, in combination with the trade costs that drive a wedge between the local prices and the foreign prices. Accordingly, the effect on the RER is larger when trade costs are higher (a standard feature of the Krugman (1980) model).

These first calibration results thus reveal rather persistent terms of trade (real exchange rate adjusted wage ratios) and real exchange rates. These results do not match the rather large changes in both of these variables, reported in the last two columns of Table 1.[20] However, I do not read this

[20] Underlying to the change of relative wage ratio are Swiss and the German real wage index, expressed in a common currency; data sources are the Swiss *Bundesamt für Statistik*

discrepancy as a failure of the model. Indeed, for a small open economy with a large financial sector, the real exchange rate cannot be expected to be driven or predicted by trade volumes but rather by international capital flows that are not directly related to export and import flows.[21] Instead, the calibration shows that the changes in trade flows contributed very little (if any) to the recent appreciation of the Swiss franc and to improvement of Switzerland's terms of trade.

The third and final variable of interest are net exports. It turns out that average net exports of the periods $1994 - 2003$ were positive already, as reported in the last but one column of the table. I therefore focus on the increase of GDP-normalized net exports (2.65 percent of GDP in the data) as a metric to assess the performance and success of the model. In the baseline model, reported in the first column of the table, this increase is over-predicted by a factor of roughly 3. When the elasticity of substitution is changed from $\varepsilon = 2$ to $\varepsilon = 5$ (as typically specified in calibrations of trade models) the increase in net exports (3.255 percent of GDP) is rather well matched (second column), exceeding the increase in the data by 23%. These number remain relatively unchanged, when assuming relatively high ad valorem trade costs of 74 percent.

Alternatively, one may compare calibration to net exports of the end-points of the period considered 1993 and 2013, reported in the last column of the table. The according increase in the data is 6.29 percent of GDP, a number that the calibrated model underpredicts by 49 percent (at $(\delta, \tau, \varepsilon) = (0.599, 1.74, 5)$) or overpredicts by 64 percent (at $(\delta, \tau, \varepsilon) = (1.045, 1.2, 2)$).

Overall, however, it seems that the calibration to reasonable parameters tends to overpredict the increase in Switzerland's net exports. A reason of this discrepancy, might be the real appreciations of the Swiss currency (driven, as argued above, by independent financial flows). These parts of the appreciations, exogenous to the trade dynamics might have dampened the increase in the Swiss net exports.

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and the IFS. The change in the RER is based on the Swiss real exchange rate, narrow definition, from the BIS.

[21] This statement is especially obvious in the period of the financial crisis, when financial flows to heaven currencies and the unwinding of carry trades appeared to be dominant effects shaping the valuation of the Swiss currency (see, e.g., IMF 2013 and 2014). Accordingly, the strong (real and nominal) appreciations of the Swiss franc occurred since 2007.

Table 2: Calibration Results wiht D-export share = 10.2; λ=5

	Model							
	δ=0.599				δ=1.045			
	τ=1.2		τ=1.74		τ=1.2		τ=1.74	
	ε=2	ε=5	ε=2	ε=5	ε=2	ε=5	ε=2	ε=5
Parameter [%]								
Ω/δ-1	-0.082	-0.033	-0.098	-0.045	-0.104	-0.043	-0.125	-0.057
Endogenous Variables [%]								
$\Delta\omega$	0.010	0.016	0.080	0.058	0.013	0.020	0.102	0.074
ΔRER	0.405	0.113	1.095	0.195	0.518	0.144	1.401	0.250
NE_{10}/GDP_{10}	-2.434	-0.981	-2.313	-0.907	-4.142	-1.695	-3.913	-1.561
NE_{11}/GDP_{11}	4.426	1.694	4.282	1.585	4.426	1.694	4.282	1.585

Note: Key equilibrium equations are (21), (22), (26) and (27). The remaining parameters are λ=5 according to the Swiss economic size and α^C=1 (that last normalization is irrelevant). The parameter Ω is chosen so that the share of D-type exports in period t=1 is 10.2.

The general picture is preserved when calibrating the model to a similar increase of trade in R&D-intensive goods on a country of much larger dimensions. Table 2 reports the corresponding calibration results, which show that neither the terms of trade not the real exchange rate exhibit strong movements. Even under large trade costs, the terms of trade barely increase by more than a tenth of percent and the real exchange rate by less than 1.5 percent.[22] At the same time, the sizable net exports are of the same order of magnitude as those reported in Table 1.[23]

4 Conclusion

This paper has proposed a novel mechanism by which global imbalances arise. It has shown that countries with a comparative advantage in a sector that is characterized by fast growth as well as large up-front R&D costs can experience substantial capital in- and outflows. These capital flows (and the trade deficits and surpluses that accompanies them) occur under relatively stable terms of trade and real exchange rates. Also, given that trade costs are moderate, the cross-country differences in savings rates and income growth –

[22] Recall that zero trade costs imply no movements at all.

[23] For equally sized countries ($\lambda = 1$), the terms of trade (real exchange rate) increase by less than 1.2 (2.7) percent.

variables that are usually cited to explain and rationalize global imbalances – are negligible. The dynamics of Swiss net export and the increased share of pharmaceutical products in the Swiss export basket are argued to exemplify the mechanism described by the theory. A calibration exercise to the increase is pharmaceutical trade matches the increase in Switzerland's net exports reasonably well.

A Appendix

Proofs

Proof of (13). Rearrange the expression for expenditure

$$\begin{aligned} e_{i,t} &= P_{i,t}C_{ii,t} + \tau P_{j,t}C_{ij,t} \\ &= \tau P_{j,t}C_{ij,t}\left(\left(\frac{P_{i,t}}{\tau P_{j,t}}\right)^{1-\varepsilon} + 1\right) \\ &= \tau P_{j,t}C_{ij,t}\left(\left(\frac{w_{i,t}}{\tau w_{j,t}}\right)^{1-\varepsilon}\frac{n_{it}}{n_{jt}} + 1\right) \end{aligned}$$

where (12) has been used in the first step and (10) in the second.

Proof that $\tau = 1$ implies $\omega_t = 1$. The crucial conditions are given by the system (21) and (22) and (26) and (27). In the case of zero trade costs, ($\tau = 1$) and normalized nominal rate of return ($R = 1$), the system (21) and (22) becomes

$$\begin{aligned} \left(\lambda\frac{\omega_0 + \Omega\omega_1}{(\omega_0)^{1-\varepsilon}\frac{n_{2,0}}{n_{1,0}} + 1} - \frac{1+\Omega}{\left(\frac{1}{\omega_0}\right)^{1-\varepsilon}\frac{n_{1,0}}{n_{2,0}} + 1}\right) &= -\lambda\left(\delta\omega_0 - \Omega\omega_1\right) \\ \lambda\frac{\omega_0 + \Omega\omega_1}{(\omega_1)^{1-\varepsilon}\frac{n_{2,1}}{n_{1,1}} + 1} - \frac{1+\Omega}{\left(\frac{1}{\omega_1}\right)^{1-\varepsilon}\frac{n_{1,1}}{n_{2,1}} + 1} &= \frac{\lambda}{\delta}\left(\delta\omega_0 - \Omega\omega_1\right) \end{aligned}$$

Guessing $\omega_t = 1$, this is

$$\begin{aligned} \frac{1+\Omega}{\frac{n_{2,0}}{n_{1,0}} + 1}\left(\lambda - \frac{n_{2,0}}{n_{1,0}}\right) &= -\lambda\left(\delta - \Omega\right) \\ \frac{1+\Omega}{\frac{n_{2,1}}{n_{1,1}} + 1}\left(\lambda - \frac{n_{2,1}}{n_{1,1}}\right) &= \frac{\lambda}{\delta}\left(\delta - \Omega\right) \end{aligned}$$

which can be rearranged as

$$
\begin{aligned}
(1+\Omega)\left(\lambda-\frac{n_{2,0}}{n_{1,0}}\right) &= -\lambda(\delta-\Omega)\left(\frac{n_{2,0}}{n_{1,0}}+1\right)\\
(1+\Omega)\left(\lambda-\frac{n_{2,1}}{n_{1,1}}\right) &= \frac{\lambda}{\delta}(\delta-\Omega)\left(\frac{n_{2,1}}{n_{1,1}}+1\right)
\end{aligned}
$$

or

$$
\begin{aligned}
(1+\delta)\lambda &= \left[(1+\Omega)-\lambda(\delta-\Omega)\right]\frac{n_{2,0}}{n_{1,0}}\\
\Omega(\delta+1)\lambda &= \left[\lambda(\delta-\Omega)+\delta(1+\Omega)\right]\frac{n_{2,1}}{n_{1,1}}
\end{aligned}
$$

This is equivalent to (26) and (27) under the same assumptions ($R=\omega_t=1$), as is readily checked.

Tables

Table A1: Calibration Results with D-export share = 27.6

	Model								Data	
	δ=0.599				δ=1.045				1994-2003 to 2004-2013	1994 to 2013
	τ=1.2		τ=1.74		τ=1.2		τ=1.74			
	ε=2	ε=5	ε=2	ε=5	ε=2	ε=5	ε=2	ε=5		
Parameter [in %]										
Ω/δ-1	-0.243	-0.094	-0.292	-0.126	-0.310	-0.120	-0.373	-0.161		
Endogenous Variables [%]										
$\Delta\omega$	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	9.034	19.832
ΔRER	0.074	0.018	0.195	0.031	0.095	0.023	0.250	0.040	1.724	14.369
NE_{10}/GDP_{10}	-7.192	-3.140	-6.716	-3.018	-11.429	-5.319	-10.376	-5.055	0.356	-2.351
NE_{11}/GDP_{11}	15.857	5.784	15.826	5.764	15.857	5.784	15.826	5.764	3.010	3.934

Note: Key equilibrium equations are (21), (22), (26) and (27). The remaining parameters are λ=114 according to the Swiss economic size and α^C=1 (that last normalization is irrelevant). The parameter Ω is chosen so that the share of D-type exports in period t=1 is 27.6.

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