Trade and Migration:
A Production-Theory Approach

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Abstract

This paper integrates the production-theory approach to import determination and the production-theory approach to immigration. The aggregate technology is described by a four-input Translog cost function, from which the demand for imports and the demand for foreign labour services can be jointly derived. Empirical estimates are reported for Switzerland. Special care is taken at describing the substitution and complementarity relationships between the four inputs under alternative maintained hypotheses. The issue of flexibility with respect to time is also examined.

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1 Introduction

Do guestworkers threaten the jobs of native workers? Do foreigners, willing to work for low wages, drive down domestic wages? These and similar questions have long preoccupied workers, policymakers and economists, in Switzerland and elsewhere, and they have become particularly pressing at a time when globalization is likely to increase exposure of workers from industrialized countries to competition from low-wage nations.

One line of research that has proven useful to address this type of question is what has become known as the production-theory approach to migration.[1] This approach, introduced by Baldwin Grossman (1982), treats foreign labour services as an input to the technology. Moreover, due to differences in characteristics and attributes, foreign labour is treated as being conceptually different from domestic labour. This makes it possible to determine whether immigrants and natives are substitutes or complements in production. One can then also assess the job-displacement and income-redistribution effects of international labour mobility.[2]

It is quite surprising, however, that none of the studies based on the production-theory framework has modeled international migration within an open-economy setting. That is, no allowance has been made for possible links between international factor movements and foreign trade.[3] Many additional questions thus remain unanswered. Does immigration reduce or enhance a country's foreign trade? Who benefits most from international movements of labour in an open-economy context? How does a change in the terms of trade affect the distribution of income in the presence of international labour mobility? This lack of empirical evidence is all the more surprising that the theoretical trade literature has examined the links between trade and factor movements quite carefully, without, however, coming to a firm conclusion. Thus, for some authors, foreign trade can

[1] See Greenwood and McDowell (1986) for a survey of the economic impact of immigration.

[2] The production-theory approach has been applied to Swiss data by Butare and Favarger (1992); see Bürgenmeier, Butare, and Favarger (1992) for a condensed version in English.

[3] Wong (1988) does discuss the impact of international labour mobility on the volume of trade. However, he treats foreign labour as a perfect substitute for domestic labour. Hence, there is no difference in his model between migration and a change in the domestic endowment of labour.

be viewed as a substitute for international factor movements,[4] while for others it acts rather as a complement.[5] The main objective of this paper is to attempt to bring an empirical answer to some of these questions, and we shall see that one has to be quite careful in defining in what sense trade and factor movements might be complements or substitutes. In what follows, we will model the production sector of the Swiss economy, taking into account the input of foreign labour together with the input of intermediate products of foreign origin. This paper can thus be viewed as a contribution towards the integration of the production-theory approach to migration and the production-theory approach to modelling foreign trade.[6]

The production-theory approach to modelling foreign trade views imports as an input to the technology.[7] Imports are used together with primary factor services to produce goods destined for domestic and foreign markets. This approach recognizes the fact that most foreign trade is in raw materials and nonfinished products, and that even most so-called finished goods must still go through a number of domestic channels before meeting up with final demand, so that a significant proportion of the final price tag is accounted for by domestic value added. An attractive feature of the production-theory approach is that it rests on solid theoretical foundations. Furthermore, it yields a wealth of results about the substitution possibilities allowed for by the technology that cannot be matched by traditional methods which typically rely on single-equation methods. Last but not least, unlike many models of international trade theory, the production-theory approach can easily be implemented empirically since the data it requires are of the type contained in the National Accounts.[8] It is a simple matter then to extend the production-theory approach to import determination to allow for international labour mobility.

One unfortunate characteristic of the production-theory approach to immigration is that it has involved a fair degree of confusion. Some of the empirical

[4] See Mundell (1957), for instance.

[5] See Markusen (1983) among others.

[6] This paper differs from our earlier work (Kohli, 1993) in several important respects, particularly the choice of specification and functional form, the derivation of the comparative statics of the model, and the modelling of technological change.

[7] See Burgess (1974a, 1974b), Woodland (1982), Kohli (1991).

[8] See Kohli (1982, 1992) for estimates for Switzerland.

evidence is in terms of Allen-Uzawa elasticities of substitution, and some of it is in terms of Hicksian elasticities of complementarity. Analysts have often failed to fully appreciate this distinction when comparing results drawn from different studies. Yet comparison of Allen-Uzawa elasticities of substitution and Hicksian elasticities of complementarity is not a simple matter since the passage from one set of elasticities to the other is far from being trivial, and it is not always well understood. Two inputs, such as domestic and foreign workers, could be complements in the Hicksian sense and substitutes in the Allen-Uzawa sense. One objective of this study is to clarify this point by reporting both Hicksian elasticities of complementarity and Allen-Uzawa elasticities of substitution between resident and nonresident workers. By presenting our results for these alternative settings, we will be better able to assess the effects of immigration on the income of domestic factors of production, and to examine the effects of changes in the payments to immigrants on the employment opportunities of resident workers. However, we will argue that other sets of elasticities may be still better suited to analyze the impact of immigration in an open economy context; this will make it possible to assess the impact of changes in domestic factor endowments and in traded good and service prices on immigration, foreign trade, production, and the distribution of income.

Immigration has long been an important issue in Switzerland where a large proportion of the resident labour force is of foreign origin, and where nonresident workers have, at times, made up nearly a quarter of the labour force. Nonresident workers either are holders of seasonal or yearly permits, or they live in neighboring countries and cross the border on a daily basis to work in Switzerland. As shown by Figure 1, relative inputs have changed substantially over time. The use of resident labour does not exhibit much of a trend throughout the postwar period. Increases in the domestic labour force have been offset to some extent by reductions in the length of the work week. The use of nonresident labour, on the other hand, has increased very substantially throughout the fifties and much of the sixties, but it has fallen dramatically in the mid-seventies. The input of capital has increased steadily, whereas the use of imports has, on average, increased at an even faster pace. The sharp reduction in the number of nonresident workers in the mid-seventies is apparent in Figure 2 which shows an implicit Tornqvist index of aggregate inputs (lower line), and it has had a marked effect on the level of gross output (upper line). The difference between the two lines can be interpreted as total factor productivity, and it has increased throughout much of the period.

Concern has been expressed recently that flexible functional forms may not be flexible enough to adequately model technological change and productivity growth; see Diewert and Wales (1992). This may be particularly relevant here, given the shock which apparently — judging from Figure 2 — has affected the Swiss economy in the mid-seventies. As suggested by Diewert and Wales, one way of handling the problem is with the help of spline functions. In this paper, we will innovate and experiment along an alternative route, by increasing the level of flexibility of the aggregator function with respect to time.

The remainder of this paper is organized as follows. Section 2 briefly reviews alternative descriptions of the aggregate technology. Section 3 discusses the comparative statics of the model, while Section 4 examines its empirical implementation. Section 5 presents our main empirical results, and Section 6 concludes.

2 The Production-Theory Approach to Modelling the Demand for Imports and Foreign Labour Services

The production-theory approach to migration treats immigrants as an input to the technology. Similarly, the production-theory approach to foreign trade views imports as intermediate products. We will therefore consider that aggregate output is produced with the use of four inputs: imports (M), nonresident labour (N), resident labour (L), and capital (K). The aggregate technology can be represented by the following production function:

$$y = f(\mathbf{x}), \tag{1}$$

where y is the quantity of gross output, $\mathbf{x} \equiv [x_j]$ $(j \in M, N, L, K)$ is the vector of input quantities. We assume that $f(\mathbf{x})$ is increasing, quasi-concave, and linearly homogeneous with respect to the components of $\mathbf{x}$.

Variable returns to scale have become an important ingredient of many models, in international trade theory as well as in growth theory. However, under variable returns to scale, aggregation over agents in order to get a representation of the country's technology may become next to impossible, due to departures from perfect competition, and because intermediate goods no longer necessarily net out. We do not believe that variable returns to scale at the plant, firm, or industry level can be adequately accounted for by simply relaxing the linear homogeneity assumption at the aggregate level. For the sake of coherence, we therefore prefer to proceed with constant returns to scale as our maintained hypothesis.

Our treatment clearly rests on some heroic assumptions about aggregation. For a start, we assume that all outputs can be aggregated into a single composite good, which can be either absorbed at home or exported to the rest of the world.[9] Furthermore, considering four inputs only may seem restrictive as well. The reader might feel that it would important to distinguish between skilled and unskilled, resident and nonresident workers, and perhaps that one should disaggregate capital and/or imports. In truth, the theoretical model which we will develop in this section and the next can easily accommodate disaggregation almost *ad infinitum*. It suffices to interpret y and the x_j's as vectors, and to use a transformation function instead of a production function as a starting point. To keep the empirical application manageable, however, one must obviously draw the line somewhere. Degrees of freedom rapidly vanish as the number of inputs and/or outputs increase, and difficulties meeting the required regularity conditions without compromising flexibility rapidly becoming overwhelming. In reference to the literature, our model of the aggregate technology, by considering four inputs, is already more general than most.

It would of course also be of interest to disaggregate labour between native and foreign-born workers, or between Swiss citizens and foreigners. This does not seem to be possible, however, since the income data would not be available. One can argue, however, that the distinction between nonresident and resident workers, which is dictated by data availability, does make sense since it amounts to distinguishing between recent and temporary immigrants ("guestworkers"), on one hand, and nonrecent and long-term immigrants on the other hand, the latter being well integrated and similar to Swiss workers in most respects.

[9] For an alternative treatment, albeit without international labour mobility, see Kohli (1991), for instance.

The use of nonresident labour services is somewhat concentrated, both in terms of industries and geographically. The number of transborder workers is naturally largest in border areas, particularly so in Geneva, Basle, and the Ticino. The "frontaliers" tend to be employed in a large variety of industries, in a wide range of skills. Holders of seasonal and yearly permits, on the other hand, tend to be more evenly distributed across the country, but they tend to be low-waged and concentrated in particular industries, such as construction or food and lodging services. This might militate in favor of using a two-sector model. However, as argued previously, even though disaggregation of output could easily be handled by the model, it would make the empirical application that much more complex, and it is not clear that if some further disaggregation were indeed contemplated, that this would be the most urgent direction in which it should be carried out.[10]

While international labour mobility is an important issue in the Swiss case, one could argue that capital mobility is even more relevant. No attempt is made here to model international capital movements. There are several reasons for this. Some practical ones first: distinguishing between domestically- and foreign-owned capital would increase the size of the model, and data on the quantity and the price of both types of capital would be difficult to obtain. In fact, it is likely that as far as production possibilities are concerned, the question of ownership is largely irrelevant. This suggests that the return to both types of capital might be same, in which case aggregation can be justified on Hicksian grounds. There are also some conceptual reasons why the issue of international capital mobility is not tackled here. By focusing on current production decisions exclusively, we do not attempt to model the investment process. In any case, international capital flows typically take the form of movements in equity and financial assets: it is the ownership of the capital stock that is traded, rather than the physical capital stock itself. Modelling international capital flows as exogenous changes in the domestic endowment of capital seems very unsatisfactory. The dismantling of a machine or a factory in order to rebuild it in a different country is the exception,

[10] The question would then arise as to whether the two (or more) outputs are produced jointly or not; see Kohli (1991) for estimates of labour demand functions under both assumptions. It is also noteworthy that there seems to be very little discussion of multiple output models in the labour demand literature; for instance, this topic is not even raised in Hamermesh's (1993) otherwise very detailed book.

not the rule. Moreover, to the extent that international capital flows can have a direct effect on the domestic endowment of capital, they should first impact on the trade account — as part of imports or exports of capital goods — and on gross output — as part of domestic investment or disinvestment.

Under cost minimization, the country's technology can also be described by the unit cost function defined as:

$$c(\mathbf{w}) \equiv \min_{\mathbf{x}} \left\{ \sum_j w_j x_j : f(\mathbf{x}) \geq 1 \right\}, \tag{2}$$

where $\mathbf{w} \equiv [w_j]$ is the vector of input prices. Under competitive conditions, unit cost is equal to the price of aggregate output (p).

By Shephard's (1953) Lemma, the unit-output cost-minimizing demand for inputs can be obtained by differentiation of (2):[11]

$$\frac{x_j}{y} = \frac{\partial c(\mathbf{w})}{\partial w_j}, \quad j \in \{M, N, L, K\}. \tag{3}$$

It is noteworthy that the demand for all inputs, including imports and foreign labour services, will generally depend on all four input prices. A change in the price of imports, for instance, is liable to affect the demand for foreign labour services, just like a change in the wage rate of nonresident workers may impact on the demand for imports.

To assess these price effects — and, more generally, the substitution possibilities allowed for by the technology — it is useful to compute the Allen-Uzawa elasticities of substitution between input j and input k, σ_{jk}. It is of course well known that:[12]

$$\sigma_{jk} = \frac{c(\mathbf{w}) c_{jk}(\mathbf{w})}{c_j(\mathbf{w}) c_k(\mathbf{w})}, \quad j, k \in \{M, N, L, K\}, \tag{4}$$

where $c_j(\mathbf{w}) \equiv \partial c(\mathbf{w})/\partial w_j$, and $c_{jk}(\mathbf{w}) \equiv \partial^2 c(\mathbf{w})/(\partial w_j \partial w_k)$; σ_{jk} is positive if inputs j and k are substitutes in the Allen-Uzawa sense, and it is negative if the two inputs are complements. These elasticities are relevant if one wishes to assess the impact of an increase in the price of one input on its quantity demanded, and on the quantities of all other inputs. Thus, if σ_{LN} is positive, one can assert that

[11] See Diewert (1974).
[12] Uzawa (1961).

a reduction in the wage paid to guestworkers will reduce the demand for native labour services, and could thus lead to increased unemployment among resident workers.

The Allen-Uzawa elasticities of substitution given by (4) are defined for given input prices, and they are not to be confused with Hicksian elasticities of complementarity, ψ_{jk}, defined for given input quantities.[13] If the production function is known, the elasticities of complementarity can be obtained directly as:

$$\psi_{jk} = \frac{f(\mathbf{x}) f_{jk}(\mathbf{x})}{f_j(\mathbf{x}) f_k(\mathbf{x})}, \qquad j, k \in \{M, N, L, K\}, \tag{5}$$

where $f_j(\mathbf{x}) \equiv \partial f(\mathbf{x})/\partial x_j$, and $f_{jk}(\mathbf{x}) \equiv \partial^2 f(\mathbf{x})/(\partial x_j \partial x_k)$; ψ_{jk} is positive if inputs j and k are q-complements in the Hicksian sense, and it is negative if they are q-substitutes. The sign of ψ_{LN} is crucial in determining whether an increase in immigration raises or reduces the return to domestic labour.

The Hicksian elasticities of complementarity can also be derived from estimates of the cost function. Let us define $\Sigma \equiv [\sigma_{jk}]$ as the Allen-Uzawa substitution matrix and $\Psi \equiv [\psi_{jk}]$ as the Hicksian q-complementarity matrix. As shown by Kohli (1991), the link between Ψ and Σ is given by:

$$\tilde{\Psi} = \tilde{S}^{-1} \tilde{\Sigma}^{-1} \tilde{S}^{-1}, \tag{6}$$

where:

$$\tilde{\Psi} \equiv \begin{bmatrix} \Psi & \mathbf{u} \\ \mathbf{u}' & 0 \end{bmatrix} \tag{7}$$

$$\tilde{\Sigma} \equiv \begin{bmatrix} \Sigma & \mathbf{u} \\ \mathbf{u}' & 0 \end{bmatrix}. \tag{8}$$

$\tilde{S}$ is a 5×5 diagonal matrix with the four cost shares and a one as elements, and $\mathbf{u}$ is a 4-dimensional unit vector. Thus, the passage from one set of elasticities to the other is not trivial, and it involves the inversion of a bordered matrix. Note that as soon as the number of inputs exceeds two, one cannot infer anything about

[13] See Hicks (1970). We use the terminology of Sato and Koizumi (1973), and Syrquin and Hollender (1982).

the sign of σ_{jk} from the sign of ψ_{jk} alone.[14] Thus, two inputs could be Hicksian q-complements, and yet they could equally well be Allen-Uzawa substitutes or complements.

3 Comparative Statics

3.1 The Cost-Function Setting

While both the Allen-Uzawa substitution matrix Σ and the Hicksian q-complementarity matrix Ψ are informative as to the relationships between the various inputs, their elements — particularly their size — are somewhat difficult to interpret. It is often more convenient to resort to ordinary price and quantity elasticities. Consider demand system (3). The comparative statics of that system can be captured by a matrix of price elasticities of demand $E \equiv [\varepsilon_{jk}]$ defined as follows:

$$\varepsilon_{jk} \equiv \frac{\partial \ln x_j(\mathbf{w}, y)}{\partial \ln w_k}. \tag{9}$$

It is well known that the elements of E can be obtained directly from the Allen-Uzawa elasticities of substitution:[15]

$$\varepsilon_{jk} = \sigma_{jk} s_k, \tag{10}$$

where s_k is the cost share of the k-th input, $s_k \equiv w_k x_k / (\sum w_j x_j)$. Moreover, it follows directly from (2) and (3) that $\partial \ln x_j(\mathbf{w}, y)/\partial \ln y = 1$, that $\partial \ln c(\mathbf{w})/\partial \ln y = 0$, and that $\partial \ln c(\mathbf{w})/\partial \ln w_j = s_j$. The full comparative statics of the model can

[14] This point is also made by Hamermesh (1993).

[15] See Kohli 1991, for instance.

therefore be summarized by the following system:

$$\begin{bmatrix} \hat{x}_M \\ \hat{x}_N \\ \hat{x}_L \\ \hat{x}_K \\ \cdots \\ \hat{p} \end{bmatrix} = \begin{bmatrix} \varepsilon_{MM} & \varepsilon_{MN} & \varepsilon_{ML} & \varepsilon_{MK} & \vdots & 1 \\ \varepsilon_{NM} & \varepsilon_{NN} & \varepsilon_{NL} & \varepsilon_{NK} & \vdots & 1 \\ \varepsilon_{LM} & \varepsilon_{LN} & \varepsilon_{LL} & \varepsilon_{LK} & \vdots & 1 \\ \varepsilon_{KM} & \varepsilon_{KN} & \varepsilon_{KL} & \varepsilon_{KK} & \vdots & 1 \\ \cdots & \cdots & \cdots & \cdots & & \cdots \\ s_M & s_N & s_L & s_K & \vdots & 0 \end{bmatrix} \begin{bmatrix} \hat{w}_M \\ \hat{w}_N \\ \hat{w}_L \\ \hat{w}_K \\ \cdots \\ \hat{y} \end{bmatrix}, \tag{11}$$

where the hats ($\hat{}$) denote relative changes.

3.2 The Production-Function Setting

Alternatively, if one departs from the Hicksian elasticities of complementarity, one would naturally be led to the matrix of quantity elasticities of inverse demand, $H \equiv [\eta_{jk}]$, to describe the comparative statics of the model. These elasticities are defined as:

$$\eta_{jk} \equiv \frac{\partial \ln w_j(\mathbf{x}, p)}{\partial \ln x_k}. \tag{12}$$

The elements of H can be obtained directly from the Hicksian elasticities of complementarity as follows:

$$\eta_{jk} = \psi_{jk} s_k, \tag{13}$$

where s_k is again the cost share of the k-th input. The full comparative statics of the model can now be summarized in the following way:

$$\begin{bmatrix} \hat{w}_M \\ \hat{w}_N \\ \hat{w}_L \\ \hat{w}_K \\ \cdots \\ \hat{y} \end{bmatrix} = \begin{bmatrix} \eta_{MM} & \eta_{MN} & \eta_{ML} & \eta_{MK} & \vdots & 1 \\ \eta_{NM} & \eta_{NN} & \eta_{NL} & \eta_{NK} & \vdots & 1 \\ \eta_{LM} & \eta_{LN} & \eta_{LL} & \eta_{LK} & \vdots & 1 \\ \eta_{KM} & \eta_{KN} & \eta_{KL} & \eta_{KK} & \vdots & 1 \\ \cdots & \cdots & \cdots & \cdots & & \cdots \\ s_M & s_N & s_L & s_K & \vdots & 0 \end{bmatrix} \begin{bmatrix} \hat{x}_M \\ \hat{x}_N \\ \hat{x}_L \\ \hat{x}_K \\ \cdots \\ \hat{p} \end{bmatrix}, \tag{14}$$

where we have taken account of the first-order conditions for profit maximization which imply that $\partial \ln f(\mathbf{x})/\partial \ln x_j = s_j$. Moreover, $\partial \ln w_j(\mathbf{x}, p)/\partial \ln p = 1$, and $\ln f(\mathbf{x})/\partial \ln p = 0$. It is immediately visible that the square matrix in (14) is simply the inverse of the square matrix in (11); this illustrates our earlier result (6).

3.3 The GNP-Function Setting

While both the price elasticities of demand (matrix E) and the quantity elasticities of inverse demand (matrix H) are relevant in some circumstances, one can argue that in an open-economy context, yet another set of elasticities is necessary. Indeed, it is reasonable to assume that the endowments of domestic factors (capital and resident labour) are given. At the same time, considering Switzerland as a small open economy, we can view the prices of output, imports, and nonresident labour services as predetermined as well.[16] In such a setting, which is known as the GNP-function framework,[17] the substitution possibilities allowed for by the technology can be described by the following matrix of price and quantity elasticities, $\mathcal{E} \equiv [\epsilon_{jk}]$:

$$\begin{bmatrix} \hat{y} \\ \hat{x}_M \\ \hat{x}_N \\ \cdots \\ \hat{w}_L \\ \hat{w}_K \end{bmatrix} = \begin{bmatrix} \epsilon_{YY} & \epsilon_{YM} & \epsilon_{YN} & \vdots & \epsilon_{YL} & \epsilon_{YK} \\ \epsilon_{MY} & \epsilon_{MM} & \epsilon_{MN} & \vdots & \epsilon_{ML} & \epsilon_{MK} \\ \epsilon_{NY} & \epsilon_{NM} & \epsilon_{NN} & \vdots & \epsilon_{NL} & \epsilon_{NK} \\ \cdots & \cdots & \cdots & & \cdots & \cdots \\ \epsilon_{LY} & \epsilon_{LM} & \epsilon_{LN} & \vdots & \epsilon_{LL} & \epsilon_{LK} \\ \epsilon_{KY} & \epsilon_{KM} & \epsilon_{KN} & \vdots & \epsilon_{KL} & \epsilon_{KK} \end{bmatrix} \begin{bmatrix} \hat{p} \\ \hat{w}_M \\ \hat{w}_N \\ \cdots \\ \hat{x}_L \\ \hat{x}_K \end{bmatrix}. \tag{15}$$

[16] This differential treatment of resident and nonresident labour is made possible by our assumption that the two types of workers have different attributes, and hence are separate inputs.

[17] See Kohli (1978, 1991), Woodland (1982); the GNP-function label comes from the fact that this setting corresponds to the description of the technology by a variable profit function which is the solution of maximizing GNP, for given factor endowments and given prices of traded goods and services. In truth, because net labour payments abroad are taken into account, but net capital payments are not, the function is a hybrid of GNP and GDP.

These elasticities are defined for given prices of gross output, imports, and foreign labour services, and for given domestic factor endowments. The elasticities in the northwest corner of (15) are the price elasticities of output supply and variable input demand. The elasticities in the southwest corner indicate the impact of changes in the prices of output and variable inputs on domestic factor rental prices (the Stolper-Samuelson effects). The elasticities in the northeast corner of (15) capture the effect of changes in domestic factor endowments on the supply of output and on the demand for variable inputs (the Rybczynski effects). In the southeast corner, finally, we find the quantity elasticities of the inverse demand for the domestic factors.

It is noteworthy that the homogeneity properties of the GNP function that is dual to $f(\mathbf{x})$ imply the following restrictions:

$$\begin{aligned}
\sum_h \epsilon_{ih} &= 0, \quad i, h \in \{Y, M, N\} \\
\sum_k \epsilon_{jk} &= 0, \quad j, k \in \{L, K\} \\
\sum_j \epsilon_{ij} &= 1, \quad i \in \{Y, M, N\}, j \in \{L, K\} \\
\sum_i \epsilon_{ji} &= 1, \quad j \in \{L, K\}, i \in \{Y, M, N\}.
\end{aligned}$$

The signs of ϵ_{LN} and ϵ_{KN} are particularly important in determining the impact of increased immigration on domestic factor payments; thus, if $\epsilon_{LN} > 0$ a reduction in w_N, which leads to an increase in the demand for guestworkers, will tend to reduce the rental price of resident labour. The sign of ϵ_{MN}, on the other hand, will indicate the impact of changes in the wage rate paid to nonresident workers on the demand for imports. If $\epsilon_{MN} > 0$, immigration will tend to act as a substitute for foreign trade in the sense that an increase in the cost of nonresident labour would tend to favor imports.

The elasticities contained in (15) can easily be calculated from the estimates of the price elasticities of input demands contained in (11). That is, it is a simple matter to solve the system of equations (11) for $\hat{y}$, $\hat{x}_M$, $\hat{x}_N$, $\hat{w}_L$ and $\hat{w}_K$, as functions of $\hat{p}$, $\hat{w}_M$, $\hat{w}_N$, $\hat{x}_L$ and $\hat{x}_K$.[18] Of course, the GNP-function elasticities could be obtained directly if one chose to use the GNP function to describe the aggregate

[18] See Kohli (1991) for additional details.

technology, just like the elasticities in (14) could be obtained directly from the production function, without having to rely on (6). In order to best illustrate the difference between the various sets of elasticities, however, we want to derive them all from the same set of econometric parameter estimates. That is, we do not want to change the econometric specification as we move from one set of elasticities to the next.

3.4 Immigration Quotas

One might argue that the GNP-function setting is inappropriate in that it treats foreign labour services as a variable input, whereas, in practice, working permits are not issued freely. This militates in favor of treating x_N as a fixed, rather than as a variable, input. Thus, compared to (15) there would now be three — rather than just two — fixed inputs. The comparative statics of the model could then be summarized by the following matrix of price and quantity elasticities, $\Phi \equiv [\phi_{jk}]$:

$$\begin{bmatrix} \hat{y} \\ \hat{x}_M \\ \cdots \\ \hat{w}_N \\ \hat{w}_L \\ \hat{w}_K \end{bmatrix} = \begin{bmatrix} \phi_{YY} & \phi_{YM} & \vdots & \phi_{YN} & \phi_{YL} & \phi_{YK} \\ \phi_{MY} & \phi_{MM} & \vdots & \phi_{MN} & \phi_{ML} & \phi_{MK} \\ \cdots & \cdots & & \cdots & \cdots & \cdots \\ \phi_{NY} & \phi_{NM} & \vdots & \phi_{NN} & \phi_{NL} & \phi_{NK} \\ \phi_{LY} & \phi_{LM} & \vdots & \phi_{LN} & \phi_{LL} & \phi_{LK} \\ \phi_{KY} & \phi_{KM} & \vdots & \phi_{KN} & \phi_{KL} & \phi_{KK} \end{bmatrix} \begin{bmatrix} \hat{p} \\ \hat{w}_M \\ \cdots \\ \hat{x}_N \\ \hat{x}_L \\ \hat{x}_K \end{bmatrix}. \tag{16}$$

Matrix Φ can easily be computed from estimates of E. The elements of Φ will indicate the impact of higher immigration on domestic factor rental prices, as well as on imports and gross output. At the same time, they will yield information about the impact of a change in the terms of trade on domestic as well as foreign factor rental prices. A negative value of ϕ_{MN} would suggest that immigration and trade are substitutes in the sense that a larger contingent of nonresident workers tends to reduce the demand for imports.

3.5 Domestic Workers Displacement Effects

One of our original questions was does immigration tend to reduce employment opportunities for native workers? None of the settings examined so far makes it possible to directly answer this question. Indeed, to address the domestic employment issue, one should treat the input of resident workers as variable. This would be legitimate in the short run in the presence of domestic wage rigidities, for instance. Thus, it would be of interest to examine the effect of higher immigration when resident labour, together with imports and gross output, are treated as variable. The comparative statics of the model could then be described by the following matrix $\Theta \equiv [\theta]$:

$$\begin{bmatrix} \hat{y} \\ \hat{x}_M \\ \hat{x}_L \\ \cdots \\ \hat{w}_N \\ \hat{w}_K \end{bmatrix} = \begin{bmatrix} \theta_{YY} & \theta_{YM} & \theta_{YL} & \vdots & \theta_{YN} & \theta_{YK} \\ \theta_{MY} & \theta_{MM} & \theta_{ML} & \vdots & \theta_{MN} & \theta_{MK} \\ \theta_{LY} & \theta_{LM} & \theta_{LL} & \vdots & \theta_{LN} & \theta_{LK} \\ \cdots & \cdots & \cdots & & \cdots & \cdots \\ \theta_{NY} & \theta_{NM} & \theta_{NL} & \vdots & \theta_{NN} & \theta_{NK} \\ \theta_{KY} & \theta_{KM} & \theta_{KL} & \vdots & \theta_{KN} & \theta_{KK} \end{bmatrix} \begin{bmatrix} \hat{p} \\ \hat{w}_M \\ \hat{w}_L \\ \cdots \\ \hat{x}_N \\ \hat{x}_K \end{bmatrix}. \tag{17}$$

The price and quantity elasticities are defined for given output, import, and resident labour prices, and for given quantities of nonresident labour and capital. A negative value of ϕ_{MN} would indicate that immigration and trade are substitutes, in the sense that access to a larger pool of nonresident workers would tend to reduce the demand for imports, *given variable domestic employment*.

At this stage, the reader might wonder which one of the five settings reviewed here best describes reality, and which one is the most useful.[19] In fact, all five settings describe the same technology, and thus are equally "correct" or "incorrect". Yet, some settings may be more relevant than others, depending on the circumstances and on the problem which one wants to analyze. The cost-function setting is probably the one that is best known, and it is useful in the short run, when

[19]The list is not exhaustive: there are many more combinations of endogenous vs. exogenous treatments which we could have considered.

input prices may be sticky and the level of output predetermined. In the long run, on the other hand, the production function and the GNP-function settings may be more useful. If immigration quotas are the issue, then clearly the elasticities contained in (16) and (17) are more relevant. Thus, there does not exist a set of elasticities that is to be favored over all other ones. Our point here was rather to show that a custom-built set of elasticities that best suits the problem at hand can easily be obtained. Furthermore, great care should be taken when comparing elasticities drawn from different sources, since elasticities typically only show partial — or *ceteris paribus* — effects, and it is essential to always keep in mind what the *other things being held constant* actually are. The obvious implication of this is that empirical estimates of a particular effect, e.g. the impact of an increase in the number of guestworkers on the earnings of resident workers, might differ greatly depending on which other variables are allowed to adjust, and which ones are held constant. Finally, one should be aware of the fact that our approach, by focusing on production decisions exclusively, merely offers a partial equilibrium treatment. Imaginative use of this technique makes it possible to deal with a large variety of circumstances, and to answer many questions, but there is no doubt that this approach has its limits, and that ultimately only a general equilibrium approach, endogenizing the prices as well as the quantities of all inputs and outputs, can give complete answers. This is particularly true in the immigration debate, since, for instance, the supply of migrants should probably be explained as well. Similarly, one could argue that the supply of foreign goods, the work-leisure decision of domestic workers, the level of capacity utilization, domestic investment decisions, and intertemporal consumption behaviour should be modeled too ...

4 Empirical Implementation

4.1 Functional Form

Upon specification of a functional form, cost function (2) can be estimated. However, it is statistically more efficient to estimate instead the system of derived demand functions (3). The estimates can then be used to recover (2), and to calculate estimates of (4), (6), (10), (13), and (15)–(17).

In what follows, we will use the Translog functional form; Christensen, Jorgenson, and Lau (1973). It can be written as:

$$\begin{aligned}\ln c(\mathbf{w}, t) &= \alpha_0 + \sum_j \alpha_j \ln w_j + \frac{1}{2}\sum_j \sum_k \gamma_{jk} \ln w_j \ln w_k + \\ &\quad \alpha_T t + \sum_j \delta_{jT} \ln w_j t + \frac{1}{2}\delta_{TT} t^2, \quad j, k \in \{M, N, L.K\}, \quad (18)\end{aligned}$$

where t is a time trend intended to capture the effects of technological change. Symmetry implies $\gamma_{jk} = \gamma_{kj}$. Linear homogeneity requires $\sum_j \alpha_j = 1$, $\sum \gamma_{jk} = 0$, and $\sum_j \delta_{jT} = 0$.

As indicated by (3), the input demand functions can be obtained by differentiation of (18). In share form:

$$s_j = \alpha_j + \sum_k \gamma_{jk} \ln w_k + \delta_{jT} t, \quad (19)$$

where s_j is once again the cost share of the j-th input.

4.2 Smoothing

Some concern has been expressed recently that flexible functional forms may not be flexible enough to pick up the ups and downs of technological change and productivity growth; see Diewert and Wales (1992), for instance. Translog cost function (18) provides a second-order approximation to an arbitrary cost function, with respect to prices as well as with respect to time. This means that total factor productivity is modeled as a quadratic function of time, or that the rate of technological change, which can be obtained by differentiating (18) with respect to t, is a linear function of time. That is, except for the influence of changing relative prices, the rate of technological change is either monotonically increasing or decreasing throughout the entire estimation period. This may be too restrictive an assumption, and some additional flexibility might be needed. One way of handling this problem is with the help of spline functions; see Diewert and Wales (1992), and Fox (1994). An alternative may be by focusing on total factor productivity and applying a number of filters; see Fox (1994), Fox and Kohli (1998). In this paper, we will experiment along an alternative route, by increasing the level of flexibility of the aggregator function with respect to time. That is, while we continue to assume that the cost function provides a second-order approximation with respect to prices, we increase the degree of the approximation with respect to time to a degree $\tau > 2$. In what follows, we consider values for τ equal to three and four. In the $\tau = 4$ case, the Translog cost function becomes as follows:

$$\begin{aligned}\ln c(\mathbf{w}, t) \quad = \quad & \alpha_0 + \sum_j \alpha_j \ln w_j + \frac{1}{2} \sum_j \sum_k \gamma_{jk} \ln w_j \ln w_k + \\ & \alpha_T t + \sum_j \delta_{jT} \ln w_j t + \sum_j \delta_{jTT} \ln w_j t^2 + \sum_j \delta_{jTTT} \ln w_j t^3 + \\ & \frac{1}{2} \delta_{TT} t^2 + \frac{1}{6} \delta_{TTT} t^3 + \frac{1}{24} \delta_{TTTT} t^4, \quad j, k \in \{M, N, L.K\}, \qquad (20)\end{aligned}$$

where $\sum_j \delta_{jTT} = 0$ and $\sum_j \delta_{jTTT} = 0$. The case $\tau = 3$ requires $\delta_{jTTT} = \delta_{TTTT} = 0, \forall j \in \{M, N, L.K\}$. If, moreover, one imposes $\delta_{jTT} = \delta_{TTT} = 0, \forall j \in \{M, N, L.K\}$, one is back to the $\tau = 2$ standard flexible specification (18). In the general case, the input demand share equations become:

$$s_j = \alpha_j + \sum_k \gamma_{jk} \ln w_k + \delta_{jT} t + \delta_{jTT} t^2 + \delta_{jTTT} t^3. \qquad (21)$$

One could obviously keep increasing the flexibility with respect to time almost *ad infinitum*, or at least until all degrees of freedom are exhausted. However, there seems to be little point in doing so. For one thing, while one wishes to make the model sufficiently flexible with respect to time, one also wishes to keep it as parsimonious as possible. The $\tau = 4$ version of the model allows for two inflection points in the path of total factor productivity, as opposed to none with the standard specification. This should be enough to pick up the major trends in factor productivity developments over a thirty- or forty-year period, and it is precisely the number advocated by Diewert and Wales (1992) in their study. Another reason why one may not want to increase the value of τ beyond reason is that, while it will tend to increase the goodness of fit, it will gradually squeeze out any role for economic variables such as relative prices. One knows, indeed, that any economic time series can be exactly explained by a polynomial of time of sufficiently high degree.

4.3 Data

The cost function is estimated for Switzerland with annual data covering the period 1950–1986. We require price and quantity series for all four inputs and for gross output. Gross output and import figures are derived from the National Income and Product Accounts, together with the income shares of labour and capital. The price of imports is inflated by import duties, whereas the price of gross output is net of indirect taxes, but it includes subsidies.

The quantity of labour is obtained by multiplying employment figures by the average length of the work week. The quantity of capital is calculated as a Tornqvist quantity index of structures and equipment. Both stocks are obtained by cumulating the corresponding real investment series, subject to exogenous rates of depreciation; this was accomplished over an extended period of time (starting in 1914) so that by the beginning of the sample period the figures are essentially independent of initial values. The price of labour and capital services were obtained by deflation.

The disaggregation of employment between resident and nonresident labour is based on Favarger (1992). The resident worker category comprises natives as well as foreign workers who are residents of Switzerland. Nonresident workers are holders of seasonal permits, annual permits, or transborder permits. Data on the number of nonresident workers are readily available, whereas as their income can be derived from the Swiss balance of payments which records payments to nonresident workers. All prices are normalized to unity for 1980. Quantities are expressed in million 1980 Swiss francs; t is defined as a time trend with unit annual increments and normalized to zero for 1980. Summary statistics of the input data are shown in Table 1; additional details, and the series themselves, are available upon request.

4.4 Stochastic Specification and Estimation Techniques

We assume that demand functions (21) are exact, except for errors in optimization. We specify a vector of additive disturbances which we assume to be identically distributed, serially independent, normal random vectors with mean vector zero. The model is estimated by using the algorithm of Berndt, Hall, Hall, and Hausman

(1974); this is essentially an iterative version of Zellner's (1962) method for seemingly unrelated regressor equations, and it is numerically equivalent to maximum likelihood.

5 Empirical Results

Estimates of (19) are reported in Table 2, column 1. We verified that the estimated cost function satisfies all required regularity conditions (monotonicity and concavity) for all observations.[20] Asymptotic t-values are shown in parentheses. We next reestimated the $\tau = 3$ and $\tau = 4$ versions of the cost function — see (20) above. The corresponding parameter estimates are shown in columns 2 and 3 of Table 2; again, we verified that all regularity conditions are met for all observations. It is apparent that the additional flexibility with respect to time leads to a significant improvement in the goodness of fit: conducting a likelihood-ratio test for the hypothesis $\tau = 2$, conditional on the alternative hypothesis $\tau = 3$, produces a test statistic of 61.96 for a χ^2 critical value of 9.21, at the 99% confidence level with two degrees of freedom. The test for $\tau = 3$, conditional on $\tau = 4$, yield a test statistic of 30.64 for the same χ^2 critical value. The lower levels of flexibility with respect to time are therefore decisively rejected, and we proceed with the $\tau = 4$ estimates shown in Table 2, column 3, as our preferred set of estimates.[21]

The parameter estimates in Table 2 can be used to calculate Allen-Uzawa elasticities of substitution (σ_{jk}) and Hicksian elasticities of complementarity (ψ_{jk}); these are reported for selected years in Tables 2 and 3, respectively. It is apparent from Table 3 that nonresident workers are Allen-Uzawa complements for imports

[20] Monotonicty and concavity are an integral part of our theoretical framework, and they must be satisfied for the econometric estimates to be economically meaningful. Regularity condition failures have plagued previous work in the immigration literature; thus, a little known fact about Baldwin Grossman's (1982) widely cited study is that her estimates fail to satisfy concavity. In the Translog case, curvature conditions can be imposed locally if needed. However, there is no guarantee that this will be sufficient for the conditions to be met for all observations. Moreover, imposition of curvature conditions often leads to a reduction in the rank of the Hessian matrix. It is therefore fortunate that these conditions were met here at the outset, since a rank reduction would rule out some of the manipulations described in Section 3.

[21] One can see that the estimates of some of the γ_{jk}'s change substantially as τ is allowed to increase; this is not surprising since our test results indicate that restricting the value of τ does violence to the data.

as well as for capital.[22] All other pairs of inputs are Allen-Uzawa substitutes for each other. Judging from Table 4, nonresident workers and resident workers are Hicksian q-substitutes for each other,[23] whereas all other pairs of inputs are Hicksian q-complements for each other, except early on in the sample when one finds some evidence of q-substitutability between imports and capital.[24] Thus, trade and labour mobility are complements in the Swiss case, both in the Allen-Uzawa sense and in the Hicksian sense. Nonresident and resident workers, on the other hand, are substitutes in both settings. Imports and capital, as well as resident workers and capital, are substitutes in the Allen-Uzawa sense, but complements in the Hicksian sense for most of the sample period.

To get a better feeling of the magnitudes involved, we move to Tables 4 and 5 which report 1986 estimates of matrices E and H. Consider the price elasticities of input demands shown in Table 5 to begin with. The own price elasticity of the demand for imports is estimated to be -0.449 — which may seem quite low — while the own price elasticity of the demand for nonresident labour is found to be rather large in absolute value, at -2.094. Remember though that these price elasticities are defined for given input prices and a given level of gross output. The estimate of ε_{MN} shows that a 1% increase in the cost of nonresident labour services would reduce the demand for imports by about 0.2%, but increase the demand for resident labour by about 0.4%. A 1% increase in the price of imports, on the other hand, would reduce the demand for foreign labour services by about 1.3%.

Looking at the estimates of the η_{jk}'s shown in Table 6, one sees that a 1% increase in the number of nonresident workers would increase the marginal product of imports by about 0.3%, the marginal product of capital by about 0.4%, but reduce the marginal product of resident workers by about 0.3%. An increase in the endowment of capital, on the other hand, would enhance the marginal product of all three other inputs, not least nonresident workers.

[22] Butare and Favarger (1992), on the basis of a three-input Translog production function that excludes imports and for which $\tau = 2$, also find that nonresident workers are Allen-Uzawa complements for capital.

[23] This is contrast with the findings of Butare and Favarger (1992).

[24] The finding that the Hicksian elasticity of complementarity between imports and capital changes sign, even though the Allen-Uzawa elasticity of substitution does not, once again underscores the fact that the passage from one set of elasticities to the other is not trivial.

As argued earlier, it might be more appropriate to consider the prices of goods and of nonresident labour services as predetermined, together with the endowments of domestic factors. This brings us to the GNP-function setting, and to the corresponding elasticity estimates (matrix $\mathcal{E}$) shown in Table 7. The own price elasticity of the demand for imports is now found to be -1.056, while the own price elasticity of the demand for foreign labour services is -1.274. These elasticities cannot be compared directly to the ones reported in Table 5, since ϵ_{MM} and ϵ_{NN} — contrary to ε_{MM} and ε_{NN} —- are defined for variable gross output and fixed endowments of capital and domestic labour. Of considerable interest are the so-called Stolper-Samuelson elasticities ($\epsilon_{ij}, i \in \{Y, M, N\}, j \in \{L, K\}$) and Rybczynski elasticities ($\epsilon_{ji}, j \in \{L, K\}, i \in \{Y, M, N\}$). These show, for instance, that an increase in the price of imports hurts capital relatively much more than labour, whereas an increase in the price of nonresident labour actually favors resident labour. An increase in the endowment of capital will tend to heavily increase the demand for nonresident labour services. Looking at the negative signs of the cross price elasticities ϵ_{MN} and ϵ_{NM}, one can conclude that trade and labour mobility are complements in the sense that, for given domestic factor endowments, an increase in the price of either foreign input will tend to reduce the demand for both.

We next turn to the question of the effects of exogenous changes in the number of nonresident workers. The relevant elasticities (matrix Φ, 1986 figures) are shown in Table 8. If the number of nonresident workers is held constant, the own price elasticity of imports is now found to be quite a bit closer to zero than otherwise (compare the estimate of ϕ_{MM} with that of ϵ_{MM} shown in Table 7), which is an illustration of the Le Châtelier Principle. Of special interest is the estimate of ϕ_{LN} which shows that, as one might have expected it, an increase in the number of nonresident workers depresses the wages of resident workers, but the impact is very small.[25] Looking at the Stolper-Samuelson effects, it is interesting to note that nonresident workers are relatively more hurt than the domestic factors of production by a worsening in the terms of trade. Once again, we find that imports and foreign labour services seem to work hand in hand.

[25] This result confirms the findings obtained for other countries; see Greenwood, Hunt and Kohli (1996, 1997) for recent findings for the United States.

We now turn to the estimates of matrix Θ shown in Table 9. Remember that these price and quantity elasticities are valid for given prices of output, imports, and resident labour services, and given quantities of nonresident labour and domestic capital. They are thus relevant in the short run, if domestic wages are sticky. With resident labour services variable, the demand for imports is found to be quite price elastic.[26] The demand for resident labour is found to be quite price elastic as well. The estimate of θ_{LN} indicates the effect of an increase in the number of nonresident workers on the demand for resident workers. Its negative value shows that, as expected, foreign workers displace native workers. The effect is not as small as it seems since the number of resident workers is about five times larger than the number of nonresident workers. An elasticity of -0.214 thus indicates that the replacement effect is almost one for one. However, what is crucial here is the assumption of a fixed domestic wage rate. The relatively large price elasticity of the demand for resident labour reveals that not much of a reduction in domestic wages would be needed to restore full employment. Indeed, this is confirmed by the very low estimate of ϕ_{LN} shown in Table 8. Thus, if immigration causes unemployment, then the prime culprit will be domestic wage rigidity. One again, we find that trade and labour mobility are complements, in the sense this time that an increase in the number of nonresident workers will tend to increase the demand for imports.

Comparing our results with those reported in Kohli (1993), we find some interesting similarities, in spite of the differences in specification, functional form, and modelling of technological change. Thus, both studies found that nonresident workers are substitutes for resident workers, and complements for capital in the Allen-Uzawa sense. Both studies also found that imports are Hicksian complements for capital and both types of labour, and that nonresident workers are Hicksian substitutes for resident workers. There are some differences, however. Thus, the earlier study did suggest that imports might be Allen-Uzawa substitutes for foreign labour, and that nonresident labour may be a Hicksian substitute for capital. However, it is rather remarkable that in spite of these differences all ϵ_{jk} elasticities — i.e. those consistent with the GNP-function setting — have

[26] The comparison of θ_{MM} with ϕ_{MM} provides another illustration of the Le Châtelier Principle.

the same signs. In particular, both studies concur that imports and nonresident labour services are complements in the sense that an increase in one input will reduce the demand for the other, and that an increase in the cost of nonresident labour services will favor resident workers, but penalize capital owners.

6 Total Factor Productivity

Our econometric results can also be used to model total factor productivity. A state-of-the art measure of the change in total factor productivity is given by the following index:[27]

$$R_{t,t-1} \equiv \sqrt{\frac{c(\mathbf{w}_{t-1}, t-1)}{c(\mathbf{w}_{t-1}, t)} \frac{c(\mathbf{w}_t, t-1)}{c(\mathbf{w}_t, t)}}, \tag{22}$$

where the subscripts indicate the time period. This index shows the cost reduction that results from the passage of time, using either period-t or period-$t-1$ input prices as weights. It can be shown that if the cost function is Translog, then $R_{t,t-1}$ can be calculated from knowledge of the data alone as follows:

$$R_{t,t-1} = \frac{W_{t,t-1}}{P_{t,t-1}}, \tag{23}$$

where $W_{t,t-1}$ is a Tornqvist input price index:[28]

$$W_{t,t-1} = \exp\left[\sum_j \frac{1}{2}(s_{jt} + s_{jt-1})(\ln w_{jt} - \ln w_{jt-1})\right], \tag{24}$$

and $P_{t,t-1}$ is the output price change factor:

$$P_{t,t-1} = \frac{p_t}{p_{t-1}}. \tag{25}$$

[27] See Caves, Christensen and Diewert (1982), and Diewert and Morrison (1986), for instance.

[28] Given that the cost function is Translog, $W_{t,t-1}$ can also be interpreted as the geometric mean of two indexes, both measuring the cost implications of changes in input prices, but one doing it with reference to time-$t-1$'s technology, and the other one refering to time-t's technology:

$$W_{t,t-1} \equiv \sqrt{\frac{c(\mathbf{w}_t, t-1)}{c(\mathbf{w}_{t-1}, t-1)} \frac{c(\mathbf{w}_t, t)}{c(\mathbf{w}_{t-1}, t)}}.$$

Since the construction of the data ensures that the value of gross output equals the total cost of inputs:

$$p_t y_t = \sum_j w_{jt} x_{jt}, \tag{26}$$

it follows immediately that $R_{t,t-1}$ can also be calculated as:

$$R_{t,t-1} = \frac{Y_{t,t-1}}{X^{\star}_{t,t-1}}, \tag{27}$$

where $Y_{t,t-1}$ is the output change factor:

$$Y_{t,t-1} = \frac{y_t}{y_{t-1}}, \tag{28}$$

and $X^{\star}_{t,t-1}$ is an *implicit* Tornqvist index of input quantities:

$$X^{\star}_{t,t-1} \equiv \frac{P_{t,t-1} Y_{t,t-1}}{W_{t,t-1}}. \tag{29}$$

Thus, as suggested in the introduction, total factor productivity growth can be deduced from Figure 2 by looking at the difference between the two lines. The cumulated index of total factor productivity is also shown in Figure 3. One sees that total factor productivity has increased substantially during the postwar period, although the index fell very dramatically in the mid-seventies. An entire decade had elapsed before it had fully recovered.

We can also follow an econometric approach to measuring total factor productivity growth. That is, we can obtain $R_{t,t-1}$ from the estimates of the structural parameters of the cost function. We begin by introducing (20) into the logarithmic version of (22). This yields:

$$\begin{aligned} \ln R_{t,t-1} \quad = \quad & \alpha_T + \frac{1}{2} \sum \delta_{jT} (\ln w_{jt} - \ln w_{jt-1}) + \\ & \frac{1}{2} \sum \delta_{jTT} (\ln w_{jt} - \ln w_{jt-1})(2t-1) + \\ & \frac{1}{2} \sum \delta_{jTTT} (\ln w_{jt} - \ln w_{jt-1})(3t^2 - 3t + 1) + \\ & \frac{1}{2} \delta_{TT} (2t-1) + \frac{1}{6} \delta_{TTT} (3t^2 - 3t + 1) + \\ & \frac{1}{24} \delta_{TTTT} (4t^3 - 6t^2 + 4t - 1). \end{aligned} \tag{30}$$

Computation of (30) requires estimates of α_T, δ_T, and — in the higher-order flexibility cases — δ_{TTT} and δ_{TTTT}. These estimates can be obtained by regressing the so-far unexplained portion of the price of output on t, t^2, t^3 and t^4. For this purpose, we have estimated the following equation:

$$\ln u_t = \alpha_0 + \alpha_T t + \frac{1}{2}\delta_{TT}t^2 + \frac{1}{6}\delta_{TTT}t^3 + \frac{1}{24}\delta_{TTTT}t^4, \tag{31}$$

where

$$\begin{aligned} \ln u_t \;\equiv\; & \ln p_t - \sum_j \alpha_j \ln w_{jt} - \frac{1}{2}\sum_j \sum_k \gamma_{jk} \ln w_{jt} \ln w_{kt} - \\ & \sum_j \delta_{jT} \ln w_{jt} t - \sum_j \delta_{jTT} \ln w_{jt} t^2 - \sum_j \delta_{jTTT} \ln w_{jt} t^3. \end{aligned} \tag{32}$$

Our results are summarized in Figure 3 which shows the econometric estimate of the index, based on (30), using the second-order, third-order, and fourth-order approximations, respectively. One sees that the second- and the third-order approximations do a rather poor job at tracking the total factor productivity index. Both curves are concave, and they indicate a severe slowdown in the rate of technological progress. The second-order approximation actually suggests technological regress towards the end of the sample period. The fourth-order approximation, on the other hand, performs much better, and it indicates a resurgence of technological progress towards the end of the sample period, after the downturn of the mid-seventies.

The two-stage approach which we have followed here to estimate the rate of technological progress is somewhat similar to the one used by Fox and Kohli (1998). There is one major difference, however. Thus, in the present treatment, the first stage already takes account of the type of smoothing which will be applied in the second stage. That is, if a fourth-order approximation is selected, this impacts on the estimation of the input share equations since, as shown by (21), these will then be functions of t, as well as of t^2 and t^3.

7 Conclusions

The main purpose of this paper was to combine the production-theory approach to modelling immigration with the production-theory approach to modelling foreign trade. Indeed, it is rather odd that until now international labour mobility and international trade were essentially modeled separately in empirical work. Yet immigration is clearly an international phenomenon; the production-theory approach to immigration must thus be compatible with the production sector of an open economy.

An attempt was made here to increase the flexibility of flexible functional forms with respect to time. A second-order approximation with respect to time does not allow for any inflection points in the path of total factor productivity. Given the ease with which our approach can be implemented, it may be viewed as an attractive alternative to the spline method proposed by Diewert and Wales (1992).

Among our main empirical results, we have found that the displacement effects of immigration into Switzerland could be very severe in case of downward wage rigidity. If wages are flexible, increased immigration will lower the income of domestic workers, but only weakly so. Capital owners are the beneficiaries of immigration; it is therefore not surprising that the call for increased access to foreign labour markets generally emanates from business leaders.

Imports and nonresident labour are found to be complements for each other, in many different meanings of the word. They are Allen-Uzawa complements, and they also are Hicksian q-complements. Furthermore, they are also complements in the sense that more nonresident workers tend to lead to more imports; this is true whether or not resident labour services are held constant. Moreover, in the GNP-function setting, a reduction in the price of nonresident labour services, which tends to favor the demand for such services, also pulls along the demand for imports.

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Table 1: Input Data — Summary Statistics

	mean	1980-value	stand. dev.	minimum	maximum
w_M	0.77652	1.00000	0.17273	0.56926	1.12891
w_N	0.59952	1.00000	0.40951	0.11137	1.42308
w_L	0.60442	1.00000	0.40484	0.13611	1.46850
w_K	0.80162	1.00000	0.18901	0.58467	1.25165
x_M	40214.2	71760.7	23703.0	9707.8	86606.9
x_N	12520.9	8963.9	5075.9	4500.2	20925.9
x_L	80794.0	91691.4	8017.2	67127.4	91691.4
x_K	30126.0	43794.3	13832.5	8918.7	50798.1
s_M	0.27931	0.33190	0.02498	0.22901	0.33190
s_N	0.06451	0.04146	0.02651	0.02523	0.11093
s_L	0.42359	0.42408	0.03667	0.36734	0.50230
s_K	0.23259	0.20255	0.01688	0.20114	0.25374

Table 2: Parameter Estimates
(asymptotic t-values in parentheses)

	$\tau = 2$	$\tau = 3$	$\tau = 4$
α_M	0.30889	0.30778	0.30748
	(71.22)	(67.28)	(62.49)
α_N	0.04511	0.05015	0.04089
	(11.01)	(14.27)	(15.42)
α_L	0.43342	0.42502	0.43595
	(54.45)	(72.68)	(77.65)
γ_{MM}	0.08138	0.07127	0.07439
	(2.82)	(1.86)	(2.03)
γ_{MN}	-0.10102	-0.05914	-0.07482
	(-4.67)	(-2.41)	(-4.08)
γ_{ML}	0.07754	0.03797	0.04292
	(2.42)	(0.98)	(1.17)
γ_{NN}	-0.10114	-0.04785	-0.05360
	(-3.50)	(-1.68)	(-3.10)
γ_{NL}	0.25804	0.12210	0.16097
	(6.72)	(3.17)	(6.45)
γ_{LL}	-0.42431	-0.11577	-0.18427
	(-6.52)	(-1.86)	(-3.78)
δ_{MT}	0.00345	0.00292	0.00355
	(3.78)	(3.48)	(3.68)
δ_{NT}	-0.00793	-0.00724	-0.00604
	(-9.14)	(-11.09)	(-11.44)
δ_{LT}	0.00732	0.00586	0.00379
	(4.31)	(5.37)	(3.42)

Table 2, continued

δ_{MTT}	—	-0.00001	-0.00003
		(-0.39)	(-0.30)
δ_{NTT}	—	-0.00014	0.00022
		(-5.48)	(4.09)
δ_{LTT}	—	0.00029	-0.00018
		(6.67)	(-1.61)
δ_{MTTT}	—	—	0.00000
			(0.63)
δ_{NTTT}	—	—	0.00001
			(6.92)
δ_{LTTT}	—	—	-0.00001
			(-4.49)
LL	351.01	381.99	397.31

Table 3: Allen-Uzawa Elasticities of Substitution
for selected years

	1950	1960	1970	1980	1986
σ_{MM}	-1.906	-1.721	-1.613	-1.465	-1.432
σ_{MN}	-13.810	-2.734	-2.100	-4.951	-4.078
σ_{ML}	1.353	1.401	1.390	1.320	1.316
σ_{MK}	0.202	0.368	0.377	0.359	0.344
σ_{NN}	-161.943	-21.471	-17.976	-55.513	-44.574
σ_{NL}	15.506	6.232	5.813	10.030	8.914
σ_{NK}	-5.709	-0.683	-0.569	-2.692	-2.358
σ_{LL}	-1.623	-2.589	-2.770	-2.263	-2.293
σ_{LK}	0.832	0.810	0.793	0.791	0.780
σ_{KK}	-1.571	-1.466	-1.515	-1.601	-1.623

Note: These estimates are based on the parameter values shown in Table 1, column 3.

Table 4: Hicksian Elasticities of Complementarity
for selected years

	1950	1960	1970	1980	1986
ψ_{MM}	-21.928	-6.243	-5.266	-5.529	-4.984
ψ_{MN}	44.668	5.982	4.821	8.970	7.368
ψ_{ML}	9.752	1.806	1.572	2.620	2.238
ψ_{MK}	-3.712	1.809	1.885	0.885	1.203
ψ_{NN}	-118.381	-15.491	-13.190	-33.162	-27.604
ψ_{NL}	-24.268	-3.225	-2.776	-7.561	-6.245
ψ_{NK}	20.226	3.547	3.533	8.782	8.188
ψ_{LL}	-5.815	-1.824	-1.790	-2.796	-2.495
ψ_{LK}	5.447	1.991	2.039	3.350	3.255
ψ_{KK}	-10.510	-6.095	-6.728	-9.698	-10.519

Note: These estimates are based on the parameter values shown in Table 1, column 3.

Table 5: Price Elasticities of Input Demand
(Cost-Function Setting, Matrix E, 1986 estimates)

$$\varepsilon_{mn} \equiv \partial \ln h_m(y, w_M, w_N, w_L, w_K)/\partial \ln z_n$$
$$h_m \in \{x_M, x_N, x_L, x_K\}, z_n \in \{w_M, w_N, w_L, w_K\}$$

	$z_n = w_M$	$z_n = w_N$	$z_n = w_L$	$z_n = w_K$
ε_{Mn}	-0.449	-0.192	0.570	0.071
ε_{Nn}	-1.279	-2.094	3.860	-0.487
ε_{Ln}	0.413	0.419	-0.993	0.161
ε_{Kn}	0.108	-0.111	0.338	-0.335

Note: These estimates are defined for a given quantity of output and given input prices. They are based on the parameter values shown in Table 1, column 3.

Table 6: Price Elasticities of Input Demands
(Production-Function Setting, Matrix H, 1986 estimates)

$$\eta_{mn} \equiv \partial \ln h_m(p, x_M, x_N, x_L, x_K)/\partial \ln z_n$$
$$h_m \in \{w_M, w_N, w_L, w_K\}, z_n \in \{x_M, x_N, x_L, x_K\}$$

	$z_n = x_M$	$z_n = x_N$	$z_n = x_L$	$z_n = x_K$
η_{Mn}	-1.563	0.346	0.969	0.248
η_{Nn}	2.311	-1.297	-2.704	1.690
η_{Ln}	0.702	-0.293	-1.080	0.672
η_{Kn}	0.377	0.385	1.409	-2.171

Note: These estimates are defined for a given price of output and given input quantities. They are based on the parameter values shown in Table 1, column 3.

Table 7: Price and Quantity Elasticities
(GNP-Function Setting, Matrix $\mathcal{E}$, 1986 estimates)

$$\epsilon_{mn} \equiv \partial \ln h_m(p, w_M, w_N, x_L, x_K)/\partial \ln z_n$$
$$h_m \in \{y, x_M, x_N, w_L, w_K\}, z_n \in \{p, w_M, w_N, x_L, x_K\}$$

	$z_n = p$	$z_n = w_M$	$z_n = w_N$	$z_n = x_L$	$z_n = x_K$
ϵ_{Yn}	0.568	-0.420	-0.148	0.439	0.561
ϵ_{Mn}	1.338	-1.056	-0.282	0.261	0.739
ϵ_{Nn}	3.157	-1.883	-1.274	-1.620	2.620
ϵ_{Ln}	1.014	-0.189	0.176	-0.422	0.422
ϵ_{Kn}	2.719	-1.123	-0.596	0.885	-0.885

Note: These estimates are defined for given output, import and nonresident labour service prices, and for given domestic factor endowments. They are based on the parameter values shown in Table 1, column 3.

Table 8: Price and Quantity Elasticities
(Immigration-Quotas Setting, Matrix Φ, 1986 estimates)

$$\phi_{mn} \equiv \partial \ln h_m(p, w_M, x_N, x_L, x_K)/\partial \ln z_n$$
$$h_m \in \{y, x_M, w_N, w_L, w_K\}, z_n \in \{p, w_M, x_N, x_L, x_K\}$$

	$z_n = p$	$z_n = w_M$	$z_n = x_N$	$z_n = x_L$	$z_n = x_K$
ϕ_{Yn}	0.201	-0.201	0.116	0.627	0.256
ϕ_{Mn}	0.640	-0.640	0.221	0.620	0.159
ϕ_{Nn}	2.478	-1.478	-0.785	-1.272	2.057
ϕ_{Ln}	1.449	-0.449	-0.138	-0.645	0.783
ϕ_{Kn}	1.241	-0.241	0.468	1.643	-2.111

Note: These estimates are defined for given output and import prices, and for given quantities of labour (nonresident and resident) and capital. They are based on the parameter values shown in Table 1, column 3.

Table 9: Price and Quantity Elasticities
(Variable-Resident-Employment Setting, Matrix Θ, 1986 estimates)

$$\theta_{mn} \equiv \partial \ln h_m(p, w_M, w_L, x_N, x_K)/\partial \ln z_n$$
$$h_m \in \{y, x_M, x_L, w_N, w_K\}, z_n \in \{p, w_M, w_L, x_N, x_K\}$$

	$z_n = p$	$z_n = w_M$	$z_n = w_L$	$z_n = x_N$	$z_n = x_K$
θ_{Yn}	1.610	-0.637	-0.972	-0.018	1.018
θ_{Mn}	2.032	-1.071	-0.961	0.089	0.911
θ_{Ln}	2.246	-0.696	-1.550	-0.214	1.214
θ_{Nn}	-0.378	-0.593	1.971	-0.513	0.513
θ_{Kn}	4.931	-1.385	-2.547	0.117	-0.117

Note: These estimates are defined for given output, import and resident labour service prices, and for given quantities of nonresident labour and capital. They are based on the parameter values shown in Table 1, column 3.