UNIVERSITÄT
BERN

Faculty of Economics and
Social Sciences

Department of Economics

The Effects of Immigration on Wages:
An Application of the Structural Skill-Cell Approach

Michael Gerfin
Boris Kaiser

10-12

September 2010

DISCUSSION PAPERS

Schanzeneckstrasse 1
Postfach 8573
CH-3001 Bern, Switzerland
http://www.vwi.unibe.ch

The Effects of Immigration on Wages:

An Application of the Structural Skill-Cell Approach

Michael Gerfin*   Boris Kaiser**

September 14, 2010

Abstract

This paper investigates how recent immigration inflows from 2002 to 2008 have affected wages in Switzerland. This period is of particular interest as it marks the time during which the bilateral agreement with the EU on the free cross-border movement of workers has been effective. Since different types of workers are likely to be unevenly affected by recent immigration inflows, we follow the "structural skill-cell approach" as for example employed by Borjas (2003) and Ottaviano and Peri (2008). This paper provides two main contributions. First, we estimate empirically the elasticities of substitution between different types of workers in Switzerland. Our results suggest that natives and immigrants are imperfect substitutes. Regarding different skill levels, the estimates indicate that workers are imperfect substitutes across broad education groups and across different experience groups. Second, the estimated elasticities of substitution are used to simulate the impact on domestic wages using the actual immigration inflows from 2002 to 2008. For the long run, the simulations produce some notable distributional consequences across different types of workers: While previous immigrants incur wage losses (-1.6%), native workers are not negatively affected on average ($+0.4\%$). In the short run, immigration has a negative macroeconomic effect on the average wage, which, however, gradually dies out in the process of capital adjustment.

Keywords: Immigration; Wages; Labour Demand; Labour Supply; Skill Groups.

JEL: E24, F22, J61, J31

*Department of Economics, Public Economics, University of Bern, e-mail: michael.gerfin@vwi.unibe.ch

**Department of Economics, Public Economics, University of Bern, e-mail: boris.kaiser@vwi.unibe.ch

1 Introduction

In migration economics, the leading issue is concerned with the effects of immigration on the economy of the destination country. In particular, there has been much debate among economists and policymakers alike as to whether immigration exerts downward pressure on domestic wages or causes unemployment. It is generally argued that the arrival of foreign workers may bring about increased competition on the labour market among job seekers, thus worsening the position of domestic workers by driving down wages or causing higher unemployment.

From an economic viewpoint, it is important to distinguish between macroeconomic and microeconomic effects. Regarding the former, a traditional labour market model would imply that a sudden increase in immigrant labour lowers the amount of physical capital available per labour unit which decreases the marginal product of labour and thus average national wages. The question immediately arises whether physical capital responds to such a labour market shock and how fast it will take place. A partial adjustment of physical capital will cushion the fall of the capital-labour ratio. It is therefore clear that any macroeconomic impact of immigration depends on the dynamic response of physical capital accumulation. The more microeconomic aspect of the question has received more attention by labour economics and deals with the effects of immigration on the wages of individual workers. A traditional textbook analysis that considers a labour market with homogenously skilled workers implies that an increase in supply leads to a new equilibrium with lower wages. However, if labour is heterogeneous such that different types of workers are imperfect substitutes (or even complements) for one another, an increase in the supply of one type of worker may raise labour demand for another type of worker, and thus, their wages. In other words, some workers might benefits from a particular influx of foreign workers, while others might lose. For example, an increase in low-skilled immigrants can have starkly different implications for low-skilled natives vis-à-vis high-skilled natives. As individual workers are likely to be asymmetrically affected by immigration, one should attempt to gauge the distributional effects across different groups of workers. Such an analysis requires a model that enables the researcher to categorize workers into different skill groups. The interrelationships between these groups are captured by elasticities of substitution. This form of analysis is usually referred to as the structural "skill-cell" approach. In employing this approach, these elasticities of substitution play a very crucial role as they govern the direct effects and the cross effects triggered by changes in the supply of different types of workers.

In recent years, there have been an increasing number of empirical studies using the skill-cell approach to estimate how immigration affects wages. Previous studies often used city-level or state-level data to exploit spatial correlations. This method, however, is prone to a number of problems including internal native migration responses, endogeneity of immigrants' destination, and so on (Borjas, Freeman, and Katz, 1997). In contrast, the skill-cell method constitutes a "national" approach in the sense that the country's entire economy is considered. In terms of previous studies, Borjas (2003) and Borjas, Grogger, and Hanson (2008) find that immigration has exerted significant downward pressure on wages of low-skilled U.S.-born workers. In contrast, Ottaviano and Peri (2006, 2008) report benign effects on natives' wages but a sizable negative impact on previous immigrants' wages. These rather stark differences are the result of different elasticities of substitution used for simulation. As opposed to the formerly mentioned studies, the latter find that immigrants and natives are imperfect substitutes despite similar skills, and in addition, less restrictive assumptions are imposed with respect to the substitutability between different education groups. For Great Britain, Manacorda, Manning, and Wadsworth (2006) find that immigration flows increase the average native-immigrant wage differential. For Germany, two recent studies obtain moderate negative distributional effects on high-skilled natives' wages (D'Amuri, Ottaviano, and Peri, 2009; Brücker and Jahn, 2008) but the total effect on native workers seems to cluster around zero. To sum up, the above mentioned studies mostly suggest that the impact of immigration on average wages of the total native workforce is essentially zero in the long run, but across skill groups there may be significant differences.

The aim of this paper is twofold. First, we will follow the skill-cell approach in the tradition of Borjas (2003) and Ottaviano and Peri (2006, 2008) to estimate the elasticities of substitution between different types of workers in Switzerland. Second, these empirical estimates will then be employed to simulate the impact on domestic wages using the actual immigration inflows from 2002 to 2008. Section 2 contains some concise facts on immigration in Switzerland. Section 3 presents an overview of the economic literature that deals with the wage effects of immigration. In particular, it is explained which methods are used and what results have been obtained. In Section 4, we establish a theoretical framework based on a production function with a nested CES structure for the labour aggregate so that workers can be differentiated according to their skill level and their nativity. To take into account the macroeconomic consequences of immigration, we also consider the adjustment process of physical capital as a response to the observed foreign labour supply shocks. Section 5 deals with the data analyzed in this paper. It contains all the relevant information regarding the dataset and the construction of skill cells and variables. In addition, a selected number of descriptive statistics is presented. In Section 6, estimating equations are derived from the structural model in order to estimate empirically the elasticities of substitution between natives and immigrants and between different skill groups. Where appropriate, the robustness of the results is tested with respect to sample selection, fixed-effects specification and estimation method. The results are critically evaluated and compared to the findings from other studies. Section 7 simulates the wage effects of immigration by using the estimated values for the elasticities of substitution. In doing so, several scenarios that differ with respect to capital adjustment are presented. Section 8 addresses some important problems and limitations that are prevalent with the approach applied in this paper.

2 Immigration in Switzerland

In this short section, we will present some facts about immigration in Switzerland. In particular, it is shown how the nature and the magnitude of immigration into Switzerland have changed over time. Unless otherwise indicated, the relevant data and information is drawn from Haug and Müller-Jentsch (2008) and the latest report from the State Secretariat for Economic Affairs (SECO, 2009). According to the OECD[1], 24.9% of the Swiss population were born abroad and 20.8 % do not have Swiss citizenship (in 2007). These numbers are similar to some of the traditional immigration countries, such as Australia, New Zealand and Canada, but they are much higher than in most other European OECD countries. For example, the share of the foreign-born population is 13% in Germany (in 2003), 8.5% in France and 10% in the United Kingdom.

From a recent historical perspective, there have been several waves of immigration into Switzerland. From 1950 to 1970, Switzerland's economy experienced a period of rapid expansion with high growth rates. There was an increasingly strong demand of domestic firms for cheap labour that domestic labour supply could not meet. Consequently, many foreign workers, predominately

[1] OECD: statistics on international migration

from Italy and to a lesser extent from Spain, were drawn into Switzerland. During these twenty years, the number of non-Swiss residents increased from 0.3 million to roughly 1.15 million. This large influx was largely due to domestic labour market conditions, that is, "pull-factors". During the 1970s, many migrant workers had to return to their home countries as Switzerland slipped into recession in the wake of the oil crisis in 1973. The number of foreign residents declined to less than 1 million. It was not until the second half of the 1980s that immigration started to rise again, but there was a clear shift to other source countries: new immigrants mainly came from former Yugoslavia, Turkey and Portugal. An important "push-factor" for large-scale immigration from former Yugoslavian countries was clearly the Yugoslav wars in the 1990s.

Since 2000, there has been a marked shift in immigration towards EU-27/EFTA countries, while the number of new immigrants from other countries has been declining. This development can largely be ascribed to changes in Swiss immigration policies. Switzerland greatly eased immigration restrictions for EU/EFTA nationals as the bilateral agreement with the EU on the free cross-border movement of workers (*Abkommen zur Personenfreizügigkeit*) came into effect in 2002. In particular, there have been a rapidly increasing number of new immigrants from Germany and Portugal. The former group accounts for 66% and the latter group for 20% of net immigration originating from EU/EFTA countries. Due to this shift, it appears that the nature of most recent immigration flows better serves the needs of the domestic economy than previous flows (in the 1980s and 1990s) because immigration is more directly linked to the labour market. In fact, growing employment in recent years is to a considerable degree associated with the influx of foreign workers. According to the Federal Office of Statistics (BFS)[2], the number of employed persons (*Erwerbsbevölkerung*) rose by 462'000 from 2000 to 2008, and 56% of this change is explained by the increase in foreign workers. From 1990 to 1999, the stock of employed persons rose by only 218'000, while the number of foreign workers actually declined by 6'000 (which corresponds to a negative contribution to growth of -3%). These numbers clearly illustrate that immigrants in the 1990s had a much looser labour market attachment compared to the more recent inflows. Furthermore, this is reflected in the fact that new immigrants are much better educated on average. Between 1997 and 2007, around 50% of new immigrants are reported to have tertiary education, while during the 10 years before that, this share was only half as large. Total net immigration of foreign nationals has generally

[2] BFS: Employment Statistics

trended upwards since 1997 and has risen sharply in 2007 and 2008[3].

3 Overview of the Literature

When it comes to analyzing empirically how immigration affects domestic wages, there are two major approaches that can be found in the literature. The first one is referred to as the "spatial correlations method" or sometimes as the "area approach", which exploits correlations between immigrant concentrations and wages across geographic regions while controlling for a host of other determinants of wages. The second and more recent approach is often referred to as the "skill-cell method", which focuses on the national labour market and treats skill groups as heterogenous factors of production. In this section, we will briefly present an overview as to how these two methods have been applied in the literature.

3.1 The Spatial Correlations Method

Most studies using the spatial correlations method only find modest effects of immigration on natives' labour market outcomes (e.g. LaLonde and Topel (1991), Altonji and Card (1991), De New and Zimmermann (1994) and Pischke and Velling (1997)). However, there are a number of problems associated with this approach. First, immigration flows and wages can suffer from a simultaneity bias. If foreign workers tend to move to places where wages are high, immigration is endogenous to local labour market conditions. Put simply, immigration affects wages, but wages also affect immigration. Second, Borjas, Freeman, and Katz (1996) argue that the effects of immigration tend to diffuse across the boundaries of the spatial unit, i.e. the city or the state. For instance, natives might respond to immigration by moving to other cities or by entering new occupations. Such responses would naturally offset the measured impact on natives' wages. To avoid these difficulties, they therefore conclude that one should focus on the national labour market to measure how immigration affects domestic labour market outcomes.

[3] BFS: Data on Immigration Flows

3.2 The Skill-Cell Method

In light of the above-mentioned problems attached to the spatial correlations method, researchers began focusing on national labour market data instead of city-level or state-level data. This approach gained momentum after the seminal work of Borjas (2003). He categorizes workers in cells according to their education and work experience. Using national panel data, Borjas' (2003) regression results imply that a 10% increase in immigrants lowers average weekly earnings by 4%. In contrast, if skill cells are defined by state, the impact of immigration is smaller by two thirds. He sees this as strong evidence that the spatial approach obscures the true magnitude of the immigration effect. Borjas (2003) most important contribution is the specification and application of a structural model based on a production function with a nested CES structure. This framework explicitly captures the interrelationships between various skill cells through several elasticities of substitution. Borjas uses his own estimates of the elasticities between different education and experience groups to calculate the wage effects. He finds that the immigration influx into the U.S. from 1980 to 2000 reduced average wages by some 3%. Most dramatically, his simulations predict that high school dropouts experienced wage declines of almost 9%. These numbers suggest a much stronger adverse impact of immigration than virtually all spatial correlations studies.

However, Ottaviano and Peri (2006) point out some important limitations of Borjas (2003) approach that they correct for in their paper. First, they lift Borjas' restrictive assumption that natives and immigrants are perfect substitutes. They argue that immigrants differ systematically in their skills and preferences and therefore choose different types of jobs in the labour market. Indeed, their empirical estimates confirm an imperfect degree of substitutability between nativity groups. Second, Ottaviano and Peri (2006, 2008) relax Borjas (2003) assumption of a fixed capital stock. Instead, their model takes into account that physical capital adjusts to increases in labour supply. Their argument is supported by long-term data on the capital-labour ratio that appears to follow a balanced growth path. Third, they simulate the wage effects taking into account all cross-elasticities implied by the model. In this way, changes in supply of one type of worker can also affect labour demand of all other types of workers. In contrast, Borjas (2003) uses the partial elasticity that only considers the changes in supply occurring in the same skill cell. As a further refinement, Ottaviano and Peri (2008) relax the constraint that the elasticity of substitution between education groups must be the same for all groups. Their estimation results imply that low-educated and highly-educated workers have much higher (possibly infinite) within-group elasticities than workers across these broad groups. Their long-run simulations predict that immigration from 1990 to 2004 had small positive effects on natives' wages (+0.6%) but detrimental effects on previous immigrants' wages (-6.4%).

A number of studies focus on European labour markets. For Great Britain, Manacorda, Manning, and Wadsworth (2006) report that a 10% rise in all immigrants raises the native-immigrant wage differential by 2.3%. Studies on Germany include Brücker and Jahn (2008), Felbermayr, Geis, and Kohler (2008) and D'Amuri, Ottaviano, and Peri (2009). On the whole, these studies find small positive effects for natives and negative effects for previous immigrants in the long run. Allowing for wage rigidities and a more sclerotic labour market, they report that a negative impact on unemployment induced by immigration partially offsets a decline in wages.

From this brief overview, it has become clear that the literature provides no clear consensus on the wage effects of immigration. For the most part, however, researchers have found rather small adverse effects or no significant effects. However, Bodvarsson and van den Berg (2009) argue that the current state of research still neglects important adjustment processes. Most importantly, they stress that immigration affects the demand side of the economy. That is, new immigrants certainly increase aggregate demand since they spend some of their earnings on locally-produced goods and services. In this way, they will automatically boost domestic labour demand of firms and therefore also influence wages. Empirical studies by Bodvarsson and van den Berg (2006) and Bodvarsson, van den Berg, and Lewer (2008) find clearly positive consumer demand effects induced by immigration that increase the average wage of local workers. Moreover, immigration may also affect the rate of economic growth if they raise the average education level of the population (cf. Barro, 2001).

4 Theoretical Framework

This section will introduce a theoretical framework that constitutes the basis for the analysis. The model is largely based on Ottaviano and Peri (2008), where workers with different education, work experience and nativity are allowed to be imperfect substitutes. Moreover, the model builds on a general equilibrium framework in which factor prices of labour and capital equal their marginal products.

4.1 Production Function

We consider a neoclassical framework in which firms operate on perfectly competitive markets and maximize profits such that all factors are paid their marginal products. As in Borjas (2003), Ottaviano and Peri (2008), D'Amuri, Ottaviano, and Peri (2009), we specify the production function of the economy in the widely used Cobb-Douglas form:

$$Y_t = A_t N_t^{\alpha} K_t^{1-\alpha} \tag{1}$$

where Y_t is aggregate output, A_t is total factor productivity (TFP), K_t is the physical capital stock and N_t is the CES aggregate containing all types of labour supply. The subscript t denotes the time period. This functional form implies that $\alpha \in (0, 1)$ corresponds to the income share of the labour aggregate and is assumed to be constant over time.[4]

As mentioned above, N_t represents aggregate labour supply. Since our neoclassical framework assumes flexible wages and perfectly inelastic labour supply, labour markets clear in every period t, so that aggregate labour demand equals aggregate labour supply. (In Section 8.2, the implications of these assumptions will be discussed.) N_t has a nested CES structure that combines labour supply of different education and experience groups as well as labour supply of native and foreign workers. On the first level, it can be disaggregated as follows:

$$N_t = [\theta_{Ht} N_{Ht}^{\varepsilon_{HL}} + \theta_{Lt} N_{Lt}^{\varepsilon_{HL}}]^{1/\varepsilon_{HL}}, \tag{2}$$

[4] This assumption is supported by Swiss national data (see BFS: GDP by income), since the labour income share of GDP has roughly been around 62 percent for the last 20 years and never deviated more than 2 percentage points from this value.

where N_{Ht} and N_{Lt} measure the labour supplied by individuals with high and low education, respectively, in period t. The parameters θ_{Ht} and θ_{Lt} are the corresponding productivity parameters that capture the relative efficiency of the labour aggregates in the production process. We constrain them to add up to unity, i.e. $\theta_{Ht}+\theta_{Lt} = 1$, so that any common productivity shock will be absorbed by TFP. The parameter ε_{HL} equals $(\sigma_{HL} - 1)/\sigma_{HL})$, where σ_{HL} is the elasticity of substitution between highly-educated and less-educated labour.

In the literature, the question of how to assign workers to different education groups has been resolved in various ways. First, workers are split in two groups of "high" and "low" education, e.g. in Katz and Murphy (1992)[5] and Card and Lemieux (2001). This, of course, implies that all workers within the same group are perfect substitutes for one another. Second, some studies (Borjas, 2003; Ottaviano and Peri, 2006) attempt to allow for a greater deal of heterogeneity by considering 4 educational categories: some high school, high school graduates, some college, and college graduates.

As the estimates of Ottaviano and Peri (2008) show, the degrees of substitutability among education groups vary considerably. To allow for the possibility that workers within broad education groups are closer substitutes than they are across broad groups, we further disaggregate N_{Lt} and N_{Ht} into the following subgroup:

$$N_{Lt} = [\theta_{L1t} N_{L1t}^{\varepsilon_L} + \theta_{L2t} N_{L2t}^{\varepsilon_L}]^{1/\varepsilon_L} \tag{3}$$

$$N_{Ht} = [\theta_{H1t} N_{H1t}^{\varepsilon_H} + \theta_{H2t} N_{H2t}^{\varepsilon_H}]^{1/\varepsilon_H} \tag{4}$$

The terms N_{bkt} with $bk \in \{L1, L2, H1, H2\}$ are labour aggregates for 4 education groups. The relative productivity within the two broad groups is represented by the θ's, where $\theta_{b1t} + \theta_{b2t} = 1$ for $b \in \{L, H\}$. Similarly, the parameter $\varepsilon_b = (\sigma_b - 1)/\sigma_b$ captures the degree of substitutability within group $b \in \{L, H\}$, with $\sigma_b > 0$ being the elasticity of substitution between group $b1$ and $b2$.

In the case of Switzerland, it seems to make most sense to use three educational categories as D'Amuri, Ottaviano, and Peri (2009) do for Germany: group $L1$ are workers who have not attained a vocational degree, group $L2$ have a vocational degree (Berufslehre) or completed upper secondary education (Maturität, Berufsmaturität), and group $H1$ contains workers with higher

[5] Note: Katz and Murphy (1992) apply a weighting procedure to construct the two education groups.

vocational training or college or university degrees. Therefore, all workers within this group are perfect substitutes and equally productive, such that $\sigma_H = \infty$ and $\theta_{H1t} = \theta_{H2t}$. As a consequence, expression (4) collapses to

$$N_{Ht} = \theta_{Ht}(N_{H1t} + N_{H2t}) \tag{5}$$

Expression (5) implies that H1 and H2 form a homogenous group. For simplicity, it will henceforth be referred to as H1.

As a next step, we assume that individuals with different work experience are not perfect substitutes for one another. Put differently, a young, inexperienced individual systematically differs in his skills and abilities compared to an old and experienced individual despite the same educational attainment. To account for this, we disaggregate each labour composite N_{bkt} into experience groups:

$$N_{bkt} = \left[\sum_{j=1}^{4} \theta_{bkj} N_{bkjt}^{\varepsilon_X} \right]^{1/\varepsilon_X} \tag{6}$$

where N_{bkjt} stands for the labour aggregate of education group bk and experience group j, with $j \in \{1, 2, 3, 4\}$. The parameters θ_{bkj} indicate productivity levels specific to the education-experience groups and their sum is constrained to one, i.e. $\sum_{j=1}^{4} \theta_{bkj} = 1$. It is important to note the relative productivity between experience groups is assumed to remain constant over time. In other words, we abstract away from the possibility that technology shocks might have asymmetric effects on workers with the same education but different experience. The elasticity of substitution is given by $\sigma_X = 1/(1 - \varepsilon_X)$.

As recent evidence suggests for the United States (Ottaviano and Peri, 2006, 2008), Great Britain (Manacorda, Manning, and Wadsworth, 2006) and Germany (Brücker and Jahn, 2008; Felbermayr, Geis, and Kohler, 2008; D'Amuri, Ottaviano, and Peri, 2009), there is reason to believe that native and foreign-born workers are not perfect substitutes even if they have comparable education and experience. The reason is that immigrant workers are likely to differ systematically with respect to certain characteristics, such as manual skills, language proficiency, and so on. This, in turn, suggests that natives and immigrants have differentiated preferences and opportunities in the labour market. Thus, we break down each education-experience group N_{bkjt} into a CES aggregate consisting of native and foreign labour supply:

$$N_{bkjt} = \left[\theta_{Dbkjt} N_{Dbkjt}^{\varepsilon_I} + \theta_{Fbkjt} N_{Fbkjt}^{\varepsilon_I}\right]^{1/\varepsilon_I} \tag{7}$$

Labour supplied by native ('domestic') and immigrant ('foreign') workers is denoted by N_{Dbkjt} and N_{Fbkjt}, respectively. As previously, θ_{Dbkjt} and θ_{Fbkjt} measure the relative productivity of the corresponding labour supplies and add up to one. The elasticity of substitution between native and foreign-born labour supply is defined as $\sigma_I = 1/(1-\varepsilon_I)$.

4.2 Physical Capital Adjustment

Since markets are assumed to be perfectly competitive, labour is paid its marginal product in equilibrium. Given the production function, the average wage in the economy is given by:

$$\overline{w}_t = \frac{\partial Y_t}{\partial N_t} = \alpha A_t \kappa^{1-\alpha}, \tag{8}$$

with $\kappa = (K_t/N_t)$. The above expression suggests that a rise in the labour aggregate N_t will cause the average wage to fall. In other words, an inflow of foreign workers will, ceteris paribus, lead to a new labour market equilibrium with lower average wages. If we assume that the rate of technological change A_t remains unaffected by immigration, we can write the (log) change of the average wage as follows:

$$\left(\frac{\Delta w_t}{w_t}\right)_i = (1-\alpha)\left(\frac{\Delta \kappa_t}{\kappa_t}\right) \tag{9}$$

If capital is perfectly inelastic to changes in labour supply, i.e. $K_t = \overline{K}$, the change in the average wage equals $(1-\alpha)\left(-\frac{\Delta F_t}{N_t}\right)$. However, if immigration triggers capital accumulation, the fall in the average wage is attenuated. This follows from the fact that $\left|\frac{\Delta \kappa_t}{\kappa_t}\right| < \left|\frac{\Delta F_t}{N_t}\right|$ if $K_{t+1} > K_t = \overline{K}$.

What are the implications of immigration in the long run? If long-run growth is considered exogenous as in Ramsey (1928) and Solow (1956), the economy follows a balanced growth path in the long run. In our framework, long-run growth takes place through the increase in TFP, i.e. A_t. The capital-labour ratio in steady state is then given by $\kappa_t^* = \left(\frac{1-\alpha}{r+\delta}\right)^{1/\alpha} A_t^{1/\alpha}$, where r is the real interest rate and δ is the depreciation rate (see Ottaviano and Peri, 2008, for a more detailed description). This implies that the capital-labour ratio, and thus the average wage, does nod depend on labour supply in the long-run. Hence, the long-run impact of immigration on average wages must be equal to zero. However, the nested structure of the aggregate N_t in the model implies that wages across labour supply groups will be asymmetrically affected if the inflows of immigrant workers do not spread across skill groups in proportion to the size of these groups. As a result, we can conclude that, while the long-run impact on average wages is zero due to full capital adjustment, the model implies that immigration is likely to have permanent distributional effects across labour supply groups.

To simulate the dynamics of capital adjustment, one needs to know how fast physical capital will adjust to shocks in the labour market. In Section 7, we will attempt to estimate the speed of convergence directly from Swiss data.

4.3 Wages in the Labour Market Equilibrium

In expression (8), we have already derived the average wage level if the labour market is in equilibrium. Expression (9) captures the macroeconomic effect on wages caused by a change in labour supply. However, since we are mainly interested in the distributional effects, we must derive the equilibrium wage for each nativity-education-experience groups in the model. In equilibrium, the wage of a worker with broad education $b \in \{H, L\}$, fine education $k \in \{1, 2\}$, experience $j \in \{1, 2, 3, 4\}$ and nativity $n \in \{D, F\}$ is equal to his marginal productivity. Due to the nested structure of the CES labour aggregate, we obtain the wage by differentiating (1) with respect to N_{nbkjt}. If we apply the natural logarithm and substitute in the elasticities of substitution for σ_{HL}, σ_b, σ_X and σ_I, the expression can be written as

$$\begin{aligned}\ln w_{nbkjt} =& \ln(\alpha A_t \kappa_t^{1-\alpha}) + \frac{1}{\sigma_{HL}} \ln N_t + \ln \theta_{bt} - \left(\frac{1}{\sigma_{HL}} - \frac{1}{\sigma_b}\right) \ln N_{bt} \\ &+ \ln \theta_{bkt} - \left(\frac{1}{\sigma_b} - \frac{1}{\sigma_X}\right) \ln N_{bkt} + \ln \theta_{bkj} - \left(\frac{1}{\sigma_X} - \frac{1}{\sigma_I}\right) \ln N_{bkjt} \\ &+ \ln \theta_{nbjkt} - \frac{1}{\sigma_I} \ln N_{nbkjt}\end{aligned} \tag{10}$$

The left-hand side of (10) denotes the log of the average wage in group (n, bk, j), and the terms on the right-hand side show how the components of the nested production function affect the wage. It is important to note that we assume that total factor productivity A_t and the relative productivity parameters, the θ's, are not affected by any changes of labour supply. In contrast, the capital-labour ratio and the labour composites are directly affected by an inflow of workers with education bk and experience j. On the one hand, there is a *macroeconomic* effect operating through $\ln\left(\alpha A_t\, \kappa_t^{1-\alpha}\right)$ that shows how the average wage in the economy is affected by immigration. As previously pointed out, immigration lowers the average wage if capital adjusts partially but the effect gradually dies out in the course of the capital adjustment process. On the other hand, there are a number of permanent *distributional* effects due to changes in labour supply operating through the labour composites N_t, N_{bt}, N_{bkt}, N_{bkjt}, N_{nbkjt}. Due to the rather complex nature of the RHS in (13), we discuss the implications of the terms one by one.

The first term $\frac{1}{\sigma_{HL}}\ln N_t$ constitutes a positive effect on the productivity of all types of workers if aggregate labour supply increases. This is explained by the imperfect substitutability among workers with different skills. The second channel of influence operates through $-\left(\frac{1}{\sigma_{HL}} - \frac{1}{\sigma_b}\right)\ln N_{bt}$. It is sensible to conjecture that workers within broad education groups are closer substitutes than across broad groups, i.e. $\sigma_{HL} < \sigma_b$. Then, an increase of labour supply in the same broad education group negatively affects the wage. Likewise, if $\sigma_b > \sigma_X$ holds, the third term $-\left(\frac{1}{\sigma_b} - \frac{1}{\sigma_X}\right)\ln N_{bkt}$ is positive and raises workers' wages in the same education group bk as the immigrant inflow occurs. The implications of the fourth term $-\left(\frac{1}{\sigma_X} - \frac{1}{\sigma_I}\right)\ln N_{bkjt}$ are somewhat more ambiguous; the direction of the effect depends on the substitutability between experience groups relative to the substitutability between nativity groups. If $\sigma_X < \sigma_I$, immigration negatively affects the wage in education-experience group (bk, j), but in the opposite case the effect is positive. Finally, the term $-\frac{1}{\sigma_I}\ln N_{nbkjt}$ suggests that an increase of workers with nativity n has a negative impact on workers' wages in the same nativity group. This is to say, that, given native and foreign workers are imperfect substitutes, an immigrant influx has a stronger negative effect on immigrants' wages than on natives' wages even if they are located within the same education-experience group. In other words, new immigration is more detrimental for previous immigrants if they are not perfect substitutes for natives.

The analysis has made clear that the effect of immigration on wages works through the complex and nested structure of the production function, where workers' marginal productivity is not only affected by changes in supply in the same skill cell, but also by changes in all other skill cells. What is more, we have seen that the magnitude and the direction of the effects on wages heavily hinges on the elasticities of substitution σ_{HL}, σ_b, σ_X and σ_I. Therefore, we will place a strong emphasis on the estimation of these elasticities in Section 6 and critically discuss the results.

5 Data

This section provides the relevant information about the datasets used for estimation. Second, it will be explained how skill cells are constructed and how average weekly wages and labour supply measures are computed for each cell. Finally, descriptive statistics are presented.

5.1 Dataset

To perform empirical estimation of the structural model presented in the previous section, we elicit all the required data from the Swiss Workers Survey (*Schweizerische Arbeitskräftebefragung,* short*:* SAKE). The data has been gathered by means of telephone interviews. The dataset provides annual data for the time span from 1991 to 2008. The sample size varies considerably from roughly 16000 to 48000 observations, with older waves generally being smaller than more recent ones. For our purposes, we only consider men and women aged between 18 and 64, and only those who are currently employed, thus dropping all self-employed, unemployed and early retirees.

5.2 Construction of Skill Cells and Variables

To implement the model empirically, we need to categorize and assign workers to cells according to nativity ("native" or "immigrant"), education and work experience. Since we have defined 3 education and 4 experience groups, we obtain 12 skill cells for natives and 12 skill cells for immigrants per year. This subsection will explain how we allot workers to the respective cells.

First, we assign workers to cells by nativity and either categorize them as being "natives" or "immigrants". For this purpose, we apply a simple rule and define native workers as those holding Swiss citizenship. Therefore, previously naturalized individuals are also categorized as natives. In contrast, Swiss residents who only hold foreign passports are defined as immigrants. Second, we assign all individuals to one of our 3 education groups. The crucial criterion here is the highest degree attained at the time of data collection. The low education group (bk=$L1$) includes all people who have completed mandatory schooling or dropped out before completion. In addition, we add those who had minor job training of one or two years (*Anlehre*). Individuals are assigned to the medium education group ($bk{=}L2$) if they hold vocational degrees (*Berufslehre*) or upper secondary school diplomas (*Maturität*, *Berufsmaturität*). The high education group ($bk{=}H1$) includes all workers with higher vocational training (*höhere Fachschule, Technikerschule*) and those with college or university degrees (*Fachhochschule*, *Universität*). Third, we need to construct a measure of potential work experience, since we do not have explicit data on how long individuals have been active in the labour market. For this reason, we employ the following formula for each individual i to obtain a simple measure of potential work experience:

$$Potential\ Experience_i = Age_i - \mathrm{E}\left[Duration\ of Education_i\right] - 6 \tag{11}$$

Since we do not know when people entered the labour market, we need to impute the duration of education. Therefore, we use the expected (i.e. average) duration of schooling which is required to obtain the educational degree that person i holds. It is important to note that this procedure results in a somewhat crude measure of work experience, since employers may evaluate immigrants' experience differently. To attenuate the impact of any potential bias, we categorize workers in only 4 but rather broad experience groups, each spanning an interval of 10 years of experience. In contrast, most other studies use 8 experience groups and five-year intervals, e.g. Borjas (2003), Ottaviano and Peri (2006, 2008), D'Amuri, Ottaviano, and Peri (2009), but they also manage to produce more accurate measures of potential work experience. Having constructed the variable for work experience, we drop individuals whose imputed experience is below zero or above 40 years.

Having assigned all individuals to the respective cell according to their education, experience and nativity, the problem emerges that there are only few observations in some cells in certain years. Especially in the data prior 2002, the cells for highly educated and highly experienced foreign workers contain only very few observations, so that a reliable construction of average wages and labour supply becomes problematic. To alleviate the problem, the following couples of years are pooled together: 1991/1992, 1993/1994, 1996/1997, 1998/1999, and 2000/2001. As a result, the "weakest" cell ($bk{=}H1$, $j{=}4$, $n{=}F$) contains never less than 35 observations, and the second-to-weakest cell ($bk{=}H1$, $j{=}3$, $n{=}F$) contains never less than 72 observations. All other cells never include less than 100 observations. All in all, the SAKE data from 1991 to 2008 translate into 13 waves (and thus 156 observations) available to be used for estimation.

As a next step, we produce a measure of average weekly real wages, hours worked and employment for native and immigrant workers in each nativity-education-experience cell. For a detailed description as to how these variables are constructed, see Section A in the Appendix.

5.3 Descriptive Statistics

In this subsection, we will provide descriptive statistics of the variables described above. In particular, we focus on immigration from 2002 to 2008 since it marks the time period in which the bilateral agreement on the free movement of people with the EU (*Personenfreizügigkeitsabkommen*) has been effective. The simulations in Section 7 will also consider the same time span.

Table 1 presents the percentage changes in hours worked with respect to total hours worked for each education group over the period from 2002 to 2008. Columns 1 and 2 show how much of the change in hours worked in a particular education group can be attributed to natives and immigrants, respectively, so that the sum of the two corresponds to the change in total hours worked (column 3) in that group. The numbers in column 2 are most interesting since they reflect the cumulative changes in foreign labour supply that occurred during the period in question. It shows clearly that immigrant inflows did not take place evenly across education group: while the increase in hours worked due to immigration was moderate in the low education group (2.8%), the high education group experienced a very sizable increase (13.8%). In contrast, medium-educated foreign labour slightly declined (-0.5%) in terms of total hours worked in that group. On the whole, total foreign labour supply increased by some 3.9% with respect to total labour supply in 2002. Column 3 indicates that there is a strong composition effect: labour supplied by highly educated individuals rose substantially partly because aggregate labour supply has increased (6.7%) and partly because labour supplied by the other two education groups fell in absolute terms. The former effect could be due to growth of the labour force, less unemployment or higher average working hours. The latter effect reflects a rising education level of the workforce.

Table 2 contains the percentage changes in average weekly real wages by nativity and education over the same time period. In addition, it is shown how the relative size of education groups changed with respect to hours worked. (For more detailed data on wages and hours worked across groups, see Section B in the Appendix) It is important to note that the wage of each person is weighted by her hours worked and corrected for inflation. While native workers *within* education groups earn

Table 1: Changes Relative to Total Hours Worked in the Group from 2002 to 2008

	Percentage change due to native workers	Percentage change due to foreign workers	Percentage change in total hours worked
Low education	-7.6%	2.8%	-4.8%
Medium education	-7.7%	-0.5%	-8.3%
High education	30.2%	13.8%	44.0%
All	2.8%	3.9%	6.7%

lower average wages in 2008, the average wage among natives roughly stayed constant (-0.2%). This is possible because the labour supply share of the highly educated group grew substantially (by 9.7 percentage points), while the labour supply shares of the other groups fell (by -1.6 and -8.1 percentage points). This can be interpreted as follows: well-paid individuals within the lower groups have moved to a higher education group by attaining higher educational degrees. Those who newly entered the high-education group (individuals who completed higher vocational training and college and university graduates) are paid below average compared to the rest of the group and thus reduce the average wage in that group. Hence, the "composition effect" of labour supply left the average wage of natives roughly constant, although average wages within education groups declined significantly. The changes in wages among immigrant workers are much more uneven: average wages of less educated workers declined, while average wages of highly educated workers rose. In total, immigrant workers earned significantly higher wages (+5.5%) in 2008 compared to 2002. Again, this is to a large extent due to the composition effect of foreign labour supply. On the one hand, some foreign individuals may have moved to a higher education group through higher educational attainment. On the other hand, many high-skilled workers (mostly from Germany) entered the Swiss labour market during the period, and thus raised the average wage in that group. Moreover, since the share of low educated and low-paid workers is high among immigrants, the relatively high-skilled influx led to a sizable increase in average wages of immigrants.

By comparing the aggregate summary statistics on labour supply and wages, we cannot draw any conclusions about the effects of immigration on native wages. Even if correlations between foreign labour supply and wages would be discernable, they are likely to be misleading because they fail to uncover the true causal effect between the two variables. After all, the reasons of changes in wages are manifold; they respond not only to labour supply shocks, but are the result of complex and intertwined economic forces at work. They are, among other things, strongly determined by labour

Table 2: Change in Wages and Shares of Hours Worked from 2002 to 2008

	Natives		Immigrants	
Education group	Change in average weekly real wages	Percentage-point change in the share of hours worked	Change in average weekly real wages	Percentage-point change in the share of hours worked
Low	-6.1%	-1.6%	-4.3%	-2.8%
Medium	-4.0%	-8.1%	-0.1%	-7.4%
High	-4.8%	9.7%	1.8%	10.2%
All	-0.2%		5.5%	

Notes: To calculate average weekly real wages, the wage distribution within each education group is trimmed on both ends by one percentile.

demand which, in turn, is influenced by productivity shocks and changes in aggregate demand, business cycle fluctuations and changes in the institutional framework of the economy. To gain a better understanding as to how the inflows of foreign workers affect domestic wages, we must be able to isolate the effect of immigration. In order to do this, we employ the structural model to estimate the causal effect. Before we can proceed with these simulations, however, we must estimate the elasticities of substitution between the various labour supply groups in the CES aggregate of the production function.

6 Estimating the Elasticities of Substitution

6.1 Between Natives and Immigrants

The elasticity of substitution between native and immigrant labour σ_I has been subject to a great deal of debate in empirical labour economics. This is because the magnitude of the pressure on natives' wages caused by immigration largely depends on this parameter. From the RHS in equation (10), one can see that the scale of the "immigration effect" is dependent on σ_I: the larger the parameter, the more substitutable are native and foreign labour, and the larger is the negative impact on natives' wages.

On the one hand, a number of empirical studies, e.g. Borjas, Freeman, and Katz (1997), Borjas (2003), Borjas and Katz (2007), a priori assume that native and immigrant labour are homogenous factor inputs. Others do not obtain estimates of the inverse elasticity that are significantly different from zero (e.g. Borjas, Grogger, and Hanson (2008) and Jaeger (1996)).

On the other hand, some studies have found that the σ_I is indeed finite: Ottaviano and Peri (2008) and Raphael and Smolensky (2008) for the United States, Brücker and Jahn (2008), D'Amuri, Ottaviano, and Peri (2009) and Felbermayr, Geis, and Kohler (2008) for Germany, and Manacorda, Manning, and Wadsworth (2006) for Great Britain.

We estimate the elasticity of substitution σ_I for Switzerland by means of the constructed skill-cell data. In order to this, we take equation (10) for native workers (n=D) and subtract the corresponding expressions for foreign workers (n=F) on both sides. Since all the terms without subscript n cancel out, we are left with:

$$\left(\frac{w_{Fbkjt}}{w_{Dbkjt}}\right) = \ln\left(\frac{\theta_{Fbkjt}}{\theta_{Dbkjt}}\right) - \frac{1}{\sigma_I}\ln\left(\frac{N_{Fbkjt}}{N_{Dbkjt}}\right) \tag{12}$$

Consequently, the dependent variable is the log relative average wage in cell (bk, j) in period t. On the RHS, the first term captures the relative productivity of native and immigrant labour and the second term corresponds to the log relative labour supply with a coefficient equal to the inverse elasticity of substitution. Figure 1 plots the log relative wage against the log relative supply marked by education groups.[6] It is conspicuous that the cells are clustered by education groups; especially the low-education group has a much higher relative supply because the share of immigrants' hours worked is much higher than in the other groups. It is essential to note that it would be misleading to draw tentative conclusions from this figure regarding the elasticity of substitution; equation (12) shows that the variation in relative wages is also explained by the relative productivity term $\ln\left(\frac{\theta_{Fbkjt}}{\theta_{Dbkjt}}\right)$ that varies across education-experience groups and across time.

Now, equation (12) can be implemented empirically. To achieve this, we replace the relative productivity term by fixed effects and add an error term to the equation:

$$\ln\left(\frac{w_{Fbkjt}}{w_{Dbkjt}}\right) = d_{bkj} + d_t + d_{jt} - \frac{1}{\sigma_I}\ln\left(\frac{N_{Fbkjt}}{N_{Dbkjt}}\right) + u_{bkjt} \tag{13}$$

The vector d_{bkj} contains 12 education-experience-specific dummy variables that absorb systematic differences in labour efficiency across education-experience cells. The vector d_t introduces a common time trend, and d_{jt} allows for experience-specific time trends in relative productivity. These fixed effects take into account that the quality of immigrants' skills across experience groups

[6] cell ($bk = H1, j = 3, t = 1991/1992$) is omitted from the sample as it appears to be a substantial outlier.

might have changed over time (cf. Ottaviano & Peri 2008). Analogously, we can also include education-year-specific fixed effects, but this leads to a very saturated model.

Table 3 summarizes the estimation results. Every entry in the table represents an estimate for $-(1/\sigma_I)$ from a separate regression. Every regression uses employment (E) as analytical weights to take into account the different sizes of the education-experience-year cells. Standard errors are heteroskedasticity-robust and clustered around education-experience groups. The columns indicate different fixed-effects specifications: column (1) omits experience-specific time trends, column (2) is the specification as defined above and column (3) additionally includes education-specific time trends, which results in a quite saturated model with somewhat larger standard errors. Row (1) reports estimates from OLS regressions. The estimated coefficients vary across fixed-effects specifications: the obtained values range from 0.05 to 0.19, though the lower bound is not significantly different from zero. These results suggest that the elasticity of substitution lies between 5 and 20. In row (2), we apply 2SLS following the approach of Ottaviano & Peri (2008). That is, we instrument the supply variable of hours worked (H) by using employment (E) as an instrumental variable. In this way, we want to take into account that relative hours worked may be endogenous in explaining relative wages. In fact, a simple heteroskedasticity-robust Hausman test indicates that hours worked is endogenous in the basic fixed-effects specification (the p-value is 0.037). However, it is doubtful whether the available IV strategy manages to eliminate the potential endogeneity problem because the correlation of hours worked and employment is very high. As a result, the 2SLS regressions produce very similar estimates as OLS. On the whole, the results of our full-sample estimations indicate that the elasticity of substitution between natives and immigrants is very likely to be smaller than infinity. For the simulation, we will choose $\sigma_I = 10$ as our preferred estimate.

6.2 Between Experience Groups

In this section, we will turn to the elasticity of substitution between different experience groups, denoted by σ_X in this paper. Previous studies mostly indicate that σ_X is well below infinity, thus implying that individuals who differ in their work experience are imperfect substitutes in production. For example, Katz and Murphy (1992) and Borjas (2003) report estimates of around 3 and 3.5, respectively. Card and Lemieux (2001) do not specify experience groups, but age groups,

Table 3: Estimation Results for $-(1/\sigma_I)$ 1991-2008

	(1) Fixed Effects: Edu-Exp Year	(2) Fixed Effects: Edu-Exp Exp-Year	(3) Fixed Effects: Edu-Exp Exp-Year Edu-Year	Observations
OLS	-0.05	-0.19**	-0.14**	155
	(0.06)	(0.06)	(0.06)	
2SLS, Employment as IV for Hours Worked	-0.07	-0.23***	-0.16**	155
	(0.06)	(0.07)	(0.06)	

Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

and conclude that the elasticity of substitution most likely lies between 4 and 6. Similarly, Ottaviano & Peri (2008) provide estimates in the range of 6.2 and 7.7. On the other hand, Brücker & Jahn (2008, Table 5) obtain much larger values for Germany, namely between 15 and 30 depending on sample selection, while Felbermayr, Geis & Kohler (2008) even fail to reject the hypothesis that $-(1/\sigma_X) = 0$. This brief overview of previous studies shows that there is a considerable range in estimated values for σ_X.

Having estimated σ_I, we can now proceed to estimate the elasticity of substitution between experience groups. First, however, we must obtain values for the productivity terms $\widehat{\theta}_{Dbkjt}$ and $\widehat{\theta}_{Fbkjt}$ and second, use them to compute the labour composites $\hat{N}_{bkjt}$ for each education-experience group (bk, j). Using equation (13), if we define $\hat{D}_{bkjt} = \hat{d}_{bkj} + \hat{d}_t + \hat{d}_{jt}$ and replace the error term with the residuals $\hat{u}_{bkjt}$, it follows that

$$\hat{D}_{bkjt} = \frac{1}{\widehat{\sigma}_I}\ln\left(\frac{N_{Fbkjt}}{N_{Dbkjt}}\right) - \ln\left(\frac{w_{Fbkjt}}{w_{Dbkjt}}\right) - \hat{u}_{bkjt} \tag{14}$$

As the sum of the productivity terms is constrained to one in each education-experience group, we are able to compute them as follows:

$$\widehat{\theta}_{Fbkjt} = \frac{\exp(\hat{D}_{bkjt})}{1+\exp(\hat{D}_{bkjt})}\ ;\ \widehat{\theta}_{Dbkjt} = \frac{1}{1+\exp(\hat{D}_{bkjt})} \tag{15}$$

The parameter values obtained above and the estimated elasticity of substitution can be plugged into equation (14) to compute a model-based measure of aggregate labour supply for each education-experience cell: $\hat{N}_{bkjt} = \left[\widehat{\theta}_{Dbkjt}N_{Dbkjt}^{\widehat{\varepsilon}_I} + \widehat{\theta}_{Fbkjt}N_{Fbkjt}^{\widehat{\varepsilon}_I}\right]^{1/\widehat{\varepsilon}_I}$, with $\widehat{\varepsilon}_I = (\widehat{\sigma}_I - 1)/\widehat{\sigma}_I$. In this way, we can now move up one step in the nested production function. To specify labour market equilibrium conditions on this level of the CES aggregator, we equate the average weekly wage with the marginal productivity of labour, i.e. $w_{bkjt} = \partial \mathrm{Y_t}/\partial N_{bkjt}$. By applying the chain rule to derive marginal productivity and expressing everything in log-terms, we obtain:

$$\begin{aligned}\ln \overline{w}_{bkjt} &= \ln\left(\alpha A\, \kappa_t^{1-\alpha}\right) + \frac{1}{\sigma_b} \ln N_t + \ln \theta_{bt} - \left(\frac{1}{\sigma_{HL}} - \frac{1}{\sigma_b}\right) \ln N_{bt} + \ln \theta_{bkt} \\ &\quad + \left(\frac{1}{\sigma_b} - \frac{1}{\sigma_X}\right) \ln N_{bkt} + \ln \theta_{bkj} - \frac{1}{\sigma_X} \ln N_{bkjt}\end{aligned} \tag{16}$$

The log average weekly wage in cell $(bk,\ j)$ in period t is defined as $\ln \overline{w}_{bkjt} = (\overline{w}_{Fbkjt} N_{Fbkjt} + \overline{w}_{Dbkjt} N_{Dbkjt})/(N_{Fbkjt} + N_{Dbkjt})$, a labour-supply-weighted average of native and immigrant wages. To implement the above expression empirically, we replace all but the last term on the RHS with fixed effects. Thus, we can write

$$\ln \overline{w}_{bkjt} = d_t + d_{bkt} + d_{bkj} - \frac{1}{\sigma_X} \ln \hat{N}_{bkjt} + u_{bkjt} \tag{17}$$

The vectors $d_t + d_{bkt} + d_{bkj}$ represent a common time-trend, education-specific time trends and education-experience-specific fixed effects, respectively, and capture the variation in the productivity terms, the $\theta' s$, and the labour aggregates on the higher levels of the production function. u_{bkjt} is the error term in cell $(bk,\ j)$ in period t and absorbs any random disturbances.

Now, we are able to estimate σ_X by means of the above equation. Table 4 summarizes the estimation results. As previously, every entry in the table constitutes an estimate for $-(1/\sigma_X)$ from a separate regression. Similarly, standard errors are heteroskedasticity-robust and clustered around education-experience group. A cursory look at the results reveals that the estimated values for $-(1/\sigma_X)$ lie in a fairly narrow range from -0.08 to -0.11 with standard errors between 0.03 and 0.05. In comparing columns (1) and (2), it is clear that it does not matter whether we construct $\hat{N}_{bkjt}$ using $\sigma_I = 10$ or $\sigma_I = \infty$. The results are essentially the same. This has also been pointed out by Brücker and Jahn (2008). Rows (1) and (2) contain OLS and 2SLS estimates, respectively. To implement 2SLS, we instrument the supply variable hours worked in cell $(bk,\ j)$ by employment in the same cell. Although the 2SLS method produces higher estimates than OLS, the differences are rather small. All in all, the results imply that the elasticity of substitution between different experience groups lies somewhere between 9 and 12.5. The preferred estimate is defined as $\sigma_X = 10$. This value is somewhat larger than what most U.S. studies have found but lower than those obtained for Germany. It is therefore safe to say that the obtained results seem plausible.

Table 4: Estimation Results for $-(1/\sigma_X)$, 1991-2008

	(1) $\sigma_I = 10$	(2) $\sigma_I = \infty$
OLS	-0.09**	-0.09**
	(0.03)	(0.03)
2SLS, Employment as IV	-0.10***	-0.10***
for Hours Worked	(0.03)	(0.03)

Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Observations: 155

6.3 Between Education Groups

When it comes to the elasticity of substitution between education groups, it is crucial to consider how these groups are categorized. Katz and Murphy (1992) analyse 4 groups: high-school dropouts (HSD), high-school graduates (HSG), some college (SCO) and college graduates (COG), but they apply a weighting procedure to express all workers in terms of HSG equivalents and COG equivalents. The elasticity of substitution between these two groups is then found to be 1.4. Card and Lemieux (2001) proceed in a similar way with two broad education groups and obtain estimates between 2 and 2.5, though they use a sample of men only. Borjas (2003), Ottaviano & Peri (2006) and Borjas & Katz (2007) specify their structural model with 4 education groups, but constrain the elasticities of substitution between them to be equal, i.e. $\sigma_{HL} = \sigma_H = \sigma_L$. This restriction is necessary as there would not be enough degrees of freedom to identify the individual parameters otherwise. However, this restriction is not in line with intuition, since one would expect workers within broad education groups to be closer substitutes than workers across broad groups. In other words, a high school dropout is expected to be more "similar" to a high-school graduate than to a college graduate with respect to his skill composition, hence $\sigma_L > \sigma_{HL}$. This argument is also backed up by empirical evidence by Ottaviano & Peri (2008). For this reason, we attempt to estimate these parameters separately by following the approach of Katz & Murphy (1992) as also do Ottaviano & Peri (2008).

6.3.1 Between Broad Education Groups

To estimate σ_{HL}, we can derive the estimation equation of Katz & Murphy (1992) from the theoretical model. First, using the equilibrium condition that the average wage equals the marginal product of labour in each broad education group b, $w_{bt} = \partial \mathrm{Y_t}/\partial N_{bt}$, we can write:

$$\ln w_{bt} \ = \ln\left(\alpha A \kappa_t^{1-\alpha}\right) \ + \frac{1}{\sigma_{HL}} \ln N_t \ + \ln \theta_{bt} \ - \frac{1}{\sigma_{HL}} \ln N_{bt} \tag{18}$$

Second, taking the difference between b=H and b=L on both sides reduces the above equation to:

$$\ln\left(\frac{w_{Ht}}{w_{Lt}}\right) \ = \ln\left(\frac{\theta_{Ht}}{\theta_{Lt}}\right) \ - \frac{1}{\sigma_{HL}} \ln\left(\frac{N_{Ht}}{N_{Lt}}\right) \tag{19}$$

where $\ln\left(w_{Ht}/w_{Lt}\right)$ measures the wage gap between highly-educated and less-educated workers, $\ln\left(\theta_{Ht}/\theta_{Lt}\right)$ captures the relative efficiency of these workers, and $\ln\left(N_{Ht}/N_{Lt}\right)$ measures relative supply in terms of hours worked. Empirical implementation can be achieved by

$$\ln\left(\frac{w_{Hkt}}{w_{Lkt}}\right) \ = d_t - \frac{1}{\sigma_{HL}} \ln\left(\frac{N_{Ht}}{N_{Lt}}\right) + u_t \tag{20}$$

where the vector d_t contains time-specific fixed effects that absorb changes in the relative efficiency term $\ln\left(\theta_{Ht}/\theta_{Lt}\right)$ and u_t captures random disturbances in year t. The problem arises that we do not have enough observations to include t-1 fixed-effects dummy variables. Even if the constant were dropped, the model remains completely saturated with no degrees of freedom left to identify σ_{HL}. Katz & Murphy (1992) and Ottaviano & Peri (2008) circumvent this problem by assuming that d_t follows a linear time trend. To see whether this is a reasonable assumption for the sample used in this paper, Figure 2 plots the dependent variable $\ln\left(w_{Ht}/w_{Lt}\right)$ and the relative supply $\ln\left(N_{Ht}/N_{Lt}\right)$ against time.

The evolution of the wage gap illustrates that this assumption does not fit the data: the trend is clearly non-linear. Figure 2 shows that the wages of highly-educated workers increased sharply in the second half of the 1990s relative to the wages of less-educated workers. Contemporaneously, relative labour supply fell or grew only modestly. This period is therefore characterized by a higher level of relative scarcity of highly-educated labour. To better fit the model to the data, we include dummy variables for period 2 (1997-2002) and period 3 (2003-2008), respectively, to modify the intercept and the slope of the time trend. These period-specific intercepts and slope coefficients are meant to capture the non-linearities in the time trend.

The results for $-(1/\sigma_{HL})$ are set out in Table 5. Every entry in the table represents an estimate from a separate regression. The estimation method is OLS using aggregate employment as analytical weights. Standard errors are Newey-West autocorrelation-robust, since the error term may be serially correlated. Column (1) reports the estimation results from the model where the time trend has period-specific intercepts and slopes. In column (2), the model contains only a linear time trend, analogous to Katz and Murphy (1992) and Ottaviano and Peri (2008). In comparing the results for $-(1/\sigma_{HL})$, two observations are worth commenting on. First, the model using a linear time trend produces much lower estimates with larger standard errors than in column (1), despite a higher number of degrees of freedom. Second, the choice of the supply variable, that is, whether hours worked or employment is used, has no significant impact on the results. In terms of the elasticity of substitution, column (1) implies a value of around 3.7 to 4, and column (2) implies a value of 8.3 to 9. Since we consider the period-specific time trend to be more appropriate, the lower range is probably more plausible. It is worth recalling that these values are still somewhat higher than what has been found by previous studies mentioned at the beginning of this section.

Before we conclude, it is tested for whether the model in column (1) is well-specified. A series of F-tests for the slope and intercept dummies confirm that the time trend exhibits structural breaks and is significantly non-linear. We can therefore conclude that values between 3.7 and 4 provide a reasonable range for σ_{HL}. In light of the results of previous studies, we choose the lower bound of 3.7 as the preferred estimate for the elasticity of substitution between highly-educated and less-educated workers.

Table 5: Estimation Results for $-(1/\sigma_{HL})$, 1991-2008

	(1) Period-specific time trend	(2) Linear time trend
Supply variable: Hours worked	-0.27***	-0.11
	(0.05)	(0.07)
Supply variable: Employment	-0.25***	-0.12*
	(0.03)	(0.06)

Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Observations: 18

6.3.2 Between Education Subgroups

As pointed out in the beginning of this section, Ottaviano & Peri (2008) provide evidence that the restriction $\sigma_{HL} = \sigma_H = \sigma_L$ of Borjas (2003) is overwhelmingly rejected by the data. Applying the Katz & Murphy (1992) method, their findings suggest that σ_{HL} is between 1.5 and 2, whereas the point estimates for the within-group elasticities σ_H and σ_L are much larger (Table 6 in OP 2008), so that the null hypotheses $-(1/\sigma_H) = 0$ and $-(1/\sigma_L) = 0$ mostly cannot be rejected at a reasonable level of significance. Overall, their results imply that $\sigma_{HL} < \sigma_H < \sigma_L$. Relaxing the rather stringent equality restriction has revealed that the elasticities substantially differ in size. Therefore, we attempt to estimate σ_H and σ_L individually by proceeding in the same fashion as before.

To derive estimating equations from the structural model, we differentiate the production function with respect to N_{bkt} and equate it to the wage of workers in cell *(bk)* in period *t*, i.e. $w_{bkt} = \partial \mathrm{Y_t}/\partial N_{bkt}$, since this must hold in equilibrium. Using the chain rule and applying the natural logarithm, the equation reads:

$$\ln w_{bkt} = \ln\left(\alpha A \kappa_t^{1-\alpha}\right) + \frac{1}{\sigma_{HL}} \ln N_t + \ln \theta_{bt} - \left(\frac{1}{\sigma_{HL}} - \frac{1}{\sigma_b}\right) \ln N_{bt} + \ln \theta_{bkt} + \left(\frac{1}{\sigma_b}\right) \ln N_{bkt} \quad (21)$$

If we take the difference between subgroup k=2 and subgroup k=1 within broad group b, we are left with:

$$\ln\left(\frac{w_{b2t}}{w_{b1t}}\right) = \ln\left(\frac{\theta_{b2t}}{\theta_{b1t}}\right) + \left(\frac{1}{\sigma_b}\right) \ln\left(\frac{N_{b2t}}{N_{b1t}}\right) \quad (22)$$

This expression enables us to implement it empirically by simply replacing the relative efficiency term $\ln(\theta_{b2t}/\theta_{b1t})$ with a time trend and by adding a random disturbance for group b in period t:

$$\ln\left(\frac{w_{b2t}}{w_{b1t}}\right) = d_{bt} + \left(\frac{1}{\sigma_b}\right)\ln\left(\frac{N_{b2t}}{N_{b1t}}\right) + u_{bt} \tag{23}$$

First, we turn to the low-education group. Figure 3 plots the dependent variable $\ln(w_{L2t}/w_{L1t})$ and the supply variable $\ln(N_{L2t}/N_{L1t})$ against time. Since the wage gap between education groups $L2$ and $L1$ does not seem to follow a particular trend, we therefore consider a time series model with no time trend. Figure 4 plots the same variables for b=H. Broadly speaking, the relative wage declines at the beginning of the time period and reaches a trough in 1999. After 1999, the trend is generally positive, but there are large fluctuations. To fit a time series model, we use a period-specific time trend in that we include dummy variables that allow for a different slope and intercept in the period from 1999 to 2008.

The estimation results for $-(1/\sigma_L)$ and $-(1/\sigma_H)$ are summarized in Table 6. The estimation method is OLS using employment as analytical weights and standard errors are Newey-West autocorrelation robust. The results for $-(1/\sigma_L)$ in column (1) are essentially zero, which implies that $\sigma_L = \infty$. That is to say, workers within the low-education group are estimated as being perfect substitutes. In other words, those with vocational training and those without vocational training supply homogenous labour. This result is rather surprising, since one would expect that vocational degrees differentiate workers from those who have not attained the same educational level. However, the data does not provide support for this line of reasoning.

In Section 4, we argued that workers within the high-education group are perfect substitutes for each other, such that $\sigma_H = \infty$. Now, we want to test for this assumption by estimating the elasticity of substitution for the two subgroups $H1$ and $H2$. The results in Table 6 in column (2) suggest that the point estimates of $-(1/\sigma_H)$ lie around -0.05, but not significantly different from zero at the 10%-level. To test whether the modification of the time trend is justified, we test the significance of the period-specific intercept through $H_0 : c_{1999-2008} = 0$ and the period-specific slope coefficient through $H_0 : \delta_{1999-2008} = 0$. The corresponding t-tests yield p-values of 0.03 and thus reject the null hypotheses at the 5%-level, which leads us to conclude that the post-1999 time trend is significantly different from the pre-1999 time trend.

Our estimation results are consistent with the empirical evidence of other studies (cf.

Table 6: Estimation Results for $-(1/\sigma_b)$, 1991-2008

	$-(1/\sigma_L)$	$-(1/\sigma_H)$
Supply variable:	0.04	-0.04
Hours worked	(0.04)	(0.05)
Supply variable:	0.04	-0.05
Employment	(0.06)	(0.06)
Time trend	no	period-specific

Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Observations: 18

Ottaviano and Peri, 2008). First, workers with high and low education are imperfect substitutes given an elasticity of 3.7. Second, workers within those groups are found to be perfect substitutes. This implies that those with and without vocational education constitute a homogenous labour supply group.

7 Simulating the Effects of Immigration from 2002 to 2008

This section will now make use of the estimated elasticities of substitution to analyze the impact on wages in Switzerland caused by immigration inflows from 2002 to 2008. As mentioned previously, this time period is deliberately chosen because it marks the period during which the bilateral agreement with the EU on the free movement of workers across borders has been effective. As described in Section 2, both the magnitude of total immigration flows and the fraction of those with high education have increased significantly.

As a first step, an equation must be derived from the model that allows us to simulate the percentage changes in the average wage of each skill and nativity group due to the above mentioned sequence of immigration flows. Using equation (10), we can take the difference between period $t+p$ and t for all expressions on both sides. Since TFP and relative productivity levels are assumed to be unaffected by immigration, the causal effect on the average wage of any group (n, bk, j) is given by

$$
\begin{aligned}
\left(\frac{\triangle w_{nbkjt}}{w_{nbkjt}}\right)_i = & (1-\alpha)\left(\frac{\triangle \kappa_t}{\kappa_t}\right)_i + \frac{1}{\sigma_{HL}} \sum_{cq \in C} \sum_{i=1}^{4} \left(s_{Fcqit} \frac{\triangle N_{Fcqit}}{N_{Fcqit}}\right) \\
& - \left(\frac{1}{\sigma_{HL}} - \frac{1}{\sigma_b}\right)\left(\frac{1}{s_{bt}}\right) \sum_{q \in b} \sum_{i=1}^{4} \left(s_{Fbqit} \frac{\triangle N_{Fbqit}}{N_{Fbqit}}\right) \\
& - \left(\frac{1}{\sigma_b} - \frac{1}{\sigma_X}\right)\left(\frac{1}{s_{bkt}}\right) \sum_{i=1}^{4} \left(s_{Fbkit} \frac{\triangle N_{Fbkit}}{N_{bkit}}\right) \\
& - \left(\frac{1}{\sigma_X} - \frac{1}{\sigma_I}\right)\left(\frac{1}{s_{bkjt}}\right)\left(s_{Fbkjt} \frac{\triangle N_{Fbkjt}}{N_{Fbkjt}}\right) - I_F \frac{1}{\sigma_I}\left(\frac{\triangle N_{Fbkjt}}{N_{Fbkjt}}\right)
\end{aligned}
\tag{24}
$$

where s_{bt}, s_{bkt}, s_{bkjt} and s_{Fbkjt} are the shares of the total wage bill paid to the respective groups and I_F is an indicator for immigrant workers, i.e. $I_F = \{1 \mid n = F\}$ and equals zero for native workers. For a step-by-step description as to how the above equation is derived, see Section C in the Appendix. In addition, Section D in the Appendix explains how the wage effects can be aggregated up to the higher levels of the nested CES structure.

As a next step, it is no possible to simulate the effects on wages induced by the increase in foreign labour supply from 2002 to 2008. Equation (24) provides the basic instrument for the calculations, but we also aggregate up the results to obtain the average effects on individual education groups (by using (36)), on natives and immigrants (by using (37)) and on the average national wage (by using ((38)). For all simulations, we use the preferred values for the elasticities of substitution obtained from estimation. To be consistent with the original specification of skill groups, the simulation of the distributional effects will be conducted using 3 education groups because this represents the most appropriate categorization for Switzerland. Thus, we set $\sigma_I = 10$, $\sigma_X = 10$, $\sigma_{HL} = 3.7$, $\sigma_L = 1000$ (which implies perfect substitution).

7.1 Long-Run Effects with Full Capital Adjustment

First, we focus on the long-run implications of immigration which entails complete convergence to the steady-state growth path, and thus, full capital adjustment. In other words, the term $(1-\alpha)\left(\frac{\triangle \kappa_t}{\kappa_t}\right)_i$ in equation (24) is zero, so that we can concentrate on the purely *distributional* effects and disregard for a moment the *macroeconomic* effects occurring in the short and medium run. The simulation results are reported in column (1) of Table 7. It is very important to note that all numbers in Table 7 show how the increase in foreign labour supply from 2002 to 2008 affects wages in comparison to the situation in which foreign labour supply remains constant during the same period. Plainly stated, the numbers represent the causal effects of immigration on wages and not the actual change in wages over the period.

Turning to the effects on natives' wages first, the results imply that immigration flows from 2002 to 2008 have fairly moderate distributional effects in the long run. While the impact on workers with low and medium education is positive (1.5% and 1.3%), the high education group incurs a small wage loss (−0.9%) due to immigration. Overall, the increase in foreign labour supply raises the average wage of native workers by 0.4% in steady state. So there is in fact a small but positive effect on natives' wages in the long run. Turning to the long-run effects on immigrants, we see that the distributional effects across education groups roughly follow the same pattern but their magnitude is larger. This has of course to do with the fact that natives and immigrants are found to be imperfect substitutes for one another. As a most salient result, the steady-state wages of highly-educated foreign workers are 7.4% lower due to immigration. In contrast, low-educated and medium-educated foreign workers experience wage gains of 1.1% and 1.5% in steady state, respectively. All in all, the immigrant influx from 2002 to 2008 causes the average wage of immigrants to fall by 1.6% in steady state.

An important question is how sensitive the results are with respect to the elasticities of substitution. Table 8 illustrates how the average long-run effects on natives and previous immigrants change if one standard error is added or subtracted from the inverse values of σ_I, σ_{HL} or σ_X while leaving all other parameters unchanged. Two results emerge from the numbers in the table. First, σ_{HL} and σ_X only exert a negligibly small influence on the aggregate outcomes of nativity groups, despite having distributional consequences *within* nativity groups (which are not shown in Table 8). Second and not surprisingly, σ_I strongly affects average native and immigrant wages: the larger σ_I is, the more shifts the adverse impact from previous immigrants to natives. However, even as σ_I approaches infinity, native workers' wages are barely negatively affected on average. In other words, immigration does not lower average native wages in the long run, even if the elasticity of substitution between natives and immigrants is infinite. This finding can be directly compared to Ottaviano and Peri (2007, Table 7) who report average long-run wage effects for natives and immigrants of 0.1% and −0.9%, respectively, when imposing $\sigma_I = \infty$. Borjas and Katz (2007)

Table 7: Effects on Wages in Switzerland due to Immigration from 2002 to 2008

	Long-Run effects: Full capital adjustment	Short-run effects: Fixed capital (counterfactual)	Short-run effects: Capital adjustment (2008)	Medium-Run effects: Capital adjustment (2012)	
			Percentage change impact on natives		
Low education	1.5%	0.1%	0.5%	1.0%	
Medium education	1.3%	-0.2%	0.3%	0.7%	
High education	-0.9%	-2.4%	-1.9%	-1.4%	
Weighted average	0.4%	-1.0%	-0.5%	-0.1%	
		Percentage change impact on previous immigrants			Change in hours worked by immigrants relative to total hours worked
Low education	1.1%	-0.4%	0.1%	0.6%	2.8%
Medium education	1.5%	0.0%	0.5%	1.0%	-0.5%
High education	-7.4%	-8.9%	-8.4%	-8.0%	13.8%
Weighted average	-1.6%	-3.0%	-2.6%	-2.1%	3.9%
Weighted total	0.0%	-1.5%	-1.0%	-0.5%	

do not report these outcomes for nativity groups separately, but Ottaviano and Peri (2008, Table 8, Column 10) provide these estimates using Borjas & Katz' parameters: aggregate outcomes are essentially the same as in Ottaviano and Peri (2007). Put simply, these numbers are of opposite sign because skill groups are affected differently in the U.S. and because these skill groups have different wage shares than in Switzerland. It is worth recalling that the effects across education-experience cells are exactly the same for natives and immigrants if $\sigma_I = \infty$. But since the wage share of each group (n, bk, j) is used as a weight to aggregate up the effects (see equation (37)), the average effects for natives and immigrants are different from one another. From the numbers in Table 8, it then follows that Swiss workers incur a slight wage loss (given $\sigma_I = \infty$) because highly educated workers, who are negatively impacted, earn a higher wage share among natives than among immigrants. Moreover, one can point out that the numbers in this paper are generally smaller compared to the aforementioned U.S. studies because their simulations take into account a much longer time period.

Table 8: Sensitivity of Long-Run Wage Effects with Respect to the Elasticities of Substitution

	modified value for the elasticity of substitution		average effect on natives	average effect on previous immigrants
	basic estimates		0.45%	-1.57%
σ_I	low	6.66	0.70%	-2.44%
	high	20	0.21%	-0.73%
	"infinite"	1000000	-0.03%	0.11%
σ_{HL}	low	3	0.44%	-1.54%
	high	4.8	0.46%	-1.60%
σ_X	low	7.7	0.45%	-1.58%
	high	14	0.45%	-1.56%

Notes: low/high elasticity values are calculated by adding/subtracting the average standard error to/from the basic inverse elasticity of substitution. For σ_I, the inverse is 0.1 and the average standard error is 0.05. For σ_{HL}, the inverse is 0.27 and the average standard error is 0.06. For σ_X, the inverse is 0.1 and the average standard error is 0.03.

To sum up the results from the long-run simulation, three important results are obtained. First, natives are on average not negatively affected in the long run as opposed to immigrants, who have lower steady-state wages. This stems from imperfect substitutability between the two groups. Second, the uneven patterns of immigrant inflows across education groups are reflected in the distributional effects on wages. Highly educated workers are exposed to more competition on the labour market due to larger inflows of immigrants with the same skill level. And third, the elasticities of substitution between education groups that are used in the simulation play a very crucial role in determining the distribution of wage effects. On one hand, low substitutability between broad education groups leads to positive cross-effects. That is to say, less educated workers can benefit from large increases in highly educated foreign labour. On the other hand, the effects of immigration can easily spill over across education subgroups within the same broad group as consequence of large within-group elasticities. Hence, low-educated workers benefit from the fall in supply of medium-educated immigrants.

7.2 Short-run Effects with Fixed Capital

The traditional way of analyzing the impact of labour supply shocks on wages is to focus on the labour market equilibrium and assume that the capital stock is perfectly inelastic (as in Borjas (2003, Table 9) and Manacorda, Manning, and Wadsworth (2006, Table 8)). Given the immigration inflows over the period from 2002 to 2008, the effect on the average wage equals $(1-\alpha)\left(-\frac{\triangle \mathrm{F}_{2002-2008}}{\mathrm{N}_{2002}}\right)$ which amounts to $0.38 * (-3.9\%) = -1.5\%$. As one can see in column (2) in Table 7, all numbers are scaled down by this constant when compared to the long-run effects in column (1). Put differently, this macroeconomic wage effect caused by the decline in the capital-labour ratio affects all workers to the same extent and leaves the relative wage effects across groups unchanged. It is crucial to note that this scenario is rather unrealistic as it assumes no response of capital over the entire period considered. In the section below, this assumption will be dropped.

7.3 Short-Run and Medium-Run Effects with Capital Adjustment

To simulate the dynamics of capital adjustment, we need to specify how fast the economy converges back to steady state. Empirical growth literature provides several estimates of the so-called "speed of adjustment" with which the economy converges to steady state. Caselli, Esquivel, and Lefort (1996) and Islam (1995) estimate the speed of convergence as being roughly 10 percent per annum. In a more recent study, McQuinn and Whelan (2007) provide an average estimate of around 7 percent.[7] To simulate the adjustment of the capital-labour ratio, Ottaviano and Peri (2008) normalize

[7] For a detailed overview of the convergence literature, see Islam (2003).

the balanced growth path to zero and use the following first-order difference equation:

$$\ln \kappa_t = 0.9 \ln \kappa_{t-1} - 0.9 \left(\frac{\Delta F_t}{N_t} \right) \tag{25}$$

They use an adjustment parameter of 0.9 (equivalent to a speed of convergence of 10%) and set the impact parameter of the labour supply shock equal to -0.9 which implies that capital adjustment begins in the same period as the labour supply shock occurs.

To simulate the dynamics for Switzerland, we attempt to estimate the speed-of-convergence parameter directly from Swiss data. In order to do this, we use the estimating equation of Ottaviano and Peri (2008, equation (24)):

$$\ln(\kappa_t) \;= \beta_0 + \beta_1 \ln(\kappa_{t-1}) \;+ \beta_2(trend) + \gamma \frac{\triangle F_t}{N_t} + u_t \tag{26}$$

The capital-labour ratio is constructed using annual data from 1991 to 2007 available from the BFS: the physical capital stock[8] at constant prices is divided by the total actual hours worked drawn from the AVOL[9] (*Arbeitsvolumenstatistik*). The AVOL data is used because it provides a more comprehensive measure of hours worked than the SAKE data. The time trend is approximated by a deterministic linear trend. As for the labour supply shock, we test two specifications: the change in labour supply relative to total labour supply $\left(\frac{\triangle N_t}{N_t}\right)$, and the change in labour supply due to foreign workers only $\left(\frac{\triangle F_t}{N_t}\right)$. As Ottaviano and Peri (2008), we attempt to correct for potential endogeneity by instrumenting these variables with the percentage change in the population. The estimation results for β_1 are summarized in Table 9. At first glance, all point estimates yield plausible values for β_1. The speed of convergence defined as $(1 - \beta_1)$ is estimated between 0.08 and 0.15. Unfortunately, only once out of four times can the null hypothesis of β_1 equal to one be rejected at a reasonable significance level. Otherwise, standard errors are too large and render the estimates insignificantly different from one.

Two critical comments are necessary. First, the data only covers a short period. Since we are interested in the long-run behaviour of the capital-labour ratio, a solid estimation would require much longer time series data. Second, the problem of biasedness due to serial correlation is in-

[8] BFS: Physical Capital Stock
[9] BFS: AVOL (labour volume statistics)

Table 9: Estimation Results for β_1, 1991-2007

	Labour supply shock: $\left(\frac{\triangle N_t}{N_t}\right)$	Labour supply shock: $\left(\frac{\triangle F_t}{N_t}\right)$
OLS	0.92	0.91
	(0.13)	(0.10)
2SLS	0.85**	0.87
	(0.05)	(0.27)
Significance levels for $H_0 = 1$: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$		
Observations: 16		

Notes: 2SLS uses the percentage change in the population as IV for the labour supply shock. All standard errors are Newey-West autocorrelation-robust.

herent, since the lagged dependent variable enters as a regressor. The ACFs of the residual series reveal significantly autocorrelated residuals. Therefore, it must be borne in mind that the results obtained have to be treated with a great deal of caution. However, since the estimated values are roughly consistent with the findings of Ottaviano and Peri (2008) and other empirical growth studies mentioned earlier, we define $\beta_1 = 0.9$, and simulate the dynamics of the capital-labour ratio as specified in equation (25) and exactly as do Ottaviano and Peri (2008). Figure 5 plots the simulation results against time. It is readily discernable that the labour supply shocks greatly increased in magnitude as of 2003.

Given the simulated series in Figure 5, it is now possible to calculate the macroeconomic effect of the increase in foreign labour supply from 2002 to 2008. As of 2008, the decline in the capital-labour ratio is equal to $\ln(\kappa_{2008}) - \ln(\kappa_{2002}) = -2.6\%$. Using equation (9), this amounts to an effect of -1.0% $(= 0.38 * (-2.6\%))$ on average real wages in Switzerland. Note that this corresponds exactly to the value in the very last row of column (3) in Table 7. In the medium term (in 2012), the the capital-labour ratio is only 1.4% lower than in 2002, which translates into a mere -0.5% effect on the average wage. Again, this is the number found in the last row of column (4) in Table 7. Since we are only interested in the causal effect of immigration from 2002 to 2008, it is assumed that labour supply remains constant after 2008. This can readily be seen in Figure 5, since $\ln(\kappa_t)$ begins to rise monotonically as of 2008. In sum, the simulated dynamics of the capital-labour ratio show that, as of 2008, 33% of the distance to the long-run impact is eliminated, and 66% as of 2012.

8 Critical Issues and Limitations

This section will critically evaluate and discuss the approach and the methods employed by this paper. In doing so, we will point out some crucial problems and limitations and discuss their implications for the results. First, we will deal with the problem of endogeneity which is relevant in the simulation of the wage effects as well as in the estimation of the elasticities of substitution. Second, two underlying assumptions of the theoretical framework will be critically discussed: the properties of flexible wages and perfectly inelastic labour supply.

8.1 The Endogeneity Problem

The most important problem with respect to the analysis conducted in this paper is that of endogeneity. As hinted at above, the problem is twofold: first, potential endogeneity biases the simulation of the wage effects of immigration, and second, it obstructs the estimation of the elasticities of substitution. As for the first aspect, the problem arises because the model used for simulation treats the influx of foreign labour as unanticipated, exogenous shocks, meaning that the nature and magnitude of immigrant inflows are entirely determined outside the theoretical framework. This is consistent with the argument that immigration is largely conditioned by "push" factors; the decision to leave the sending country and to move to a particular destination country is, for instance, independent of labour demand in the destination country. It is more likely, however, that immigration flows are indeed influenced by economic conditions in the destination country such as labour demand, i.e. by "pull" factors. For instance, if there is a shortage of skilled workers and labour markets are open, this is likely to attract foreign workers with the qualifications required to serve the needs of domestic firms. Such inflows would then be regarded as endogenous because it is determined by the conditions within the domestic economy. In such a case, there need not be any detrimental effect on wages of natives and settled immigrants, since foreign workers merely fill in job gaps and do not bring about an increased level of competition in the labour market. Treating the increase in foreign labour supply as purely exogenous is therefore not innocuous as it tends to overestimates the negative impact on wages.

Second, estimating the elasticities of substitution is also inherently prone to the endogeneity problem. This stems from the fact that labour supply (usually hours worked) is used to explain weekly wages in the regression equations. It is reasonable to conjecture, however, that weekly wages also have some bearing on labour supply such that both variables may be simultaneously determined. For example, if immigration rates in a particular skill group are high *because of* rising wages in that group, the measured impact on the relative wage will be smaller compared to the case where immigration is purely exogenous. Since the inverse elasticity of substitution is identified by the variation in relative wages and relative labour supply, estimates will be biased towards zero. This results in an upward bias in the elasticities of substitution, and thus larger adverse spill-over effects across nativity and skill groups. In this paper, it has been attempted to resolve this problem by employing available instrumental variables for labour supply, e.g. employment or population, but the validity of these instruments must be questioned.

8.2 Limitations of the Theoretical Framework

An aspect that needs mentioning concerns the underlying assumptions of the structural model. The most important limitation concerns the assumption of flexible wages. In this paper, the theoretical framework is based on a neoclassical production function with perfect competition and labour market clearing in all periods. The latter property entails that there are no frictions in the labour market such that wages adjust to their equilibrium level in every period and no involuntary unemployment prevails. Given the ample evidence of downward rigidities of nominal wages, this assumption is clearly restrictive. First, due to fairness, firms may abstain from lowering wages and cut costs by shrinking the workforce instead (cf. Akerlof 1982). Second, collective labour agreements pin down the wages of workers for a certain amount of time. In Switzerland, 1.68 million employees, roughly 50% of all employees (excluding apprentices), are covered by such agreements (*Gesamtarbeitsverträge*).[10] As a result, employers are unwilling or unable to lower wages when marginal productivity drops due to immigration shocks and may lay off workers instead. In other words, wages are probably not flexible in responding to changes in labour supply. Instead of driving wages all the way to the new market-clearing equilibrium, immigration shocks may have repercussions on unemployment. If this is the case, wage rigidities incorporated in the model would lead to a smaller impact on wages at the expense of a transitory increase in unemployment.

[10] BFS: Data on Collective Labour Agreements

9 Conclusions

The objective of this paper was to investigate how recent immigration inflows have affected wages of native and foreign-born workers in Switzerland. The analysis was conducted using the structural "skill-cell approach" as employed by Borjas (2003); Borjas and Katz (2007); Ottaviano and Peri (2006, 2008). The first important contribution of this paper was to estimate the elasticities of substitution between different types of workers for Switzerland. Regarding natives and immigrants, our results suggest that they are in fact imperfect substitutes, which is in line with the results of Ottaviano and Peri (2006, 2008); Brücker and Jahn (2008); Felbermayr, Geis, and Kohler (2008); D'Amuri, Ottaviano, and Peri (2009); Manacorda, Manning, and Wadsworth (2006). This implies that a rise in foreign labour supply exerts stronger pressure on wages of already settled immigrants than on those of native workers. Regarding different skill levels, the estimates indicate that workers are imperfect substitutes across broad education groups and across different experience groups. In contrast, education subgroups within broad groups are found to have much larger, possibly infinite, elasticities. On the whole, this paper produces a set of parameter values that seems plausible and is largely consistent with the findings of a fair number of other studies.

The second important contribution of this paper was to simulate the impact of immigration on wages using the actual increases of foreign labour supply from 2002 to 2008. For the long run, the simulations produce some notable distributional consequences across different types of workers: While previous immigrants incur wage losses, native workers are not negatively affected on average. It is interesting to note that this holds true even if the elasticity of substitution between nativity groups approaches infinity. Across education groups, highly-educated workers clearly receive the largest amount of competition from new immigrants and therefore face the strongest downward pressure on their wages. For the short run, the simulations predict a negative impact of immigration on the macroeconomic level, meaning that all labour supply groups are equally affected. Taking into account the dynamic response of physical capital, however, the effect is predicted to die out in the course of the adjustment process.

While the simulations certainly provide an idea as to how immigration affects domestic wages, there are a number of critical aspects associated with the approach chosen in this paper. First, it cannot be ruled out that the simulation results suffer from an endogeneity bias given that the model treats the increases in foreign labour supply as exogenous shocks. If such a bias is present, the true impact on wages is smaller than predicted. Second, the theoretical framework has some clear limitations: it assumes labour-market clearing and flexible wages such that immigration cannot induce unemployment amongst natives and/or previous immigrants. If this assumption does not hold in reality, the actual wage effects would again be smaller than predicted by the simulations. Furthermore, labour supply choices of workers are assumed to be completely inelastic to immigrant inflows. Although this represents another potential source of distortion, the direction of this type of bias remains obscure. In sum, the numbers produced by the simulations probably represent an "upper bound"; the true impact of immigration on wages is therefore likely to be smaller than predicted in this paper.

With regard to immigration policy, it is important to gain a better understanding as to how domestic labour markets are affected by an increasing number of foreign workers. Since there is an ongoing debate about these issues among economists and policymakers, we believe that this study helps to contribute to the discussion and that it may even instigate further research in the field.

References

Altonji, J. G., and D. Card (1991): "The Effects of Immigration on the Labor Market Outcomes of Less-skilled Natives," in *Immigration, Trade and the Labor Market*, ed. by NBER, chap. The Effects of Immigration on the Labor Market Outcomes of Less-skilled Natives, pp. 201–234. NBER.

Barro, R. J. (2001): "Human Capital and Growth," *American Economic Review*, 91(2), 12–17.

Bodvarsson, O., and H. F. van den Berg (2006): "Does Immigration Affect Labor Demand? Model and Test," *Research in Labor Economics*, 24, 135–66.

——— (2009): *The Economics of Immigration*. Springer-Verlag Berlin Heidelberg.

Bodvarsson, O., H. F. van den Berg, and J. J. Lewer (2008): "Measuring Immigration's Effects on Labor Demand: A Reexamination of the Mariel Boatlift," *Labour Economics*, 15(4), 560–574.

Borjas, G. (2003): "The Labor Demand Curve is Downward Sloping: Reexamining the Impact of Immigration on the Labor Market," *Quarterly Journal of Economics*, 118(4), 1335–1374.

Borjas, G., R. Freeman, and L. Katz (1996): "Searching for the Effect of Immigration on the Labor Market," Discussion paper, NBER.

——— (1997): "How Much Do Immigration and Trade Affect Labor Market Outcomes?," *Brookings Papers on Economic Activity*, 1, 1–90.

Borjas, G., J. Grogger, and G. Hanson (2008): "Imperfect Substitution between Immigrants and Natives: A Reappraisal," Discussion paper, NBER.

Borjas, G., and L. Katz (2007): "The evolution of the Mexican-born workforce in the United States," in *Mexican immigration to the United States*.

Brücker, H., and E. J. Jahn (2008): "Migration and the Wage Curve: A Structural Approach to Measure the Wage and Employment Effects of Migration," *IZA*.

CARD, D., AND T. LEMIEUX (2001): “Can Falling Supply Explain The Rising Return To College For Younger Men? A Cohort-Based Analysis,” *The Quarterly Journal of Economics*, 116(2), 705–746.

CASELLI, F., G. ESQUIVEL, AND F. LEFORT (1996): “Reopening the Convergence Debate: A New Look at Cross-Country Growth Empirics,” *Journal of Economic Growth*, 1(3), 363–89.

D’AMURI, F., G. OTTAVIANO, AND G. PERI (2009): “The labor Market Impact of Immigration in Western Germany in the 1990’s,” *CReAM*.

DE NEW, J. P., AND K. F. ZIMMERMANN (1994): “Native Wage Impacts of Foreign Labor: A Random Effects Panel Analysis,” *Journal of Population Economics*, 7(2), 177–92.

FELBERMAYR, G. J., W. GEIS, AND W. KOHLER (2008): “Restrictive Immigration Policy in Germany: Pains and Gains Foregone?,” Discussion paper, University of Tübingen.

HAUG, W., AND D. MÜLLER-JENTSCH (2008): *Die Neue Zuwanderung*. NZZ Libro, Zürich.

ISLAM, N. (1995): “Growth Empirics: A Panel Data Approach,” *The Quarterly Journal of Economics*, 110(4), 1127–70.

——— (2003): “What have We Learnt from the Convergence Debate?,” *Journal of Economic Surveys*, 17(3), 309–362.

JAEGER, D. (1996): “Skill Differences and the Effect of Immigrants on the Wages of Natives,” Discussion paper, U.S. Bureau of Labor Statistics, revised 2007.

KATZ, L. F., AND K. M. MURPHY (1992): “Changes in Relative Wages, 1963-1987: Supply and Demand Factors,” *The Quarterly Journal of Economics*, 107(1), 35–78.

LALONDE, R. J., AND R. H. TOPEL (1991): “Immigrants in the American Labor Market: Quality, Assimilation, and Distributional Effects,” *American Economic Review*, 81(2), 297–302.

MANACORDA, M., A. MANNING, AND J. WADSWORTH (2006): “The Impact of Immigration on the Structure of Male Wages: Theory and Evidence from Britain,” Discussion paper, IZA.

MCQUINN, K., AND K. WHELAN (2007): “Conditional Convergence and the Dynamics of the Capital-Output Ratio,” *Journal of Economic Growth*, 12(2), 159–184.

Ottaviano, G., and G. Peri (2006): "Rethinking the Effects of Immigration on Wages," Discussion paper, NBER.

——— (2007): "The Effects of Immigration on U.S. Wages and Rents: A General Equilibrium Approach," Discussion paper, CReAM, University College London.

——— (2008): "Immigration and National Wages: Clarifying the Theory and the Empirics," Discussion paper, NBER.

Pischke, J.-S., and J. Velling (1997): "Employment Effects Of Immigration To Germany: An Analysis Based On Local Labor Markets," *The Review of Economics and Statistics*, 79(4), 594–604.

Ramsey, F. (1928): "A Mathematical Theory of Saving," *Economic Journal*, 38(152), 543–559.

Raphael, S., and E. Smolensky (2008): "Immigration and Poverty in the Unites States," Manuscript, UC Berkeley.

SECO (2009): "Auswirkungen der Personenfreizügigkeit auf den Schweizer Arbeitsmarkt: 5. Bericht des Observatoriums zum Freizügigkeitsabkommen Schweiz-EU," Annual Report.

Solow, R. (1956): "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics*, 70(1), 65–94.

Figures

Figure 1: Education-Experience-Year Groups, 1991 - 2008

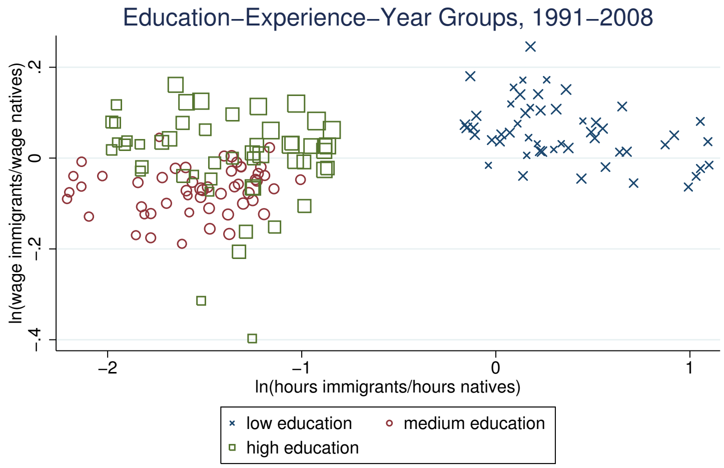


Figure 2: Relative Wage and Relative Supply (High and Low Education)

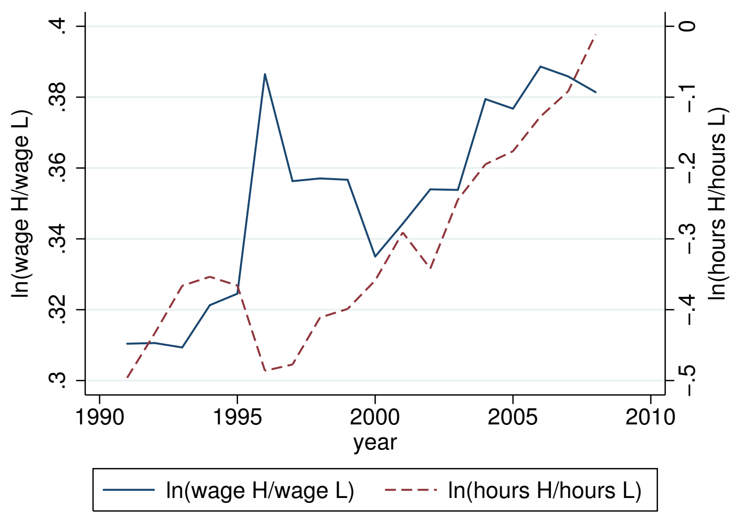


Figure 3: Relative Wage and Relative Supply of Education Subgroups L2 and L1

Figure 4: Relative Wage and Relative Supply of Education Subgroups H2 and H1

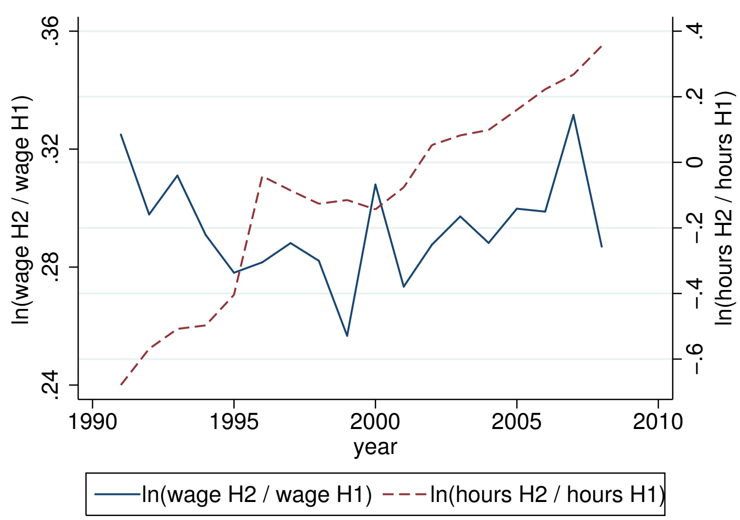
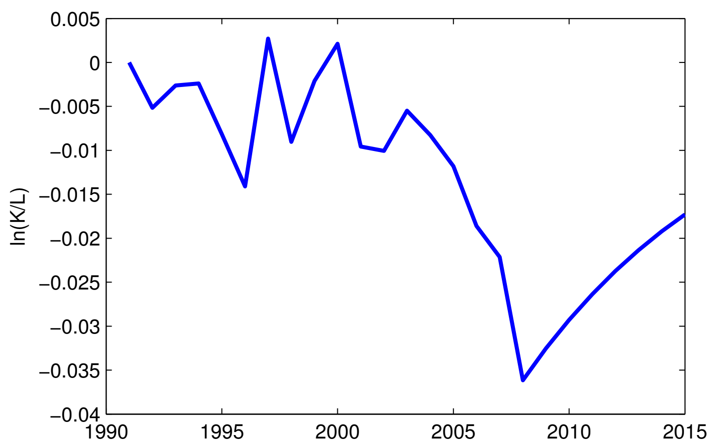


Figure 5: Simulation of the log Capital-Labour-Ratio



Appendix

A Construction of Variables: Wages, Hours Worked and Employment

We construct the average weekly wage $\overline{w}$ for each cell as follows:

$$\overline{w} = \frac{\sum_{i=1}^{N} w_i * \omega_i * H_i}{\sum_{i=1}^{N} \omega_i * H_i} \tag{27}$$

The weekly wage w_i of person i is obtained by dividing reported annual labour income by 52. This method has a clear weakness because we unconditionally assume that everybody in the sample was employed all year. We are bound to make this assumption as we do not have data on the number of weeks worked per annum. The term ω_i denotes the person's weight in the sample as calculated by the Federal Office of Statistics (BFS) and is a measure of "representativeness" with respect to the Swiss population above the age of 15. H_i denotes the weekly hours worked of person i and is reset to zero if negative and reset to 60 if this threshold is exceeded. With the number of individuals in the cell being N, the enumerator corresponds to the total wage bill of the cell scaled by hours worked, so that $\overline{w}$ is the hours-weighted average weekly wage in the labour supply cell. In this way, part-time workers are assigned less weight than full-time workers in the calculation of the average wage. This is an advantageous feature because H_i might be correlated with w_i, such that the fraction of part-time workers in a cell influences the average wage. Scaling wages by hours at least partially corrects for this distortion. Since wages are reported in nominal terms, they need to be adjusted for inflation. We use the Swiss Consumer Price Index[11] published by the BFS to express all wages in terms of 2005 Swiss francs.

As a next step, we construct labour supply measures. Compared to the wage sample, we use a more comprehensive dataset in that we include all those individuals who do not report wage income but state the number of hours worked per week. This makes sense because some interviewees may refuse to report wage income because of privacy concerns. In contrast, they are unlikely to have the same considerations when it comes to hours worked. Therefore, it seems reasonable to use this broader sample for the construction of labour supply. For each nativity-education-experience cell, we compute a measure for total hours worked (H) as

[11] BFS: Consumer Price Index

$$H = \frac{1}{40} \sum_{i=1}^{N} \omega_i * H_i \tag{28}$$

We simply sum up weighted hours worked across all individuals N in each cell and scale it down by a factor of 40 so that the measure roughly corresponds to the number of full-time-equivalent workers. In addition, we produce an alternative measure of labour supply which is insensitive to hours worked, as hours worked might be endogenous in explaining wage differentials. For this purpose, we compute a simple measure of employment (E) for each cell as follows:

$$E = \sum_{i=1}^{N} \omega_i \tag{29}$$

This variable is simply the sum of all personal weights in each cell and corresponds to the size of the labour force (without the self-employed) in each nativity-education-experience group.

B Descriptive Statistics: Wages and Hours Worked

Table 10 below contains additional descriptive statistics pertaining to the numbers in Table 2. It sets out average weekly real wages and shares of hours worked across education groups. To obtain the numbers in Table 2, one must simply calculate the difference between 2002 and 2008.

Table 10: Average Weekly Real Wages and Shares of Hours Worked

	Natives			
	Average weekly real wages		shares of hours worked	
	2002	2008	2002	2008
Low education	1024	962	7.9%	6.3%
Medium education	1342	1288	63.0%	55.0%
High education	1990	1895	29.1%	38.8%
Average/total	1506	1503	100.0%	100.0%
	Immigrants			
	Average weekly real wages		shares of hours worked	
	2002	2008	2002	2008
Low education	1036	991	30.6%	27.8%
Medium education	1197	1196	46.2%	38.9%
High education	1879	1913	23.1%	33.3%
Average/total	1306	1378	100.0%	100.0%

Notes: To calculate average weekly real wages, the wage distribution within each education group is trimmed on both ends by one percentile.

C Construction of the Wage-Effect Equation

Using equation (10), we can take the difference between period t+p and t for all terms on both sides. If all terms assumed to be unaffected by immigration, such as A_t and the productivity parameters, the $\theta' s$, are dropped, we are left with:

$$\begin{aligned}\ln\left(\frac{w_{nbkj,t+p}}{w_{nbkjt}}\right)_i &= (1-\alpha)\ln\left(\frac{\kappa_{t+p}}{\kappa_t}\right)_i + \frac{1}{\sigma_{HL}}\ln\left(\frac{N_{t+p}}{N_t}\right)_i - \left(\frac{1}{\sigma_{HL}} - \frac{1}{\sigma_b}\right)\ln\left(\frac{N_{b,t+p}}{N_{bt}}\right)_i \\ &- \left(\frac{1}{\sigma_b} - \frac{1}{\sigma_X}\right)\ln\left(\frac{N_{bk,t+p}}{N_{bkt}}\right)_i - \left(\frac{1}{\sigma_X} - \frac{1}{\sigma_I}\right)\ln\left(\frac{N_{bkj,t+p}}{N_{bkjt}}\right)_i \\ &- \frac{1}{\sigma_I}\ln\left(\frac{N_{nbkj,t+p}}{N_{nbkjt}}\right)_i\end{aligned} \tag{30}$$

where the subscript i denotes the change due to immigration. Since we are interested in the causal effect of immigration, only the log change in the labour supply aggregates *caused by immigration* is considered. The LHS denotes the immigration-induced log change in workers' wages with nativity n, education bk and experience j from period t to period t+p. The first term on the RHS captures the change in the capital-labour ratio, which depends on the assumptions made with respect to capital adjustment. This term represents the macroeconomic effect of immigration on wages. Clearly more intricate are the distributional effects that make up the remainder of the RHS. They are explained one by one below.

The second term $\ln\left(\frac{N_{t+p}}{N_t}\right)_i$ denotes the change in the total labour aggregate due to immigration. To calculate this, we sum across all education groups $bk \in C = \{L1, L2, H1\}$ and all experience groups $j \in \{1, 2, 3, 4\}$ and weight the change of foreign labour supply in every education-experience cell (bk, j) with foreign workers' wage share in period t. Hence:

$$\ln\left(\frac{N_{t+p}}{N_t}\right)_i = \sum_{bk\in C}\sum_{j=1}^{4}\left(s_{Fbkjt}\frac{\triangle N_{Fbkjt}}{N_{Fbkjt}}\right), \text{ with} \tag{31}$$

$$s_{Fbkjt} = \frac{W_{Fbkjt}N_{Fbkjt}}{\sum_{bk\in C}\sum_j W_{Fbkjt}N_{Fbkjt} + W_{Dbkjt}N_{Dbkjt}}$$

The term s_{Fbkjt} is the share of the total wage bill in period t that is paid to immigrant workers with education bk and experience j. The term $\frac{\triangle N_{Fbkjt}}{N_{Fbkjt}}$ is the log change in foreign labour supply in the same group. The next term $\ln\left(\frac{N_{b,t+p}}{N_{bt}}\right)_i$ in equation (24) measures the impact on wages due to immigrant inflows in the same broad education group b. Therefore, for each group b, we sum across all education subgroups $k \in b$ and across all experience groups $j \in \{1, 2, 3, 4\}$ and weight the change in foreign labour supply in each cell (k, j) with s_{Fbkjt} relative to the wage share of group b in period t:

$$\ln\left(\frac{N_{b,t+p}}{N_{bt}}\right)_i = \sum_{k \in b} \sum_{j=1}^{4} \left(\frac{s_{Fbkjt}}{s_{bt}} \frac{\triangle N_{Fbkjt}}{N_{Fbkjt}}\right), \text{ with} \tag{32}$$

$$s_{bt} = \frac{\sum_{k \in b} \sum_j (W_{Fbkjt} N_{Fbkjt} + W_{Dbkjt} N_{Dbkjt})}{\sum_{bk \in C} \sum_j (W_{Fbkjt} N_{Fbkjt} + W_{Dbkjt} N_{Dbkjt})}$$

The term s_{bt} is the share of the total wage bill in period t going to broad education group b. The forth term $\ln\left(\frac{N_{bk,t+p}}{N_{bkt}}\right)_i$ captures the effect of immigration inflows in the same broad education group b and the same subgroup k. Thus, for each education group bk, we sum across experience groups $j \in \{1, 2, 3, 4\}$ and weight the change in foreign labour supply in each experience cell j with s_{Fbkjt} relative to the wage share paid to group bk:

$$\ln\left(\frac{N_{bk,t+p}}{N_{bkt}}\right)_i = \sum_{j=1}^{4} \left(\frac{s_{Fbkjt}}{s_{bkt}} \frac{\triangle N_{Fbkjt}}{N_{bkjt}}\right), with \tag{33}$$

$$s_{bkt} = \frac{\sum_j (W_{Fbkjt} N_{Fbkjt} + W_{Dbkjt} N_{Dbkjt})}{\sum_{bk \in C} \sum_j (W_{Fbkjt} N_{Fbkjt} + W_{Dbkjt} N_{Dbkjt})}$$

The s_{bkt} represents the share of the total wage bill going to education group bk. The fifth term $\ln\left(\frac{N_{bkj,t+p}}{N_{bkjt}}\right)_i$ captures the effect on workers with the same education bk and experience j. For each education-experience cell (bk, j), we weight the change in foreign labour supply with s_{Fbkjt} relative to the wage share paid to all workers in the same group (bk, j).

$$\ln\left(\frac{N_{bkj,t+p}}{N_{bkjt}}\right)_i = \left(\frac{s_{Fbkjt}}{s_{bkjt}} \frac{\triangle N_{Fbkjt}}{N_{Fbkjt}}\right), \text{ with} \tag{34}$$

$$s_{bkjt} = \frac{W_{Fbkjt} N_{Fbkjt} + W_{Dbkjt} N_{Dbkjt}}{\sum_{bk \in C} \sum_j (W_{Fbkjt} N_{Fbkjt} + W_{Dbkjt} N_{Dbkjt})}$$

The s_{bkjt} denotes the share of the total wage bill in period t paid to all workers in group (bk, j). The last term in equation (A4) can only be non-zero for foreign workers, i.e. if n=F. This is because, by assumption, there is no change in native labour supply due to immigration. Thus, the last term reads:

$$\ln\left(\frac{N_{nbkj,t+p}}{N_{nbkjt}}\right)_i = \begin{cases} \frac{\triangle N_{Fbkjt}}{N_{Fbkjt}} & \text{if } n = F \\ 0 & \text{if } n = D \end{cases} \tag{35}$$

We can now plug in all the expressions derived above in equation (30), so that the effect of immigration on wages of workers in cell (n, bk, j) is given by equation (24) in the text. Regarding (24), note that the wage shares s_{bt}, s_{bkt} and s_{bkjt} can be factored out as they do not enter the respective summations. In addition, the term I_F is an indicator for immigrant workers, i.e. $I_F = \{1 \mid n = F\}$, and equals zero for native workers.

D Aggregation of the Wage Effects

To obtain the effect on the average wage in any nativity-education cell (n, bk), the wage effects across experience groups j are aggregated within that cell. More precisely, the wage effect on each experience group j in cell (n, bk) is weighted by s_{nbkjt}, the corresponding wage share of the total wage bill.

$$\left(\frac{\triangle\overline{w}_{nbkt}}{\overline{w}_{nbkt}}\right)_i = \frac{\sum_j \left[\left(\frac{\triangle w_{nbkjt}}{w_{nbkjt}}\right)_i s_{nbkjt}\right]}{\sum_j s_{nbkjt}}, \text{ with} \tag{36}$$

$$s_{nbkjt} = \frac{W_{nbkjt}N_{nbkjt}}{\sum_n \sum_{bk\in C} \sum_j W_{nbkjt}N_{nbkjt}}$$

If we aggregated up one step further, we can calculate the effect of immigration on the average wage of natives and immigrants. Therefore, for nativity group n, we weight the effect on each education-experience group (bk, j) with s_{nbkjt}, its corresponding share of the total wage bill and sum up across all education-experience groups. For nativity group n, the average wage effect is then given by:

$$\left(\frac{\triangle\overline{w}_{nt}}{\overline{w}_{nt}}\right)_i = \frac{\sum_{bk\in C}\sum_j \left[\left(\frac{\triangle w_{nbkjt}}{w_{nbkjt}}\right)_i s_{nbkjt}\right]}{\sum_{bk\in C}\sum_j s_{nbkjt}}, \text{ for } n = D, F \tag{37}$$

It is worth reminding that it follows from equation (24) that the effects on average wages of natives and immigrants are the same if $1/\sigma_I = 0$. However, if $1/\sigma_I > 0$, an increase in foreign labour supply will have a stronger negative impact on average wages of immigrants than on those of natives. Proceeding in the same fashion, the effect of immigration on the average wage in the economy can be calculated as follows:

$$\left(\frac{\triangle \overline{w}_t}{\overline{w}_t}\right)_i = \left(\frac{\triangle \overline{w}_{Dt}}{\overline{w}_{Dt}}\right)_i s_{Dt} + \left(\frac{\triangle \overline{w}_{Ft}}{\overline{w}_{Ft}}\right)_i s_{Ft} \text{ , with} \tag{38}$$

$$s_{nt} = \frac{\sum_{bk \in C} \sum_j W_{nbkjt} N_{nbkjt}}{\sum_{bk \in C} \sum_j \left(W_{Dbkjt} N_{Dbkjt} + W_{Fbkjt} N_{Fbkjt}\right)} \text{ , for } n = D, F$$

The change in the average wage is simply a weighted average of the wage effects on natives and immigrants, using the wage shares of the nativity groups as weights. Note that there is no denominator because $s_{Dt} + s_{Ft} = 1$. Recall that in the long run, $\left(\frac{\triangle \overline{w}_t}{\overline{w}_t}\right)_i = 0$ must hold, so that the effects on immigrants' wages and natives' wages cancel out. This was shown by means of equations (9), which say that immigration does not have any permanent impact on the average national wage due to full capital adjustment in the long run. Put yet another way, the constant returns to scale property of the production function implies that a proportionate increase in labour and capital (as is the case in the long run) increases output by the same amount and leaves factor prices, i.e. wages, unaffected.