Capital-Skill Complementarity and the Immigration Surplus

Michael Ben-Gad
University of Haifa*

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Abstract

We build a neo-classical growth model with overlapping dynasties and capital-skill complementarities, to evaluate changes in immigration policy. Calibrating the model using U.S. data, we quantify the differential effects of skilled and unskilled immigration on factor returns, and on the welfare of different sectors of the population. An influx of high-skilled immigrants lowers the wages of skilled workers, raises the wages of unskilled workers, and because of the relative complementarity between capital and skilled labor, substantially raises the rate of return to native-owned capital. By contrast, an influx of unskilled immigrants produces an opposite effect on wages, and has only a negligible effect on the return to capital. Because of capital skill-complementarity, increases in the number of skilled immigrants generates an immigration surplus—the overall welfare benefit accruing to the native population—that is approximately twelve times larger than the immigration surplus, generated by an identical increase in the number of unskilled immigrants. This differential welfare effect is far higher, than can be accounted for by the disparity between the productivities of each type of worker.

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*Department of Economics, Mt. Carmel, Haifa 31905, Israel, *mbengad@econ.haifa.ac.il.* I thank Avner Ahituv, Benjamin Bental, Micael Castanheira, Jean-Olivier Hairault, Yishay Maoz, Arie Melnik, Francesc Ortega, Dan Peled, and Robert Shimer for helpful comments and suggestions. I have also benefited from comments from seminar participants at the Bank of Israel, Bar-Ilan University, ECARE–Universite Libré de Bruxelles, Hebrew University of Jerusalem, Paris 1-Panthéon-Sorbonne /Paris-Jourdan, Tel-Aviv University, University of Haifa, and the 2005 World Congress of the Econometric Society at University College London. Thank you also to participants at the 2003 meetings of the Society for Economic Dynamics in Paris for comments on an earlier version of this paper. I wish to thank Ruth Cohen for research assistance. This work was funded by a grant from the Edelstein Foundation.

1 Introduction

In most countries of the developed world, immigration, rather than natural increase, is now the dominant source of population growth (see Figure 1). Nonetheless, the combination of low birth rates and increasing life spans will in the future compel governments to either admit even more working-age immigrants, or cope with the economic consequences of a declining share of working-age people within the population. Those countries that choose to permit more immigration will also need to decide whom to admit from among a vast available pool of potential immigrants who differ in age, culture, nationality, and skill level.

In this paper we focus on the last of these distinctions. We build an overlapping dynasties model of the U.S. economy with two types of labor inputs, to demonstrate that skilled and unskilled immigrants have profoundly different welfare implications for the resident population. We find that if capital and skilled labor are complementary, there is a very large contrast between the size of the immigration surplus that an influx of high-skilled immigrants generates when compared to the surplus generated by a similar sized influx of low-skilled immigrants. Furthermore differences in productivity between the two types of workers do not account for the much larger surplus generated by skilled immigrants. Rather, because of the complementarity between the labor of skilled immigrants and native owned capital, the pattern of changes in factor returns is most propitious for the native population when the influx of immigrants is composed of skilled workers.

Until 1965, the United States allocated a set number of immigration visas to citizens of each country. The 1965 amendments to the Immigration and Nationality Act replaced these country quotas, as well as preferences for certain skilled occupations, with a system that made family unification the primary criterion for admission to the United States. Immediate relatives of United States citizens enter without limit—in the year 2004, just over four hundred thousand arrived. Other relatives of U.S. citizens are admitted as family-sponsored preference immigrants—since 1990 the limit for all family-sponsored immigrants has been either 226,000, or 480,000 minus the number of people admitted under the category of immediate relatives during the previous year, whichever is larger. By contrast, the number of visas for workers with special skills or training (as well as investors) is much smaller—in 2000, the limit for employment-based preferences was 140,000.

The net rate of immigration to the United States has more than doubled since 1965, from 1.5 per thousand to an average of 3.2 per thousand during the 1990's. The rules no longer favor immigration from countries in Europe with levels of educational attainment similar to those that prevail in the United States. Now people from less developed countries arrive legally as immediate relatives of U.S. citizens, family sponsored immigrants, or as illegal aliens (and

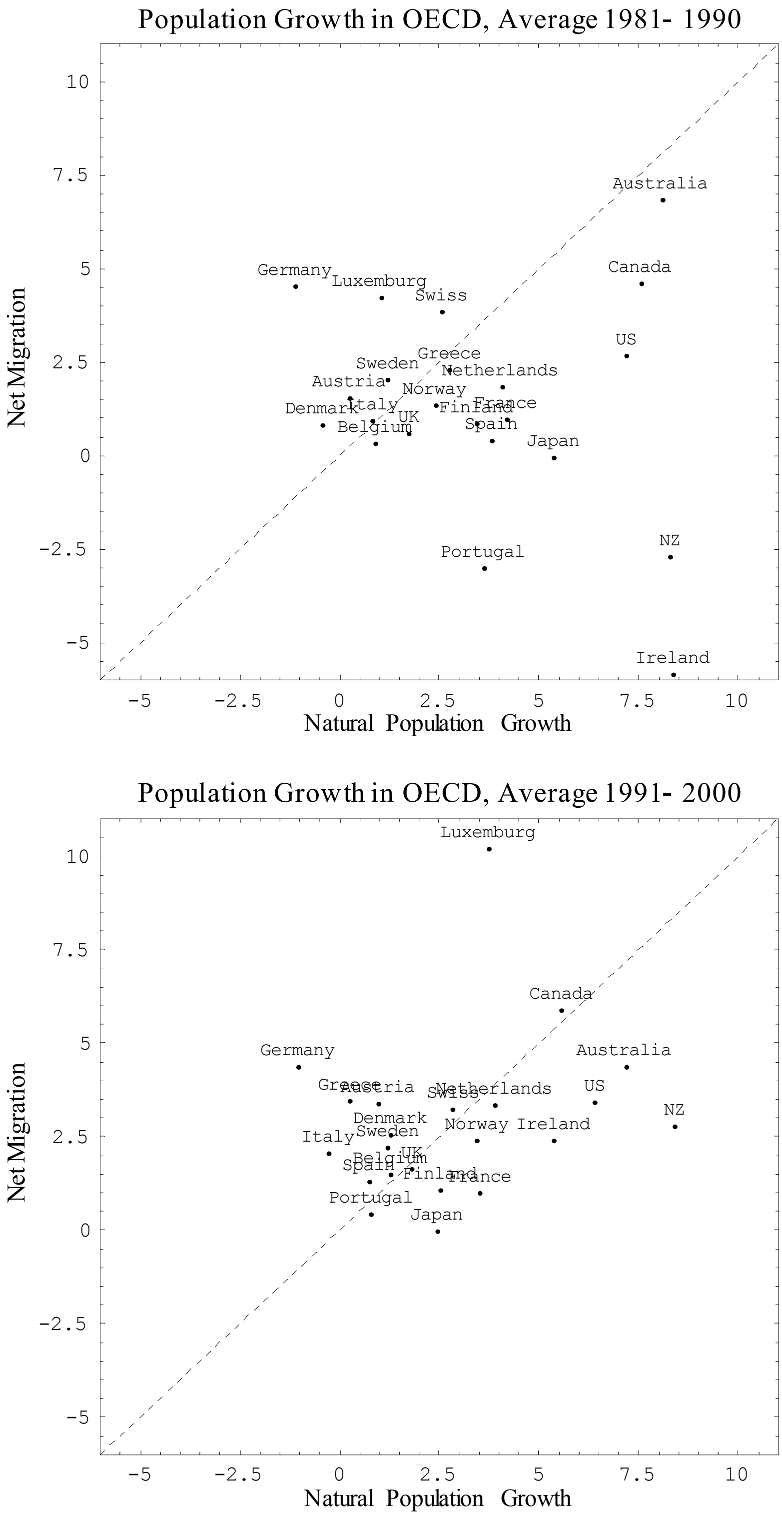

Figure 1: The Sources of Population Growth in OECD countries, net migration versus, natural population growth, decade averages for 1991-2000. Source: Organization of Economic Co-operation Development, *Components of Total Population Growth,* Vol 2001.

then legalize their status). Upon attaining citizenship, these immigrants bring their immediate relatives, and sponsor members of their extended families, who in turn repeat the process once they are naturalized. If in 1960, 75.0% of the foreign born population in the United States were from Europe and 9.8% from Latin America, by 2000 the relative shares had reversed, reaching 15.3% and 51.0% respectively.

At one time, the public mostly concerned themselves with whether immigrants were too successful when competing with natives for jobs. Today the focus has shifted to doubts about whether, because of their lack of education, today's immigrants have the skills necessary to support themselves in a modern economy. Among immigrants from Latin America, 34.6% have less than nine years of schooling, and the percentage with less than five years' schooling equals the percentage with at least a Bachelor's degree—11.2%. More than half the Latin American immigrants are from Mexico—48.4% of Mexican immigrants have less than nine years of schooling, 16.5% less than five, and only 4.2% at least a Bachelor's degree. Among native-born Americans, 25.6% have at least a Bachelor's degree and only 4% less than nine years of schooling.

Not all newcomers are uneducated. Beginning in 1992, the United States began granting 65,000 visas to temporary workers with special skills—nearly all recipients of these H1-B visas have college or advanced degrees. In 1998 Congress passed the American Competitiveness in the Workforce Act, temporarily increasing the number of H1-B visas to 115,000 per year in 1999 and 2000, and 107,500 in 2001. The American Competitiveness in the Twenty-First Century Act of 2000 (AC21) added an extra 347,500 visas by raising the cap to 195,000 for each of the years 2001, 2002, and 2003—for a total of 585,000 over three years.[1] The visas themselves are temporary, but after a few years in the United States, most of those admitted under the H1-B visa program easily attain permanent residence status. The program has served in the recent past as a significant conduit for immigration by highly skilled workers.

In terms of educational attainment, immigrants are far more heterogeneous than the rest of the U.S. population—the contrast between the average years of schooling attained by Latin American immigrants arriving under the auspices of family unification, and the recipients of H1-B visas (two thirds of the total are from Asia) highlights the diversity of today's immigration flows.[2] The distinction between these two sources of immigration also demonstrates how Western countries can design policies that determine, to a large degree, what kind of immigrants they

[1] In 2004 the number of visas returned to its original ceiling of 65,000.

[2] Overall, the most educated immigrants are from Africa (49.3% have at least a Bachelor's degree and 17.4% graduate degrees) and Asia (44.9% have at least a Bachelor's degree and 16.9% graduate degrees). European immigrants occupy the middle ground—32.9% have at least Bachelor's degrees but 12.7% have less than nine grades of schooling.

admit.

Australia, Canada, and the U.K. have long used point systems with weights for educational attainment, language proficiency, and employment history to determine who may obtain work permits and immigration visas. Many European countries, as well as Australia, are tightening rules for those claiming political asylum to stem the flow of unskilled immigrants, while also experimenting with new schemes to attract workers with specific skills.

In a static economy with undifferentiated labor (Borjas (1995)), immigrants generate higher rates of return to capital, which more than compensates for concomitant drops in wages—representative native households enjoy a small 'immigration surplus'. Using Weil's (1989) optimal growth model with overlapping dynasties, Ben-Gad (2004) demonstrates that the immigration surplus is much smaller if capital accumulation and the labor supply are endogenous. In Section 2, we extend the overlapping dynasties model to include skilled and unskilled workers, each supplying a distinct type of labor. The number of each type of workers grows continuously from natural increase, and a constant inflow of both skilled and unskilled immigrants.

We present in Section 3, our method for simulating changes in immigration policy as temporary perturbations to either one or both these inflows. Here, we also demonstrate how immigration's impact on the economy can be divided between two main effects. First, if immigrants of either type own less than the prevailing amount of capital per person, their arrival dilutes per-capita capital and temporarily raises its rate of return. Second, and far more important, even temporary changes in immigration can permanently upset the skill composition of the overall labor force. Capital's rate of return may temporarily rise or fall, but because of the composition effect, the two wage rates do not necessarily return to their previous levels.

In Section 4, we introduce the nested constant elasticity of substitution production function (Sato (1967) and Krusell *et. al.* (2000)), which combines the two types of labor with capital to produce the single consumption good. We also briefly describe the U.S. data and empirical studies we use to parameterize the baseline model.

In Section 5, we use the model to consider how skilled and unskilled wages, and the rate of return to capital behave following a decision by the U.S. government to raise the number of either skilled or unskilled immigrants arriving in the country by an additional 29,500 each year, over the course of a decade. This means that the ordinary net flow of immigration to the United States, on average 3.2 per thousand during the 1990's, is augmented by an additional one per ten thousand additional people for ten years only.

Weil's framework permits us to isolate the welfare effects of changes in immigration policy by vintage of dynasty, as well as skill-type. To measure the welfare impact of a change in the size and/or composition of future immigration flows on the population already resident we use the impulse responses to calculate compensating differentials—the equivalent permanent percentage changes in consumption that yield identical changes in utility—for members of these 'native' dynasties. In Section 6 we first consider how the influx of additional skilled immigrants affects the welfare of skilled and unskilled members of native 'dynasties' separately, and then calculate the immigration surplus—the overall affect of the policy on the native population when considered as a whole. The substitution elasticities Krusell *et. al.* (2000) estimate for the United States economy, imply a high degree of complementarity between the labor supplied by skilled immigrants and native-owned capital. Hence the immigration of skilled workers generates a much larger surplus, than the surplus generated by an overall increase in immigration that does not change the skill-composition of the population.

In the second half of Section 6, we analyze the welfare effects of a same-sized influx of unskilled immigration. These immigrants' labor is a relative substitute for native–owned capital—the return to capital rises but only by a small amount. For the baseline model, an unskilled immigrant generates a surplus, that is just under a twelfth the surplus generated by a skilled immigrant. Compressing or lengthening the time period over which a given number of immigrants arrive, does not change the welfare results. We also consider the effect of different-sized increases and decreases in the rates of immigration on the immigration surplus.

Finally, in Section 7, we investigate the sensitivity of our results to different parameterizations of the production function. Storesletten (2000) demonstrates that immigration by high-skilled workers is beneficial to natives, while unskilled immigration is harmful—all on purely fiscal grounds. Likewise, given the growing empirical evidence in favor of capital-skill complementarities, we find strong reasons to believe that skilled immigration is far more beneficial to the economy than unskilled immigration, abstracting from fiscal considerations.

For most developed countries, the marginal supply of both skilled and unskilled immigrants from impoverished foreign countries is both very large and not very elastic—we do not model the decision to move made by the immigrants themselves. Instead, the number and type of immigrants are policy variables, regulated by the rationing of visas, or by the resources invested in the prevention of illegal immigration.[3]

2 The Basic Model

Consider an economy in which new immigrants—both skilled and unskilled—join the economy as founding members of new infinite lived dynasties. Initially we assume that all present and future members of a given dynasty supply inelastically only skilled labor l_S, or unskilled labor

[3] See Galor (1986), Djajic (1989), and Borjas (1994) for models with endogenously determined patterns of immigration.

l_U. Throughout we employ the subscript $i \in \{U, S\}$ to distinguish between the two different types of dynasties. An immigrant of type i who arrived in the country at time s, and his (or her) descendants maximize utility beginning at time s:

$$\max_{c_i} \int_s^\infty e^{(\rho-n)(s-t)} \ln c_i(s,t)\, dt, \quad i \in \{U, S\}, \tag{1}$$

subject to a time t budget constraint:

$$\dot{k}_i(s,t) = w_i(t) l_i + (r(t) - n)\, k_i(s,t) - c_i(s,t), \quad \forall s, t, \quad i \in \{U, S\}, \tag{2}$$

where $c_i(s,t)$,and $k_i(s,t)$ represent the time t consumption and holdings of capital of the members of a type i dynasty of vintage s, $w_i(t)$ and $r(t)$ represent their time t wages and the rate of return of capital, ρ is the subjective discount rate, and n is the rate of natural population increase.

The consumption rule for dynasty s at time t is:

$$c_i(s,t) = (\rho - n)\left[\psi_i(t) + k_i(s,t)\right], \quad \forall s, t, \quad i \in \{U, S\}, \tag{3}$$

where $\psi_i(t) = \int_t^\infty e^{-\int_t^u (r(v)-n)dv} w_i(u) l_i du$ is the present discounted value of all future income from labor of type i from time t forward. Immigrant households of type i enter the economy at time t at a rate of $m_i(t)$, and arrive with an average amount of capital, $k_i(t,t) \geq 0$, brought from the old country. Aggregate consumption and capital evolve according to:

$$\dot{C}_i(t) = (\rho - n)\left[r(t)\Psi_i(t) - C_i(t) + r(t)K_i(t) + e^{nt} M_i(t) m_i(t)\left(\psi_i(t) + k_i(t,t)\right)\right], \; i \in \{U, S\}, \tag{4}$$

$$\dot{K}_i(t) = w_i(t) L_i(t) + r(t) K_i(t) - C_i(t) + e^{nt} M_i(t) m_i(t)\, k_i(t,t), \tag{5}$$

where $C_i(t)$, $K_i(t)$, and $\Psi_i(t)$, are respectively, the time t consumption, physical capital holdings, and the present value of future earnings aggregated over all the households with skill-level i, and $M_i(s)$ is the number of households with skill-level i that have accumulated by time s.[4] A labor enhancing technology growing at the rate x ensures the existence of steady state per-capita output growth—total effective labor input of type i at time t is $L_i(t) = e^{(n+x)(t-b)} M_i(t)\, l_i$.

The behavior of the economy is determined by four laws of motion for stationary per-capita consumption $\tilde{c}_i(t) = \frac{C_i(t)}{e^{(x+n)(t-b)} M_i(t)}$ and capital $\tilde{k}_i(t) = \frac{K_i(t)}{e^{(x+n)(t-b)} M_i(t)}$:

$$\dot{\tilde{c}}_i(t) = (r(t) - x - \rho)\, \tilde{c}_i(t) - (\rho - n)\, \tilde{k}_i(t)\, m_i(t)\, \kappa_i(t) \quad i \in \{U, S\}, \tag{6}$$

[4] Define $t = b$ as a date in the arbitrarily distant past $b < 0$, when the economy was founded by an initial cohort of size $M_U(b) + M_S(b) = 1$. Then $C_i(t)$, $K_i(t)$, and $\Psi_i(t)$ are the consumption, capital and the future earnings for the initial type i population at time b, and all the additional cohorts accumulated at rate $m_i(s)$ since b, all growing at the rate of n. Hence $C_i(t) = e^{n(t-b)} \int_b^t M_i(s)\, m_i(s)\, c_i(s,t) ds + e^{n(t-b)} M_i(b)\, c_i(b,t)$, $K_i(t) = e^{n(t-b)} \int_b^t M_i(s)\, m_i(s)\, k_i(s,t) ds + e^{n(t-b)} M_i(b)\, k_i(b,t)$, $\Psi_i(t) = e^{n(t-b)} \left(\int_b^t M_i(s)\, m_i(s)\, ds + M_i(b)\right) \psi_i(t)$, and $M_i(s) = M_i(b)\, e^{\int_b^s m_i(v) dv}$.

$$\dot{\tilde{k}}_i\left(t\right) = \tilde{w}_i(t)l_i + \left(r(t) - x - n - m_i\left(t\right)\kappa_i\left(t\right)\right)\tilde{k}_i\left(t\right) - \tilde{c}_i\left(t\right) \quad i \in \{U, S\}\,, \tag{7}$$

where $\kappa(t) = \frac{k(t)-k(t,t)}{k(t)}$ is the fractional difference between per-capita capital and the capital imported by immigrants, and $\tilde{w}_i(t)$ is the stationary wage for type i. The production function $F : \mathbb{R}^3 \to \mathbb{R}$ is constant returns to scale in both types of labor and aggregate capital. Factors receive their marginal products:

$$r(t) = F_K\left(\tilde{k}_U\left(t\right) + \eta\left(t\right)\tilde{k}_S\left(t\right), l_U, \eta\left(t\right)l_S\right) - \delta, \tag{8}$$

$$\tilde{w}_i(t) = F_{H_i}\left(\tilde{k}_U\left(t\right) + \eta\left(t\right)\tilde{k}_S\left(t\right), l_U, \eta\left(t\right)l_S\right), \tag{9}$$

where δ is the rate of depreciation for physical capital, and $\eta\left(t\right)$ is the ratio of skilled, $M_S\left(t\right)$ to unskilled workers $M_U\left(t\right)$ in the economy at time t, $\eta\left(t\right) = \frac{M_S(t)}{M_U(t)} = \frac{M_S(0)}{M_U(0)}e^{\int_0^t(m_S(z)-m_U(z))dz}$.

3 Capital Dilution versus Changes in Population Composition

In this section we employ the perturbations method developed by Judd (1998), to demonstrate that a change in the rate of immigration by either unskilled or skilled workers, affects the dynamic behavior of the model in two very different ways. We define m as the initial steady state rate of immigration for both skilled and unskilled workers, and replace $m_i\left(t\right)$ in (6)-(9), with $m + \epsilon\pi_i\left(t\right)$, where $\pi_i\left(t\right)$ is a bounded dynamic perturbation to the rate of migration by type-i workers, and ϵ is a small positive number that regulates its magnitude.[5]

Defining $\pi = \{\pi_S\left(t\right), \pi_U\left(t\right)\}_{t=0}^{\infty}$, we assume that consumption and capital for each skill-type are the functions of π and ϵ: $\tilde{c}_i(t, \epsilon, \pi)$ and $\tilde{k}_i(t, \epsilon, \pi)$, $i \in \{U, S\}$. Differentiating (6) and (7) with respect to ϵ at the point $\epsilon = 0$ yields:

$$\begin{bmatrix} \frac{\partial}{\partial\epsilon}\dot{\tilde{c}}_U(t,\epsilon,\pi) \\ \frac{\partial}{\partial\epsilon}\dot{\tilde{c}}_S(t,\epsilon,\pi) \\ \frac{\partial}{\partial\epsilon}\dot{\tilde{k}}_U(t,\epsilon,\pi) \\ \frac{\partial}{\partial\epsilon}\dot{\tilde{k}}_S(t,\epsilon,\pi) \end{bmatrix} = \mathbf{J}\begin{bmatrix} \frac{\partial}{\partial\epsilon}\tilde{c}_U(t,\epsilon,\pi) \\ \frac{\partial}{\partial\epsilon}\tilde{c}_S(t,\epsilon,\pi) \\ \frac{\partial}{\partial\epsilon}\tilde{k}_U(t,\epsilon,\pi) \\ \frac{\partial}{\partial\epsilon}\tilde{k}_S(t,\epsilon,\pi) \end{bmatrix} - \begin{bmatrix} \left(\rho - n\right)\tilde{k}_U\kappa_U\pi_U\left(t\right) \\ \left(\rho - n\right)\tilde{k}_S\kappa_S\pi_S\left(t\right) \\ \tilde{k}_U\kappa_U\pi_U\left(t\right) \\ \tilde{k}_S\kappa_S\pi_S\left(t\right) \end{bmatrix} - \begin{bmatrix} \tilde{c}_U\Omega_K \\ \tilde{c}_S\Omega_K \\ \tilde{k}_U\Omega_K + l_U\Omega_U \\ \tilde{k}_S\Omega_K + l_S\Omega_S \end{bmatrix}\eta\left(0\right)\int_0^t\left(\pi_S\left(z\right) - \pi_U\left(z\right)\right)dz, \tag{10}$$

where $\mathbf{J}$ is a 4×4 Jacobian matrix, $\tilde{k}_U$ and $\tilde{k}_S$ are the initial steady state levels of capital holdings, and $\Omega_K = l_S\frac{\partial^2 F}{\partial L_S\partial K} + \tilde{k}_S\frac{\partial^2 F}{\partial K\partial K}$, $\Omega_U = l_S\frac{\partial^2 F}{\partial L_S\partial L_U} + \tilde{k}_S\frac{\partial^2 F}{\partial K\partial L_U}$, $\Omega_S = l_S\frac{\partial^2 F}{\partial L_S\partial L_S} + \tilde{k}_S\frac{\partial^2 F}{\partial K\partial L_S}$. Solving

[5] To guarantee convergence to an interior balanced growth path we also impose the restriction on $\pi_S\left(t\right)$ and $\pi_U\left(t\right)$ that $\lim_{T\to\infty}\int_0^T\left(\pi_S\left(t\right) - \pi_U\left(t\right)\right)dt$ is finite.

(10) yields a first order approximation of the time paths of consumption and capital following a change in immigration policy.

The shocks in (10) are separated into two different vectors. The first vector of perturbations (the second vector on the right-hand side of (10)) contains the terms κ_U and κ_S, which regulate the fractional gap in capital-holdings between new immigrants and the rest of the population. Unless κ_i is equal to zero, a change in the rate of immigration directly alters the capital-labor ratio. Hence the first vector of perturbations in (10) captures the degree to which immigrants dilute (or deepen if $\kappa_i < 0$) the capital stock, and also tells us the patterns of consumption and savings that prevail, until the accumulated changes in the capital stock match the overall change in the size of the population. If $\pi_S(t) = \pi_U(t)$ the change in both rates of immigration is identical and the size of the population changes, but not its composition. Such overall 'undifferentiated' changes in the rates of immigration are completely described by the first vector of perturbations in (10) alone. This is also the total effect of immigration in a model with homogenous labor as described by Borjas (1995) in his static model, and Ben-Gad (2004) in a dynamic setting.

Differential changes in the rates of immigration—changes that affect the ratio of skilled to unskilled workers—necessitate further adjustments to the capital stock, beyond those induced by the first vector of shocks in (10). The terms Ω_K, Ω_U, and Ω_S in the second vector of perturbations in (10) (the third vector on the right-hand side), capture the means by which changes in the ratio between skilled and unskilled immigrants directly affect the returns to capital, unskilled wages, and skilled wages respectively. Changes in factor returns induce changes in savings behavior, until the stock of capital is exactly appropriate to the economy's new mix of skills.

If a surge in immigration is temporary ($\pi_S(t)$ and $\pi_U(t)$ have bounded support), the elements in the first vector of perturbations in (10) are transitory and do not generate permanent changes in any of the factor returns. By contrast, the elements of the second vector of perturbations accumulate the differences between $\pi_S(t)$ and $\pi_U(t)$ and temporary surges in immigration continue to affect the economy through this channel long after the immigration surge itself has ended. Indeed, the second perturbations vector generates permanent changes in wages, whereas the effect of the first vector on wages begins to dissipate once the surge in immigration ceases. Hence the former and not the latter, ultimately accounts for the lion's share of immigrants' impact on factor returns and welfare.

When simulating the impact of immigration on factor returns, and their subsequent implications for native welfare—we always distinguish between the total impulse responses generated by π on (10), and the effects of a corresponding level of undifferentiated immigration operating through the first vector of shocks alone.

Solving (10) yields first order approximations of the dynamic behavior of the model, adequate for predicting the behavior of factor returns but not sufficiently accurate for welfare measurements unless the proposed policy changes are extremely small. Differentiating (6) and (7) twice with respect to ϵ at the point $\epsilon = 0$, and then three times yields third order approximations of the models variables: $\tilde{c}_i(t,\epsilon,\pi) = \tilde{c}_i + \epsilon\frac{\partial}{\partial\epsilon}\tilde{c}_i(t,\epsilon,\pi) + \frac{1}{2}\epsilon^2\frac{\partial^2}{\partial\epsilon\partial\epsilon}\tilde{c}_i(t,\epsilon,\pi) + \frac{1}{6}\epsilon^3\frac{\partial^3}{\partial\epsilon\partial\epsilon\partial\epsilon}\tilde{c}_i(t,\epsilon,\pi)$ and $\tilde{k}_i(t,\epsilon,\pi) = \tilde{k}_i + \epsilon\frac{\partial^2}{\partial\epsilon}\tilde{k}_i(t,\epsilon,\pi) + \frac{1}{2}\epsilon^2\frac{\partial^2}{\partial\epsilon\partial\epsilon}\tilde{k}_i(t,\epsilon,\pi) + \frac{1}{6}\epsilon^3\frac{\partial^3}{\partial\epsilon\partial\epsilon\partial\epsilon}\tilde{k}_i(t,\epsilon,\pi)$, $i \in \{U, S\}$, where $\tilde{c}_i$ and $\tilde{k}_i$ are the initial steady state values of consumption and capital holdings for each type i (see Appendix).[6]

4 Parameterizing the Baseline Model

4.1 The Nested CES Production Function

Empirical studies—starting with Griliches (1969)—typically find that the elasticity of substitution between skilled labor and capital is substantially lower than that between unskilled labor and capital. Subsequent work by Berndt and Christensen (1974), and Denny and Fuss (1977) confirmed Griliches' findings.

To permit the elasticity of substitution between capital and the two different types of labor to differ, we employ the nested constant elasticity of substitution aggregate production function developed by Sato (1967):

$$F\left(K\left(t\right), L_U\left(t\right), L_S\left(t\right)\right) = \left[\alpha L_U\left(t\right)^{\vartheta} + \left(1-\alpha\right)\left(\beta K\left(t\right)^{\gamma} + \left(1-\beta\right) L_S\left(t\right)^{\gamma}\right)^{\frac{\vartheta}{\gamma}}\right]^{\frac{1}{\vartheta}}, \qquad (11)$$

where $K(t) = K_U(t) + K_S(t)$ is the total stock of capital.[7] For the nested CES production function, the Allen-Hicks elasticities of substitution between unskilled labor L_U and the other two factors, skilled labor L_S and capital K, are identical: $\sigma_{US} = \sigma_{UK} = \frac{1}{1-\vartheta}$. The Allen-Hicks elasticity of substitution between capital and skilled labor is a function of factor shares, however following Krusell *et. al.* (2000) we employ a simplified definition of elasticity: $\sigma_{SK} = \frac{1}{1-\gamma}$.[8] Fallon and Layard (1975) measured the parameters of the nested CES function (11).

[6] Because the sets of equations for each type are similiar, the condition number of the 4×4 Jacobian matrix can be very high—leading to innacurate results. For numerical simulations we replace the two equations in (6) with a law of motion for the logarithm of consumption for unskilled households $a_U(t) = \ln\tilde{c}_U(t)$, and a law of motion for the ratio between the present values of skilled and unskilled labor income $\chi(t) = \frac{\omega_S(t)}{\omega_U(t)}$ (see Appendix)

[7] Also known as the two stage CES production function. The first stage combines skilled labor and raw capital to develop and maintain production capital: $K^* = \left(\lambda K^{\gamma} + (1-\lambda)(H_S)^{\gamma}\right)^{\frac{1}{\gamma}}$. K^* is used by unskilled labor in the second stage to manufacture final goods: $Y = \left[\mu\left(H_U\right)^{\vartheta} + (1-\mu)\left(K^*\right)^{\vartheta}\right]^{\frac{1}{\vartheta}}$. See Goldin and Katz (1998).

[8] For the nested CES function the Allen-Hicks partial elasticity of substitution between capital and

	Preferences, Technology and Factor Shares:
$r(0) = .04$	ρ chosen to match 4% initial rate of return on capital.
$x = .02$	Average U.S. per-capita growth rate: 1991-2000.†
$\delta = .045$	Average rate of depreciation on fixed assets: 1991-2000.†
γ=-.495, ϑ=.401	Krusell, Ohanian, Ríos-Rull, and Violante (2000).
ϕ_K= .282	The average share of capital in U.S. National Income: 1991-2000.†
α=.427, β=.781	Matches the values of ϕ_K, and 4% rate of return on capital.
	Population:
$n = .0067$	Average U.S. natural rate of population growth: 1991-2000.‡
$m_S = m_U = .0032$	Average U.S. rate of net migration: 1991-2000.‡
$\kappa_S = \kappa_U = 1$	Immigrants arrive without physical capital.
$\eta(0) = .344$	Ratio of population with/without college degrees.‡
$d = 2.7$	Ratio of initial earnings and wealth. for households with/without college degrees.‡§

Table 1: Paramaterization of Baseline Model. †Bureau of Economic Analysis. ‡U.S. Census Bureau. §1998 Survey of Consumer Finances.

Defining a skilled worker as someone with more than eight years of education, for their full sample of 23 countries, they estimated ϑ to be .33 and γ to be -2.45, implying partial elasticities of substitution of $\sigma_{UK} = 1.49$ and $\sigma_{SK} = .29$. For a restricted sample of rich countries the estimates were ϑ= .46 and γ = -.81, or $\sigma_{UK} = 1.85$ and $\sigma_{SK} = .55$. For our baseline model, we adopt the parameter estimates found by Krusell *et. al.* (2000) for the U.S. economy. We define a skilled worker as someone with at least a four-year Bachelor's Degree, and for the baseline model set ϑ= .401 and $\gamma = -.495$ ($\sigma_{UK} = 1.67$ and $\sigma_{SK} = .67$).[9]

skilled labor is $\frac{1}{1-\vartheta} + \frac{1}{\phi_{SK}}\left(\frac{1}{1-\gamma} - \frac{1}{1-\vartheta}\right)$ where ϕ_{SK} is the combined share of aggregate capital and skilled labor in production.

[9]Lindquist (2003) finds very similar results for the Swedish economy. For the full sample of countries the implied Allen-Hicks elasticity in Fallon and Layard's (1975) study is -.49 or -.29 when the sample is restricted to rich countries, and for Krusell *et. al.*, (2000) the Allen-Hicks partial elasticity of substitution between capital and skilled labor is .36. By comparison, Berndt and Christensen (1974) estimate a translog production function—their estimates are: $\sigma_{UK} = 3.72$, $\sigma_{SK} = -3.77$, and $\sigma_{US} = 7.88$. Rather than counting years of schooling, the authors distinguish between production and non-production workers, and assume that the latter group is more skilled. A similar study by Denny and Fuss (1977) finds $\sigma_{UK} = 2.86$, $\sigma_{SK} = -1.88$, and $\sigma_{US} = 4.76$ when the production function is estimated, and $\sigma_{UK} = 1.5$, $\sigma_{SK} = -.91$, and $\sigma_{US} = 2.06$ when a cost function is used. Finally, Polgreen and Silos (2005), reestimate the Krussel *et. al.* (2000) model use Baysian estimation techniques, and two alternative measures of the capital equipment stock, find that the value of σ_{UK} ranges from 2.087 to 9.052, and the value of σ_{SK} ranges from 0.607 to 0.857.

4.2 U.S. Immigration Policy Since 1990

Most legal immigrants arrive in the United States through some form of family sponsorship. Immediate relatives of United States citizens may enter without limit; during the 1990's about a quarter of a million arrived each year. Other relatives of U.S. citizens are admitted as family-sponsored preference immigrants—the Immigration Act of 1990 set the limit for all family sponsored immigrants as either 226,000, or 480,000 minus the number of people admitted under the category of immediate relatives during the previous year, whichever is larger. The United States also allocates 140,000 employment-based preference visas for workers with special skills or training (as well as investors), and an additional 55,000 visas are allocated by lottery under the diversity program. Finally, the United States admits refugees and asylum seekers (refugees are admitted from abroad on the basis of a yearly quota set annually by the president). After a year, refugees and asylees are eligible for permanent residence—between 1991 and 2000 just over one million were admitted.

In addition to immigration visas, in 1992 the United States began granting, 65,000 H-1B visas to temporary workers with special skills—nearly all recipients have college or advanced degrees.[10] To ameliorate a perceived shortage of qualified workers in the information technology sector, Congress passed the American Competitiveness in the Workforce Act of 1998, temporarily increasing the number of visas to 115,000 per year in 1999 and 2000, and 107,500 in 2001. The American Competitiveness in the Twenty-First Century Act of 2000 (AC21) added an extra 347,500 visas by raising the cap to 195,000 for each of the years 2001, 2002, and 2003, for a total of 585,000 over three years. The cap for 2004 and beyond is once again 65,000.

Finally, the gross inflow of illegal immigrants is about 350,000 per year.[11] The net increment to the population from this source is smaller—eighty percent of those who leave the United States are foreign born and a substantial fraction of these are illegal aliens returning home. In the year 2000 there were approximately seven million people living in the United States illegally, of whom 1.5 million arrived between 1991 and 2000—a net inflow of 150,000 per year.[12]

In total, the net rate of migration to the United States between 1991 and 2000 was 3.2 per thousand. Although a much larger fraction of immigrants have less than nine years of schooling, the percentage of the foreign-born with Baccalaureate degrees closely matches that of the general

[10] H-1B visas are granted for a maximum of two consecutive three-year stays. However, workers are no longer required to demonstrate an intention to return to their home countries and most recipients are soon eligible to apply for permanent residency. In the past at least half of those admitted under the program changed status and ultimately became permanent residents (see Lowell (2001)).

[11] U.S. Department of Homeland Security, Office of Immigration Statisitics, *2002 Yearbook of Immigration Statistics.*

[12] U.S. Immigration and Naturalization Service, Office of Policy and Planning, *Estimates of the Unauthorized Immigration Population Residing in the United States: 1990 to 2000.*

population—25.8% of foreign-born people in the United States over the age of 25 have college degrees, as compared to 25.6% of the total U.S. population. For the initial stock of skilled and unskilled workers we set $M_S(0) = .256$ and $M_U(0) = .744$ and set the steady state rates of immigration for both skill types to $m_S = m_U = .0032$.[13] We further assume that all immigrants arrive in the United States after having exhausted any savings on travel expenses or establishing a household—we set $\kappa_S = \kappa_U = 1$. If the rates of legal and illegal immigration to the United States during the decade of the 1990's carry forward, and the rate of out migration continues to hold steady at one per thousand, foreign migration will augment the U.S. population with close to ten million additional people over the course of this decade.

4.3 The Baseline College Premium and Distribution of Capital

We choose the other parameters of the model to match U.S. data in steady state. The ratio of mean earnings and income for households as well as individuals with bachelor's degrees to those without, range from 2.13 and 2.71 as measured by the U.S. Census. The 1998 Survey of Consumer Finances reports on net wealth as well as income and earnings. The ratio of mean earnings is 2.35, income is 2.3 while net wealth is 3.3. The gap between median earnings and wealth is smaller—2.4 versus 3.06. In steady state, the ratio of capital held by skilled and unskilled agents must be equal to the ratio of their wages—we choose an intermediate number 2.7 for our simulations.

5 Temporary Surges in the Rate of Immigration

5.1 Raising Skilled Immigration for Ten Years

Suppose the United States government were to announce that it will permit the overall rate of immigration to immediately rise from 3.2 to 3.3 per thousand, but only for one decade. This corresponds to a decision to allocate an additional two hundred and ninety-five thousand visas, so that instead of absorbing approximately nine million six hundred thousand new immigrants over the course of a decade, about nine million nine hundred thousand immigrants arrive. How would the increased influx affect the economy? How much will the type of immigrants, whether

[13] At the high end, graduate education declines slightly with the degree of nativity: 9.7% of the foreign born have graduate degrees, as do 8.9% of natives with foreign-born parents, but only 8.2% of natives with native-born parents. Grade school education rises more steeply with nativity—22.2% of the foreign-born and 10.1% of the natives with foreign-born parents have less than nine grades of schooling (7.2% of the foreign-born have less than five), against only 4.5% with less than nine grades among the native-born population with native parents (See U.S. Department of Commerce, Bureau of Census, *Profile of the Foreign-Born Population in the United States: 2000*, December 2001).

they are skilled or unskilled, affect the results?

Once again we define the rate of immigration as $m_i(t) = m + \epsilon\pi_i(t)$, $i \in \{U, S\}$. The increase in the overall rate of immigration is ϵ. Define μ_S as the fraction of additional immigrants that are skilled workers, and T as the duration of the immigration surge. The dynamic perturbations to the rate of immigration for skilled and unskilled workers are $\pi_S(t) = \frac{1}{\epsilon}\ln\left[1 - \left(1 - e^{T\epsilon}\right)\frac{\mu_S}{M_S(0)}\right]\mathcal{U}(T-t)$ and $\pi_U(t) = \frac{1}{\epsilon}\ln\left[1 - \left(1 - e^{T\epsilon}\right)\frac{1-\mu_S}{1-M_S(0)}\right]\mathcal{U}(T-t)$, where the function $\mathcal{U}$ is the unit step indicator function.[14]

First, we consider what happens to factor returns, if all the additional two hundred and ninety-five thousand visas are allocated over the decade to skilled immigrants only—we set $\mu_S = 1$, ϵ =0.0001, and T=10, and then calculate the behavior of unskilled wages, skilled wages and the rate of return to capital. The solid lines describe the impulse responses generated by both perturbation vectors in (10)—the change in the behavior of factor returns that results from the surge of additional immigration.

We generate the curves with dashes by setting $\mu_S = M_S(0)$. In this case $\pi_S(t) = \pi_U(t)$, and the impulse responses represent the effects of the first perturbations vector in (10) alone. This is the behavior of factor returns if the same sized immigration surge is not biased towards either type of worker, but rather matches the pre-existing distribution of skilled and unskilled workers in the United States. In other words, the dashed curves illustrate the effects of an alternative policy—admitting during the decade just under an additional seventy-five thousand skilled, together with nearly two hundred fifteen thousand unskilled immigrants. We emphasize the area between the solid and dashed curves in Figure 2 in gray. This is the effect of the new immigration policy, abstracting from the mere change in the overall size of the population—the net change in factor returns resulting from the increase in the relative share of skilled workers from 25.6% to 25.6744%.

The arrival of extra skilled immigrants causes skilled wages to immediately begin declining (Panel a) of Figure 2). In the long-run, long after the surge of additional immigration has passed, and the economy has converged to its new steady state, the supply of skilled workers has increased .39% above its previous trend and skilled workers' wages—detrended for exogenous technological growth—has declined by just over .15%. Thus the long-run wage elasticity for skilled workers is .39—close to the .4 weekly wage elasticity (across all skill groups) measured by Borjas (2003). However, towards the end of the decade, as the last of the extra immigrants are arriving, the decline in skilled wages is far more substantial—almost .3%.

Why does the drop in skilled wages initially overshoot its long-run value? Sixty-five percent

[14]The Unit Step function $\mathcal{U}(x)$ takes the value zero if $x \leq 0$ and one if $x > 0$. Therefore $\mathcal{U}(10-t)$ is equal to zero if $t > 10$ and to one if $t \leq 10$.

of the overshooting occurs because the economy fails to accumulate capital at a pace sufficient to compensate for capital dilution that results from the increase in the size of the work force, until the last of the extra immigrants has arrived. The remainder of the overshooting—thirty-five percent—results from the delay in accumulating the capital necessary to accommodate the changed composition of the workforce—a workforce whose labor is now more complementary to capital. Only in the long run, can higher savings provide the economy with the extra capital required to accommodate both the relatively sudden jump in the size of the work force, and also its changed composition.

As the enhanced flow of skilled workers continues, the labor unskilled workers provide becomes relatively more scarce; the unskilled wage in Panel b) of Figure 2 rises until it is just .14% higher than it would be otherwise. Capital dilution slightly detracts from their gains—capital complements unskilled labor even though the two factors are also relative substitutes. Overall, wage inequality declines. In the initial steady state equilibrium, workers with college degrees earn 170% more than their unskilled counterparts. The temporary surge in immigration eventually reduces this premium to 169.2%.

In Borjas (1995), an influx of capital-poor immigrants permanently lowers the capital-labor ratio, and by permanently raising its rate of return, generates a small surplus for native owners of capital. In this model, capital supply is endogenous, so temporary influxes do not affect its long-run rate of return, and as in Ben-Gad (2004), the impact of capital dilution alone is modest—just under three-tenths of a basis point at its peak, if both rates of immigration rise by the same amount. By contrast the impact of skilled immigration is almost three times greater—almost nine-tenths of a basis point in year ten. Capital-skill complementarity generates the entire gray-colored gap between the two curves in Panel c) of Figure 2. As we demonstrate in Section 6, these higher rates of return imply that most of the native population derives a substantial benefit from this type of immigration.

5.2 Raising Unskilled Immigration for Ten Years

Does an influx of the same number of unskilled immigrants generate similar, perhaps symmetric patterns in the behavior of factor returns? Not completely. We once again set $\epsilon = 0.0001, T = 10$, but $\mu_S = 0$. Figure 3 presents the response of factor returns when all the additional two hundred and ninety-five thousand immigrants are unskilled.

By the end of the decade the policy raises the supply of unskilled labor by slightly over .13% above its previous path. Unskilled wages in Panel b) of Figure 3 drop by just under .05% in the long run, and slightly more than .05% in the short run.[15] Once again the own-wage elasticity

[15] As we see in Table 5 below, the Allen Hicks own wage partial elasticities of complementarity for

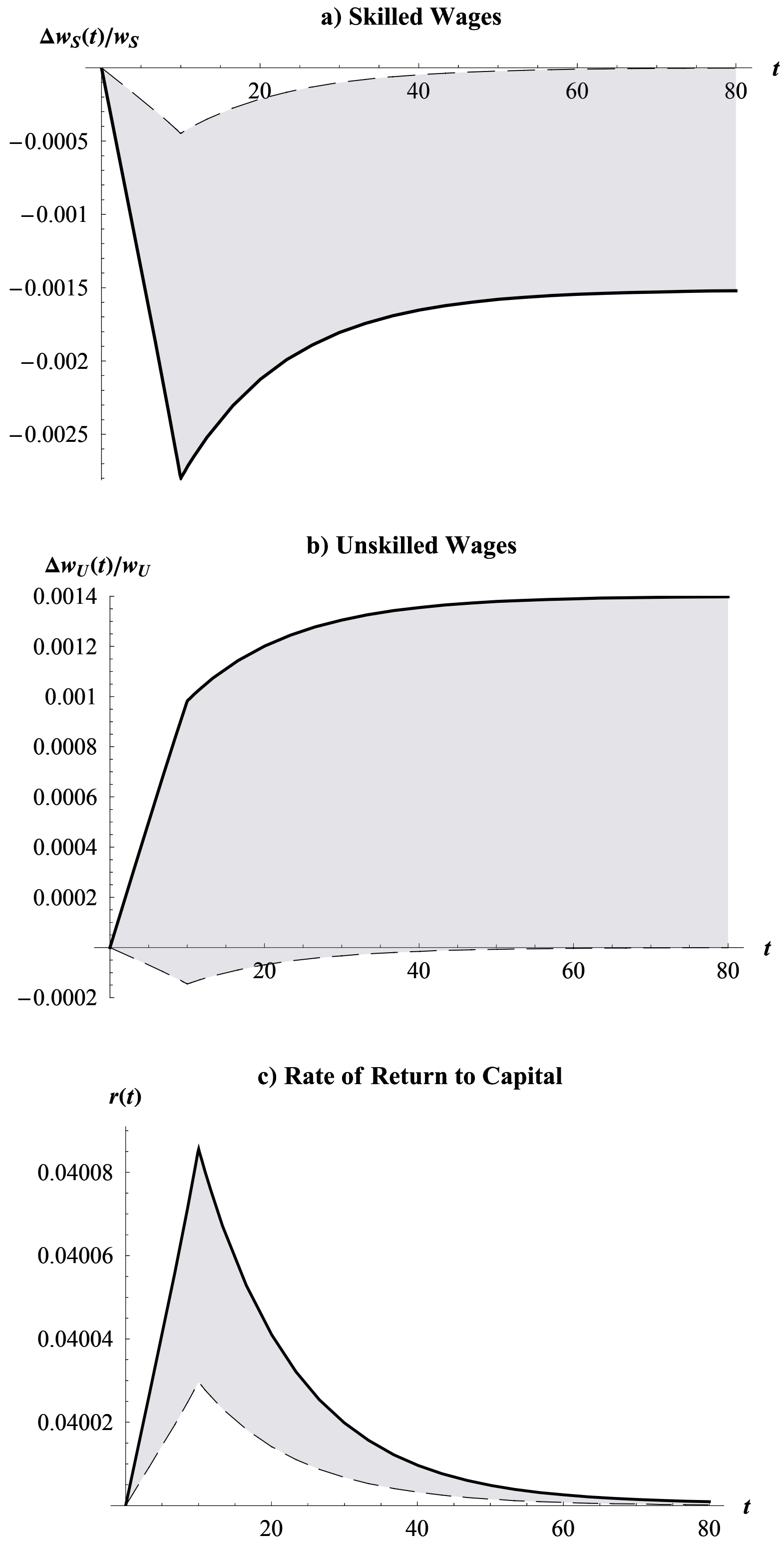

Figure 2: The total rate of immigration increases from 3.2 to 3.3 per thousand per annum, for ten years only, and all the additional immigrants are members of households with skilled workers. The solid curves are the total impulse responses of factor returns from (10). The curves with the short dashes are the impulse responses generated by (10) when the rates of immigration for the skilled and unskilled both rise. The gray areas between the two curves isolate the overall influence of changes in the composition, rather than the size of the population. The impulses in Panels a) and b) are the fractional deviations of the de-trended wage from the initial balanced growth path. For the rates of return to capital in Panel c), the horizontal axis is the baseline rate of 4%.

roughly matches the estimates in Borjas (2003).

The increase in the share of unskilled workers dampens the effects of capital dilution on factor returns. More importantly, capital dilution no longer offsets the increase in unskilled wages as in Figure 2, but rather in Figures 3 exacerbates their decline. Because the share of unskilled in the work force increases, the economy responds by adjusting downward, rather than upward, the long-run capital-labor ratio.

The long-run wage for skilled workers rises by just over a twentieth of one percent. Capital dilution dampens the short-term rise in skilled wages, causing it to increase monotonically, without achieving the temporary peak it would have otherwise. Despite the differences in magnitudes, overall immigration by skilled or unskilled workers produces a roughly symmetric qualitative pattern of changes in the different wages. The surge in unskilled immigration, though temporary, raises the long-run college premium to 170.03%.

When the additional immigrants are skilled, capital skill complementarity and capital dilution raise in tandem, the rate of return to capital. By contrast, if the immigrants are unskilled, the relative substitutability between capital and unskilled labor counteracts the positive effect of capital dilution, dragging down the rate of return to capital in Panel c) of Figure 3. At its peak, in year ten, the rate of return rises by a mere tenth of a basis point—a small fraction of the rise induced by immigration of the same number of skilled workers. By the same token, a decision to lower the number of unskilled immigrants arriving in the United States, by two hundred ninety-five thousand, over the course of a decade, lowers the rate of return by approximately the same, very small amount.

How can the contribution of unskilled immigration to capital's rate of return be so small? On one hand, by abstracting from the many different types of physical, and organizational capital, we no doubt miss the serious harm that the imposition of severe restrictions on the immigration of unskilled workers will cause certain sectors of the U.S. economy. On the other hand, for owners of the types of capital that might replace some of these workers in the production process, a drop in the number of unskilled immigrants will prove beneficial. At the aggregate level, given the elasticities of substitution found by Krusell *et. al.* (2000), we conclude that overall, the common perception that unrestricted immigration by low-skilled workers strongly serves the overall interests of a country's *rentier* class deserves serious reexamining.

the baseline model are much higher (in absolute value) for skilled than unskilled workers. However, the long-run equilibrium wage elasticities generated by the model are approximately the same across the two groups, and close to the elasticities measured by Borjas (2003).

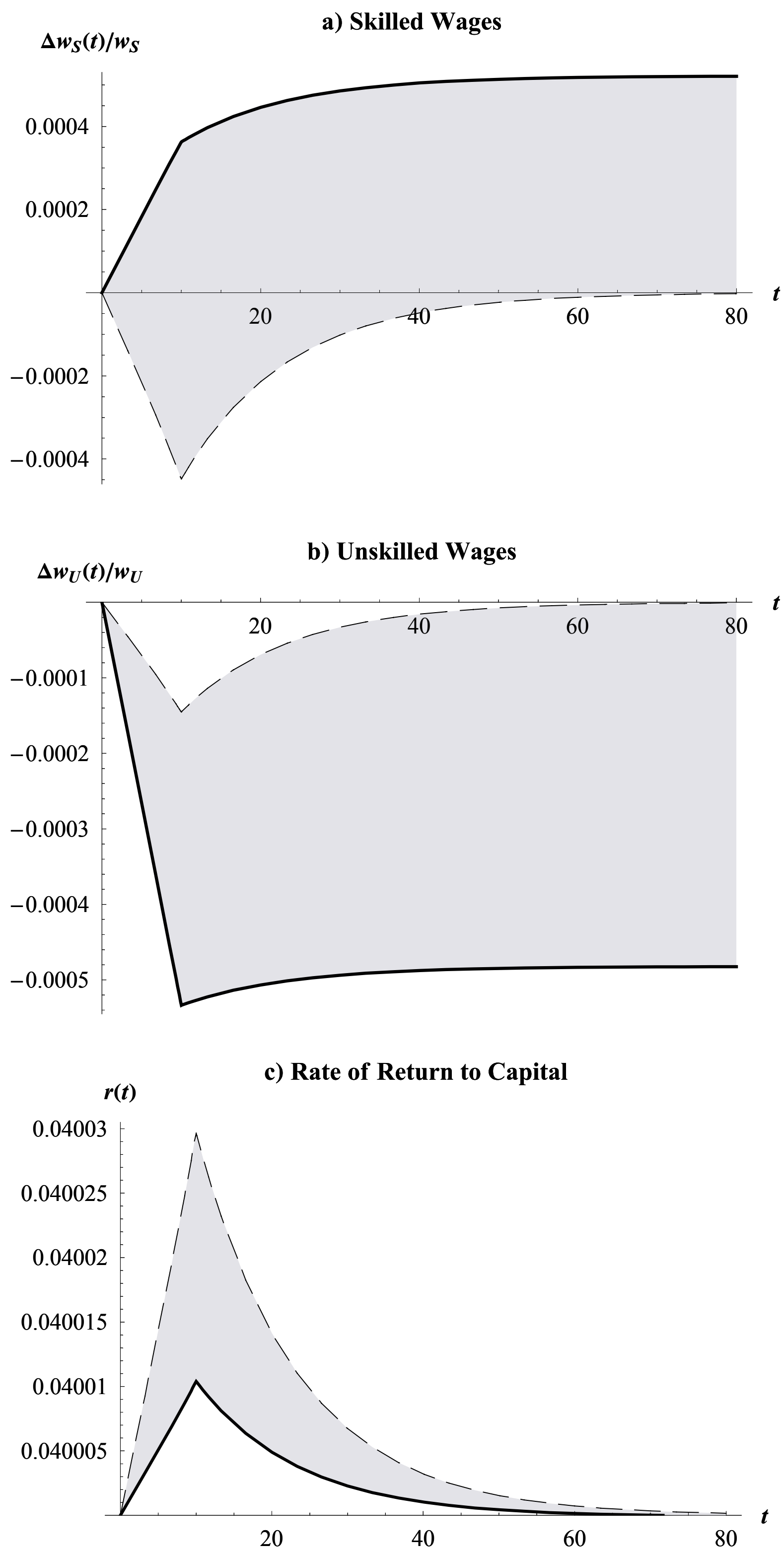

Figure 3: The total rate of immigration increases from 3.2 to 3.3 per thousand per annum, for ten years only, and all the additional immigrants are members of households with unskilled workers. The solid curves are the total impulse responses of factor returns from (10). The curves with the short dashes are the impulse responses generated by (10) when the rates of immigration for the skilled and unskilled both rise. The gray areas between the two curves isolate the overall influence of changes in the composition, rather than the size of the population. The impulses in Panels a) and b) are the fractional deviations of the de-trended wage from the initial balanced growth path. For the rates of return to capital in Panel c), the horizontal axis is the baseline rate of 4%.

5.3 An Overall Rise in Immigration for Ten Years

Consider once again, the across the board increase in immigration that permits an additional seventy-five thousand skilled, and two hundred and twenty thousand unskilled immigrants to enter the United States over the course of ten years; these are the impulses represented by the dashed curves in both Figures 2 and 3. The rate of return to capital rises by just over four-tenths of a basis point which is more than four times higher than if all the immigrants are unskilled, but less than half as high as when all the immigrants are skilled. Both types of wages decline but they do not decline at the same rate—skilled labor is relatively more complementary to capital, hence the temporary drop in per-capita capital causes skilled wages to decline by .045% in year ten, whereas unskilled wages decline by less than .015%. Therefore an overall rise in immigration that merely replicates the pre-existing distribution of the labor force temporarily lowers both types of wages while reducing the gap between them.

5.4 Changing the Duration of the Impulses

Changing the number of immigrants that continuously arrive over the course of ten years, simply scales up or down the factor returns' impulse responses. What happens if the duration of the policy is no longer ten years? What happens to factor returns, if the country absorbs the same two hundred and ninety-five thousand skilled immigrants over the course of a single year? Or fifteen? Because capital supply is endogenous, immigration surges affect wages in the long-run only if they alter the long-run ratio of skilled to unskilled workers. Hence the long-run impact of a surge of immigration on wages is a function of its overall size and composition, and not the rate at which it occurs. However, the shorter the duration of time between the policy announcement and the arrival of the last of the additional immigrants, the less time capital has to adjust, and the greater the short-run impact on wages.

Consider what happens if the entire surge in immigration is concentrated within a span of three years. In Figure 4, the arrival of nearly an additional hundred thousand skilled immigrants per year, causes skilled wages to drop by nearly .35% by year three. If the identical number of skilled immigrants is evenly spread across a fifteen year interval, the maximum drop in the skilled wage is just over .25% in year fifteen.

Similarly, the rate of return to capital begins to gradually fall to its previous value of 4%, once immigration for both types reverts to its previous rate of 3.2 per thousand. Nonetheless, the shorter the duration of time over which a given surge of skilled immigration is concentrated, the more the immigrants overwhelm the ability of the economy to adequately adjust its capital stock through additional savings. If two hundred and ninety-five thousand additional skilled immigrants join the economy over the course of three years, the short-run rate of return rises

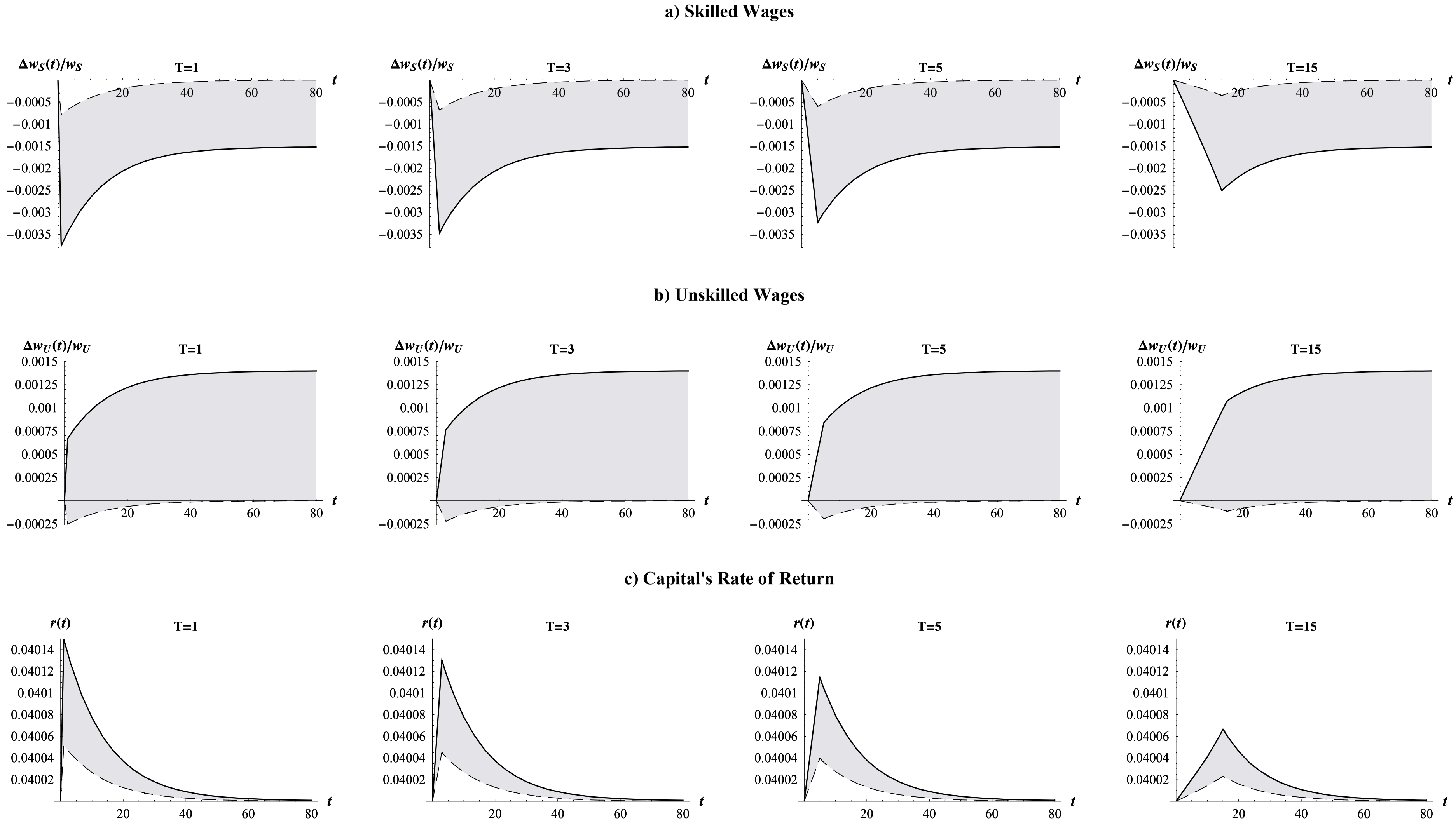

Figure 4: The solid curves represent factor returns generated by two hundred ninety-five thousand additional skilled immigrants over the course of T years. The dashed curves are the effects of a corresponding increasing in undifferentiated immigration.

by 1.3 basis points in Figure 4. If the same number arrive gradually over the course of fifteen years, the rate of return adjusts gradually as well, reaching a peak of less than four tenths of an additional basis point before beginning its descent. The more the time over which skilled immigrants arrive is compressed, the more intensely immigrants compete in the labor market to work with the existing capital stock, and the more the rate of return on capital rises at the expense of skilled wages.

To accommodate the additional two hundred ninety five thousand unskilled workers, a rise of .1%, aggregate capital ultimately rises by only .035% and per-capita capital declines by .065%. Accommodating the same-sized influx of skilled immigrants requires an increase of .295%–more than eight times larger and per-capita capital increases by .195%. That is why the short-run own-wage elasticity of unskilled workers in Panel b) of Figure 5 is far less sensitive to changes in the duration of unskilled immigration. The overall effect of unskilled immigration on the return to capital is small because the labor force composition effect counteracts, rather than reinforces, the positive effect on the rate of return from capital dilution.

6 Welfare Analysis

Changes in immigration policy affect the welfare of the already resident, or 'native' population through their impact on all the different factor returns. In this section, we quantify these welfare effects in terms of compensating differentials. For members of a household with workers of skill level i, already resident in the country when the new policy is announced, the consumption path that follows the policy announcement is $c_i(0,t) = e^{\int_0^t (r(v)-\rho)dv} c_i(0)$, where $c_i(0)$ is per-capita consumption at the moment that follows the announcement of the change in policy. We equate the utility derived from this time path of consumption, multiplied by a constant value $(1 - p_i/100)$, to that obtained from consumption under a counterfactual assumption that the old policy was maintained $\bar{c}_i(0,t)$:

$$\int_0^\infty e^{-(\rho-n)t} \ln\left[c_i(0,t)(1-p_i/100)\right] dt = \int_0^\infty e^{-(\rho-n)t} \ln \bar{c}_i(0,t)\, dt. \tag{12}$$

Solving for the compensating differential $p_i, i \in \{U, S\}$ yields:

$$p_i = 100 \times \left(1 - e^{(n-\rho)\int_0^\infty \left(e^{(n-\rho)t}\int_0^t (r(v)-r)dv + \ln c_i(0) - \ln \bar{c}_i(0)\right)dt}\right), \tag{13}$$

which is the percentage permanent increase in consumption that exactly compensates resident households of type i, for the government's decision to deviate from its previous immigration policy. Calculating compensating differentials provides a convenient way to weigh the relative effects of the changes in the different factor returns—particularly when wages and the return on capital move in opposite directions.

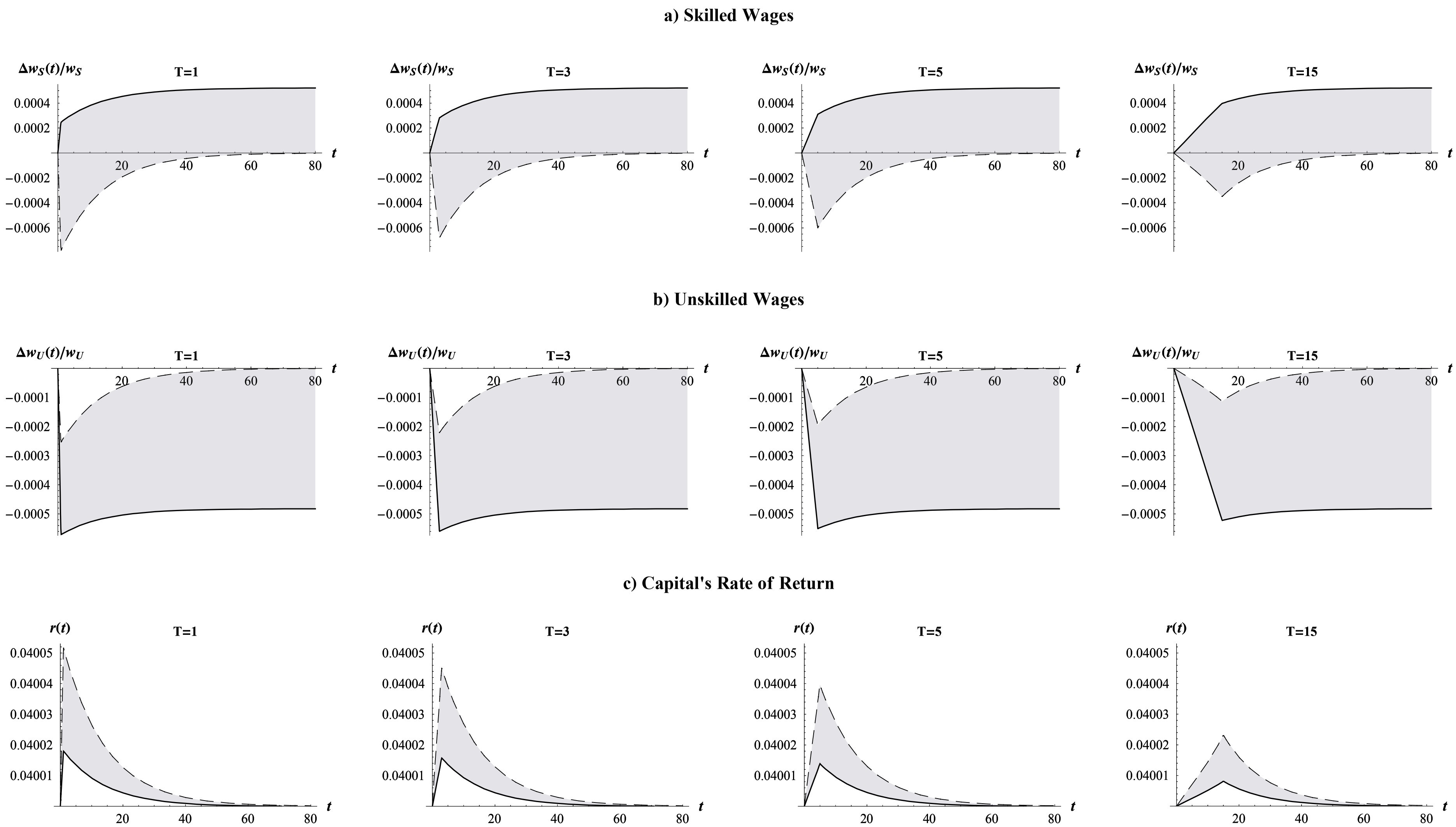

Figure 5: The solid curves represent factor returns generated by two hundred ninety-five thousand additional unskilled immigrants over the course of T years. The dashed curves are the effects of a corresponding increasing in undifferentiated immigration.

Consider once again, an across the board increase in immigration that permits an additional seventy-five thousand skilled, and two hundred twenty thousand unskilled immigrants to enter the United States over the course of ten years. In an economy with homogenous labor, the complementarity between immigrant labor and native-owned capital generates a welfare improvement for natives—what Borjas (1995) calls an immigration surplus—because the rise in the return to native-owned capital more than compensates for the drop in their wages. The benefit is small, and smaller still, if the supply of capital and labor is endogenous, as in Ben-Gad (2004). Similarly, in an economy with skilled and unskilled workers, as well as capital, and elasticities of substitution equal between all the different inputs, across the board rises in immigration generate small welfare improvements for both skilled and unskilled natives.

However, if there is a higher degree of complementarity between skilled labor and capital, than between unskilled labor and capital, the temporary drop in per-capita capital that typically accompanies a surge of immigration reduces skilled wages more than it reduces unskilled wages. This is why (in the entries in the next-to-last two rows, first column of Table 2), though both types enjoy the same proportional rise in capital income, the unskilled derive a small benefit, the equivalent of a permanent rise of 0.0028% in consumption at the expense of skilled natives who suffer a small loss, equivalent to a 0.0024% drop in permanent consumption.

Despite the heterogeneity of the native population, it is still possible to calculate an overall immigration surplus—we define it as the compensating differential for a household whose labor income is derived from both skilled and unskilled labor in proportions that match the distribution in the initial population, and whose capital holdings match the per-capita holdings for the entire native population:

$$\begin{aligned} & \int_0^\infty e^{-(\rho-n)t} \ln\left[(1-p/100)\left(M_S(0)\, c_S(0,t) + M_U(0)\, c_U(0,t)\right)\right] dt \qquad (14) \\ = & \int_0^\infty e^{-(\rho-n)t} \ln\left[M_S(0)\, \bar{c}_S(0,t) + M_U(0)\, \bar{c}_U(0,t)\right] dt, \end{aligned}$$

which yields p as a weighted average of p_S and p_U :

$$p = \frac{M_S(0)\, c_S(0)\, p_S + M_U(0)\, c_U(0)\, p_U}{M_S(0)\, c_S(0) + M_U(0)\, c_U(0)}. \qquad (15)$$

We can interpret p as the average between p_S and p_U, weighted by their respective shares in the native population at the time of the policy announcement, a number that reflects both the change in national income, and the ability of one group to compensate the other, and still enjoy part of the benefit from the new policy.[16]

[16] Another way to measure the welfare effects of this policy is to calculate the benefit to unskilled workers, after they compensate their skilled counterparts for the losses to their welfare. To fully compensate the native skilled, the unskilled might transfer each period the quantity of $p_S c_S(0,t)\, \eta(0)$ goods. More

	Compensating Differential, Percentage of Permanent Consumption	*Permanent Change in Annual Consumption in Millions of U.S. Dollars*	*Present Value One-Time Payment in Millions of U.S. Dollars*	*Present Value One-Time Payment Per Immigrant in U.S. Dollars*
AN INCREASE IN SKILLED IMMIGRATION:				
Skilled Households	-0.1319	$-\$5,232$ mil.	$-\$130,806$ mil.	$-\$443,410$
Unskilled Households	0.1241	$\$5,303$ mil.	$\$132,565$ mil.	$\$449,374$
Immigration Surplus	0.0010	$\$84$ mil.	$\$2,097$ mil.	$\$7,108$
AN INCREASE IN UNSKILLED IMMIGRATION:				
Skilled Households	0.0422	$\$1,674$ mil.	$\$41,861$ mil.	$\$141,902$
Unskilled Households	-0.0391	$-\$1,669$ mil.	$-\$41,728$ mil.	$-\$141,453$
Immigration Surplus	8.1×10^{-5}	$\$7$ mil.	$\$167$ mil.	$\$565$
AN INCREASE IN UNDIFFERENTIATED IMMIGRATION:				
Skilled Households	-0.0024	$-\$95$ mil.	$-\$2,375$ mil.	$-\$8,051$
Unskilled Households	0.0028	$\$118$ mil.	$\$2,939$ mil.	$\$9,963$
Immigration Surplus	2.7×10^{-4}	$\$23$ mil.	$\$564$ mil.	$\$1,913$

Table 2: Welfare effects generated by a year increase in the rate of immigration from 3.2 to 3.3 per thousand during one decade only.

The across the board decade-long rise in the rate of immigration of one per ten-thousand per

generally, comparing consumption paths to a baseline, we define q_h as the net welfare benefit a household of type h derives from a policy after they completely compensate the households of type $j \neq h$:

$$\int_0^\infty e^{-(\rho-n)t} \ln \left[\left(1 - \frac{q_h}{100}\right) \left(c_h(0,t) + \frac{M_j(0)}{M_i(0)} \frac{p_j}{100} c_j(0,t) \right) \right] dt = \int_0^\infty e^{-(\rho-n)t} \ln \left[\bar{c}_h(0,t) \right] dt.$$

Combining with (12) and (13), and replacing $c_i(0,t)$ with $e^{\int_0^t (r(v)-\rho)dv} c_i(0)$ for $i \in \{h, j\}$ yields:

$$q_h = \frac{M_h(0)\, c_h(0)\, p_h + M_j(0)\, c_j(0)\, p_j}{M_h(0)\, c_h(0) + M_j(0)\, c_j(0)\, p_j}, \qquad h \neq j.$$

The denominator is the initial amount of consumption enjoyed by h after having compensated j. The numerator is identical to the numerator in (15)—the sum of the welfare effects of the policy, weighted by population shares, and the time $t = 0$ levels of consumption of each type. For typically small values of p_U or p_S it determines the sign of q_h. Hence if the value of p is positive, then both values of q_h are positive as well, one group can always compensate the other's losses. The policy of raising the overall rate of immigration by one per ten thousand for both skill types during a single decade, yields a value of q_U=0.0005%—the permanent increase in consumption enjoyed by unskilled natives, after they have transfered enough resources to skilled natives to leave them indifferent between the new and old policies.

annum, generates an immigration surplus of $2.7 \times 10^{-4}\%$. How much is this worth? If annual private consumption in the United States was \$8.23 trillion in the year 2004, the decade-long rise in the rate of immigration for both skilled and unskilled workers from 3.2 to 3.3 per thousand generates a permanent benefit of \$24 million per year, the equivalent of a one time payment of \$576 million.

Now consider the same-sized influx of additional immigrants, but all of them skilled workers. The gain to unskilled natives is worth a permanent increase in consumption of 0.1241%—forty-five times higher than if the influx matches the economy's initial skill distribution. Not only do they enjoy a much more substantial increase in the income from the capital they own, but also a rise, rather than a decline in their earnings. Skilled workers also experience a rise in their capital income, but the losses in wage income are deeper, and the loss in welfare of 0.1319% is fifty-five times greater than the losses sustained by skilled natives when both rates of immigration increase.

Taking a weighted average over both skill-types, the average long-run de-trended wage declines by 0.088% while by the tenth year, the rate of return to the pre-existing capital stock increases by 0.2245%. In addition natives exploit the opportunity to augment their capital holdings by 0.06% through higher savings, adding an additional increment to their long-run capital income.[17] As before, and as is the case for models with homogenous labor, the rise in the rate of return to capital dominates the drop in wages. The difference is that if all the additional immigrants are skilled the immigration surplus is 0.001%—equivalent to a permanent rise in consumption of \$84 million, or a one time payment of just over two billion dollars. Hence, a rise in immigration that is completely skewed towards skilled workers, yields a benefit almost three and half times larger than that obtained from an increase in immigration, which merely replicates the veteran population and the pre-existing flow of new arrivals.

Finally, consider the welfare effects of the same increase in the number of immigrants, but now the increase is composed entirely of unskilled workers. The native unskilled suffer losses in welfare equivalent to a drop of 0.0397% as the very small rise in the rate of return to their capital cannot possibly compensate for the decline the in their wages. The loss is smaller than that sustained by skilled workers when all the additional immigrants are skilled, because the overall share of unskilled workers in the economy is nearly three times larger. The gains to skilled workers under this policy are smaller as well—equivalent to a permanent rise in consumption of 0.0428%.

How do natives fair on average? The value of p falls to $8.1 \times 10^{-5}\%$—the equivalent of a

[17] The long-run increase in capital is the same for both types of natives, but short-run, capital-holdings by unskilled natives slightly overshoots as they smooth income by saving more of their increased income immediately.

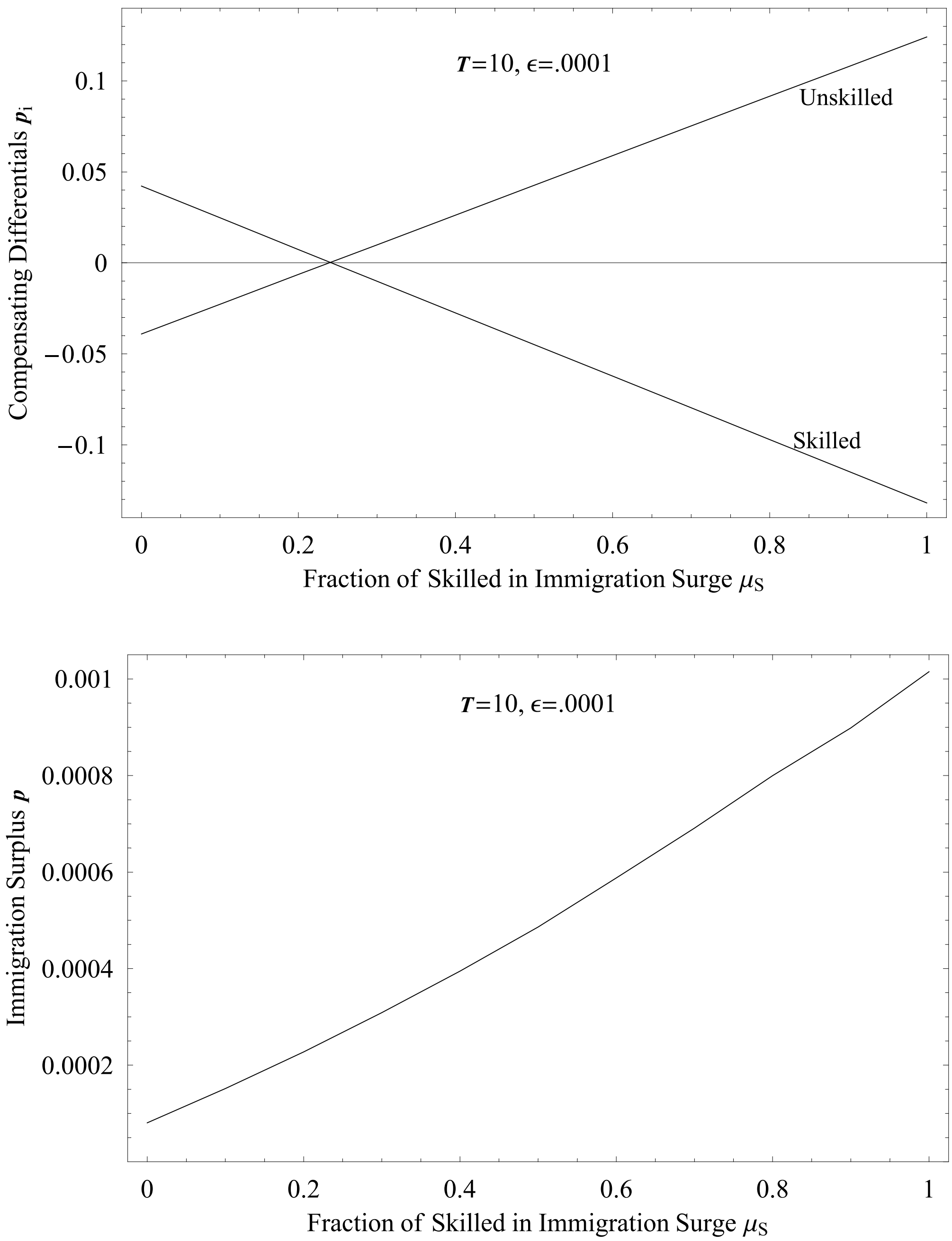

Figure 6: The compensating differentials, p_S and p_U from (13), and immigration surplus p from (15), generated by an increase of one per-ten thousand in the rate of immigration, from 3.2 to 3.3 per thousand as a function of the fraction of the additional immigrants that are skilled.

yearly rise in total consumption of seven million dollars, or a one time payment of \$183 million. This means that the overall surplus generated by an unskilled immigrant is slightly less than a twelfth the surplus generated by a skilled immigrant—a substantial difference considering that the marginal product of the latter is only 2.7 times the marginal product of the former.

In the upper half of Figure 6, we plot the compensating differentials for skilled and unskilled natives, as the share μ_S of skilled workers in the immigration surge ranges from zero to one. The relationship between μ_S and p_S, is decreasing and effectively linear, and between μ_S and p_U increasing and effectively linear. If the elasticities of substitution were equal between all the different inputs, the two curves would both cross the horizontal axis at $\mu_S = .256$, the point where the immigration surge exactly replicates the existing population. Instead here, the two curves cross at $\mu_S = .2407$, slightly above the horizontal axis. Hence there is a small region that ranges between $\mu_S = .2391$ and $\mu_S = .2422$, where the values of p_S and p_U are both positive, and increases in immigration within this narrow band of the skill-distribution are Pareto improvements (even if there is no mechanism for redistributing part of the surplus). Obviously, as long as the immigration surge is still raising the share of unskilled workers in the population, skilled natives benefit because both wages and returns to capital rise. For unskilled natives, this small region is where the wage decreases are small enough, that they are dominated by increases in the returns to capital.

The lower half of Figure 6 shows the relationship between μ_S and p, which is increasing and very slightly convex. The reason for the convexity is that the more skilled workers within a surge of immigration, the more the capital stock must rise to accommodate it. Because agents in this economy wish to smooth consumption over time, savings do not adjust linearly. Therefore the return to capital is slightly convex in the value of μ_S and so is the immigration surplus.

Value of the Perturbation ϵ	$-.00025$	$-.00015$	$-.00005$	$.00005$	$.00015$	$.00025$
Thousands of Additional (or fewer) Immigrants During the Decade	*(737.5)*	*(442.5)*	*(147.5)*	*147.5*	*442.5*	*737.5*
An Increase in Skilled Immigration:						
Skilled Households	0.3315	0.1985	0.0660	-0.0661	-0.1978	-0.3290
Unskilled Households	-0.3120	-0.1869	-0.0621	0.0623	0.1862	0.3098
Immigration Surplus	-0.0011	-8.9×10^{-4}	-3.8×10^{-4}	4.7×10^{-4}	0.0017	0.0032
An Increase in Unskilled Immigration:						
Skilled Households	-0.1056	-0.0633	-0.0211	0.0211	0.0633	0.1055
Unskilled Households	0.0977	0.0586	0.0195	-0.0196	-0.0587	-0.0977
Immigration Surplus	-1.1×10^{-4}	-8.3×10^{-5}	-3.3×10^{-5}	3.8×10^{-5}	1.3×10^{-4}	2.4×10^{-4}
An Increase in Undifferentiated Immigration:						
Skilled Households	0.0061	0.0036	0.0012	-0.0012	-0.0036	-0.0060
Unskilled Households	-0.0069	-0.0041	-0.0014	0.0014	0.0041	0.0069
Immigration Surplus	-6.4×10^{-6}	-3.9×10^{-6}	-1.3×10^{-6}	1.4×10^{-6}	4.1×10^{-6}	7.0×10^{-6}

Table 3: Compensating differentials generated by the addition of additional immigrants to the underlying immigration flow over the course of ten years.

For the same reason, the immigration surplus is increasing and convex in the value of ϵ, which regulates the size of the immigration surge. In Table 3 we present values of p_S, p_U, and p as they vary the value of ϵ between -.00025 and .00025 (in Figure 7 we vary the value of ϵ between -.00025 and .00025 and the value of μ_S over the unit interval as well). Anticipating the rise in the rate of return that accompanies higher immigration, agents temporarily cut consumption to save more. Similarly, a drop in immigration generates a rise in consumption and a decline in capital accumulation. These responses are asymmetric—because of the concavity of the utility function, agents do not forgo consumption to accumulate capital as easily as they raise consumption to lower their capital-holdings. The result is that capital accumulates more slowly than it disacumulates, and a rise in immigration raises the rate of return to capital more, than a drop in immigration causes it to decline. Therefore a cut in the number of immigrants of a certain type, generates a smaller loss in welfare, than the immigration surplus generated by the addition of the same number of these people.

Compressing the period of time over which the immigrants arrive, raises the gap between the effects of the policy on skilled and unskilled natives. If all the skilled immigrants arrive over the course of only three years, the losses to the skilled native population rise to 0.1424%, and the gains to unskilled increase to 0.1338%. Similarly, raising the time span causes both the gains and losses to slightly decline. The lower the value of T, the higher the rate of return to capital, but over a shorter period of time. Overall average native households benefit from the greater degree of capital dilution, but the changes to the surplus are quantitatively insignificant.

Under its present configuration, the H1-B visa program brings 650,000 skilled workers to the United States in a decade. Suspending the program means lowering the overall number of immigrant arrivals by just under seven percent, and lowering the number of skilled immigrants by just under 27%. For the 25.6% of the population that is skilled, and already enjoys high earnings, the welfare gain is equivalent to permanently raising their consumption by 0.296%. The 74.4% of the population that is unskilled, loses the equivalent of 0.279%. Translated into dollars, shutting down the program for one decade, generates a transfer of wealth of \$294 billion from the unskilled to the skilled and an overall welfare loss of just over \$2.5 billion. In per-capita terms this works out to a one-time payment of \$3,888 for each member of a skilled household paid for by the losses sustained by their unskilled counterparts of \$1,357 each. The overall welfare loss, measured as the surplus per skilled worker that never immigrated is \$3,886.

Consider by contrast, a doubling of the existing H1-B visa program for ten-years, so that under its auspices 130,000 skilled workers arrive per year, or 1.3 million during the decade. The transfer between the two groups is almost identical in size—\$292 billion, but passes in the other direction, from the high paid skilled minority, to the lower paid unskilled majority. The rise

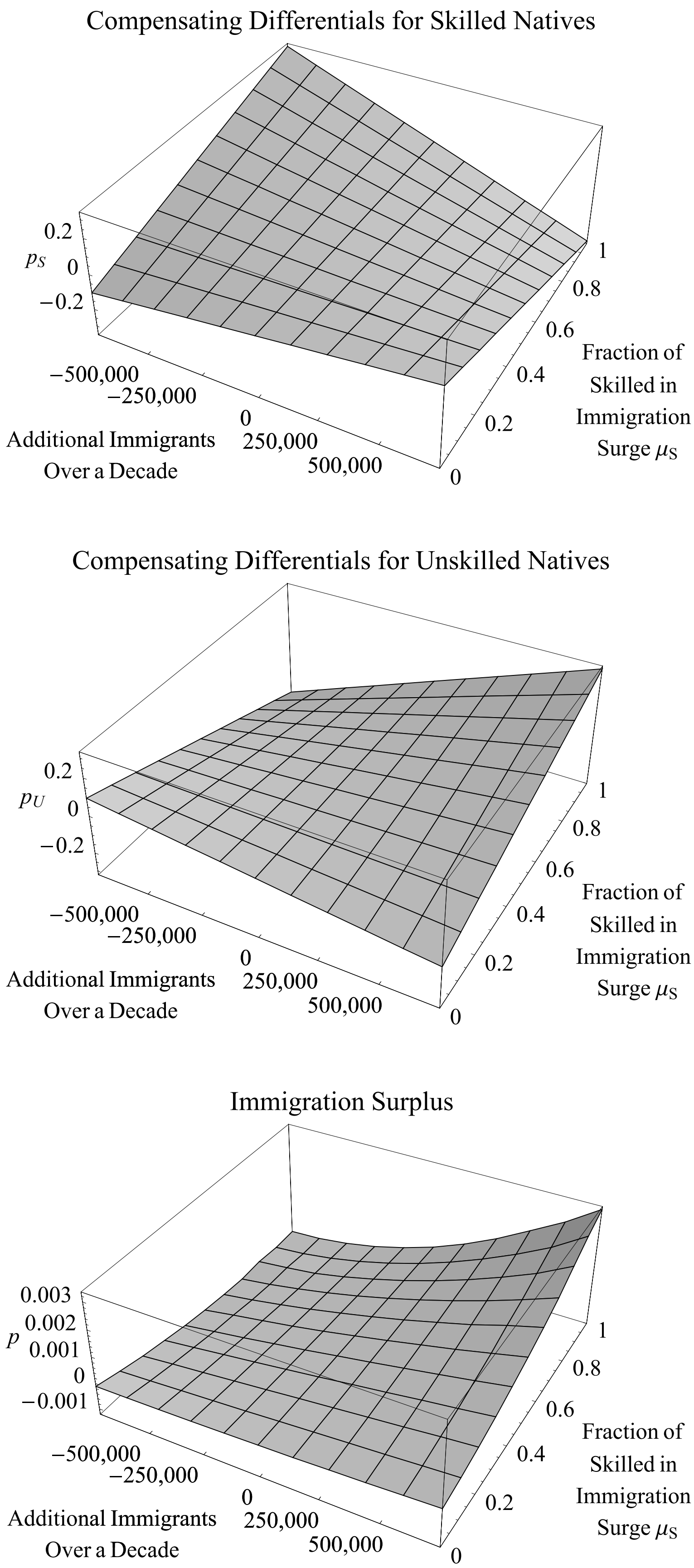

Figure 7: The compensating differentials, p_S and p_U from (13), and immigration surplus p from (15), as a function of the changes in the rates of immigration ranging between a drop and a rise of 2.5 per-ten thousand in the rate of immigration, and as a function of the fraction of the additional immigrants that are skilled.

Duration of the Policy	$T = 1$	$T = 3$	$T = 5$	$T = 15$
Thousands of Additional Immigrants per Annum	*295*	*98.33*	*59*	*19.67*
AN INCREASE IN SKILLED IMMIGRATION:				
Skilled Households	−0.1427	−0.1401	−0.1376	−0.1266
Unskilled Households	0.1342	0.1318	0.1294	0.1192
Immigration Surplus	0.0011	0.0010	0.0010	9.6×10^{-4}
AN INCREASE IN UNSKILLED IMMIGRATION:				
Skilled Households	0.0444	0.0439	0.0434	0.0410
Unskilled Households	−0.0411	−0.0407	−0.0402	−0.0379
Immigration Surplus	8.5×10^{-5}	8.5×10^{-5}	8.4×10^{-5}	8.1×10^{-5}
AN INCREASE IN UNDIFFERENTIATED IMMIGRATION:				
Skilled Households	−0.0035	−0.0032	−0.0029	−0.0020
Unskilled Households	0.0038	0.0035	0.0033	0.0024
Immigration Surplus	3.0×10^{-4}	2.8×10^{-4}	2.8×10^{-4}	2.7×10^{-4}

Table 4: Compensating differentials generated by the addition of an additional two hundred thousand and ninety-five thousand immigrants to the underlying immigration flow over the course of T years.

in welfare is nearly twice as large, an overall benefit of five billion dollars. The surplus per additional immigrant is $7,644.

7 Sensitivity Analysis

The results in the previous sections demonstrate that, given the elasticities of substitution between the input factors estimated by Krusell *et. al.* (2000), a rise in skilled immigration over and above the pre-existing flow, generates an immigration surplus, just over twelve times greater than the surplus generated by the same number of unskilled immigrants. In this section, we consider how robust this conclusion is to alternative values for the elasticities of substitution.

The impulse responses in Figure 9 describe the reaction of factor returns to, once again, the 29,500 per annum, ten-year increase in the inflow of skilled immigrants for different elasticities of substitution: when both elasticities of substitution are low ($\sigma_{SK} = .5$, $\sigma_{UK} = 1.5$) or high ($\sigma_{SK} = 1$, $\sigma_{UK} = 2$), and for each high and low combination, ($\sigma_{SK} = .5$, $\sigma_{UK} = 2$), and ($\sigma_{SK} = 1$, $\sigma_{UK} = 1.5$). The general pattern of the impulse responses—a monotonic rise in (the detrended value of) unskilled wages, a sharp drop in (the detrended value of) skilled wages followed by partial recovery, a sharp rise in the rate of return to capital followed by gradual

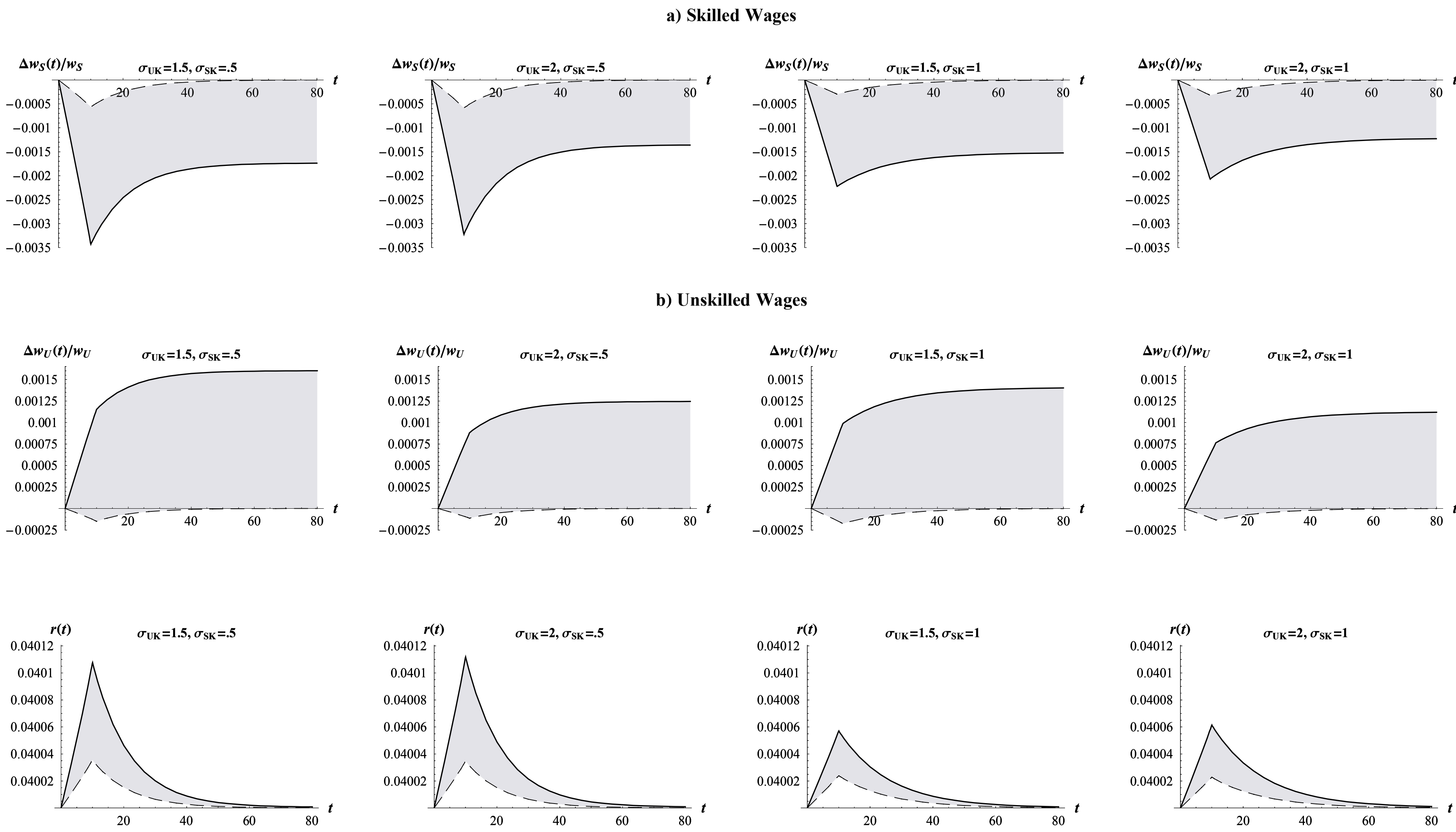

Figure 8: Sensitivity analysis: impulse responses of factor returns for different values of σ_{SK} and σ_{UK}. The solid curves represent changes in factor returns generated by an increase from 3.2 to 3.3 per thousand per annum in the rate of immigration, for ten years only, and all the additional immigrants are members of households with skilled workers. The dashed curves are the effects of a corresponding increasing in both rates of immigration.

	All values of σ_{SK}			σ_{SK}=.5			σ_{SK}=.75			σ_{SK}=1		
	c_{UK}	c_{UU}	c_{KK}	c_{SK}	c_{SS}	c_{UK}^{SK}	c_{SK}	c_{SS}	c_{UK}^{SK}	c_{SK}	c_{SS}	c_{UK}^{SK}
σ_{UK}=1.5	0.67	-1.69	-0.80	1.52	-3.35	0.85	1.18	-2.77	0.52	0.96	-2.38	0.29
σ_{UK}=1.75	0.57	-1.45	-0.68	1.41	-3.06	0.84	1.12	-2.56	0.55	0.92	-2.22	0.35
σ_{UK}=2	0.50	-1.27	-0.60	1.31	-2.81	0.81	1.07	-2.37	0.57	0.89	-2.08	0.39

Table 5: The relationship between cross and own Allen-Hicks partial elasticities of complimentarity and the cross partial elasticities of substition for the two-level CES production function: $\mathsf{c}_{US} = \mathsf{c}_{UK} = \frac{1}{\sigma_{UK}}$, $\mathsf{c}_{SK} = \frac{(1-\phi_{SK})(\sigma_{UK}-\sigma_{SK})+\sigma_{UK}}{\sigma_{UK}(\phi_{SK}\sigma_{SK}-(1-\phi_{SK})\sigma_{UK})}$, $\mathsf{c}_{UU} = -\frac{1-\phi_U}{\phi_U\sigma_{UK}}$, $\mathsf{c}_{KK} = -\frac{1-\phi_K}{\phi_K\sigma_{UK}}$, $\mathsf{c}_{SS} = -\frac{\phi_S(1-\phi_{SK})(\sigma_{SK}-\sigma_{UK})+(1-\phi_S)\sigma_{UK}}{(\phi_{SK}\sigma_{SK}-(1-\phi_{SK})\sigma_{UK})\phi_S\sigma_{UK}}$. The difference between c_{SK} and c_{UK} is $\mathsf{c}_{SU}^{SK} = \frac{\sigma_{UK}-\sigma_{SK}}{\sigma_{UK}(\phi_{SK}\sigma_{SK}-(1-\phi_{SK})\sigma_{UK})}$.

return to the long run rate of 4%—are all qualitatively robust to different values of σ_{SK} and σ_{UK}. The magnitudes of the impulse responses do vary with the values of the elasticities we choose, but these quantitative differences are best understood in the context of the Allen-Hicks partial elasticities of complementarity.[18]

Both the short and long-run impacts of an influx of skilled immigrants on the wages of skilled workers, are directly related to the absolute value of the own-price complementarity of skilled labor c_{SS} in Table 5. If both elasticities are low ($\sigma_{SK} = .5$, $\sigma_{UK} = 1.5$), the value of c_{SS} is -3.35, and by year ten when all the two hundred and ninety-five thousand additional immigrants have joined the economy, skilled wages are .34% lower than they otherwise would be. Once again, as capital accumulates to accommodate the additional workers, skilled wages recover some lost ground, but in the long-run remain .21% below their previous trend.

Similarly, the wages for unskilled workers rise the most following an influx of skilled immigrants, when the complementarity between skilled and unskilled labor is highest (and substitution is lowest). The way the stock of capital responds over time to the influx of skilled immigrants, also has an indirect effect on the reaction of unskilled wages. The higher the complementarity between the skilled immigrant's labor and capital, the greater the rise in the

[18] Partial elasticities of substitution measure the rate at which one factor is substituted for another following a shift in relative factor prices, assuming that total output and other factor prices remain constant. We are studying the effects of exogenous changes in the supply of inputs—immigrant labor. Therefore even though one input, capital, is not fixed in the long-run, the partial elasticities of complementarity—the relative changes in factor prices following a change in the ratio of inputs (with marginal costs and other inputs constant)—provide a more useful guide for understanding the behavior of the model, than the more commonly reported and estimated elasticities of substitution.

capital stock. Capital and unskilled labor are relative substitutes, but still complement each other. Hence the combination of low substitution between skilled and unskilled labor, and high complementarity between capital and unskilled labor (corresponding to $\sigma_{SK} = .5$, $\sigma_{UK} = 1.5$) implies the highest rise in wages in the short-run, .12%, and the long-run, .16%.

In a static model, the response of the return to capital to an increase in skilled immigration would be both permanent, and solely determined, by the degree of complementarity between capital and skilled labor. Here, with capital adjusting through changes in savings, temporary influxes do not affect the long-run rate of return, and though the short-run rate of return is determined primarily by the elasticity of complementarity between capital and skilled labor, the own price complementarity of capital plays a role as well. This additional factor also influences the immigration surplus.

If the elasticities of substitution are $\sigma_{SK} = .5$ and $\sigma_{UK} = 1.5$, the elasticity of complementarity between skilled labor and capital is highest, c_{SK} =1.52, and by year ten, the influx of skilled immigrants raises the rate of return to capital by 1.08 basis points. The more the elasticity of substitution between skilled labor and capital rises, the lower the elasticity of complementarity, and the lower the short-run response of the rate of return. If $\sigma_{SK} = 1$ and $\sigma_{UK} = 1.5$, then c_{SK} =0.96, and the rate of return to capital rises by no more than 0.57 of a basis point. However, holding constant the value of σ_{SK}, while raising the value of σ_{UK} lowers the value of c_{SK}, but the own price complementarity of capital is dropping (in absolute value) with increases in σ_{UK}, and this effect dominates. The lower (in absolute value) is c_{KK}, the less the rate of return is responsive to the additional capital that is gradually accumulating to accommodate the additional workers. If $\sigma_{SK} = .5$ and $\sigma_{UK} = 2$, then c_{SK} is only 1.31, but in year ten the rate of return is 1.11 basis points above its long-run value.

The response of unskilled wages to an influx of unskilled immigrants, is primarily determined by the value of c_{UU}—the higher its value (in absolute value) the greater the drop in unskilled wages. The largest long-run decline in unskilled wages, 0.055%, occurs where both the elasticities of substitution are low ($\sigma_{SK} = .5$ and $\sigma_{UK} = 1.5$), and the smallest decline, 0.039%, occurs where both elasticities are high ($\sigma_{SK} = 1$ and $\sigma_{UK} = 2$). A secondary determining factor is the relative complementarity between skilled labor and capital, when compared to the complementarity between unskilled labor and capital: c_{UK}^{SK}=c_{SK}-c_{UK}. The higher the value of c_{UK}^{SK}, the greater the drop in unskilled wages.

The complementarity between unskilled and skilled workers, c_{US} (equal to c_{UK}), is what primarily determines the response of skilled wages to the influx of unskilled immigrants. If $\sigma_{SK} = .5$ and $\sigma_{UK} = 1.5$, the complementarity between the two types of labor is high, and long-run (de-trended) wages are 0.060% higher as a consequence of the influx of unskilled immigrants.

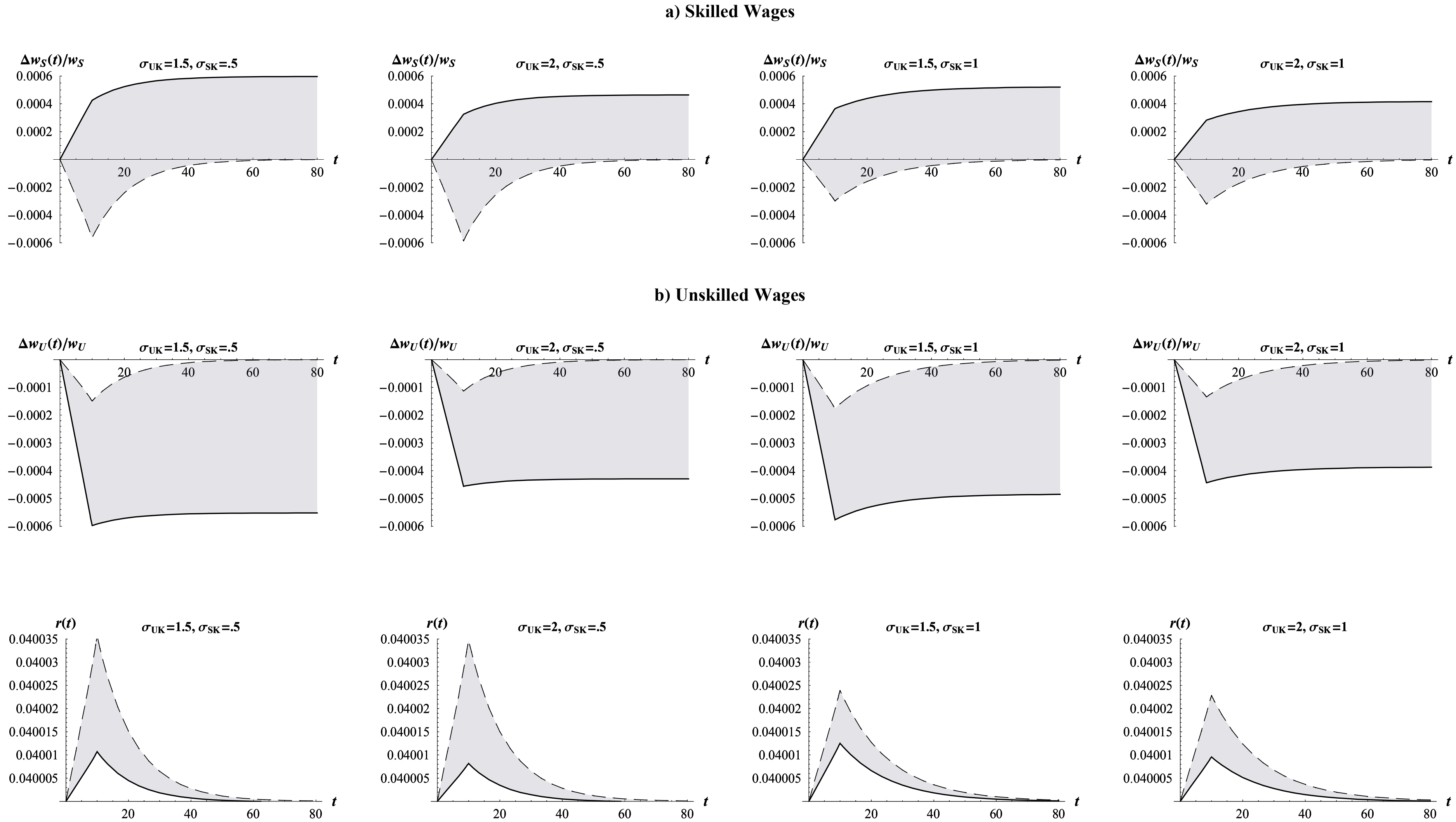

Figure 9: Sensitivity analysis: impulse responses of factor returns for different values of σ_{SK} and σ_{UK}. The solid curves represent changes in factor returns generated by an increase from 3.2 to 3.3 per thousand per annum in the rate of immigration, for ten years only, and all the additional immigrants are members of households with unskilled workers. The dashed curves are the effects of a corresponding increasing in both rates of immigration.

		$\sigma_{SK} = .5$	$\sigma_{SK} = .75$	$\sigma_{SK} = 1$
An Increase in Skilled Immigration:				
$\sigma_{UK} = 1.5$	*Skilled Households*	-0.1523	-0.1385	-0.1276
	Unskilled Households	0.1434	0.1301	0.1198
	Immigration Surplus	0.0011	9.2×10^{-4}	7.5×10^{-4}
$\sigma_{UK} = 1.75$	*Skilled Households*	-0.1358	-0.1240	-0.1148
	Unskilled Households	0.1279	0.1167	0.1079
	Immigration Surplus	0.0011	9.3×10^{-4}	8.1×10^{-4}
$\sigma_{UK} = 2$	*Skilled Households*	-0.1228	-0.1125	-0.1045
	Unskilled Households	0.1160	0.1062	0.0985
	Immigration Surplus	0.0012	9.6×10^{-4}	8.6×10^{-4}
An Increase in Unskilled Immigration:				
$\sigma_{UK} = 1.5$	*Skilled Households*	0.0484	0.0453	0.0427
	Unskilled Households	-0.0448	-0.0419	-0.0394
	Immigration Surplus	8.0×10^{-5}	1.1×10^{-4}	1.4×10^{-4}
$\sigma_{UK} = 1.75$	*Skilled Households*	0.0422	0.0398	0.0378
	Unskilled Households	-0.0391	-0.0368	-0.0349
	Immigration Surplus	6.2×10^{-5}	9.0×10^{-5}	1.2×10^{-4}
$\sigma_{UK} = 2$	*Skilled Households*	0.0375	0.0355	0.0339
	Unskilled Households	-0.0348	-0.0329	-0.0313
	Immigration Surplus	4.4×10^{-5}	7.5×10^{-5}	1.0×10^{-4}
An Increase in Undifferentiated Immigration:				
$\sigma_{UK} = 1.5$	*Skilled Households*	-0.0031	-0.0018	-9.3×10^{-4}
	Unskilled Households	0.0034	0.0022	0.0014
	Immigration Surplus	2.8×10^{-4}	2.7×10^{-4}	2.7×10^{-4}
$\sigma_{UK} = 1.75$	*Skilled Households*	-0.0034	-0.0022	-0.0013
	Unskilled Households	0.0037	0.0025	0.0017
	Immigration Surplus	2.8×10^{-4}	2.7×10^{-4}	2.7×10^{-4}
$\sigma_{UK} = 2$	*Skilled Households*	-0.0036	-0.0024	-0.0016
	Unskilled Households	0.0039	0.0028	0.0020
	Immigration Surplus	2.8×10^{-4}	2.7×10^{-4}	2.6×10^{-4}

Table 6: Compensating differentials generated by the addition of an additional two million skilled immigrants to the underlying immigration flow over the course of ten years, for different elasticities of substitution.

If $\sigma_{UK} = 2$, the rise is almost a third smaller—only 0.046%. Again the value of c_{UK}^{SK} plays a secondary role, the higher its value, the greater the rise in skilled wages. The rate of return to capital changes only slightly, regardless what parameters we choose, ranging from .082 of a basis point if $\sigma_{SK} = .5$ and $\sigma_{UK} = 2$, to .125 of a basis point if $\sigma_{SK} = 1$ and $\sigma_{UK} = 1$.

What do these patterns of factor returns imply for welfare? The simple answer is that for both influxes of skilled and unskilled immigrants, there is a monotonic, and direct relationship, between the rise in the returns to capital, and the size of the immigration surplus. In fact, the larger the surplus from high-skilled immigration, the smaller the surplus from low-skilled immigration. High skilled immigration generates the highest surplus, equivalent to a 0.0012% increase in permanent consumption, when the elasticities of substitution are $\sigma_{SK} = .5$ and $\sigma_{UK} = 2$, and low-skilled immigration generates the lowest surplus, 4.4×10^{-5}, with these very same elasticities. Skilled immigrants generate a surplus that is twenty-seven times the surplus generated by unskilled immigrants.

High-skilled immigration generates the lowest increase in the immigration surplus, 7.5×10^{-4} if the values of the elasticities are $\sigma_{SK} = 1$ and $\sigma_{UK} = 1.5$, and these are the elasticities that correspond to the highest surpluses generated by unskilled immigration, 1.4×10^{-4}. Here the immigration surplus from skilled immigration is only 5.4 times the surplus generated by unskilled immigration. This gap, though only half what is generated in the baseline model, is still substantial, considering that the skilled workers are only 2.7 times more productive than the unskilled.

In summary, these results demonstrate that for a wide range of elasticities, high-skilled immigrants generate far higher surpluses than low-skilled immigrants, far higher than implied by simple comparisons of their marginal products, and before even considering their differential impact on government expenditure and revenue.

8 Conclusion

Soaring populations, stagnant economies, and unstable politics throughout much of the undeveloped world have combined with ever cheaper transportation costs to produce a vast pool of people desperate to migrate to the West. Most of these people have little formal education—they possess little but a willingness to work very long hours at the most menial jobs. A minority, however, possess sufficient education, technical knowledge or entrepreneurial skills to quickly join the professional class of any Western society willing to admit them.

Consider competing proposals by Borjas (1999b) and Storesletten (1999) to reform U.S. immigration policy. Borjas advocates a large cut in the overall rate of immigration; remaining visas would be allocated through a points system designed to give greater precedence to potential immigrants with skills over unskilled people with family ties to current U.S. citizens. Such a policy would reduce wage inequality and might be efficient as well—the heavy reliance of unskilled immigrants on social services overwhelms whatever small surpluses he believes they generate. Storesletten advocates a dramatic increase in the number of skilled immigrants—if a sufficiently large number of college-educated foreigners are permitted to migrate to the United States, long-run fiscal imbalances can be resolved without tax increases or cuts in social insurance benefits.[19]

The two proposals share a common element—increasing the ratio of skilled to unskilled immigrants lowers the tax burden.[20] This paper does not address fiscal policy, but its conclusions complement those that do. Raising the ratio of skilled to unskilled immigrants has the potential to both lower the gap in income between skilled and unskilled workers and to generate as significant rise in the immigration surplus. Furthermore these effects are largely due to either the complementarity between skilled labor and capital, or the degree to which unskilled labor is a substitute for capital. As production technologies continue to evolve, the dichotomous welfare effects generated by different types of immigration may very well intensify. Given recent trends in immigration policy, it seems that Western governments increasingly intuit this.

Not very long ago, indeed as late as 1973, the West German government actively encouraged its industrial firms to recruit millions of guest workers to man shop floors and assembly lines. The German population is now ageing rapidly, and generous social welfare payments leave the less-educated among German workers with little incentive to accept menial low-paying jobs. Nonetheless it is hard to imagine any present-day German government ready to contemplate negotiating agreements with developing countries to once more supply millions of unskilled *Gastarbeiten*. Instead, the German government is proposing to recruit far smaller numbers of high-skilled professionals to permanently settle in Germany, and help develop and sustain its high tech sector.

Here is an important distinction. The *Bracero* programs (1942-1964) brought agricultural workers to the United States with the full agreement and cooperation of the Mexican government; likewise, between 1955 and 1968, Italy, Spain, Greece, Turkey, Morocco, Tunisia, and Yugoslavia each signed agreements to facilitate the migration of their citizens to Germany. Immigrants

[19] Storesletten (1999) calculates that if the rate of skilled immigrants between the ages of 25 to 49 is increased 11-fold, the United States can avoid raising the tax rate by 4.4%.

[20] Dolmas and Huffman (2003) and Ortega (2003), (2004) tackle the question of voting for different immigration policies in the context of redistributive politics. Though we do not consider the implications of immigrant political enfranchisement or taxation, we do provide some infrastructure for further work on the subject—in particular *vis-a-vis* unskilled immigration.

alleviated perceived labor shortages in the West, while sending home hard currency in the form of remittances.

No more. Our results suggest that as far as immigration policy is concerned, conflict rather than cooperation may increasingly become the norm. U.S. immigration policy is no longer a purely domestic issue. Instead, Mexico's President lobbies his U.S. counterpart to gain more visas for his country's low-skilled workers, and legalize the status of undocumented aliens as well. Meanwhile, recent Canadian efforts to recruit physicians from South Africa met with intense resistance, and led to a diplomatic crisis between the two countries.

How will the nations of the developing world respond if Western countries continue to erect new hurdles to immigration as a whole, even as they intensify their efforts to lure away these same countries' small numbers of highly productive workers? What steps will they employ to stop them? In its 2001 Human Development Report, the United Nations Development Program revived a proposal, first advanced by Jagdish Bhagwati in 1972, to tax emigrants from less developed countries or the foreign firms that recruit them.

During the 1980's, the government of Taiwan actively encouraged and subsidized efforts to repatriate engineers and scientists who had moved abroad in previous decades. In all likelihood some countries will seek to emulate the Taiwanese example; hopefully none will resort to harsh Soviet-style travel restrictions. The late Julian Simon referred to human ingenuity as 'the ultimate resource'. The struggle to control who will enjoy its benefits may yet define the history of the twenty-first century.

9 Appendix

Because the sets of equations for each type are similar, the condition number of the 4×4 Jacobian matrix can be very high—leading to inaccurate results. For numerical simulations we replace the two equations in (6) with a law of motion for the logarithm of consumption for unskilled households $a_U(t) = \ln \tilde{c}_U(t)$, and a law of motion for the ratio between the present values of skilled and unskilled labor income $\chi(t) = \frac{\omega_S(t)}{\omega_U(t)}$.

$$\dot{a}_U(t) = r(t) - \rho - x - (\rho - n) e^{-a_U(t)} \tilde{k}_U(t) m_U(t) \kappa_U(t) \tag{16}$$

$$\dot{\chi}(t) = (\rho - n) \frac{\chi(t) \tilde{w}_U(t) - \tilde{w}_S(t)}{e^{a_U(t)} - (\rho - n) \tilde{k}_U(t)} \tag{17}$$

$$\dot{\tilde{k}}_U(t) = \tilde{w}_U(t) + (r(t) - n - x - m_U(t) \kappa_U(t)) \tilde{k}_U(t) - e^{a_U(t)} \tag{18}$$

$$\dot{\tilde{k}}_S(t) = \tilde{w}_S(t) + (r(t) - \rho - x - m_S(t) \kappa_S(t)) \tilde{k}_S(t) + \left((\rho - n) \tilde{k}_U(t) - e^{a_U(t)}\right) \chi(t) \tag{19}$$

$$\begin{aligned} \begin{bmatrix} \frac{\partial}{\partial \epsilon} \dot{a}_U(t,\epsilon,\pi) \\ \frac{\partial}{\partial \epsilon} \dot{\chi}(t,\epsilon,\pi) \\ \frac{\partial}{\partial \epsilon} \dot{\tilde{k}}_U(t,\epsilon,\pi) \\ \frac{\partial}{\partial \epsilon} \dot{\tilde{k}}_S(t,\epsilon,\pi) \end{bmatrix} &= \mathbf{J} \begin{bmatrix} \frac{\partial}{\partial \epsilon} a_U(t,\epsilon,\pi) \\ \frac{\partial}{\partial \epsilon} \chi(t,\epsilon,\pi) \\ \frac{\partial}{\partial \epsilon} \tilde{k}_U(t,\epsilon,\pi) \\ \frac{\partial}{\partial \epsilon} \tilde{k}_U(t,\epsilon,\pi) \end{bmatrix} - \begin{bmatrix} (\rho - n) e^{-a_U} k_U \kappa_U \pi_U(t) \\ 0 \\ \tilde{k}_U \kappa_U \pi_U(t) \\ \tilde{k}_S \kappa_S \pi_S(t) \end{bmatrix} \\ &\quad - \begin{bmatrix} \Omega_K \\ \frac{(\rho-n)(\chi l_U \Omega_U - l_S \Omega_S)}{e^{a_U} - (\rho-n)\tilde{k}_U} \\ \tilde{k}_U \Omega_K + l_U \Omega_U \\ \tilde{k}_S \Omega_K + l_S \Omega_S \end{bmatrix} \eta(0) \int_0^t (\pi_S(z) - \pi_U(z))\, dz \end{aligned} \tag{20}$$

We solve (20) using Laplace transforms:

$$\begin{aligned} \begin{bmatrix} \mathcal{L}_v \left[\frac{\partial}{\partial \epsilon} a_U(t,\epsilon,\pi)\right] \\ \mathcal{L}_v \left[\frac{\partial}{\partial \epsilon} \chi(t,\epsilon,\pi)\right] \\ \mathcal{L}_v \left[\frac{\partial}{\partial \epsilon} \tilde{k}_U(t,\epsilon,\pi)\right] \\ \mathcal{L}_v \left[\frac{\partial}{\partial \epsilon} \tilde{k}_S(t,\epsilon,\pi)\right] \end{bmatrix} &= (v\mathbf{I} - \mathbf{J})^{-1} \left(\begin{bmatrix} \frac{\partial}{\partial \epsilon} a_U(0,\epsilon,\pi) - (\rho - n) e^{-a_U} \kappa_U \tilde{k}_U \mathcal{L}_v[\pi_U] \\ \frac{\partial}{\partial \epsilon} \chi(0,\epsilon,\pi) \\ - \kappa_U \tilde{k}_U \mathcal{L}_v[\pi_U] \\ - \kappa_S \tilde{k}_S \mathcal{L}_v[\pi_S] \end{bmatrix} \right. \\ &\quad \left. - \eta(0) \begin{bmatrix} \Omega_K \\ \frac{(\rho-n)(\chi l_U \Omega_U - l_S \Omega_S)}{e^{a_U} - (\rho-n)\tilde{k}_U} \\ \tilde{k}_U \Omega_K + l_U \Omega_U \\ \tilde{k}_S \Omega_K + l_S \Omega_S \end{bmatrix} \left(\frac{\mathcal{L}_v[\pi_S]}{v} - \frac{\mathcal{L}_v[\pi_U]}{v} \right) \right) \end{aligned} \tag{21}$$

The time zero values $a_U(0,\epsilon,\pi)$ and $\chi(0,\epsilon,\pi)$ are obtained from the solution to:

$$\operatorname{adj}[v_j \mathbf{I} - \mathbf{J}] \left(\begin{bmatrix} \frac{\partial}{\partial \epsilon} a_U(0,\epsilon,\pi) - (\rho - n) e^{-a_U} \kappa_U \tilde{k}_U \mathcal{L}_{v_j}[\pi_U] \\ \frac{\partial}{\partial \epsilon} \chi(0,\epsilon,\pi) \\ -\kappa_U \tilde{k}_U \mathcal{L}_{v_j}[\pi_U] \\ -\kappa_S \tilde{k}_S \mathcal{L}_{v_j}[\pi_S] \end{bmatrix} \right.$$

$$-\eta\left(0\right)\begin{bmatrix}\Omega_K\\ \frac{(\rho-n)(\chi l_U\Omega_U-l_S\Omega_S)}{e^{a_U}-(\rho-n)\tilde{k}_U}\\ \tilde{k}_U\Omega_K+l_U\Omega_U\\ \tilde{k}_S\Omega_K+l_S\Omega_S\end{bmatrix}\left(\frac{\mathcal{L}_{\upsilon_j}\left[\pi_S\right]}{\upsilon_j}-\frac{\mathcal{L}_{\upsilon_j}\left[\pi_U\right]}{\upsilon_j}\right)\Bigg)=0,\ j=\{1,2\} \tag{22}$$

where υ_1 and υ_2 are the two positive eigenvalues of the matrix $\mathbf{J}$. Solving the system yields for the first order approximation yields:

$$\begin{bmatrix}\frac{\partial}{\partial\epsilon}a_U(t,\epsilon,\pi)\\ \frac{\partial}{\partial\epsilon}\chi(t,\epsilon,\pi)\\ \frac{\partial}{\partial\epsilon}\tilde{k}_U(t,\epsilon,\pi)\\ \frac{\partial}{\partial\epsilon}\tilde{k}_S(t,\epsilon,\pi)\end{bmatrix} = e^{\mathbf{J}t}\begin{bmatrix}\frac{\partial}{\partial\epsilon}a_U(0,\epsilon,\pi)\\ \frac{\partial}{\partial\epsilon}\chi(0,\epsilon,\pi)\\ 0\\ 0\end{bmatrix}-\int_0^t e^{\mathbf{J}(t-z)}\begin{bmatrix}\left(\rho-n\right)e^{-a_U}\kappa_U\tilde{k}_U\pi_U\left(z\right)\\ 0\\ \kappa_U\tilde{k}_U\pi_U\left(z\right)\\ \kappa_S\tilde{k}_S\pi_S\left(z\right)\end{bmatrix}dz \tag{23}$$

$$-\eta\left(0\right)\int_0^t e^{\mathbf{J}(t-z)}\begin{bmatrix}\Omega_K\\ \frac{(\rho-n)(\chi l_U\Omega_U-l_S\Omega_S)}{e^{a_U}-(\rho-n)\tilde{k}_U}\\ \tilde{k}_U\Omega_K+l_U\Omega_U\\ \tilde{k}_S\Omega_K+l_S\Omega_S\end{bmatrix}\int_0^z\left(\pi_S\left(u\right)-\pi_U\left(u\right)\right)du dz.$$

Having obtained the values of $\frac{\partial a_U(t,\epsilon,\pi)}{\partial\epsilon}$, $\frac{\partial\chi(t,\epsilon,\pi)}{\partial\epsilon}$, $\frac{\partial\tilde{k}_U(t,\epsilon,\pi)}{\partial\epsilon}$, and $\frac{\partial\tilde{k}_S(t,\epsilon,\pi)}{\partial\epsilon}$ we obtain second-order approximations by differentiating the system twice by ϵ:

$$\begin{bmatrix}\frac{\partial^2}{\partial\epsilon\partial\epsilon}\dot{a}_U(t,\epsilon,\pi)\\ \frac{\partial^2}{\partial\epsilon\partial\epsilon}\dot{\chi}(t,\epsilon,\pi)\\ \frac{\partial^2}{\partial\epsilon\partial\epsilon}\dot{\tilde{k}}_U(t,\epsilon,\pi)\\ \frac{\partial^2}{\partial\epsilon\partial\epsilon}\dot{\tilde{k}}_S(t,\epsilon,\pi)\end{bmatrix}=\mathbf{J}\begin{bmatrix}\frac{\partial^2}{\partial\epsilon\partial\epsilon}a_U(t,\epsilon,\pi)\\ \frac{\partial^2}{\partial\epsilon\partial\epsilon}\chi(t,\epsilon,\pi)\\ \frac{\partial^2}{\partial\epsilon\partial\epsilon}\tilde{k}_U(t,\epsilon,\pi)\\ \frac{\partial^2}{\partial\epsilon\partial\epsilon}\tilde{k}_S(t,\epsilon,\pi)\end{bmatrix}+\begin{bmatrix}\Gamma_{1,1}\\ \Gamma_{1,2}\\ \Gamma_{1,3}\\ \Gamma_{1,4}\end{bmatrix}+\begin{bmatrix}\Gamma_{2,1}\pi_U\left(t\right)\\ 0\\ \Gamma_{2,3}\pi_U\left(t\right)\\ \Gamma_{2,4}\pi_S\left(t\right)\end{bmatrix}$$

$$+\begin{bmatrix}\Gamma_{3,1}\\ \Gamma_{3,2}\\ \Gamma_{3,3}\\ \Gamma_{3,4}\end{bmatrix}\int_0^t\left(\pi_S\left(z\right)-\pi_U\left(z\right)\right)dz+\begin{bmatrix}\Gamma_{4,1}\\ \Gamma_{4,2}\\ \Gamma_{4,3}\\ \Gamma_{4,4}\end{bmatrix}\left(\int_0^t\left(\pi_S\left(z\right)-\pi_U\left(z\right)\right)dz\right)^2 \tag{24}$$

$\{\Gamma_{i,1},\Gamma_{i,2},\Gamma_{i,3},\Gamma_{i,4}\}_{i=1}^3$ are functions of $\frac{\partial a_U(t,\epsilon,\pi)}{\partial\epsilon}$, $\frac{\partial\chi(t,\epsilon,\pi)}{\partial\epsilon}$, $\frac{\partial\tilde{k}_U(t,\epsilon,\pi)}{\partial\epsilon}$, and $\frac{\partial\tilde{k}_S(t,\epsilon,\pi)}{\partial\epsilon}$ and second and third derivatives of the production function, and $\{\Gamma_{4,1},\Gamma_{4,2},\Gamma_{4,3},\Gamma_{4,4}\}$ are functions of second and third derivatives of the production function.We then repeat this process again to obtain third-order approximations.

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