Immigration, Technology Adoption and Wage Inequality*

Ehsan Vallizadeh†

IAB and Maastricht University

May 13, 2015
Preliminary

Abstract

This paper examines the impact of immigration-induced changes in the domestic skill mix on the wage structure. A theoretical model is developed that accounts for monopolistic competition, capital-skill complementarity, and endogenous technology adoption. The analysis reveals several novel insights. Changes in the domestic wage structure induced by immigration are decomposed into two key channels: a labor supply effect, and a technology adoption effect. The interaction between the two channels depends i) on the magnitude between goods demand elasticity and market power of monopolists, and ii) on the degree of technology adoption. For a sufficient degree of imperfect technology adoption, immigration of medium-skilled workers leads to a wage polarization effect, whenever the market power of monopolists is larger than the goods demand elasticity. If immigration is biased towards low-skilled (high-skilled) workers, changes in the skill structure is similar to "unskill-bias" ("skill-bias") technical changes, whenever the goods demand elasticity is larger than the market power of monopolists.

Keywords Immigration · Skills · Technology Adoption · Wage Inequality

JEL F22 · J2 · J31 · O33

*I am grateful for valuable comments and discussions to Joan Muysken and Thomas Ziesemer. I would also like to thank seminar participants at TASK III - the 3rd International BIBB/IAB/ZEW conference in Nuremberg.

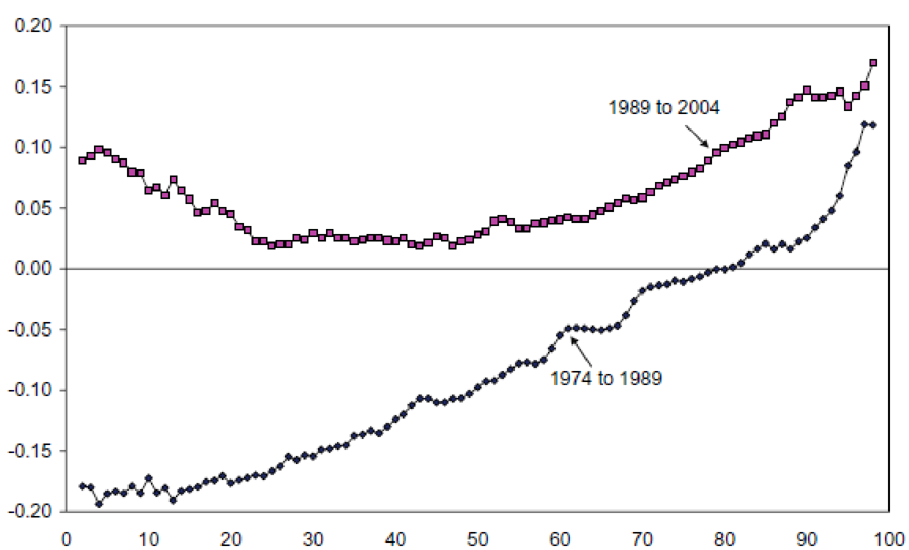
†Institute for Employment Research (IAB), Research Department B1, Weddigenstr. 20 - 22, 90478 Nürnberg, Germany. ehsan.vallizadeh@iab.de, T: +49 911 179 78 36.

1 Introduction

In many advanced countries, immigration has substantially increased the foreign-born population share, accompanied by considerable changes in their skill structure over the last decades. For example, many European Union member states have experienced a considerable shift in the skill structure of immigrants towards medium- and high-skill attainments (cf. Muysken et al., 2015). Consequently, immigration has a substantial impact on the skill mix of the workforce in the host country. Concerns regarding its labor market implication has considerably shaped both the public and academic discourse. This article exploits the potential channels by which immigration-induced changes in the skill structure affect the domestic wage structure. In doing so, I develop a model that allows for a reacher structure of the goods market, characterized by monopolistic competition, firm heterogeneity, and endogenous technology adoption, next to skill heterogeneity. As I elaborate below, these features are substantial to improve our understanding of adjustment mechanism behind the changes in the wage structure.

What does the empirical evidence tell us regarding the relationship between skill mix changes and potential adjustment mechanisms? One set of studies emphasizes the role of endogenous technology changes, the so-called directed technical change (cf. Acemoglu, 1998, 2002). The idea is that the increase in the endowment of skilled workers (including those by immigration) induces a faster growth of skill-complement technologies, which in turn leads to a higher skill premium. This feature is captured in this article through increasing returns to scale property and the endogenous adjustment of the mass of firms to changes in the skill mix, indicating changes at the intensive margin. Related to this view, it has become a widespread consensus that skill-bias technical changes (SBTC) has importantly contributed to the pervasive wage inequality in the 1980s, especially observed in the US. Instead, the puzzling U-shaped wage trends after 1990 has been at-

Figure 1: Changes in real male wages in the US by percentile



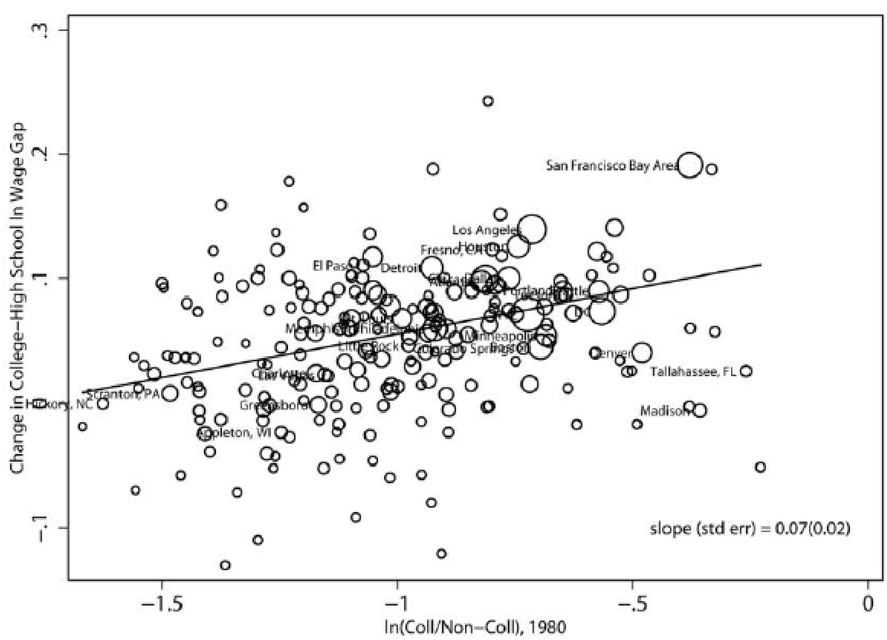
Source: Lemieux (2008).

tributed to advances in information communication technology (ICT), substituting mostly routine-intensive job tasks that are concentrated in the middle of the skill distribution and easily codifiable (cf. Acemoglu and

Autor, 2011; Autor and Dorn, 2013; Autor et al., 2003) – also referred to as the computerization/routinization phenomenon.[1] Figure 1 depicts these contrasting trends in the male wage structure that occurred at different time periods for the US. In this article I argue that a supply shock of medium-skilled workers may partly explain recent polarization trends due to a price effect for technology modes that complement low-skilled and high-skilled workers. I show that the key determinant behind this effect is the market power of monopolists.

Another set of studies provide a more competing view by highlighting the implications of changes in the skill endowment on endogenous technology adoption behavior of firms (Beaudry et al., 2010; Lewis, 2011). For example, Lewis (2011), provides evidence that the low adoption rate of automation machinery in manufacturing plants between 1988 and 1993 was associated with immigration-induced increase of low-skilled workers. Beaudry et al. (2010), using U.S. metropolitan area-level panel data, explore empirically the link between personal computer (PC) adoption and skill attainment. They find a positive relationship, where areas with an initially high relative supply of skill have experienced an increase in the skill premium when PC was introduced, see Figure 2. However, both studies show that over time the relation between skill

Figure 2: Changes in college-high school wage gap 1980-2000, by initial skill-supply and metropolitan area in the U.S.



Source: Beaudry et al. (2010).

supply and its return dissipates since "investments in automation induced by immigration reduce the effect immigration has on wages" (Lewis, 2011, p. 1063), and thus balances the initial supply-driven wage effects.

This channel denotes the important aspects of firm heterogeneity, explaining the asymmetry of firms in terms of productivity which has taken the center-stage in the new trade theory (cf. Melitz, 2003). In this paper, this feature is also captured but instead of a random selection, firms choose endogenously between var-

[1] See Lemieux (2008) for a detailed survey of the literature regarding alternative explanations, such as changes in wage-setting institutions, regarding the rise in income inequality in many advanced countries.

ious technology modes according to their comparative advantages (cf. Acemoglu and Zilibotti, 2001; Yeaple, 2005). I will refer to this channel as changes at the extensive margin.

Thus, the objective of this paper is to jointly investigate how changes at the extensive and intensive margin are determined and how they interact with each other. In doing so, I develop a model in which a continuum of industries (final goods) is combined to produce an aggregate consumption good. Each final good, in turn, can be produced by three different technology modes, where the extend of technology adoption are endogenous and reflect principles of comparative advantage, as in Acemoglu and Zilibotti (2001); Yeaple (2005).[2] Each technology mode utilizes a distinct composite of intermediate goods, which are, in turn, produced under monopolistic competition, as in Krugman (1979). Furthermore, labor is the sole production factor in the intermediate goods market, implying that the labor market is heterogeneous and consists of three skill groups, each complement to one specific technology mode. In this setup, the equilibrium technology adoption is characterized by two endogenous margins, dividing the economy into three endogenous sets of sectors, each consisting of a continuum of industries.

This model uncovers several novel predictions regarding distributional effects of immigration-induced changes in the skill structure. First, I show that changes in the domestic wage structure can be decomposed into two key channels: i) a labor supply effect, and ii) technology adoption effect. Second, the interaction between these two channels is importantly determined by the interplay between two additional forces. On the one hand, it depends on the magnitude between consumer preferences (i.e. goods demand elasticity) and the market power of monopolists (i.e. elasticity of substitution between intermediate goods). On the other hand, it depends on the degree of adoption between the different technology modes (the extensive margin) which may mitigate the direct labor supply effect. The key implication of the model is that changes at the extensive margin (captured by the degree of technology adoption) countervail the direct supply effect. At the extreme case of easy adoption (i.e. perfect substitutability between technology modes) the two channels are balanced, so that changes in the wage structure become insensitive to labor supply shocks, reconciling the empirical evidence regarding the neutral long-run labor market effects of immigration.

Moreover, considering a more realistic range of parameter values, the analysis provides additional insights that reconcile the empirical observations regarding labor supply shocks and changes in the wage structure. For a sufficient degree of imperfect technology adoption, an immigration-induced increase of high-skilled workers induces changes in the wage structure similar to a "skill-bias" technical change, leading to a monotonic increase in the wage gap across the skill groups, whenever the demand elasticity is higher than the market power of monopolists. This conforms what Acemoglu (2002) gives as explanation for why the relative demand for skill-complements goods has outpaced the skill supply over the last decades. These results uncover a new channel and highlight the importance of firm heterogeneity and endogenous technology adoption in analyzing labor market impacts of immigration. Particularly, these features help substantially to gain new insights regarding the underlying mechanism and the determinants of the adjustment process to immigration-induced changes in the domestic skill structure.

The paper is organized as follows. The next section reviews the existing studies and describes the novel contributions of this paper. In section 3, the setup of the theoretical framework is presented, followed by an elaborating discussion of technology adoption conditions, and firm's optimization problem. The character-

[2] The structure of this model is similar to the Ricardian model with a continuum of goods as in Dornbusch et al. (1977), except that now the equilibrium margins characterize the specialization pattern of the domestic industry, instead of between countries.

istics of the equilibrium are discussed in section 4. The assessment of changes in the optimal technology adoption margins are presented in section 5, followed by the comparative statics of immigration-induced changes in the skill structure on the domestic wage structure in section 6. Finally, concluding remarks are provided in section 7.

2 Literature review

There exist by now a vast number of studies that have examined various mechanisms by which immigration-induced changes in the skill mix affect native workers. Guided by the canonical nested CES-approach, with various extensions regarding capital-skill complementarity and labor market frictions, a large body of these studies provide empirical evidence that highlights the importance of complementarity and substitutability between immigrants and natives, translating mechanically the impact of immigration on the skill mix into an impact on wages – through the elasticity of substitution parameter.[3]

However, it is widely accepted that the effect of immigration on host country's labor market goes beyond this convenient mechanical relationship.[4] Recent empirical studies, including Dustmann and Glitz (2012) for Germany, González and Ortega (2011) for Spain, and Lewis (2003) for the US, have found strong evidence that much of the response to immigration-induced changes in the skill mix occurs within industries (or within firms), through changes in the skill intensity. They find that wages are relatively insensitive to labor supply shocks. These findings support the view "that immigration shocks induce changes in production technology at the industry level" (González and Ortega, 2011, p. 68).

Recent theoretical contributions have emphasized the adjustment channel through changes in the output mix (Felbermayr and Kohler, 2006, 2007; Iranzo and Peri, 2009; Muysken et al., 2015). According to these studies, an unbalanced immigration flow impacts the domestic wage structure through changes in output price, inducing shifts in the output structure. For instance, Muysken et al. (2015) show that the impact of labor supply shock on domestic wage structure depends importantly on the interaction between consumer preferences (i.e. the demand elasticity) and production technology (i.e. the elasticity of substitution between skill groups).[5] In the context of the East-West European integration, Iranzo and Peri (2009) discuss the gains from immigration and trade. They show that overall trade and immigration generate beneficial welfare effects for both regions, low-skilled workers in the West gain unambiguously in terms of real wages, while the real wage effect for high-skilled workers depends on the magnitude between the forces described by Muysken et al. (2015).

However, these models often rely on the standard assumption of representative agent and ex-ante fixed production technology. Thus, this article augments these studies by taking alternative and richer structure of the goods market that allows for firm heterogeneity and endogenous choice of technique (Acemoglu and Zilibotti, 2001; Yeaple, 2005). The key implication of this set of models is that it allows to capture a broader impact of changes in the skill structure on the economy, as both the optimal choice of technology, the com-

[3] Important contributions, among many others, are Borjas (2003); Borjas et al. (2011); Brücker and Jahn (2011); Brücker et al. (2014); Card (2009); D'Amuri et al. (2010); Ottaviano and Peri (2008, 2012); Manacorda et al. (2011); Peri (2011).

[4] See Lewis (2013) for a thorough survey of the literature on immigration.

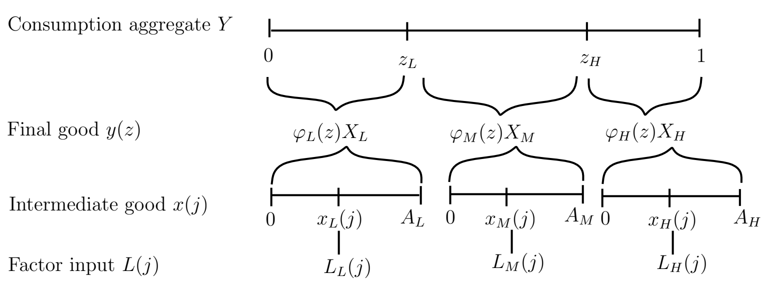
[5] Moreover, they allow for two types of labor market frictions, low-skill unemployment and skill-downgrading of medium-skilled workers, and discuss the importance of labor market institutions for labor market outcomes of low-skilled workers. A shift from a rigid to a flexible unemployment benefit scheme regime induces a complementarity effect between low-skilled unemployment rate and the skill downgrading rate of medium-skilled workers, attenuating potential crowding-out effects of low-skilled workers.

position and the number of firms using different production techniques depend on the skill structure. Thus, the response of producers regarding the adoption of various production techniques to immigration-induced changes in the skill mix “may mediate immigration’s ultimate labor market impact” (Lewis, 2013, p. 10). As I discuss below, the change in the domestic wage structure due to immigration-induced shifts in the skill mix is importantly affected by the degree of technology adoption. This is the novel contribution of this article.

3 Theoretical framework

I consider an economy that is characterized by an aggregated consumption good, which consists of a continuum of final goods. The final goods market is perfectly competitive, where final good producers are homogeneous ex ante. Following a widely used approach in the literature (cf. Acemoglu and Autor, 2011; Acemoglu and Zilibotti, 2001; Yeaple, 2005), I allow for ex post heterogeneity by introducing endogenous sorting into different technology modes based on comparative advantage differences, where firms self-elect endogenously into the most cost-efficient production techniques.[6] The production of a final good requires the adoption of a distinct technology mode and the utilization of a complement composite of intermediate goods. Finally, monopolistically competitive firms produce an intermediate variety by utilizing labor as the sole factor. To get a better idea, Figure 3 illustrates the structure of the framework, which will be discussed in detail in the next section.

Figure 3: Structure of model



3.1 Aggregate consumption good, final goods, and technology adoption

As in Acemoglu and Zilibotti (2001), the aggregate consumption good Y is produced by combining a continuum of final goods, $y(z)$, in a constant elasticity of substitution (CES) aggregate over the interval $[0, 1]$. Each final good variety z can be produced in different technology modes. More precisely, there exist three different modes: low (φ_L), medium (φ_M) or high (φ_H). Similar to Yeaple (2005), the productivity schedule of each technology mode $\varphi(z)$ exhibits the following properties:

[6] Notice the difference to the firm heterogeneity à la Melitz (2003), which allows for ex ante productivity heterogeneity According to this view, heterogeneity is characterized by a random process.

Assumption 1 (Technology schedule)**.**

$$\varphi_L(0) = \varphi_M(0) = \varphi_H(0) = 1 \textit{ and}$$
$$0 < \frac{\mathrm{d}\ln\varphi_L(z)}{\mathrm{d}z} < \frac{\mathrm{d}\ln\varphi_M(z)}{\mathrm{d}z} < \frac{\mathrm{d}\ln\varphi_H(z)}{\mathrm{d}z}, \textit{ for all } z \in [0,1].$$

Therefore, the final goods are ordered so that the higher indexed goods are most productive with the high-quality technology.

Given the properties of the productivity schedules imposed by Assumption 1, there exist two thresholds, denoted by z_L and z_H, which determine the cost-efficient allocation of the three technology modes in the economy. More precisely, we get that the aggregate consumption good Y is produced as follows

$$Y = \left[\int_0^{z_L} y_L(z)^{\frac{\sigma-1}{\sigma}}\mathrm{d}z + \int_{z_L}^{z_H} y_M(z)^{\frac{\sigma-1}{\sigma}}\mathrm{d}z + \int_{z_H}^{1} y_H(z)^{\frac{\sigma-1}{\sigma}}\mathrm{d}z\right]^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

where $\sigma \geq 1$ denotes the elasticity of substitution between the final goods. Each final good is produced by combining a composite of intermediate goods, X_k with the complement technology $\varphi_k(z)$

$$y(z) = \begin{cases} \varphi_L(z)X_L & \text{for all} \quad z \in [0, z_L], \\ \varphi_M(z)X_M & \text{for all} \quad z \in (z_L, z_H), \\ \varphi_H(z)X_H & \text{for all} \quad z \in [z_H, 1]. \end{cases} \tag{2}$$

The cost-efficient conditions are defined by the following lemma.

Lemma 1 (Efficient Technology Allocation)**.** *In equilibrium, the final good price adjusts endogenously for the productivity differences in technology. For marginal final goods z_L and z_H and the price indexes P_L, P_M and P_H of the respective technology mode, it follows*

$$\frac{P_L}{P_M} = \Lambda_L(z_L),\ \Lambda_L(z_L) \equiv \frac{\varphi_L(z_L)}{\varphi_M(z_L)}, \tag{3}$$
$$\frac{P_M}{P_H} = \Lambda_H(z_H),\ \Lambda_H(z_H) \equiv \frac{\varphi_M(z_H)}{\varphi_H(z_H)}, \tag{4}$$

and

$$0 < z_L < z_H < 1, \quad \textit{for} \quad \frac{P_L}{P_M} \in \Big(\Lambda_L(z_H), \Lambda_L(0)\Big) \textit{ and } \frac{P_M}{P_H} \in \Big(\Lambda_H(1), \Lambda_H(z_L)\Big). \tag{5}$$

Proof. See Appendix B.1.

From the optimization problem

$$\max_{y(z)} \Pi_Y = P_Y Y - \int_0^1 p(z)y(z)\mathrm{d}z, \quad \text{s.t. Eq. (1)},$$

the optimal demand for final good $y(z)$ is obtained

$$y_k(z) = P_Y Y p_k(z)^{-\sigma}, \text{ for } k = \{L, M, H\} \tag{6}$$

From Eqs. (1) and (6) the price index of Y is given by

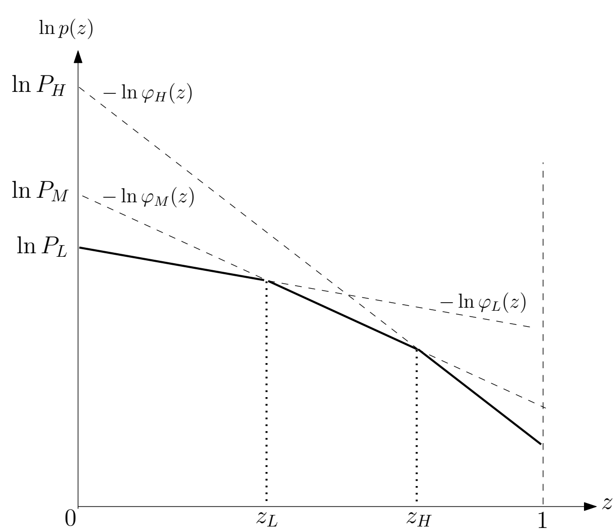
$$P_Y = \left[\int_0^{z_L} p_L(z)^{1-\sigma} \mathrm{d}z + \int_{z_L}^{z_H} p_M(z)^{1-\sigma} \mathrm{d}z + \int_{z_H}^{1} p_H(z)^{1-\sigma} \mathrm{d}z \right]^{\frac{1}{1-\sigma}}. \tag{7}$$

In what follows, the price of the consumption aggregate is normalized to unity, i.e. $P_Y = 1$, so that all goods and factor prices are in real terms. The final goods price can be, then, written as

$$p(z) = \begin{cases} P_L \varphi_L(z)^{-1} & \text{for all} \quad z \in [0, z_L], \\ P_M \varphi_M(z)^{-1} & \text{for all} \quad z \in (z_L, z_H), \\ P_H \varphi_H(z)^{-1} & \text{for all} \quad z \in [z_H, 1], \end{cases} \tag{8}$$

where P_k denotes the effective price index of final goods, i.e. the price per productive technology k, which will be defined below. Figure 4 depicts the equilibrium price and technology schedules, where the solid

Figure 4: Final goods price and technology productivity schedules



kinked curve denotes the equilibrium price-technology frontier (PTF).

3.2 Intermediate goods market

In contrast to the final goods market, the intermediate goods market is characterized by monopolistic competition, where each intermediates, in turn, is manufactured by workers. In addition, each variety requires a product development fixed cost, f_k. As in Yeaple (2005), I assume that fixed costs are measured in terms of the numeraire good and the size of this fixed cost depends on the technology mode adopted, where $f_H > f_M > f_L$ is imposed. This specification of the fixed costs aims for the sake of tractability of the model. Alternative specification, such as measuring the fixed costs in terms of factor labor, would complicate considerably the labor market clearing condition. The production technology of the composite good X_k is represented by a Constant Elasticity of Substitution (CES) aggregator over a continuum of varieties, indexed by j:

$$X_k = \left(A_k^{\frac{\nu-1}{\epsilon}} \int_0^{A_k} x_k(j)^{\frac{\epsilon-1}{\epsilon}} \mathrm{d}j \right)^{\frac{\epsilon}{\epsilon-1}}, \tag{9}$$

where $x(j)$ denotes the amount of variety $j \in [0, A_k]$, $\epsilon \geq 1$ captures the elasticity of substitution between varieties, and A_k measures the mass of monopolists in technology mode k. The parameter ν determines the degree of external increasing returns to scales of the production process. For limiting values of $\nu = 0$, the differentiated good X is independent of A, cf. Egger et al. (2013). For $\nu = \epsilon - 1$, the CES aggregator becomes becomes linear in A, as in Acemoglu et al. (2012). Here, I impose the special case where $\nu = 1$, as in Iranzo and Peri (2009). In this case the production technology is characterized by external increasing returns of scales.[7]

Each intermediate is produced by a single monopolist which is characterized by a constant return to scale production technology with labor as the sole input:

$$x_k(j) = L_k(j), \tag{10}$$

where L_k is the quantity of labor employed by the firm using technology k.

Demand for intermediate goods

In any technology mode $k = \{L, M, H\}$, the optimal amount of intermediates is obtained by minimizing the cost, $\int_0^{A_k} p_k(j)x_k(j)\mathrm{d}j$ subject to (9) which yields the following inverse demand function for intermediates (see Appendix A.1 for the derivation):

$$p_k(j) = \zeta_k X_k^{\frac{1}{\epsilon}} x_k(j)^{-\frac{1}{\epsilon}}, \, \forall \, k = \{L, M, H\}, \tag{11}$$

where $p_k(j)$ is the price of each intermediate variety produced with technology mode k. Combining (11) with (9) yields the marginal cost of composite intermediate goods

$$\zeta_k = \left(\int_0^{A_k} p_k(j)^{1-\epsilon} \mathrm{d}j \right)^{\frac{1}{1-\epsilon}}. \tag{12}$$

Intermediate firm behavior

Under the constant elastic demand function (11) of degree $\epsilon > 1$ and the linear property of the production technology, the profit maximizing monopolist sets the price equal to a markup $\epsilon/(\epsilon - 1)$ over the respective marginal cost, i.e.

$$p_k(j) = \frac{\epsilon}{\epsilon - 1} w_k, \tag{13}$$

[7] However, it is worth mentioning that for an empirically plausible value of the elasticity of substitution $\epsilon = 2$ both limiting cases $\nu = 1$ and $\nu = \epsilon - 1$ generate equivalent analytical results (cf. Ottaviano and Peri, 2012).

where w_k denotes the marginal cost of k-type labor.

Having defined the structure of the economy and the optimality conditions, the next section proceeds with the characteristics of the equilibrium.

4 Characteristics of equilibrium

In a standard symmetric equilibrium, the varieties of the differentiated good X_k employ the same amount of factor labor $L_k(j) = L_k$, are sold at the same price $p_k(j) = p_k$ and are produced in equal amount $x_k(j) = x_k$, for all $k = \{L, M, H\}$.

Resource constraint: Let the total amount of labor used in each set of technology $[0, A_k]$ be denoted by n_k, and the total resource constraint (i.e. over the range of final goods produced with technology mode k) by

$$\begin{aligned}\int_{z\in\mathcal{S}_k} n_k \mathrm{d}z &= N_k,\\ \mathcal{S}_k &= \begin{cases}\{0, z_L\} & \text{for } k = L\\ \{z_L, z_H\} & \text{for } k = M\\ \{z_H, 1\} & \text{for } k = H\end{cases}\end{aligned}$$

such that

$$L_L = \frac{n_L}{A_L} = \frac{N_L}{z_L A_L}, \tag{14}$$

$$L_M = \frac{n_M}{A_M} = \frac{N_M}{(z_H - z_L)A_M}, \tag{15}$$

$$L_H = \frac{n_H}{A_H} = \frac{N_H}{(1 - z_H)A_H}. \tag{16}$$

Thus, the first equalities in Eqs. (14), (15), and (16), denote the resource usage by the differentiated-good firms, while the second equalities reflect the overall utilization of factor labor by each final good producer in the economy so that N_L, N_M, and N_H are the total (exogenously given) endowments of labor.

Free entry: Recall the assumption that each monopolists bears a fixed cost in terms of a quantity of numeraire output that must be produced but cannot be sold (cf. Yeaple, 2005). This implies that the effective factor labor employed by each firm in technology mode k is given by $f_k + x_k$. Free entry ensures that each differentiated-good firm makes zero profits so that the quantity for each variety is defined by

$$x_k = (\epsilon - 1)f_k, \quad \forall \quad k = \{L, M, H\}. \tag{17}$$

Marginal costs: Next, using the monopolistic pricing behavior, Eq. (13), the marginal cost of the differentiated good ζ_k, defined in (12), simplifies to

$$\zeta_k = A_k^{\frac{1}{1-\epsilon}} p_k = \frac{\epsilon}{\epsilon - 1} A_k^{\frac{1}{1-\epsilon}} w_k, \ \forall\, k = \{L, M, H\}, \tag{18}$$

Mass of monopolists: Substituting the zero profit condition (17) into the composite intermediate goods function, Eq. (9), and using Eqs. (2) and (8) and the resource constraints (14), (16), and (15), then from the the budget constraint for any final good producer z,

$$p(z)y(z) \quad = \quad w_k \int_0^{A_k} L_k \mathrm{d}j,$$

the mass of monopolists in technology mode k can be pinned down to the skill endowment, fixed costs, the range of final goods, and the degree of substitutability between final goods (see Appendix A.2 for details of the formal derivation).

$$A_L = \frac{N_L}{\epsilon f_L z_L}, \tag{19}$$

$$A_M = \frac{N_M}{\epsilon f_M (z_H - z_L)}, \tag{20}$$

$$A_H = \frac{N_H}{\epsilon f_H (1 - z_H)}. \tag{21}$$

Before proceeding, it is worth noticing the following properties of the equilibrium measure of the mass of monopolists. From Eqs. (19)–(21), it is readily seen that changes in the endowment of labor induce an increase in the respective the mass monopolists in the complementary technology mode. This effect captures the aforementioned the directed technical change at the intensive margin. However, as elaborated below, the technology modes margins, z_L and z_H, will respond endogenously to skill mix changes, generating a "spill-over" effect for the other technology modes. This effect captures changes at the extensive margin. The implication of these forces for the wage structure and their interaction with each other are elaborated below.

Intermediate output: Next, utilizing the labor market clearing conditions (14), (15) and (16), the output per monopolist using technology modes $k = \{L, M, H\}$ can be written, respectively, as

$$x_L = \frac{n_L}{A_L} = \frac{N_L}{z_L A_L}, \quad x_M = \frac{n_M}{A_M} = \frac{N_M}{(z_H - z_L) A_M}, \quad x_H = \frac{n_H}{A_H} = \frac{N_H}{(1 - z_H) A_H}. \tag{22}$$

Substituting (22) into the composite intermediate goods function (9) for the respective technology mode, we obtain

$$\begin{aligned} X_L &= A_L^{\frac{1}{\epsilon-1}} \frac{N_L}{z_L}, \\ X_M &= A_M^{\frac{1}{\epsilon-1}} \frac{N_M}{z_H - z_L}, \\ X_H &= A_H^{\frac{1}{\epsilon-1}} \frac{N_H}{1 - z_H}. \end{aligned} \tag{23}$$

Final goods: Utilizing (23) into Eq. (2), then the production function of final goods can be rewritten as

$$y(z) = \begin{cases} \varphi_L(z) X_L = \varphi_L(z) A_L^{\frac{1}{\epsilon-1}} \frac{N_L}{z_L}, & \text{for all} \quad z \in [0, z_L], \\ \varphi_M(z) X_M = \varphi_M(z) A_M^{\frac{1}{\epsilon-1}} \frac{N_M}{z_H - z_L}, & \text{for all} \quad z \in (z_L, z_H), \\ \varphi_H(z) X_H = \varphi_H(z) A_H^{\frac{1}{\epsilon-1}} \frac{N_H}{1 - z_H}, & \text{for all} \quad z \in [z_H, 1], \end{cases} \tag{24}$$

Aggregate output by technology modes: Finally, we derive the equilibrium aggregate levels of output and expenditure for each technology mode k. Let the total cost using technology k be

$$P_k Y_k = \int_{z\in\mathcal{S}_k} p(z)y(z)\mathrm{d}z,$$

where Y_k denotes the aggregate level of output of final goods using technology mode k. Now, utilizing Eqs. (8) and (24) in the previously derived equation and manipulating slightly, yields the aggregate level of output per technology mode k (see Appendix A.3 for the formal derivation)

$$\begin{aligned} Y_L &= A_L^{\frac{1}{\epsilon-1}} N_L, \\ Y_M &= A_M^{\frac{1}{\epsilon-1}} N_M, \\ Y_H &= A_H^{\frac{1}{\epsilon-1}} N_H. \end{aligned} \tag{25}$$

Relative expenditure on technology modes: The optimal demand condition for final goods, Eq.(6), implies that $p(z)y(z) = Yp(z)^{1-\sigma}$ for all $z \in [0,1]$. Furthermore, Eqs. (8) and (2) imply that $p_L(z_L)y_L(z_L)/Y = p(z_L)^{1-\sigma} = p_M(z_L)y_M(z_L)/Y$ and $p_M(z_H)y_M(z_H)/Y = p(z_H)^{1-\sigma} = p_H(z_H)y_H(z_H)/Y$. That is, the expenditure share on final goods, produced under different technology modes, must be equal at the equilibrium margins, z_L and z_H. Utilizing the optimal demand condition for final goods, Eq. (6), together with Eqs. (8), (24) and (25) imply

$$\frac{P_L Y_L}{z_L} = \frac{P_M Y_M}{z_H - z_L}, \quad \text{and} \quad \frac{P_M Y_M}{z_H - z_L} = \frac{P_H Y_H}{1 - z_H} \tag{26}$$

Finally, we solve for the equilibrium expressions of the margins, z_L and z_H. Substituting Eqs. (25) for the respective aggregate output Y_L, Y_M, and Y_H in Eqs. (26) and using the equilibrium values of the mass of monopolists, (19), (20), and (21), and taking ratios, we obtain the relative aggregated demand for final goods produced with technology mode $k = M$.

$$\frac{P_L}{P_M} = \left(\frac{f_L}{f_M}\right)^{\frac{1}{(\epsilon-1)}} \left(\frac{N_M}{N_L}\right)^{\frac{\epsilon}{(\epsilon-1)}} \left(\frac{z_L}{z_H - z_L}\right)^{\frac{\epsilon}{(\epsilon-1)}}, \tag{27}$$

$$\frac{P_M}{P_H} = \left(\frac{f_M}{f_H}\right)^{\frac{1}{(\epsilon-1)}} \left(\frac{N_H}{N_M}\right)^{\frac{\epsilon}{(\epsilon-1)}} \left(\frac{z_H - z_L}{1 - z_H}\right)^{\frac{\epsilon}{(\epsilon-1)}}. \tag{28}$$

Next, combine (27) and (28) with the efficient allocation of technology modes, Eqs. (3) and (4), derived in Lemma 1, respectively. Now, taking logs, manipulating and rearranging slightly, we obtain two implicit functions $\mathcal{F}_L(\cdot)$ and $\mathcal{F}_H(\cdot)$ that define the equilibrium technology margins z_L and z_H as functions of parameters and exogenous variables.

$$\mathcal{F}_L(z_L, z_H, f_L, f_M, N_L, N_M) \equiv \frac{1}{\epsilon}\ln\left(\frac{f_L}{f_M}\right) + \ln\left(\frac{N_M}{N_L}\right) - \frac{(\epsilon-1)}{\epsilon}\ln\Lambda_L(z_L) - \ln\left(\frac{z_H - z_L}{z_L}\right) = 0, \tag{29}$$

$$\mathcal{F}_H(z_L, z_H, f_H, f_M, N_H, N_M) \equiv \frac{1}{\epsilon}\ln\left(\frac{f_M}{f_H}\right) + \ln\left(\frac{N_H}{N_M}\right) - \frac{(\epsilon-1)}{\epsilon}\ln\Lambda_H(z_H) - \ln\left(\frac{1 - z_H}{z_H - z_L}\right) = 0. \tag{30}$$

This implicit system of equations can be used to compute basic comparative statics of changes in factor endowment and fixed market entry costs and their implications for technology adoption.

5 Immigration and changes in technology adoption margins

Consider first the implication of immigration-induced changes in the medium-skill endowment on the equilibrium technology mode margins, z_L and z_H. Total differentiation of the implicit Eqs. (29) and (30) yields

$$\begin{pmatrix} \frac{\partial \mathcal{F}_L}{\partial z_L} & \frac{\partial \mathcal{F}_L}{\partial z_H} \\ \frac{\partial \mathcal{F}_H}{\partial z_L} & \frac{\partial \mathcal{F}_H}{\partial z_H} \end{pmatrix} \begin{pmatrix} \mathrm{d}z_L \\ \mathrm{d}z_H \end{pmatrix} = \begin{pmatrix} -\frac{\partial \mathcal{F}_L}{\partial N_M} \\ -\frac{\partial \mathcal{F}_H}{\partial N_M} \end{pmatrix} \times \mathrm{d}N_M,$$

$$\Leftrightarrow \begin{pmatrix} \frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_L}{z_L} + \frac{1}{z_H-z_L} + \frac{1}{z_L} & -\frac{1}{z_H-z_L} \\ -\frac{1}{z_H-z_L} & \frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_H}{z_H} + \frac{1}{1-z_H} + \frac{1}{z_H-z_L} \end{pmatrix} \begin{pmatrix} \mathrm{d}z_L \\ \mathrm{d}z_H \end{pmatrix} = \begin{pmatrix} -\frac{1}{N_M} \\ \frac{1}{N_M} \end{pmatrix} \times \mathrm{d}N_M,$$

where $\tilde{\varepsilon}_k \equiv -\frac{\partial \Lambda_k(z_k)}{\partial z_k}\frac{z_k}{\Lambda_k(z_k)} > 0$, for $k = \{L, H\}$ denotes the elasticity (in absolute value) of relative efficiency schedules of technology modes k at the equilibrium margin z_k. The inspection of the matrix verifies that the Jacobi has a positive sign, i.e. $\mathcal{D}_J = \frac{\partial \mathcal{F}_L}{\partial z_L}\frac{\partial \mathcal{F}_H}{\partial z_H} - \frac{\partial \mathcal{F}_L}{\partial z_H}\frac{\partial \mathcal{F}_H}{\partial z_L} > 0$, and thus the solution to the above 2×2 system is unique. Then, applying Cramer's rule, we obtain

$$\frac{\mathrm{d}z_L}{\mathrm{d}N_M} = \frac{\mathcal{D}_L}{\mathcal{D}_J} = -\frac{1}{N_M}\frac{\frac{1}{1-z_H} + \frac{(\epsilon-1)\tilde{\varepsilon}_H}{\epsilon z_H}}{\mathcal{D}_J} < 0, \quad (31)$$

and

$$\frac{\mathrm{d}z_H}{\mathrm{d}N_M} = \frac{\mathcal{D}_H}{\mathcal{D}_J} = \frac{1}{N_M}\frac{\frac{\epsilon+(\epsilon-1)\tilde{\varepsilon}_L}{\epsilon z_L}}{\mathcal{D}_J} > 0. \quad (32)$$

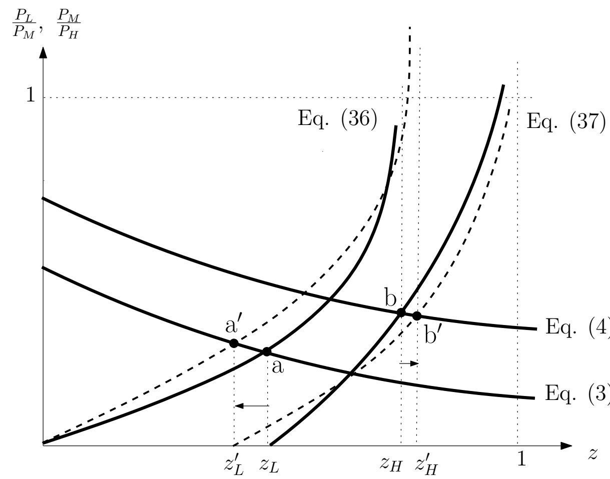
In addition, it can be shown how the range of final goods produced with technology mode M is affected by the increase in the medium-skilled labor endowment

$$\frac{\mathrm{d}(z_H - z_L)}{\mathrm{d}N_M} > 0.$$

Figure 5 depicts the equilibrium technology margins and the results of the above comparative statics for any arbitrary values of relative goods prices. It can be easily verified that the relative technology demand condition (27) is increasing in z_L from the origin, for given values of z_H, while Eq. (3) is decreasing in z_L from above. Thus, there is a single crossing, characterizing the equilibrium technology margin z_L. This is denoted by point a in Figure 5. Similarly, from the relative technology demand condition (28) and the efficiency condition (4) one can show the single crossing between the two curves, as denoted by point b in Figure 5.

Now, changes in the composite factor labor N_M (e.g. due to easier offshoring or immigration of medium-skilled workers) induce simultaneously an upward and downward shift of the curves Eq. (27) and Eq. (28), respectively. This leads to a decline and increase in equilibrium margins z_L and z_H, respectively. After further adjustments in both curves – a slight rightward shift in Eq. (27) and a leftward shift in Eq. (28) – due to changes in the z_L and z_H, the new equilibrium approaches eventually to points a' and b'.

Figure 5: Medium-skill immigration and changes in the equilibrium technology margins



A similar exercise can be performed to compute the comparative statics for changes in both fixed costs (f_k) and labor endowments N_L and N_H. The following proposition summarizes the main results.

Proposition 1 (Comparative statics of technology adoption for changes in fixed costs and labor endowment)**.** *Exogenous changes in the skill endowment and in fixed costs will affect the technology margins z_L and z_H in the following way:*

- *Immigration of high-skill workers and H-fixed cost*

$$\left\{\frac{\mathrm{d}z_L}{\mathrm{d}\ln N_H}, \frac{\mathrm{d}z_H}{\mathrm{d}\ln N_H}\right\} < 0, \ \left\{\frac{\mathrm{d}z_L}{\mathrm{d}\ln f_H}, \frac{\mathrm{d}z_H}{\mathrm{d}\ln f_H}\right\} > 0,$$

- *Immigration of medium-skilled workers and M-fixed cost*

$$\left\{\frac{\mathrm{d}z_L}{\mathrm{d}\ln f_M}, \frac{\mathrm{d}z_H}{\mathrm{d}\ln N_M}\right\} > 0, \left\{\frac{\mathrm{d}z_L}{\mathrm{d}\ln N_M}, \frac{\mathrm{d}z_H}{\mathrm{d}\ln f_M}\right\} < 0,$$

- *Immigration of low-skilled workers and L-fixed cost*

$$\left\{\frac{\mathrm{d}z_L}{\mathrm{d}\ln N_L}, \frac{\mathrm{d}z_H}{\mathrm{d}\ln N_L}\right\} > 0, \ \left\{\frac{\mathrm{d}z_L}{\mathrm{d}\ln f_L}, \frac{\mathrm{d}z_H}{\mathrm{d}\ln f_L}\right\} < 0.$$

Proof. A full analytical derivation is provided in Appendix B.2.

Intuitively, an increase in the factor endowment N_k, results in an expansion of X_k as a larger factor market allows for more varieties, i.e. the state of technology A_k increases. A larger factor market also implies a higher competition among workers of the same type and thus by the perfectly competitive nature of the labor markets, induces a decline in their wages. This, in turn, reduces the marginal cost of the differentiated good (ζ_k) and thus the overall price index of final goods (P_k), making the utilization of technology k more profitable compared to other types of technology, $k' \neq k$. Consequently, more final good producers adopt technology k, and the economy becomes disproportionately more specialized in technology mode k.

Changes in technology fixed costs (f_k) induce the opposite effect. Intuitively, higher fixed costs increase the market entry barriers for firms. In the symmetric equilibrium, a proportion of firms are forced to leave the market, shrinking the available set of differentiated goods, A_k, which can be verified from Eqs. (19)–(21).[8] Consequently, the overall price index of final goods (P_k) increases, making the utilization of technology mode k less profitable.

6 Immigration and distributional effect

Equipped with the comparative statics for technology adoption, the impact of immigration-induced changes in the skill endowment on the domestic wage structure can be analyzed. In equilibrium, the intermediate goods demand condition (11) and the monopolistic price-setting condition (13) imply

$$\begin{aligned}\frac{\epsilon}{\epsilon-1}w_L = \quad & p_L & = \zeta_L X_L^{1/\epsilon} x_L^{-1/\epsilon},\\ \frac{\epsilon}{\epsilon-1}w_M = \quad & p_M & = \zeta_M X_M^{1/\epsilon} x_M^{-1/\epsilon},\\ \frac{\epsilon}{\epsilon-1}w_H = \quad & p_H & = \zeta_H X_H^{1/\epsilon} x_H^{-1/\epsilon}.\end{aligned}$$

To compute the changes in the domestic wage structure, take the ratio between low- and medium-skilled wages and between medium- and high-skilled wages to obtain

$$\frac{w_L}{w_M} = \frac{\zeta_L}{\zeta_M}\left(\frac{X_L}{X_M}\right)^{1/\epsilon}\left(\frac{x_L}{x_M}\right)^{-1/\epsilon}, \tag{33}$$

$$\frac{w_M}{w_H} = \frac{\zeta_M}{\zeta_H}\left(\frac{X_M}{X_H}\right)^{1/\epsilon}\left(\frac{x_M}{x_H}\right)^{-1/\epsilon}. \tag{34}$$

Recall again that due to the perfectly competitive nature of the final goods market in equilibrium $P_k = \zeta_k$ for all $k = \{L, M, H\}$ must hold. Using this observation together with the equilibrium outcomes (22), (23), (25), (26), (27), and (28) in Eqs. (33) and (34), and taking logs, we obtain the following relative wage rate of medium-skilled workers (see Appendix A.4 for the formal derivation):

$$\ln\left(\frac{w_L}{w_M}\right) = -\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}\ln\left(\frac{z_L}{z_H-z_L}\right) + \frac{\sigma-\epsilon}{(\epsilon-1)\sigma}\ln N_L - \frac{\sigma-\epsilon}{(\epsilon-1)\sigma}\ln N_M + \ln \mathcal{K}_{L,M}, \tag{35}$$

$$\ln\left(\frac{w_M}{w_H}\right) = -\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}\ln\left(\frac{z_H-z_L}{1-z_H}\right) - \frac{\sigma-\epsilon}{(\epsilon-1)\sigma}\ln N_H + \frac{\sigma-\epsilon}{(\epsilon-1)\sigma}\ln N_M + \ln \mathcal{K}_{H,M}, \tag{36}$$

where $\mathcal{K}_{H,M} \equiv \left(\frac{f_M}{f_H}\right)^{-\frac{\sigma-1}{(\epsilon-1)\sigma}}$, $\mathcal{K}_{L,M} \equiv \left(\frac{f_L}{f_M}\right)^{-\frac{\sigma-1}{(\epsilon-1)\sigma}}$.

Thus, changes in the domestic wage structure can be decomposed into two key factors: i) a labor supply effect, $\ln N_L$, $\ln N_H$, and $\ln N_M$; ii) a technology adoption effect, $\ln\left(\frac{z_L}{z_H-z_L}\right)$ and $\ln\left(\frac{z_H-z_L}{1-z_H}\right)$. Moreover, an inspection of Eqs. (35) and (36) reveals immediately that the extent of the direct labor supply effect and the technology adoption effect depends crucially on the interaction between the goods demand elasticity (σ) and the market power of monopolists (ϵ). The intuition behind these two forces is the following. Immi-

[8] In a more general, asymmetric equilibrium with firm heterogeneity á la Melitz (2003), the least productive firms would exit the market.

gration induces a market size effect, leading, on the one hand, to higher competition among same skilled workers and to a reduction in their wages. On the other hand, the immigration-induced increase in the labor endowment induces a directed technical change effect (the intensive margin) by raising the mass of monopolists due to higher profits. This effect raises the relative wages of workers affected by immigration and will be stronger the lower the market power of monopolists is. These are the well-defined forces which have been addressed in the literature, mentioned in the Introduction.

However, immigration also raises the comparative advantages of skill-complement technology mode, inducing an increase in the adoption of this production technology (the extensive margin). The wage effects of this channel countervails those forces mentioned above, reconciling the empirical findings discussed earlier. I discuss now the these channels and their interaction in more detail.

6.1 Low-skill and high-skill immigration and distributional effect

In this section, I analyze the wage effects of immigration at the tails of the skill distribution. Although in many advanced countries the past pattern of international migration was often characterized by this bimodal skill distribution (cf. Felbermayr and Kohler, 2007), I will separately examine the effects of low-skill and high-skill immigration in order to provide clear analytical results.[9]

Low-skill Immigration

To compute the impact of low-skill immigration, take the total differentiation of Eqs. (35) and (36) with respect to N_L to obtain

$$\begin{aligned} \frac{\mathrm{d}\ln(w_L/w_M)}{\mathrm{d}\ln N_L} &= \frac{\sigma-\epsilon}{(\epsilon-1)\sigma}\left[1-\Gamma_{N_L}\right], \\ \frac{\mathrm{d}\ln(w_M/w_H)}{\mathrm{d}\ln N_L} &= -\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}\Delta_{N_L}. \end{aligned}$$

where $\Gamma_{N_L} \equiv \frac{\mathrm{d}\ln[z_L/(z_H-z_L)]}{\mathrm{d}\ln N_L}$ and $\Delta_{N_L} \equiv \frac{\mathrm{d}\ln[(z_H-z_L)/(1-z_H)]}{\mathrm{d}\ln N_L}$ denote the relative change in the range of technology modes due to low-skill immigration and by Proposition 1 $\Gamma_{N_L} > 0$ and $\Delta_{N_L} < 0$.

High-skill Immigration

Similarly, computing the impact of high-skill immigration, we obtain from Eqs. (35) and (36)

$$\begin{aligned} \frac{\mathrm{d}\ln(w_L/w_M)}{\mathrm{d}\ln N_H} &= -\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}\Gamma_{N_H}, \\ \frac{\mathrm{d}\ln(w_M/w_H)}{\mathrm{d}\ln N_H} &= -\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}\left[1+\Delta_{N_H}\right], \end{aligned}$$

where now Γ_{N_H} and Δ_{N_H} denote the relative change in the range of technology modes due to low-skill immigration and by Proposition 1 $\Gamma_{N_H} > 0$ and $\Delta_{N_H} < 0$.

[9] However, each scenarios may be considered to reflect specific moments in the past, e.g. the guest workers program in many European countries in the 1970s, reflecting low-skill immigration scenario; or the collapse of Soviet Union early 1990s which lead to an increase of immigration of scientists (e.g. mathematicians and physicists) to the US, reflecting high-skill immigration scenario.

It is immediately evident that low-skill and high-skill immigration affects relative wages between low-skilled and medium-skilled workers and between medium-skilled and high-skilled workers through the two channels, the labor supply and the technology adoption effects, respectively. However, the endogenous technology choice will affect the overall wage structure in the economy. As mentioned earlier, changes in the wage structure is determined by the interaction between goods demand elasticity and the market power of monopolists, and the extent final-good producers are able to adopt the skill-complement technology modes in the neighborhood of z_L and z_H. The next proposition summarizes the main results.

Proposition 2 (Low-skill and High-skill Immigration and Changes in the Wage Structure)**.** *Immigration of low-skilled and high-skilled workers generates a market size effect, raising the competition among same skilled workers, and the comparative advantage of the technology mode and the mass of intermediate goods complementing the respective skill. For a sufficient degree of imperfect technology adoption, i.e.* $\infty > \{\tilde{\varepsilon}_L, \tilde{\varepsilon}_H\} > 0$*, changes in the wage structure induced by*

(i) ***Low-skilled immigration*** *are similar to a "unskill-bias" technical change, i.e. a rise in relative increase in the wage rate of low-skilled workers compared to medium-skilled workers, and a relative rise in the wage rate of medium-skill workers compared to high-skilled workers, whenever the goods demand elasticity is larger than the market power of monopolists (elasticity of substitution between intermediate goods), i.e.* $\sigma > \epsilon$*; the converse is true if* $\sigma < \epsilon$*.*

(ii) ***High-skill immigration*** *leads to a monotonic increase in the skill premium similar to a "skill-bias" technical change, i.e. a relative increase in the wage rate of medium-skilled workers compared to low-skilled workers, and a relative rise in the wage rate of high-skill workers compared to medium-skilled workers,, whenever the goods demand elasticity is larger than the market power of monopolists (elasticity of substitution between intermediate goods), i.e.* $\sigma > \epsilon$*; the converse is true if* $\sigma < \epsilon$*.*

Moreover, if the degree of substitution between technology modes is extremely easy, i.e. $\{\tilde{\varepsilon}_L, \tilde{\varepsilon}_H\} \to 0$*, then the domestic wage structure is insensitive to immigration. If the degree of substitution between technology modes is extremely prohibited, i.e.* $\{\tilde{\varepsilon}_L, \tilde{\varepsilon}_H\} \to \infty$*, then the relative wage between medium-skilled and high-skilled workers is insensitive to low-skill immigration, while the relative wage between low-skilled and medium-skilled is insensitive to high-skill immigration.*

Proof. See Appendix B.3.

As discussed above, lower values of $\tilde{\varepsilon}_L$ ($\tilde{\varepsilon}_H$) indicate that for final good producer it is easy to substitute (H-) L-technology mode by M-technology mode in the neighborhood of z_L (z_H). Recalling Figure 5, in the limit of perfect substitutability, i.e. $\{\tilde{\varepsilon}_L, \tilde{\varepsilon}_H\} \to 0$, Eqs. (3) and (4) become horizontal lines, so that any changes in the exogenous variables, leads to a proportional shift along these horizontal lines. In contrast, higher values of $\tilde{\varepsilon}_L$ ($\tilde{\varepsilon}_H$) imply a low substitutability between (H–) L– and M–technology modes in the neighborhood of z_L (z_H). In this case, the curves denoted by Eqs. (3) and (4) become vertical lines. Consequently, in the limiting case when technology adoption is extremely prohibitive, i.e. $\{\tilde{\varepsilon}_L, \tilde{\varepsilon}_H\} \to \infty$, the relative range of final goods employing technology mode M stays constant.

These results highlight the rich pattern of interaction between immigration, endogenous technology choice, and between consumer preferences and monopolist's market power. They also underline the importance of general equilibrium implications, e.g. the "spillover" effects of low-skill immigration for medium-skilled and high-skilled workers due to the endogenous response of firms to technology choice and changes in the skill mix. Particularly, the results highlight the important role of endogenous technology choice, mitigating the direct labor supply driven wage effects, and thus reconciling the empirical findings.

6.2 Medium-skilled immigration and distributional effect

In this section, I discuss the potential wage effects of medium-skilled migration scenario, reflecting recent observations in many old member states of the EU which have experienced a rapid increase in the share of immigrants with medium-skill attainments in the course of EU enlargement towards Eastern and Central European countries (cf. Muysken et al., 2015). To compute the comparative statics, utilize Eqs. (35) and (36) and differentiate with respect to medium-skilled labor endowment ($\mathrm{d}N_M > 0$) to obtain

$$\begin{aligned}\frac{\mathrm{d}\ln(w_L/w_M)}{\mathrm{d}\ln N_M} &= \frac{\sigma-\epsilon}{(\epsilon-1)\sigma}\left[\Gamma_{N_M}-1\right],\\ \frac{\mathrm{d}\ln(w_M/w_H)}{\mathrm{d}\ln N_M} &= -\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}\left[\Delta_{N_M}-1\right],\end{aligned}$$

where $\Gamma_{N_M} \equiv \frac{\mathrm{d}\ln[z_L/(z_H-z_L)]}{\mathrm{d}\ln N_M}$ and $\Delta_{N_M} \equiv \frac{\mathrm{d}\ln[(z_H-z_L)/(1-z_H)]}{\mathrm{d}\ln N_M}$ denote the relative change in the range of technology modes due to medium-skill immigration and by Proposition 1 $\Gamma_{N_M} < 0$ and $\Delta_{N_M} > 0$. Next proposition summarizes the main results.

Proposition 3 (Medium-skill Immigration and Wage Polarization)**.** *Immigration of medium-skilled workers generates a market size effect, raising the competition among same skilled workers, and the comparative advantage of the medium-skill complement technology mode and the mass of intermediate goods utilizing medium-skilled workers. If the degree of technology adoption is sufficiently imperfect, i.e.* $\{\tilde{\varepsilon}_L, \tilde{\varepsilon}_H\} > 0$, *then medium-skilled immigration induce unambiguously a*

(i) A polarization effect, where medium-skilled wages decline relative to low-skilled and high-skilled wages, whenever monopolist's market power is higher than the goods demand elasticity, i.e. $\sigma < \epsilon$.

(ii) An increase in medium-skilled wages relative to low-skilled and high-skilled wages, whenever $\sigma > \epsilon$.

Proof. See Appendix B.4.

The intuition behind the results is similar to the one discussed in Proposition 2. However, Proposition 3 denotes an important difference to low-skilled and high-skilled immigration scenarios. Medium-skill immigration may potentially generate a polarizing wage effect.

7 Conclusion

Immigration has a potential impact on the skill structure of the host economy. The existing studies have emphasized the important role of endogenous technology changes, firm heterogeneity, and endogenous choice between different production techniques in explaining the differential trends in wage inequality in many advanced countries over the last decades. One set of studies has highlighted the role of skill-capital complementarity and endogenous technical change, translating changes in the skill mix into changes in factor intensity and to higher returns for those factors. Another set of studies has emphasized the role of endogenous choice of production technology. The implication of this latter channel differs from the former one by indicating that the initial direct supply effect on wages may dissipates over time as immigration induces higher investments by firms in production techniques, complements workers who were affected by immigration.

Yet, we are lacking in understanding the determinants of and the interaction between these two competing arguments. The objective of this article is to provides a simple model that allows for a richer structure of the goods market regarding endogenous technology adoption, monopolistic competition and technology-skill complementarity. Moreover, the labor market consists of low-, medium- and high-skilled workers and the production technology exhibits increasing returns to scale. This latter property allows to capture the implications of directed technical change regarding changes in the skill mix skill premium. In doing so, I investigate jointly the extent and the direction of potential driving forces in the general equilibrium context.

The theoretical analysis uncovers several new insights. First, changes in the domestic wage structure is decomposed into two key channels: i) a labor supply effect, and ii) a technology adoption effect. Second, the extent and interaction between these two channels depend crucially on two additional forces. On the one hand, immigration-induced changes in the skill structure generates a market size effect, increasing the mass of intermediate-goods producers employing those type of workers. On the other hand, it leads to a price effect, indicating higher competition among similar skilled workers. The market size effect dominates the price effect, whenever the goods demand elasticity is larger than the market power of monopolists (the elasticity of substitution between intermediates). Third, the technology adoption effect mitigates the direct labor supply effect. At the extreme case of easy adoption (i.e. perfect substitutability between technology modes), the two channels are balanced, leaving the wage structure insensitive to immigration-induced changes in the skill mix.

Moreover, for sufficient degree of imperfect substitutability between technology modes, low-skilled (high-skill) immigration induces changes in the wage structure similar to a "skill-bias" ("unskill-bias") technical change, while medium-skilled immigration induces a polarization of the wage structure, whenever the market power of monopolists is larger than the goods demand elasticity. Thus, this framework contributes to the existing literature by highlighting the key features that are substantial to improve our understanding of adjustment mechanisms behind immigration-induced changes in the wage structure.

References

Acemoglu, D. (1998). Why do new technologies complement skills? directed technical change and wage inequality. *The Quarterly Journal of Economics*, 113(4):pp. 1055–1089.

Acemoglu, D. (2002). Technical change, inequality, and the labor market. *Journal of Economic Literature*, 40:7–72.

Acemoglu, D. and Autor, D. (2011). Chapter 12 - Skills, Tasks and Technologies: Implications for Employment and Earnings. In Ashenfelter, O. and Card, D., editors, *Handbook of Labor Economics*, volume 4, Part B, pages 1043–1171. Elsevier.

Acemoglu, D., Gancia, G., and Zilibotti, F. (2012). Offshoring and direct technical change. *NBER, Working Paper 18595*.

Acemoglu, D. and Zilibotti, F. (2001). Productivity differences. *Quarterly Journal of Economics*, 116:563–606.

Autor, D. H. and Dorn, D. (2013). The growth of low skill service jobs and the polarization of the U.S. labor market. *American Economic Review*, 103(5):1553–1597.

Autor, D. H., Levy, F., and Murnane, R. J. (2003). The Skill Content of Recent Technological Change: An Empirical Investigation. *The Quarterly Journal of Economics*, 118:1279–1333.

Beaudry, P., Doms, M., and Lewis, E. (2010). Should the personal computer be considered a technological revolution? evidence from us metropolitan areas. *Journal of Political Economy*, 118(5):988–1036.

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

Borjas, G. J., Grogger, J., and Hanson, G. H. (2011). Substitution between Immigrants, Natives, and Skill Groups. *NBER, Working Paper 17461*.

Brücker, H., Hauptman, A., Jahn, E., and Upward, R. (2014). Migration and imperfect labor markets: Theory and cross-country evidence from Denmark, Germany and the UK. *European Economic Review*, 66:205–225.

Brücker, H. and Jahn, E. J. (2011). Migration and Wage-Setting: Reassessing the Labor Market Effects of Migration. *Scandinavian Journal of Economics*.

Card, D. (2009). Immigration and inequality. *American Economic Review, Papers and Proceedings*, 99:1–21.

Dornbusch, R., Fischer, S., and Samuelson, P. A. (1977). Comparative advantage, trade, and payments in a Ricardian model with a continuum of goods. *The American Economic Review*, 67(5):823–839.

D'Amuri, F., Ottaviano, G. I. P., and Peri, G. (2010). The Labor Market Impact of Immigration in Wstern Germany in the 1990s. *European Economic Review*, 54:550–570.

Dustmann, C. and Glitz, A. (2012). How do industries and firms respond to changes in local labor supply? IZA Discussion Paper No.6257.

Egger, H., Kreickemeier, U., and Wrona, J. (2013). Offshoring domestic jobs. mimeo.

Felbermayr, G. J. and Kohler, W. (2006). Immigration and Wages in General Equilibrium: A Theoretical Perspective. In Foders, F. and Langhammer, R., editors, *Labor Mobility and the World Economy*, pages 51–80. Springer.

Felbermayr, G. J. and Kohler, W. (2007). Immigration and Native Welfare. *International Economic Review*, 48:731–760.

González, L. and Ortega, F. (2011). How do very open economies adjust to large immigration flows? Evidence from Spanish regions. *Labour Economics*, 18:57–70.

Iranzo, S. and Peri, G. (2009). Migration and trade: Theory with an application to the Eastern-Western European integration. *Journal of International Economics*, 79:1–19.

Krugman, P. R. (1979). Increasing returns, monopolistic competition, and international trade. *Journal of International Economics*, 9:469–479.

Lemieux, T. (2008). The changing nature of wage inequality. *Journal of Population Economics*, 21(1):21–48.

Lewis, E. (2011). Immigration, skill mix, and capital skill complementarity. *The Quarterly Journal of Economics*, 126(2):1029–1069.

Lewis, E. G. (2003). Local open economies within the U.S.: How do industries respond to immigration. Federal Reserve Bank of Philadelphia Working Paper No. 04-03.

Lewis, E. G. (2013). Immigration and production technology. *Annual Review of Economics*, 5:165–191.

Manacorda, M., Manning, A., and Wadsworth, J. (2011). The Impact of Immigration on the Structure of Male Wages: Theory and Evidence from Britain. *Journal of the European Economic Association*, 10:120–151.

Melitz, M. (2003). The Impact of Trade on Intra-Idustry Reallocations and Aggregate Industry Productivity. *Econometrica*, 71:1695–1725.

Muysken, J., Vallizadeh, E., and Ziesemer, T. (2015). Migration, Unemployment, and Skill Downgrading. *The Scandinavian Journal of Economics*, 117:403–451.

Ottaviano, G. I. and Peri, G. (2008). Immigration and National Wages: Clarifying the Theory and the Empirics. NBER Working Paper No. 14188.

Ottaviano, G. I. and Peri, G. (2012). Rethinking the Effects of Immigration on Wages. *Journal of the European Economic Association*, (10):152–197.

Peri, G. (2011). Rethinking the area approach: Immigrants and the labor market in California. *Journal of International Economics*, 84(1):1–14.

Yeaple, S. R. (2005). A simple model of firm heterogeneity, international trade, and wages. *Journal of International Economics*, 65:1–20.

Appendix

A Derivation of equilibrium results

A.1 Demand for intermediate goods

Any firm in the final goods market chooses the optimal amount of intermediate goods by minimizing the production cost

$$C_k = \int_0^{A_k} p_k(j)x_k(j)\mathrm{d}j,\ \forall\, k = \{L, M, H\}$$

subject to CES aggregate (9). The optimization programming can be defined by the following Lagrangian:

$$\max_{x_k(j)} \mathcal{L}_k = \int_0^{A_k} p_k(j)x_k(j)\mathrm{d}j - \zeta_k \left(X_k - \left[\int_0^{A_k} x_k(j)^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}} \right),$$

where ζ_k denotes the Lagrangian multiplier. From the first-order condition

$$\frac{\partial \mathcal{L}_k}{\partial x_k(j)} = p_k(j) - \zeta_k X_k^{1/\epsilon} x_k(j)^{-1/\epsilon} = 0, \tag{A.1}$$

we obtain the optimal inverse demand condition for each intermediate goods produced under technology mode k. Utilizing (A.1) into the constraint, Eq. (9), the Lagrangian multiplier denotes the "cost index" of the composite good

$$\zeta_k = \left[\int_0^{A_k} p_k(j)^{1-\epsilon}\mathrm{d}j \right]^{\frac{1}{1-\epsilon}}, \tag{A.2}$$

and inserting (A.1) back into the cost function yields

$$C_k = \zeta_k X_k. \tag{A.3}$$

A.2 Derivation of the mass of monopolists

Notice that the perfectly competitive nature of the final goods market requires zero profits, i.e.

$$p_k(z)y_k(z) = \zeta_k X_k,\ \ \forall\ \ k = \{L, M, H\}$$

Moreover, using Eqs. (2) and (8), it follows that in any competitive equilibrium the price index of technology mode k must equal its marginal cost, i.e.

$$P_k = \zeta_k \tag{A.4}$$

Now, utilizing the equilibrium value of ζ_k from Eq. (18), yields

$$P_k = \zeta_k = \frac{\epsilon}{\epsilon - 1} A_k^{\frac{1}{1-\epsilon}} w_k. \tag{A.5}$$

Then, the total budget constraint of any final good producer $z \in \mathcal{S}k$ requires

$$p(z)y(z) = w_k n_k = \frac{w_k N_k}{\mathcal{S}_k},$$

where the second equality follows from Eqs. (14)–(16), for the respective technology mode.

Utilize Eqs. (2) and (8) in the left hand side of the previous equation and manipulate to obtain

$$P_k A_k^{\frac{\epsilon}{\epsilon-1}} x_k = \frac{w_k N_k}{\mathcal{S}_k}.$$

Next, use the FE condition (17), and Eq. (A.5) to substitute for x_k and P_k in the previous equation, respectively, so that after some manipulation we obtain

$$A_k \epsilon f_k w_k = \frac{w_k N_k}{\mathcal{S}_k}.$$

Rearranging and solving w.r.t. A_k yields the equilibrium mass of monopolists in the respective technology mode.

A.3 Derivation of aggregate sectoral output

The derivation of the aggregate sectoral output is illustrated for technology mode complementing low-skilled workers. The aggregation over the range of all final goods using the other two types of technology can be derived similarly. Define the total cost using low-skilled technology as

$$P_L Y_L = \int_0^{z_L} p(z)y(z)\mathrm{d}z.$$

Utilizing Eqs. (8) and (24) yields

$$\begin{aligned} P_L Y_L &= \int_0^{z_L} p(z)\varphi_L(z) A_L^{\frac{1}{\epsilon-1}} \frac{N_L}{z_L}\mathrm{d}z, \\ &= \int_0^{z_L} P_L A_L^{\frac{\epsilon}{\epsilon-1}} \frac{N_L}{z_L}\mathrm{d}z. \end{aligned}$$

Manipulating slightly, we get

$$Y_L = A_L^{\frac{1}{\epsilon-1}} N_L.$$

Following the same steps, we obtain

$$\begin{aligned} Y_M &= A_M^{\frac{1}{\epsilon-1}} N_M, \\ Y_H &= A_H^{\frac{1}{\epsilon-1}} N_H. \end{aligned}$$

A.4 Derivation of relative wages

To derive the relative domestic wages between low- and medium-skilled workers (w_L/w_M), utilize (25) and (26) to obtain the relative demand for technology mode $k = M$

$$\frac{P_L}{P_M} = \left(\frac{z_L}{z_H - z_L}\right)^{\frac{1}{\sigma}} \left(\frac{Y_L}{Y_M}\right)^{-\frac{1}{\sigma}} = \left(\left[\frac{A_L}{A_M}\right]^{\frac{1}{\epsilon-1}} \frac{N_L}{N_M} \left[\frac{z_L}{z_H - z_L}\right]^{-1}\right)^{-\frac{1}{\sigma}}. \tag{A.6}$$

Next, recall the zero profit condition (A.4) in the final good sector and take the ratio between technology mode $k = L$ and $k = M$ to obtain

$$\frac{\zeta_L}{\zeta_M} = \frac{P_L}{P_M}. \tag{A.7}$$

Substituting Eq. (A.6) for P_L/P_M into Eq. (A.7) and inserting the outcome into Eq. (33) yields

$$\frac{w_L}{w_M} = \left(\left[\frac{A_L}{A_M}\right]^{\frac{1}{\epsilon-1}} \frac{N_L}{N_M} \left[\frac{z_L}{z_H - z_L}\right]^{-1}\right)^{-\frac{1}{\sigma}} \left(\frac{X_L}{X_M}\right)^{1/\epsilon} \left(\frac{x_L}{x_M}\right)^{-1/\epsilon}.$$

Notice that due to symmetry assumption it follows from (9) $X_k = A_k^{\frac{\epsilon}{\epsilon-1}} x_k$. Recall from Eqs. (19) and (20) the equilibrium values of A_L and A_M and utilize them in the previous equation, respectively, and manipulating slightly to obtain

$$\frac{w_L}{w_M} = \left(\frac{N_L}{N_M}\right)^{\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}} \left(\frac{z_L}{z_H - z_L}\right)^{-\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}} \mathcal{K}_{L,M}.$$

where $\mathcal{K}_{L,M} \equiv \left(\frac{f_L}{f_M}\right)^{-\frac{\sigma-1}{(\epsilon-1)\sigma}}$. Thus, the relative wage rates between low-skill and medium-skill workers can be decomposed into the following terms

$$\frac{w_L}{w_M} = \left(\frac{z_L}{z_H - z_L}\right)^{-\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}} N_L^{\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}} (N_M)^{-\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}} \mathcal{K}_{L,M}.$$

Following similar steps, one can derive the relative wage rate between medium-skill and high-skill workers:

$$\frac{w_M}{w_H} = \left(\frac{z_H - z_L}{1 - z_H}\right)^{-\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}} N_H^{-\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}} (N_M)^{\frac{\sigma-\epsilon}{(\epsilon-1)\sigma}} \mathcal{K}_{H,M},$$

where $\mathcal{K}_{H,M} \equiv \left(\frac{f_M}{f_H}\right)^{-\frac{\sigma-1}{(\epsilon-1)\sigma}}$.

B Proof of the main results

B.1 Proof of Lemma 1

Perfect competition implies that in equilibrium the profit of a firm using technology k to producing good z must be zero, i.e. $\pi_k(z) = 0$ for all z. Thus, considering two firms using the same technology, we must have

$$\begin{aligned} p_L(z)\varphi_L(z) &= p_L(z')\varphi_L(z'), \quad \forall\ z, z' \in [0, z_L] \\ p_M(z)\varphi_M(z) &= p_M(z')\varphi_M(z'), \quad \forall\ z, z' \in (z_L, z_H) \\ p_H(z)\varphi_H(z) &= p_H(z')\varphi_H(z'), \quad \forall\ z, z' \in [z_H, 1] \end{aligned}$$

This implies that the price of each final good, $p(z)$, adjusts to changes in the productivity of the technology, $\varphi(z)$. Let P_k denote the price index of technology mode $k = \{L, M, H\}$, then we can rewrite the price schedule of each technology mode as follows

$$p_k(z) = P_k \varphi_k(z)^{-1}. \tag{B.8}$$

The unit cost of Y is given by

$$C_Y = \left[\int_0^{z_L} p_L(z)^{1-\sigma} \mathrm{d} + \int_{z_L}^{z_H} p_M(z)^{1-\sigma} \mathrm{d} + \int_{z_H}^{1} p_H(z)^{1-\sigma} \mathrm{d} \right]^{\frac{1}{1-\sigma}}.$$

Now, the optimal choice of cut-off points z_L and z_H is obtained by minimizing C_Y w.r.t. z_L and z_H:

$$\frac{\mathrm{d}C_Y}{\mathrm{d}z_L} = \frac{1}{1-\sigma} C_Y^{\sigma} \Big(p_L(z_L)^{1-\sigma} - p_M(z_L)^{1-\sigma} \Big) = 0, \tag{B.9}$$

$$\frac{\mathrm{d}C_Y}{\mathrm{d}z_H} = \frac{1}{1-\sigma} C_Y^{\sigma} \Big(p_M(z_H)^{1-\sigma} - p_H(z_H)^{1-\sigma} \Big) = 0. \tag{B.10}$$

Using (B.8) for the respective technology mode, we get that $\frac{\mathrm{d}C_Y}{\mathrm{d}z_L} = 0$ and $\frac{\mathrm{d}C_Y}{\mathrm{d}z_H} = 0$ if and only if

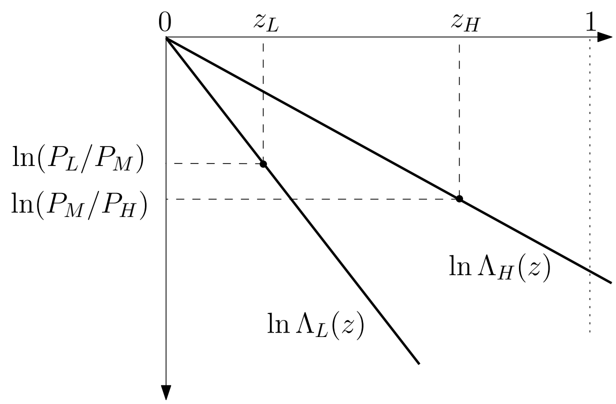
$$\begin{aligned} \frac{P_L}{P_M} &= \Lambda_L(z), \quad \Lambda_L(z) \equiv \left(\frac{\varphi_L(z_L)}{\varphi_M(z_L)} \right), \\ \frac{P_M}{P_H} &= \Lambda_H(z), \quad \Lambda_H(z) \equiv \left(\frac{\varphi_M(z_H)}{\varphi_H(z_H)} \right). \end{aligned}$$

To prove that $0 < z_L < z_H < 1$, recall from Assumption 1 that

$$\frac{\mathrm{d} \ln \Lambda_L(z)}{\mathrm{d}z} < \frac{\mathrm{d} \ln \Lambda_H(z)}{\mathrm{d}z} < 0.$$

Given this property, there must exist a range of values of the relative price indexes such that $0 < z_L < z_H < 1$. It can be easily verified that if $\frac{P_L}{P_M} > \Lambda_L(0)$, then low-tech technology has no comparative advantages to be installed for production of any final good $z \in [0, 1]$. Similarly, if $\frac{P_M}{P_H} < \Lambda_H(1)$, it is not cost-efficient to install high-tech technology to produce any final good $z \in [0, 1]$. Thus, in Lemma 1, Eq. (5) provides the range of values of $\frac{P_L}{P_M}$ and $\frac{P_M}{P_H}$ that permits the existence of all the three technology modes. Figure 6 depicts the equilibrium technology allocation for arbitrary values of relative price indexes that satisfy these conditions.

Figure 6: Equilibrium technology allocation



■

B.2 Proof of Proposition 1

The computation of the comparative statics for the other exogenous changes is similar to the one conducted for changes in the composite factor labor N_M due to exogenous variation in marginal offshoring cost and immigration of medium-skilled workers. To do so, recall the implicit 2×2 system of equations, Eqs. (29) and (30). Now, differentiating totally this system and applying Cramer's rule, we obtain the following results for exogenous variation in:

- High-skill endowment

$$\frac{\mathrm{d}\ln z_L}{\mathrm{d}\ln N_H} = \frac{\mathcal{D}_H}{\mathcal{D}_J} = -\frac{\frac{1}{z_L(z_H - z_L)}}{\mathcal{D}_J} < 0, \tag{B.11}$$

$$\frac{\mathrm{d}\ln z_L}{\mathrm{d}\ln f_H} = -\frac{\mathrm{d}\ln z_L}{\mathrm{d}\ln N_H} > 0 \tag{B.12}$$

and

$$\frac{\mathrm{d}\ln z_H}{\mathrm{d}\ln N_H} = \frac{\mathcal{D}_H}{\mathcal{D}_J} = -\frac{\frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_L}{z_H z_L} + \frac{1}{z_L(z_H - z_L)}}{\mathcal{D}_J} < 0. \tag{B.13}$$

$$\frac{\mathrm{d}\ln z_H}{\mathrm{d}\ln f_H} = -\frac{\mathrm{d}\ln z_H}{\mathrm{d}\ln N_H} > 0 \tag{B.14}$$

- Low-skill endowment

$$\frac{\mathrm{d}\ln z_L}{\mathrm{d}\ln N_L} = \frac{\mathcal{D}_L}{\mathcal{D}_J} = \frac{\frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_H}{z_L z_H} + \frac{1-z_L}{z_L(1-z_H)(z_H - z_L)}}{\mathcal{D}_J} > 0, \tag{B.15}$$

$$\frac{\mathrm{d}\ln z_L}{\mathrm{d}\ln f_L} = -\frac{\mathrm{d}\ln z_L}{\mathrm{d}\ln N_L} < 0 \tag{B.16}$$

and

$$\frac{\mathrm{d}\ln z_H}{\mathrm{d}\ln N_L} = \frac{\mathcal{D}_L}{\mathcal{D}_J} = \frac{\frac{1}{z_H(z_H-z_L)}}{\mathcal{D}_J} > 0. \tag{B.17}$$

$$\frac{\mathrm{d}\ln z_H}{\mathrm{d}\ln f_L} = -\frac{\mathrm{d}\ln z_H}{\mathrm{d}\ln N_L} < 0 \tag{B.18}$$

where the Jacobi is given by

$$\mathcal{D}_J = \left(\frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_L}{z_L} + \frac{1}{z_L}\right)\left(\frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_H}{z_H} + \frac{1-z_L}{(1-z_H)(z_H-z_L)}\right) + \frac{1}{z_H-z_L}\left(\frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_H}{z_H} + \frac{1}{1-z_H}\right) > 0 \tag{B.19}$$

Moreover, from (B.11) and (B.13) it can be readily verified that

$$\frac{\mathrm{d}\ln z_H - \mathrm{d}\ln z_L}{\mathrm{d}\ln N_H} = -\frac{1}{\mathcal{D}_J}\left(\frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_L}{z_H z_L}\right) < 0 \tag{B.20}$$

and similarly from (B.15) and (B.17)

$$\frac{\mathrm{d}\ln z_H - \mathrm{d}\ln z_L}{\mathrm{d}\ln N_L} = -\frac{1}{\mathcal{D}_J}\left(\frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_H}{z_H z_L} + \frac{1}{z_H z_L(1-z_H)}\right) < 0 \tag{B.21}$$

■

B.3 Proof of Proposition 2

Low-skill immigration

To obtain explicit solution for the terms $\Gamma_{N_L} \equiv \frac{\mathrm{d}\ln[z_L/(z_H-z_L)]}{\mathrm{d}\ln N_L}$ and $\Delta_{N_L} \equiv \frac{\mathrm{d}\ln[(z_H-z_L)/(1-z_H)]}{\mathrm{d}\ln N_L}$, we can utilize the results of the comparative statics in Eqs. (B.15) and (B.17) to obtain the following terms

$$\begin{aligned}\Gamma_{N_L} &= \frac{z_H}{z_H-z_L}\left(\frac{\mathrm{d}\ln z_L - \mathrm{d}\ln z_H}{\mathrm{d}\ln N_L}\right) \\ &= \frac{1}{\mathcal{D}_J}\left(\frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_H}{z_L(z_H-z_L)} + \frac{(1-z_L)}{z_L(1-z_H)(z_H-z_L)}\right) > 0 \end{aligned}\tag{B.22}$$

and

$$\begin{aligned}\Delta_{N_L} &= -\left(\frac{z_L}{z_H-z_L}\frac{\mathrm{d}\ln z_L}{\mathrm{d}\ln N_L} - \frac{z_H(1-z_L)}{(1-z_H)(z_H-z_L)}\frac{\mathrm{d}\ln z_H}{\mathrm{d}\ln N_L}\right) \\ &= -\frac{1}{\mathcal{D}_J}\left(\frac{z_L}{z_H-z_L}\left(\frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_H}{z_L z_H} + \frac{1-z_L}{z_L(1-z_H)(z_H-z_L)}\right) - \frac{z_H(1-z_L)}{(1-z_H)(z_H-z_L)}\frac{1}{z_H(z_H-z_L)}\right) \\ &= -\frac{1}{\mathcal{D}_J}\left(\frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_H}{(z_H-z_L)z_H}\right) < 0 \end{aligned}\tag{B.23}$$

It is immediately evident from Eqs. (B.22) and (B.23) that the extent of changes in the technology margins z_L and z_H depends crucially on the elasticity of technology adoption in the neighborhood of z_L ($\tilde{\varepsilon}_L$) and z_H ($\tilde{\varepsilon}_H$). We can distinguish between several cases.

If it is extremely difficult for final good producer to replace technology mode M by L in the neighborhood of z_L, then it follows

$$\lim_{\tilde{\varepsilon}_L \to \infty} \mathcal{D}_J \Big|_{\tilde{\varepsilon}_H > 0} = \infty \quad \Rightarrow \lim_{\tilde{\varepsilon}_L \to \infty} \Gamma_{N_L} \Big|_{\tilde{\varepsilon}_H > 0} = \Delta_{N_L} \Big|_{\tilde{\varepsilon}_H > 0} = 0,$$

implying no changes at the extensive margin. In other extreme case, where technology adoption is very easy, we obtain

$$\begin{aligned} \lim_{\{\tilde{\varepsilon}_H, \tilde{\varepsilon}_L\} \to 0} \mathcal{D}_J &= \frac{1}{z_L(z_H - z_L)(1 - z_H)} \\ \Rightarrow \lim_{\{\tilde{\varepsilon}_H, \tilde{\varepsilon}_L\} \to 0} \Gamma_{N_L} &= 1 \\ \Rightarrow \lim_{\{\tilde{\varepsilon}_H, \tilde{\varepsilon}_L\} \to 0} \Delta_{N_L} &= 0. \end{aligned}$$

This implies that changes in the technology margin z_L is proportional to changes in the low-skilled labor supply and so does the relative range between low-skill and medium-skill technology modes, while the usage of medium-skill technology mode relative to high-skill technology mode stays constant.

Hence, for an intermediate range of values of the parameters, $\infty > \{\tilde{\varepsilon}_L, \tilde{\varepsilon}_H\} > 0$, i.e. for a sufficient degree of imperfect substitutability between technology modes,

$$0 < \Gamma_{N_L} < 1, \qquad 0 < |\Delta_{N_L}| < 1.$$

High-skill immigration

To obtain explicit solution for the terms $\Gamma_{N_H} \equiv \frac{\mathrm{d} \ln[z_L/(z_H - z_L)]}{\mathrm{d} \ln N_H}$ and $\Delta_{N_H} \equiv \frac{\mathrm{d} \ln[(z_H - z_L)/(1 - z_H)]}{\mathrm{d} \ln N_H}$, we can utilize the results of the comparative statics in Eqs. (B.11) and (B.13) to obtain the following terms

$$\begin{aligned} \Gamma_{N_H} &= \frac{z_H}{z_H - z_L} \left(\frac{\mathrm{d} \ln z_L - \mathrm{d} \ln z_H}{\mathrm{d} \ln N_H} \right) \\ &= \frac{1}{\mathcal{D}_J} \left(\frac{\epsilon - 1}{\epsilon} \frac{\tilde{\varepsilon}_L}{(z_H - z_L) z_L} \right) > 0 \end{aligned} \tag{B.24}$$

and

$$\begin{aligned} \Delta_{N_H} &= \left(\frac{z_H(1 - z_L)}{(1 - z_H)(z_H - z_L)} \frac{\mathrm{d} \ln z_H}{\mathrm{d} \ln N_H} - \frac{z_L}{z_H - z_L} \frac{\mathrm{d} \ln z_L}{\mathrm{d} \ln N_H} \right) \\ &= -\frac{1}{\mathcal{D}_J} \left(\frac{z_H(1 - z_L)}{(1 - z_H)(z_H - z_L)} \left(\frac{\epsilon - 1}{\epsilon} \frac{\tilde{\varepsilon}_L}{z_H z_L} + \frac{1}{z_L(z_H - z_L)} \right) - \frac{z_L}{z_H - z_L} \frac{1}{z_L(z_H - z_L)} \right) \\ &= -\frac{1}{\mathcal{D}_J} \left(\frac{\epsilon - 1}{\epsilon} \frac{\tilde{\varepsilon}_L(1 - z_L)}{(1 - z_H)(z_H - z_L) z_L} + \frac{1}{z_L(z_H - z_L)(1 - z_H)} \right) < 0 \end{aligned} \tag{B.25}$$

High-skill immigration induces an opposite effect compared to low-skill immigration. Now, it is immediately evident from Eqs. (B.24) and (B.25) that the magnitude of changes in the technology margins z_L and z_H now depends crucially on the elasticity of technology adoption at the margin z_H, $\tilde{\varepsilon}_H$. Thus, if it is extremely difficult for final good producer to replace technology mode M by H, it follows

$$\lim_{\tilde{\varepsilon}_H \to \infty} \mathcal{D}_J \Big|_{\tilde{\varepsilon}_L > 0} = \infty \quad \Rightarrow \lim_{\tilde{\varepsilon}_H \to \infty} \Gamma_{N_H} \Big|_{\tilde{\varepsilon}_L > 0} = \Delta_{N_H} \Big|_{\tilde{\varepsilon}_L > 0} = 0.$$

In other extreme case, where technology adoption is very easy, we obtain

$$\begin{aligned}
\lim_{\{\tilde{\varepsilon}_H,\tilde{\varepsilon}_L\}\to 0} \mathcal{D}_J &= \frac{1}{z_L(z_H - z_L)(1-z_H)} \\
\Rightarrow \lim_{\{\tilde{\varepsilon}_H,\tilde{\varepsilon}_L\}\to 0} \Gamma_{N_H} &= 0 \\
\Rightarrow \lim_{\{\tilde{\varepsilon}_H,\tilde{\varepsilon}_L\}\to 0} \Delta_{N_H} &= 1.
\end{aligned}$$

This implies that changes in the technology margin z_H is proportional to changes in the high-skilled labor supply and so does the relative range between high-skill and medium-skill technology modes, while the usage of medium-skill technology mode relative to low-skill technology mode stays constant.

Hence, for an intermediate range of values of the parameters, $\infty > \{\tilde{\varepsilon}_L, \tilde{\varepsilon}_H\} > 0$, i.e. for a sufficient degree of imperfect substitutability between technology modes,

$$0 < \Gamma_{N_H} < 1, \qquad 0 < \Delta_{N_H} < 1.$$

■

B.4 Proof of Proposition 3

To derive the explicit solution for $\Gamma_{N_M} \equiv \frac{\mathrm{d}\ln[z_L/(z_H - z_L)]}{\mathrm{d}\ln N_M}$ and $\Delta_{N_M} \equiv \frac{\mathrm{d}\ln[(z_H - z_L)/(1-z_H)]}{\mathrm{d}\ln N_M}$, utilize the results of the comparative statics in Eqs. (31) and (32) to obtain the following terms

$$\begin{aligned}
\Gamma_{N_M} &= -\frac{z_H}{z_H - z_L}\left(\frac{\mathrm{d}\ln z_H - \mathrm{d}\ln z_L}{\mathrm{d}\ln N_M}\right) \\
&= -\frac{1}{\mathcal{D}_J}\left(\frac{1}{z_L(z_H - z_L)(1-z_H)} + \frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_L + \tilde{\varepsilon}_H}{(z_H - z_L)z_H}\right) < 0 \qquad \text{(B.26)}
\end{aligned}$$

and

$$\begin{aligned}
\Delta_{N_M} &= \frac{z_H(1-z_L)}{(1-z_H)(z_H - z_L)}\frac{\mathrm{d}\ln z_H}{\mathrm{d}\ln N_M} - \frac{z_L}{z_H - z_L}\frac{\mathrm{d}\ln z_L}{\mathrm{d}\ln N_M} \\
&= \frac{1}{\mathcal{D}_J}\left(\frac{z_H(1-z_L)}{(1-z_H)(z_H - z_L)}\left(\frac{1}{z_H z_L} + \frac{\epsilon-1}{\epsilon}\frac{\tilde{\varepsilon}_L}{z_H z_L}\right) + \frac{z_L}{z_H - z_L}\left(\frac{1}{(1-z_H)z_L} + \frac{(\epsilon-1)\tilde{\varepsilon}_H}{\epsilon z_H z_L}\right)\right) \\
&= \frac{1}{\mathcal{D}_J}\left(\frac{1}{(1-z_H)(z_H - z_L)z_L} + \frac{\epsilon-1}{\epsilon}\left(\frac{(1-z_L)}{(1-z_H)(z_H - z_L)}\frac{\tilde{\varepsilon}_L}{z_L} + \frac{1}{z_H - z_L}\frac{\tilde{\varepsilon}_H}{z_H}\right)\right) > 0 \qquad \text{(B.27)}
\end{aligned}$$

where the Jacobi is given by Eq. (B.19). Now, taking the limits of the elasticities $\tilde{\varepsilon}_L$ and $\tilde{\varepsilon}_H$, it can be readily verified

$$\begin{aligned}
\lim_{\{\tilde{\varepsilon}_L,\tilde{\varepsilon}_H\}\to 0} \mathcal{D}_J &= \frac{1}{(1-z_H)(z_H - z_L)z_L} \Rightarrow \lim_{\{\tilde{\varepsilon}_L,\tilde{\varepsilon}_H\}\to 0} \Gamma_{N_M} = -\Delta_{N_M} = -1 \\
\lim_{\{\tilde{\varepsilon}_L,\tilde{\varepsilon}_H\}\to \infty} \mathcal{D}_J &= \infty \qquad\qquad \Rightarrow \lim_{\{\tilde{\varepsilon}_L,\tilde{\varepsilon}_H\}\to \infty} \Gamma_{N_M} = \Delta_{N_M} = 0
\end{aligned}$$

■