Chapter 17
Trade Integration and Wage Inequality

17.1 Introduction

A sharp increase in wage inequality has taken place from the 1990s. The inequality concerns especially the rise in the wage of skilled labour (college educated workers). Typically the wage of skilled labour is larger than the wage of unskilled labour, therefore, an increase in the relative wage of the former means an increase in wage inequality. This is why often in the literature the increase in the skill premium is synonymous with wage inequality. We adopt this terminology here whenever confusion does not arise.

A change in the skill premium may occur for various reasons, but the fact that this one occurred at a time of rising globalization makes international trade a prime suspect. In this chapter, we study the possible links between trade integration and rising skill premium. The matter is of obvious importance and has been the subject of a lively debate since the beginning of this century. The initial debate focused particularly on the appropriate use of the factor content of trade to extrapolate the effects of trade integration on the skill premium and the role of trade versus technical change as the cause of rising skill premia; see, e.g., Deardoff (2000), Krugman (2000), Leamer (2000), and Panagariya (2000). Later works explored the possibility that technical change induced by trade integration could be the cause of an increase in the skill premium: works by Acemoglu (2002, 2003), Burstein and Vogel (2012), and Costinot and Vogel (2010) belong to this group. Other works, e.g., Feenstra and Hanson (1997, 1999), Antràs and Helpman (2004), Antràs, Garicano, and Rossi-Hansberg (2006), Garicano and Rossi-Hansberg (2006) and Grossman and Rossi-Hansberg (2008) have identified in offshoring a plausible explanation for the rise in the skill premium. Other authors, such as Neary (2002), Epifani and Gancia (2008), and Dinopoulos et al. (2011) have highlighted the role of market structure and economies of scale. Krugman and Venables (1995) have proposed a model where agglomeration forces give rise to changes in the skill premium. Manasse and Turrini (2001), Yeaple (2005), Bustos (2011), Helpman, Itskhoki, and Redding

(2010), Amiti and Davis (2011), and Unel (2010) are examples of works that have put forward the role of heterogeneity of firms and/or labour as a key element linking trade integration to the increase in the skill premium.[1]

Although this chapter focuses on the theoretical literature, it is important to mention that the empirical literature has also progressed very rapidly; for a review see, e.g., Goldberg and Pavcnik (2007) and Bernard, Jensen, Redding, and Schott (2007). Perhaps one of the most notable results is that the skill premium has increased in both skill-abundant and skill-scarce countries: a fact that runs against the convergence of relative factor prices predicted by the standard Heckscher-Ohlin model.

We begin our study precisely from the Heckscher-Ohlin model, which offers a very useful starting point to discuss the matter.

17.2   Comparative Advantage, Technical Change, and the Skill Premium

In this section factor names are unskilled labour (L) and skilled labour (S) instead of labour (L) and capital (K) as we have done in previous chapters. This is a mere relabelling which obviously leaves the Heckscher-Ohlin model unchanged. Consistently with this notation, we denote factor prices by w_L and w_S and use the convention that wage inequality is measured in terms of the relative wage of skilled labour, w_S/w_L. The phenomenon we want to explain is the rise in w_S/w_L.

17.2.1   Trade Integration

We recall that in autarky, the relative price of the skill-intensive good is lower in the skill-abundant country than in the skill-scarce country. This is indeed one way of stating that the skill-abundant country has a comparative advantage in the skill-intensive good. Trade integration brings about convergence of goods prices: the relative price of the skill-intensive good rises in the skill-abundant country and declines in the skill-scarce country. But, as we learnt in Sect. 4.1.1, there is a one-to-one correspondence between the relative price of goods and the relative

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[1]The first group of studies is based on the Heckscher-Ohlin model studied in Chaps. 4 and 5. The second group of studies uses model structures related to the Krugman model studied in Sect. 9.2.1. The work by Krugman and Venables relates to models of economic geography studied in Sect. 16.4.2. The last group of studies uses models related to the work of Melitz studied in Sect. 9.2.7.
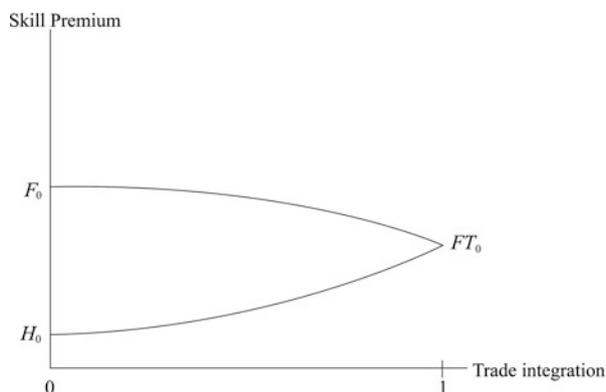
Fig. 17.1 Trade integration and the skill premium

price of factors.[2] Therefore, in the skill-abundant country, the increase in the relative price of the skill-intensive good will bring about an increase in the skill premium. Likewise, in the skill-scarce country, the decline in the relative price of the skill-intensive good will cause a fall of the skill premium. Ultimately, then, trade integration brings about an increase in the skill premium in the skill-abundant country and a decline of it in the other country. This is shown in Fig. 17.1.

Countries are labelled H and F and we use the convention that H is skill-abundant relative to F. Trade integration goes from zero (autarky) to one (free trade). The skill premium increases with trade integration in the skill-abundant country (from H_0 to FT_0) and decreases in the skill-scarce country (from F_0 to FT_0). In the literature, the evolution of the skill premium depicted in Fig. 17.1 is sometimes referred to as the Stolper-Samuelson effect[3] and we adopt this convention here.[4]

17.2.2   Technical Change

What type of technical change could explain the rise in the skill premium? In Sect. 13.5 we studied different types of technical change. With respect to the

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[2]We assume here that the conditions that give rise to such a correspondence are satisfied.

[3]See, e.g., Epifani and Gancia (2008) and Costinot and Vogel (2010, p. 782).

[4]The Stolper-Samuelson theorem is a constitutive element of the Stolper-Samuelson effect but does not coincide with it. In fact, the Stolper-Samuelson theorem only establishes a relationship between price of goods and price of factors stemming from profit maximization, and is not necessarily related to any specific general equilibrium evolution of prices.

factor bias, we recall that technical change is Hicks-neutral when the marginal productivity of factors changes equiproportionally; conversely, technical change is biased toward a factor when the marginal productivity of that factor increases more than proportionally with respect to the marginal productivity of the other factor. With respect to the sector, we say that there is a sector-bias in the direction of the sector that benefits most from the technical change. Both the sector and the factor dimensions are potentially important in explaining the changes in the skill premium. Recall, for instance, the case of Hicks-neutral technical progress (Sect. 13.5.2) in the skill-intensive industry. At constant commodity-price ratio, this change induces an increase in the skill-premium. Conversely, a Hicks-neutral technical progress in the low-skill-intensive industry gives rise, at constant commodity-price ratio, to a decline in the skill-premium. So, at constant commodity-price ratio, the sector bias of technical change determines the consequences on the skill premium. The assumption of constant commodity-price ratio, however, is only tenable when referring to small countries. When we abandon the assumption of constant commodity-price ratio there are further consequences. Take the case of Sect. 13.5.2 again. We noted there that in general equilibrium a Hicks neutral technical progress in the skill-intensive sector brings about a decline in the relative price of the skill-intensive good which will reduce the skill premium via the Stolper-Samuelson theorem . Thus, the effects resulting from the sector bias should be weighed against the effects resulting from changes in the commodity-price ratio. This is not a marginal matter; under very common assumptions about the production and the utility functions the effect of the change in the commodity-price ratio completely neutralizes the effect due to the sector bias. More in general, the sector bias may be attenuated, neutralized or reversed by the change in the commodity-price ratio. Coming to the role of the factor bias, recall the analysis in Sect. 13.5.3 which showed that both skill-biased and low-skill biased technical change give rise, at constant commodity-price ratio, to an increase in the skill premium, as long as the technical change occurs in the skill-intensive industry. Symmetric results occur if the skill biased technical change occurs in the low-skill-intensive industry. To this, we have to add that the assumption of constant commodity-price ratio can only be applied to small countries.

The ambiguity of the results is removed if we assume a pervasive worldwide skill biased technical change. This situation is represented in Fig. 17.2 where the dashed lines represent the relationship between the skill premium and trade openness after the occurrence of skill-biased technical progress worldwide and in every sector.

17.2.3   Trade Integration and Skill-Biased Technical Change

The evolution of the skill premium when trade integration and skill biased technical change occur simultaneously is given by the sum of the distinct effects of trade integration and of skill biased technical change. This is shown in Fig. 17.2.
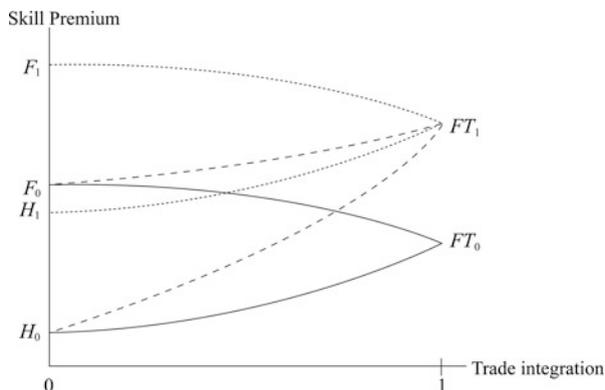
Fig. 17.2 Trade integration, technical change, and the skill premium

The skill premium in H will follow a path that goes from the autarky level H_0 to the free-trade level FT_1. The skill premium in the skill-scarce country goes from F_0 to FT_1. These paths are represented by the dotted lines. If the skill bias is sufficiently strong, as it is in the figure, point FT_1 has a larger value than F_0. In such a case, the skill premium increases in the skill-scarce country too. Otherwise the skill premium increases in H and declines in F but the decline is weaker than in the absence of skill-biased technical change.

So far, we have treated trade integration and technical change as independent causes of changes in the skill premium. We now discuss how the former may induce the latter.

17.2.4   Trade Integration Between Countries with Different Technology

The Heckscher-Ohlin model is usually treated under the assumption of identical technologies. This allows to focus on the role played by differences in factor endowments. But some studies (e.g., Acemoglu, 2003) argue that developed countries use more skill-intensive technologies than developing countries. We discuss the effect of trade integration between two countries with different technologies.

The world economy is composed of two countries, H and F, and produces two goods, Y_S and Y_L, by means of two primary factors, S and L. The countries have identical preferences over the two goods. We assume that country H uses a more skill-biased technology than country F. Specifically, though Y_S is more skill-intensive than Y_L in both countries, country H uses a more skill-intensive technology in all goods than country F. To isolate the effect of biased technology

Fig. 17.3 Identical
endowments and different
technology
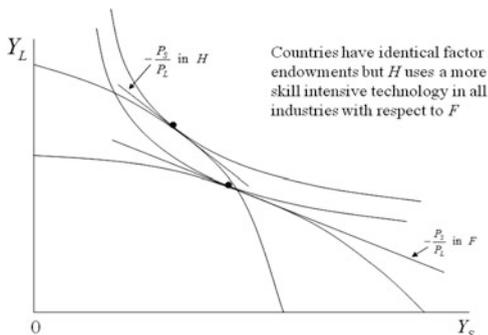
differences, we assume that countries have identical endowments. Therefore, absent
the technical bias, there would be no comparative advantage. Consider the autarky
situation. The relative demand for skilled labour, the skill-premium, and the relative
price of the skill-intensive good are higher in H than in F since the technology
is more skill-biased in H than in F. The autarky situation is represented in
Fig. 17.3.

Though the two countries have identical endowments, the transformation curves
are different because technologies are different.[5] The transformation curve of
country H is steeper because skilled labour is absorbed by skill biased technology
in H more than in F. Therefore, the intersection with the abscissa must lie closer
to the origin for country H than for country F. The two curves convex to the
origin represent the indifference curves. The autarky equilibria are represented by
the tangency points of the indifference curve to the respective transformation curve.
The relative price of the skill-intensive good is higher in H than in F as shown in
the figure.

Trade integration brings about convergence of goods prices and with it, conver-
gence of factor prices. This means that the skill premium declines in the skill-biased
country and increases in the other country.[6] If we now assume that H is skill-
abundant relative to F the overall effect of trade integration on the skill premium
will depend on which of the two forces, technical bias or endowments, dominates.
Costinot and Vogel (2010) argue that this ambiguity may explain why the overall
effect of trade integration on factor allocation and factor prices tends to be small in
practice.

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[5]See Sect. 3.1 for the derivation of the transformation curve.

[6]Convergence of factor prices is not complete because technologies are different.

Box 17.1 Globalization and Factor Prices: A Historical Perspective

An important result of the Heckscher-Ohlin model is that trade integration, via the convergence of commodity prices, causes the convergence of absolute and relative factor prices. In this box we look at factor prices convergence during one of the most important globalization periods in history: the years between 1870 and 1939. There are two other important periods of globalization, the sixteenth century and the decades between the past and the current century. For the sixteenth century data is scant. For the most recent globalization period data abounds but we prefer to show evidence of factor prices convergence for the period 1870–1939 in honor of Eli Filip Heckscher (Stockholm, 1879–1952) and his disciple Bertil Gotthard Ohlin (Klippan, 1899—Valadalen, 1979). Both authors have lived through this period of globalization, maybe they have been inspired by it, surely they did not have the Heckscher-Ohlin theory as a reference to understand what was going on.

Before moving to the data it is worth reflecting on what we expect to find in the data. The model predicts convergence of absolute and relative factor prices. When trade is completely free the equalization of commoditiy prices brings about the equalization of absolute and relative factor prices. Thus, in free trade, $w_L^H = w_L^F$, $w_S^H = w_S^F$, and $w_S^H/w_L^H = w_S^F/w_L^F$. The first remark is that trade is never really completely free (at the very least there are trade costs to make it not totally free), so we should not expect to observe *equalization* of factor prices at the end of a globalization period. The second remark is that the model excludes any productivity differences between countries. This exclusion is made on purpose in order to focus on the role of relative factor endowments. We know that differences in technology between countries are reflected in absolute factor prices (recall Trefler's works studied in Sect. 4.6.4). Thus, we should not expect to find convergence of absolute factor prices.

Hicks-neutral productivity differences are inconsequential for relative factor prices convergence while factor-biased productivity differences may counter convergence but do not, per se, invalidate the convergence mechanism (see Sect. 17.2.4). Therefore, if we look for evidence of a robust prediction of the Heckscher-Ohlin model with respect to factor prices, we should look for evidence of relative factor prices convergence.

The period 1870–1939 was marked by the transport cost revolution, commodity and factor prices convergence. We report here some of the data and examples published in Williamson (2006, Tables 2.2, 4.1 and 4.2).

Fall in trade costs. Freight cost of American export routes fell by 45 % between 1970 and 1910. The fall in freight costs as a percentage of the rice price between Rangoon and Europe in the period between 1882 and 1914 is reported to be 75 %. Towards the end of the period the fall in transport costs slowed down but did not stop. For instance, ocean transport costs fell only by 32 % between 1920 and 1940. **Commodity price convergence.** Price convergence was remarkable. The Liverpool-Odessa percentage wheat-price gap fell by 95 % in the period 1870–1906. The London-Boston percentage wool-price gap fell by 52 % between 1870 and 1913. The London-Chicago percentage wheat-price gap fell by 72 % between 1870 and 1912. The Liverpool-Bombay percentage cotton-price gap fell by 65 % between 1873 and 1913. **Factor prices convergence.** According to the model we should observe an increase in the relative price of the relatively abundant factor. The factors taken into consideration for the period are land (whose price is the rental rate) and labour (whose price is the wage). The table reports data on the wage/rental ratio for a few countries only and for three points in time (see Williamson, 2006, for the complete set of data). It is clear from these simple statistics that factor prices have moved mostly in the direction predicted by the model. The exceptions concern the second part of the period for the Land-Abundant countries. But some of these countries (Australia, the United States, Uruguay) have received massive migration flows from Europe which have probably made them a lot less land-abundant by the end of the period.

Trends of the wage/rental ratio in Europe and the new World					
	Land-abundant		Land-scarce		
Period	Australia	United States	Britain	France	Germany
1870–1874	416.2	233.6	56.6	63.5	84.4
1910–1914	100.6	101.1	102.7	99.8	100.2
1935–1939	110.5	240.1	206.5	168.2	n.a

Trends of the wage/rental ratio in the third World					
	Land-abundant		Land-scarce		
	Uruguay	Siam	Egypt	Japan	Taiwan
1870–1874	1112.5	4699.1	174.3[a]	79.9[b]	
1910–1914	117.9	109.8	79.8	107.5	96.6
1935–1939	213.5	121.6	91.0	149.9	123.6

[a] Datum for 1875–1879
[b] Datum for 1885–1889

17.2.5 Trade-Induced Skill-Biased Technical Change

Acemoglu (2002) suggests that trade integration may induce skill-biased technical change. To understand the logic of his argument we present a simplified version of his model.[7]

There are two countries, H and F, endowed with constant quantities of primary factors, $\bar{S}^H$, $\bar{S}^F$, and $\bar{L}^H$, $\bar{L}^F$. Countries produce two goods, Y_L and Y_S, and machines. The two goods are assembled to yield a final good, Y, which is used for consumption and also as the only input in the production of machines. Goods are produced by use of machines and primary factors L (unskilled labour) and S (skilled labour). Specifically, Y_L is produced by use of L and a number N_L of different L-complementary machines while Y_S is produced by use of S and a number N_S of different S-complementary machines. Factor intensity in production is extreme since each primary factor is only used in the production of one good: Y_S is S-intensive and Y_L is L-intensive. Machines are *complementary* in the sense that they can only be used by the corresponding factor.

The production of Y_S and Y_L requires different inputs but the proportion of primary factors relative to machines for any given relative price of inputs is assumed to be the same for both goods. Furthermore, it is assumed that the marginal

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[7]Acemoglu (2002) addresses a number of issues other than the effect of trade integration on factor prices. We restrict the discussion to the matter related to this chapter. Further we simplify the exposition by assuming that factors are gross substitutes. When they are gross complements trade integration does not necessarily result in skill-biased technical change.

productivity of each primary factor increases with the number of varieties of machines used by the factor. This is akin to the usual property that the marginal productivity of a factor increases as its relative use declines. Here, however, this property captures the idea that a larger number of more specific machines (tailor-made to the task) makes the primary factor more productive.

Consider the autarky equilibrium for country H (equilibrium for F is analogous) and drop the country superscript since confusion does not arise in autarky.

Primary factors are paid their marginal product. Therefore, the skill-premium, w_S/w_L, is equal to the ratio of marginal productivity, MPS/MPL, which in turn depends on the relative number of *S-complementary* machines, N_S/N_L, and on the relative supply of S, $\bar{S}/\bar{L}$. That is:

$$\frac{w_S}{w_L} = \frac{MPS}{MPL} = f\left(\underset{(+)}{\frac{N_S}{N_L}}, \underset{(-)}{\frac{\bar{S}}{\bar{L}}}\right), \tag{17.1}$$

where the notation $f\left(\frac{N_S}{N_L}, \frac{\bar{S}}{\bar{L}}\right)$ means that the skill premium depends on N_S/N_L and on $\bar{S}/\bar{L}$. The algebraic signs below these ratios indicate the direction of change of the skill premium resulting from an increase in the value of each of the ratios. An increase in N_S/N_L increases the skill-premium because it increases the relative marginal productivity of S. For the same reason, an increase in the relative supply of skilled labour, $\bar{S}/\bar{L}$, reduces the skill premium.

The markets for Y_L, Y_S, and Y are perfectly competitive. Good Y is the numéraire and p_L and p_S denote the price of Y_L and Y_S respectively. Each machine is produced by a monopolist. Machines are different but the technology of production is the same for all machines and requires a constant input of Y per unit of output.

We now discuss the link between relative goods prices, relative factor endowments, and technical change. First, the relative profit of *S-complementary* machines depends positively on the relative price of the skill-intensive good, p_S/p_L. The reason is that an increase in the relative price of this good induces an expansion of its relative production and an increase in the relative demand for *S-complementary* machines as inputs, thereby tending to increase the relative profitability of *S-complementary* machines. We refer to this mechanism as the *price effect*.

Second, the relative profitability of *S-complementary* machines increases with a rise in the relative endowment of skilled labour, $\bar{S}/\bar{L}$, precisely because of the complementarity in production. Indeed, if the input of S increases so does the input of *S-complementary* machines. We refer to this as the *market size* effect, where market means the market for machines.

Monopolists will produce *L-complementary* machines or *S-complementary* machines depending on which gives higher profits. Arbitrage between these two options assures that in equilibrium they give the same profit, i.e., $\pi_S/\pi_L = 1$.

This means that whenever there is pressure for an increase in π_S/π_L, this pressure induces an increase in the relative supply of *S-complementary* machines, restoring the equilibrium $\pi_S/\pi_L = 1$. The relative supply of *S-complementary* machines therefore depends on the relative price of goods via the price effect and on the relative number of factors via the market size effect. We write directly

$$\frac{N_S}{N_L} = f\left(\underbrace{\frac{p_S}{p_L}}_{Price\ effect\ (+)}, \underbrace{\frac{\bar{S}}{\bar{L}}}_{Market\ size\ effect\ (+)}\right), \tag{17.2}$$

where, again, the notation $f\,(.,.)$ means that N_S/N_L depends on the two variables in parentheses and the algebraic signs indicate the direction of the relationship.[8]

The relative price of the skill-intensive good depends negatively on its relative supply, but the latter depends positively on the relative availability of inputs (primary factors and machines). Therefore we can write

$$\frac{p_S}{p_L} = f\left(\underbrace{\frac{N_S\bar{S}}{N_L\bar{L}}}_{(-)}\right). \tag{17.3}$$

Let us now consider free trade between H and F and resume the country superscript. Countries are identical except for factor endowments given by $\bar{S}^H/\bar{L}^H > \bar{S}^F/\bar{L}^F$. When moving from autarky to free trade—with technology unchanged—the relative price of the *S-intensive* good will increase in the *S-abundant* country. This effect may be seen in Eq. (17.3) where, in free trade, world relative endowment $(\bar{S}^H + \bar{S}^F)/(\bar{L}^H + \bar{L}^F)$ replaces the country relative endowment $\bar{S}/\bar{L}$ and the former is smaller than the latter since H is skill-abundant. So far, we have obtained the same result as in standard Heckscher-Ohlin, namely, that the relative price of the skill-intensive good increases in the skill-abundant country (and declines in the skill-scarce country) when passing from autarky to free trade, and that in free trade the relative price of goods depends on the world relative supply of factors. What is new here is that the rise in the relative price p_S/p_L increases the profitability of *S-complementary* machines so that machine producers find it optimal to increase the production of machines *complementary* to the relatively abundant factor as indicated by the price effect in expression (17.2). As a result, the relative marginal productivity of the relatively abundant factor increases and that of the relatively scarce factor declines. There is therefore a trade-induced skill-biased technical change in the skill-abundant country. The consequences on the skill premium can be immediately seen by inspection of Eq. (17.1). The skill premium increases in the *S-abundant*

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[8]We should be using f, g, etc. for different functional forms but we neglect this matter to keep notation at a minimum.

country for two reasons. First, because of the usual Stolper-Samuelson effect . This is seen by replacing $\bar{S}/\bar{L}$ with $\left(\bar{S}^H + \bar{S}^L\right)/\left(\bar{L}^H + \bar{L}^L\right)$ in Eq. (17.1). Second, because of the increase in N_S/N_L induced by the price effect.

Naturally, the opposite occurs in the *L-abundant* country. Thus, the skill premium increases in the skill-abundant country and declines in the skill-scarce country.

In this model, the change in the skill premium is due to both international trade and technical change, but the latter is induced by the former.

17.2.6   A Generalization

The literature on wage inequality has gradually evolved from the two-factor model structure to a model structure with many (actually a continuum of) types of labour which differ in skill. Analogously, the traditional two-goods structure is replaced by a structure with any number of goods which differ by skill intensity. Furthermore, in these models the productivity of labour for any given skill depends on the matching between the type of labour and the type of good. These new modeling structures are better suited to the analysis of wage inequality. As an example of these structures we review a simplified version of the model in Costinot and Vogel (2010).

17.2.6.1   The Model

The world is composed of two countries, H and F. Workers differ in skills measured by s. The lowest and highest value of skills are $\underline{s}$ and $\bar{s}$, respectively. Let V_s^H and V_s^F be the endowment of workers of skill s in H and F, respectively. The definition of skill abundance in this environment where there are many different types of workers is as follows. Country H is skill-abundant if and only if

$$V_{s'}^H V_s^F \geq V_s^H V_{s'}^F \text{ for all } s' \geq s. \tag{17.4}$$

Note that this definition implies that $V_{s'}^H/V_{s'}^F \geq V_s^H/V_s^F$ if skill levels s' and s exist in both countries. This is the natural extension of the traditional definition of comparative advantage. If instead either s' or s or both do not exist in a country, then the definition implies that $\underline{s}^H \geq \underline{s}^F$ and $\bar{s}^H \geq \bar{s}^F$. In either case, country H is skill-abundant.

Figure 17.4a shows an example of the distribution of skills for two countries. Skill levels are plotted on the abscissa and the number of workers on the ordinate. Country F has workers with skill levels from one to seven. Country H has workers with skill levels from four to ten. Country F has two workers with skill level equal to one, country H has none, country F has three workers with skill level equal to two and country H has none, while country F has no workers with skill level equal to ten and country H has two, and so on. The mean skill is 7 in H and 4 in F. The shape of the distributions is symmetric around the mean; for each
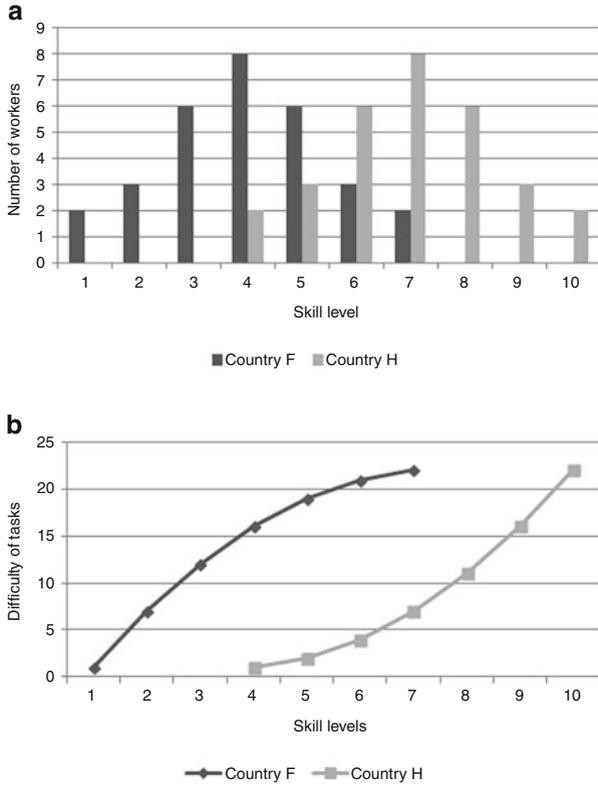
Fig. 17.4 Skills, tasks, and wages. (**a**) Skill distribution. (**b**) Wage distribution

distribution the endowment is the same for any skill level equally distant from the mean. Furthermore, the shape of the distribution is identical; each country has two workers with lowest skill-level, three workers with the second-to-lowest skill-level, etc. Naturally, neither symmetry nor identity of the distribution shape is a necessary requirement for the construction of the model, but we make these assumption here for simplicity. It is easily verified that H is skill-abundant in this example.

Total output of the economy, Y, is produced by inputting intermediate goods Y_δ, henceforth called tasks. Tasks are indexed by the difficulty of accomplishment, δ; the easiest task is $\underline{\delta}$ and the most difficult task is $\bar{\delta}$. The production function is

$$Y = \left(\sum_{\delta=\underline{\delta}}^{\bar{\delta}} (Y_\delta)^\alpha \right)^{1/\alpha}, \quad 0 < \alpha < 1. \tag{17.5}$$

Expression (17.5) simply says that the output Y is obtained from the sum powered to $1/\alpha$ of inputs Y_δ powered to α. Tasks are produced with the following production function

$$Y_\delta = \sum_{s=\underline{s}}^{\overline{s}} a_s^\delta L_s^\delta, \qquad L_s^\delta \geqslant 0, \tag{17.6}$$

where a_s^δ is the productivity of a worker with skill s applied to task δ and L_s^δ is the endogenous labour input of skill s employed in the production of task δ. One key assumption of the model is that high skill workers have the comparative advantage in difficult tasks. This means to assume that for any $s > s'$ and any $\delta' > \delta$

$$a_{s'}^{\delta'}/a_{s'}^\delta > a_s^{\delta'}/a_s^\delta. \tag{17.7}$$

In other words, inequality (17.7) says that workers with higher skills are relatively more productive in accomplishing difficult tasks.[9]

17.2.6.2   Equilibrium

Goods and factors markets are perfectly competitive. Let p_δ denote the price of task δ, let Y serve as numéraire and let its price be set to 1. Then, profits in the final goods market are given by

$$\Pi = \underbrace{\left(\sum_{\delta=\underline{\delta}}^{\overline{\delta}} (Y_\delta)^\alpha \right)^{1/\alpha}}_{Revenues} - \underbrace{\sum_{\delta=\underline{\delta}}^{\overline{\delta}} p_\delta Y_\delta}_{Total\ costs}. \tag{17.8}$$

The final goods producers maximize profits by choosing the quantity of each intermediate input (task), Y_δ. This require the marginal revenue to equal marginal cost, which yields the following demand for each intermediate input:

$$Y_\delta = (p_\delta)^{-\alpha/(1-\alpha)} Y \qquad \forall \delta. \tag{17.9}$$

Intermediate goods producers maximize profits by choosing the labour input for each skill level, $L_s^\delta \geqslant 0$. In deciding the labour input, the firm compares the marginal cost of a worker, i.e., the wage w_s, with the marginal revenue produced by a worker, i.e., the value of that worker's production, $p_\delta a_s^\delta$. Employment of skill level s will be zero ($L_s^\delta = 0$) for all the s such that $p_\delta a_s^\delta < w_s$. Conversely, employment will be positive for all s such $p_\delta a_s^\delta = w_s$. Perfect competition rules out $p_\delta a_s^\delta > w_s$ in equilibrium. Thus, the conditions for profit maximization in intermediate production are

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[9]This is reminiscent of Ricardian comparative advantage but here the comparative advantage is defined over worker-task pairs instead of country-good pairs.

$$p_\delta a_s^\delta - w_s \leq 0, \quad \forall s \tag{17.10}$$

$$p_\delta a_s^\delta - w_s = 0, \quad \forall s \text{ for which } L_s^\delta > 0 \tag{17.11}$$

Note that Eqs. (17.10) and (17.11), do not contain L_s^δ but employment must be compatible with them. Given the comparative advantage of workers established in (17.7), workers with the same skill level will never be employed in different tasks, nor will two workers with different skills be assigned to the production of the same task. Thus, if $L_s^\delta > 0$ then $L_s^{\delta'} = 0$ for all $\delta' \neq \delta$ and $L_{s'}^\delta = 0$ for all $s' \neq s$.[10]

Equilibrium in the market for tasks and for labour requires, respectively:

$$\underbrace{(p_\delta)^{-\alpha/(1-\alpha)} Y}_{\text{Demand for task } \delta} = \underbrace{\sum_{s=\underline{s}}^{\overline{s}} a_s^\delta L_s^\delta}_{\text{Supply of task } \delta} \quad \forall \delta \tag{17.12}$$

$$V_s = \sum_{s=\underline{s}}^{\overline{s}} L_s^\delta, \quad \forall s \tag{17.13}$$

where we recall that Y is the value of aggregate output and therefore the income of the economy.

To better understand the properties of the equilibrium, consider first a simple two-by-two simplification where $\delta = 1, 2$ and $s = 1, 2$. Then the eight equations (17.10), (17.11), (17.12), and (17.13) determine the equilibrium value of the eight endogenous variables $p_\delta, w_s, L_s^\delta$, from which all the other values of the endogenous variables are obtained. As an example let us assume an arbitrary employment allocation, for instance: $L_2^2 > 0, L_1^1 > 0$. Then, $L_1^2 = 0, L_2^1 = 0$, therefore $L_2^2 = V_2$ and $L_1^1 = V_1$; which implies $p_1 = w_1/a_1^1$ and $p_2 = w_2/a_2^2$ from (17.11). Inserting these prices into Eqs. (17.12) and (17.13); noting that Y, being the value of total output, is also national income, i.e., $Y = w_1 V_1 + w_2 V_2$, we obtain

$$\left(\frac{w_1}{a_1^1}\right)^{\alpha/(1-\alpha)} = \frac{w_1 V_1 + w_2 V_2}{a_1^1 V_1} \tag{17.14}$$

$$\left(\frac{w_2}{a_2^2}\right)^{\alpha/(1-\alpha)} = \frac{w_1 V_1 + w_2 V_2}{a_2^2 V_2}. \tag{17.15}$$

Equations (17.12) and (17.13) may be solved (numerically) for $\{w_1, w_2\}$. For this solution to be an equilibrium for the economy it must also satisfy inequality (17.10), otherwise the arbitrarily chosen employment allocation is not viable. It turns out that only the allocation $L_2^2 > 0, L_1^1 > 0$ satisfies all the equations, including inequality (17.10). Note that this employment allocation is such that the high-skill

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[10]This is reminiscent of the traditional Ricardian model where specialization is complete.

worker is employed in the production of the difficult task and the low-skill worker is employed in the easy task. This property can be extended to the many-skills many-tasks context: In equilibrium, for any two workers s and s' and for any two tasks δ and δ', with $s' > s$ and $\delta' > \delta$, worker s' matches with task δ' and worker s matches with task δ.

Figure 17.4b depicts the equilibrium matching between skills and tasks for each country in autarky. Skill levels are plotted on the abscissa and the difficulty of tasks ranging from 0 to 22 on the ordinate. The matching schedule M_s shows the association of any skill level s to a task δ resulting from the competitive equilibrium. The matching schedule also reflects the wage schedule, since the wage increases with productivity and productivity increases with the skill level.

Figure 17.4 shows that in both countries, more highly-skilled workers match with more difficult tasks, but any given task is performed by more highly-skilled workers in H than in F. One way of interpreting this result is that the same task is produced with a more skill-intensive technique in H than in F. This is reminiscent of the simple two-by-two Heckscher-Ohlin model, where in autarky the S-abundant country produces both goods with more S-intensive techniques than the L-abundant country. The intuition here is practically the same: each country must make more intense use of the relatively abundant factor and produce a larger quantity of the good that is intensive in the relatively abundant factor in order to satisfy full employment conditions. Perfect competition assures that this is indeed the equilibrium outcome.

Now let us consider trade integration in tasks. Trade integration results in an increase in the skill premium in H and a decrease in F. This means that for any s and s', the skill premium $w_{s'}/w_s$ increases with trade integration in H and decreases in F. This is similar to the traditional Stolper-Samuelson effect and occurs for the same reason. Furthermore, trade integration causes skill downgrading for all tasks in H and skill upgrading for all tasks in F. Skill downgrading means that each task is performed by workers with lower skills while skill upgrading means that each task is performed by workers with higher skills. Again, this is similar to the two-by-two Heckscher-Ohlin model where the rise in the relative price of the relatively abundant factor brings about the use of techniques that are less intensive in the relatively abundant factor in every country. In terms of Fig. 17.4b, trade integration is represented by a downward shift and a clockwise rotation of the matching schedule for F, and an upward shift and a counterclockwise rotation for H.

The effects of trade integration in this model are then essentially the same as those studied in the Heckscher-Ohlin model, but here we have a more general modelling structure which allows to better understand the literature that we discuss in Sect. 17.5.

17.3   Offshoring and the Skill Premium

We have studied a model of offshoring in Sect. 6.8.5. We return to this matter here, where we focus on the effect of offshoring on the skill premium. Off-shoring means relocating part of the production process abroad. This definition encompasses both multinationals (where the firm keeps ownership of the offshored activities) and foreign outsourcing (where the firm relinquishes ownership of the offshored activities). The offshored part of the production process may be material (fragmentation of the production process into different stages performed in different countries) or immaterial, typically containing knowledge or information, (assignment of different immaterial tasks to workers in different countries). In this section we describe two models of offshoring. The first is more closely related to the fragmentation of production, the second to the offshoring of knowledge output.

17.3.1   *Fragmentation of Production*

We follow closely Feenstra and Hanson (1997). They propose a simple and insightful model of offshoring in the context of the Heckscher-Ohlin framework. They consider a perfectly competitive industry where production requires many "activities", denoted z, with $z \in [0, 1]$, each of which performed by combining fixed quantities of skilled and unskilled labour. These quantities differ across activities. To simplify matters, let a_{Lz} and a_{Sz} denote the quantity of unskilled and skilled labour requested to produce activity z and let A_z denote the skill intensity of activity z, $A_z \equiv a_{Sz}/a_{Lz}$. We rank activities by increasing order of skill intensity so that A_z increases with z. Activities may be performed at home (country H for instance) or abroad (country F) and it is assumed that firms carry with them the home technology when delocalizing some activities abroad. Therefore, the input requirements per unit of output are the same regardless of whether an activity is performed at home or abroad. However, performing activities abroad increases the marginal cost by a factor $\chi > 1$. This is due, for instance, to the coordination and communication costs of organizing offshored activities. For firms in H, the marginal cost of performing an activity z in countries H and F is, respectively, $mc_z^H = w_L^H a_{Lz} + w_S^H a_{Sz}$ and $mc_z^F = \chi \left(w_L^F a_{Lz} + w_S^F a_{Sz} \right)$, and the ratio of marginal cost mc_z^H / mc_z^F is:

$$\frac{mc_z^H}{mc_z^F} = \frac{w_L^H + w_S^H A_z}{\chi \left(w_L^F + w_S^F A_z \right)} \tag{17.16}$$

Input requirements do not have a country superscript because the firm brings its technology when producing abroad. Firms in H perform activity z at home if $mc_z^F > mc_z^H$ and abroad if $mc_z^F < mc_z^H$. Solving

Fig. 17.5 Globalization and
the partition of activities
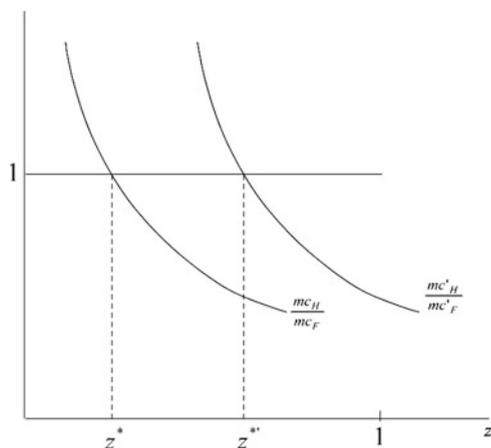
$$\frac{mc_z^H}{mc_z^H} = 1 \qquad\qquad (17.17)$$

for z gives the threshold activity z^* for which the firm is indifferent between performing it at home or abroad. If we assume that country H is skill-abundant, then $w_S^H/w_L^H < w_S^F/w_L^F$ and mc_z^H/mc_z^F is decreasing in z.

Figure 17.5 shows the determination of the equilibrium obtained by use of Eqs. (17.16) and (17.17). The intersection between the declining marginal cost ratio and the horizontal line drawn at value equal to one gives the threshold value z^*. Activities from 0 to z^* are performed in F whereas activities from z^* to 1 are performed in H. Thus, H firms perform high skill-intensive activities at home and offshore to the skill-scarce country the low skill-intensive activities. This is reminiscent of the specialization pattern occurring in the Heckscher-Ohlin model and indeed it occurs for essentially the same reasons.

Now imagine that the cost of offshoring (χ) declines. Then, as we see from Eq. (17.16), for any given z the relative marginal cost of producing at home increases. Graphically, this is represented by a movement to the right of the mc_z^H/mc_z^F curve to $mc_z'^H/mc_z'^F$ in Fig. 17.5. The threshold value of marginal cost moves to the right from z^* to $z^{*\prime}$. Activities from z^* to $z^{*\prime}$ that were produced in H are offshored to F after the decline in χ. What is the effect on the skill premium? The relative demand for skills increases at home since the newly-offshored activities are the least skill-intensive among those previously performed at home. The average skill intensity of the activities remaining at home increases and so does the relative demand for skilled labour. Therefore the skill premium increases in H. The newly-offshored activities are more skill-intensive than the activity performed in F previous to the fall in χ. The arrival of these new activities in F reduces the average skill intensity of the activities performed there and increases the relative demand for skilled labour. Therefore, the skill premium increases in F too. This is a simple

but insightful story where globalization makes it possible to increase the share of offshored activities, thereby increasing the relative demand for skilled labour and the skill premium in all countries.

17.3.2   Offshoring Knowledge Output

We review the key elements of immaterial offshoring models by studying a simplified version of the model in Antràs et al. (2006). The world economy is composed by two countries, H and F, populated by agents of different skill levels, denoted z, ranging from 0 to z_H in H and from 0 to z_F in F.

In Fig. 17.6. The skill level, z, is plotted on the abscissa. Without loss of generality, it is assumed that $z_H = 1 > z_F$. The number of agents having any given value of z is measured on the left-hand ordinate. The value of the total population in each country is normalized to 1. Agents decide whether to become managers or workers. The production process requires the solution of problems of difficulty z ranging from 0 to 1 (denoting the skill level and difficulty level by the same variable simplifies notation). An agent of skill level z', whether manager or worker, is able to solve all the problems from 0 to z'. Production of the final good requires knowledge provided by a team composed of one manager and a number of workers. The team works as follows. Each worker produces knowledge output by solving problems for which he knows the solution. If a worker faces a problem he cannot solve he asks the manager. If the manager knows the solution he tells it to the worker, who produces one unit of knowledge output. If the manager does not know the solution, knowledge output is not produced. Agents are endowed with one unit of time and a manager spends $0 < h < 1$ units of time communicating with a worker, regardless of whether the manager knows the solution to the problem. A manager in a team with n workers of skill level z_p is asked for solutions for every problem of difficulty larger than z_p, and there are $(1 - z_p)$ such problems, each requiring h units of manager communication time. With n workers in a team, the manager input time is $h(1 - z_p)n$ and the manager time constraint is $h(1 - z_p)n = 1$. Therefore, a manager can supervise at most

$$n = \frac{1}{h(1 - z_p)} \tag{17.18}$$

workers of skill level z_p. The team output of a manager of skill level z_m working in a team with n workers of skill level z_p is $y_{mp} = z_m n$, or

$$y_{mp} = \frac{z_m}{h(1 - z_p)}. \tag{17.19}$$

Let w_{z_p} denote the equilibrium wage of workers with skill level z. Manager income R_{z_m} is given by the value of output minus costs, i.e., $y_{mp} - w_{z_p}n$. Thus, a manager chooses the skill level of his workers, z_p, so as to maximize R_{z_m} subject to the
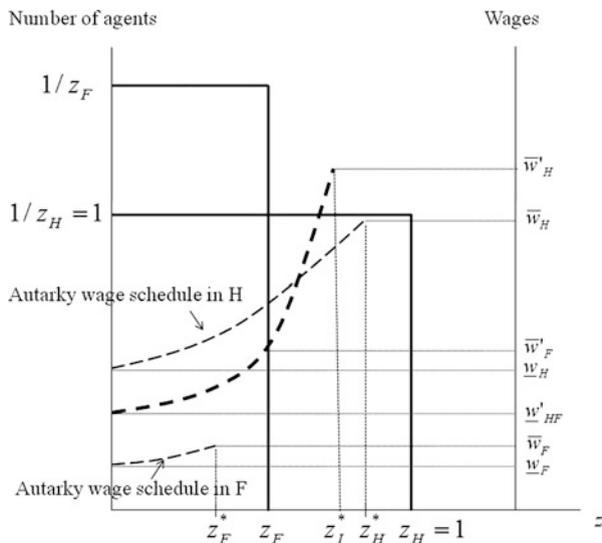
Fig. 17.6 Immaterial offshoring

time constraint $h(1 - z_p)n = 1$. Any agent of skill level z' chooses to become manager or worker by comparing the income he can get as a manager, $R_{z_m=z'}$ with the wage he can earn as a worker $w_{z_p=z'}$. This mechanism of occupational choice and the complementarity between workers and managers lead to a result in equilibrium that is pretty intuitive. The complementarity between workers and managers can be seen in the expression (17.19). It is clear from this expression that the higher the skill level of workers, z_p, the stronger the impact on team output of an increase in manager skills, z_m. Likewise, an increase in the skill level of workers is worth more to more highly-skilled managers. As a result, although $z_m > z_p$ in equilibrium, better workers will always belong to teams led by better managers.

Let us now characterize the autarky equilibria. Consider H first. The autarky equilibrium is characterized by a threshold value of skill, z_H^*, such that any agent with skill level $z = z_H^*$ is indifferent between being a manager or a worker. Thus, all agents with skill level $0 < z < z_H^*$ decide to become workers and all agents with skill level $z_H^* < z < 1$ decide to become managers. Quite naturally, the more highly-skilled agents find it optimal to become managers while the less-skilled agents find it optimal to become workers. The closed economy equilibrium in F is also characterized by a threshold value, z_F^*, but the threshold values are not the same; specifically, $z_H^* > z_F^*$. An agent with skill level $z = z_F^*$ in F is by definition indifferent between being manager or worker, but an agent in H with that same skill level is not indifferent. The reason is that he can join a team led by a manager whose skill level is higher than that of any manager in F, and there will be a manager in H with skill level higher than z_F^* willing to take him in his team. Thus, the agent in H with skill $z = z_F^*$ certainly decides to become a worker. In sum, the availability

of higher skill levels in H means that the least-skilled manager in this country has higher skills than the least-skilled manager in F. This also implies that for any two workers with the same skill levels, the worker in H is led by a better manager. The thin dashed lines in Fig. 17.6 represent the wage schedules in autarky. Observe that wage inequality is larger in H than in F. Specifically, let the difference between the wage of the most highly-skilled and least-skilled workers be the measure of the skill premium (or of wage inequality). These differences are $\bar{w}_H - \underline{w}_H$ and $\bar{w}_F - \underline{w}_F$ and we see clearly that $\bar{w}_H - \underline{w}_H > \bar{w}_F - \underline{w}_F$. This is due to two reasons. The first is the occupational choice effect: since agents with higher skills decide to become workers in H ($z_H^* > z_F^*$) and since the wage is increasing in the skill level, then the skill premium will obviously be larger in H. The second reason is the complementarity effect: since any worker is led by a better manager in H than in F, any increase in z_p is worth more in H than in F and therefore gives rise to a stronger wage increase in H than in F. In other words, the slope of the wage schedule in H is larger than in F.[11]

Let us now consider globalization, in the sense that teams may be formed by agents of both countries. The threshold value in the globalized economy, z_I^*, will be between the two autarky threshold values, $z_F^* < z_I^* < z_H^*$, which means that the number of workers increases in F and the number of managers increases in H.[12] Specifically, all agents in F and agents with skills between 0 and z_I^* in H are workers while the remaining agents are managers. These changes in threshold values occur because the world economy has a distribution of skills that is between that of each of the countries. Take, for instance, the agent with skill $z = z_F^*$ in F; he is indifferent between becoming a manager or a worker in autarky but after globalization he can be led by a manager whose skill-level was not available in autarky and he will therefore no longer be indifferent: he will want to become a worker. Likewise, the agent with skill $z = z_H^*$ in H is indifferent between occupations in autarky (as a manager he would lead workers with skills $z = 0$) but after globalization he is in demand as a manager because there are many more low-skill workers in search for managers; he will decide to become a manager and will lead workers with skills $z > 0$.

These changes in the threshold values have repercussions on wage inequality, driven by the complementarity and occupational choice effects, as we now discuss. After globalization, all workers in F match with better managers who are located

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[11]Incidentally, we also note that the wage schedule in H lies above that in F. This is again due to the fact that any worker in H is led by a better manager than any worker with the same skills in F. The convexity of the wage schedules is due to the complementarity between workers and managers established by expression (17.19).

[12]For clarity of exposition we have shown the case where z_I^* lies to the right of z_F, implying that all agents in F decide to become workers after globalization. Antràs et al. (2006) call this the "Low Quality Offshoring Equilibrium". The threshold value z_I^* could however fall to the left of z_F, in which case some agents in F will remain managers after globalisation. The case shown in the figure has simpler implications. The alternative case is more complex but still gives rise to an increase in the skill premium in F, while giving rise to ambiguous effects in H.

in H (offshoring of problem-solving). This is good for all $F-$workers, but the strength of the positive effect is proportional to each worker's skill; this is the complementarity effect. Furthermore, in F the number of workers increases from z_F^* to z_I^*, which pushes the skill premium upward; this is the occupational choice effect. Thus, wage inequality unambiguously increases in F. In H, among the workers that remain workers after globalization, the lower-skilled are matched with worse managers while the more highly-skilled are matched with better managers. Given the complementarity between managers and workers, this matching effect clearly tends to increase the skill premium among $H-$ workers. To counter this effect, there is the occupational choice effect represented by the decline in the number of workers in H. The effect is a priori ambiguous, but the skill premium unambiguously rises when communication costs (h) are low and when the endowment difference ($z_H - z_F$) is high. Thus, offshoring between very different countries and when the communication costs are low increases the skill premium in all countries. This is the situation represented by the thick dashed line in Fig. 17.6. This line represents the wage schedule after globalization (the same in both countries). By comparing $\bar{w}_H' - \underline{w}_{HF}'$ with $\bar{w}_H - \underline{w}_H$ and $\bar{w}_F' - \underline{w}_{HF}'$ with $\bar{w}_F - \underline{w}_F$ we see that globalization brings about an increase in the skill premium in both countries. There are also consequences at the level of nominal wages. Low-skill workers in F are matched with better managers after globalization while the opposite happens to low-skill workers in H. This explains why the thick dashed line intersects the left-hand ordinate in between the autarky wage schedules. Furthermore, the most highly-skilled workers among those who remain workers in H after globalization are matched with better managers than before, which explains the crossing of the thick dashed line with the H autarky wage schedule.

17.4   Economies of Scale and the Skill Premium

Some studies suggest that economies of scale at firm or at industry level may provide the link between trade integration and the skill premium. The types of economies of scale taken into consideration vary across authors, but they have in common that trade integration, via economies of scale, makes production more efficient. Crucially, the gain in efficiency is biased in favour of skilled labour.

We review two representative models. In the first, economies of scale come from the increased number of inputs made possible by trade liberalization. In the second, economies of scale come from the expansion of output caused by international trade and declining average costs.

17.4.1   Intermediate Inputs and Productivity

In this section we describe a simplified version of the model proposed in Epifani and Gancia (2008). Consumers derive utility from the consumption of two goods,

Y_L and Y_S. The utility function defined over these two goods takes the form already encountered in Eq. 9.2, which yields the following relative demand for Y_S:

$$\frac{Y_S^d}{Y_L^d} = \left(\frac{P_L}{P_S}\right)^{\varepsilon}, \quad \varepsilon > 1 \tag{17.20}$$

where the superscript d indicates that these are quantities demanded. The parameter ε represents the elasticity of substitution between goods. These goods are produced in perfect competition by assembling n_i intermediate inputs specific to good i ($i = L, S$). Production of any variety of intermediate input, y_i, requires a fixed amount of labour and a constant marginal labour input. It is assumed that the production of intermediate inputs for the S industry requires only skilled labour while the production of the intermediate inputs for the L industry requires only unskilled labour. This is an extreme form of factor intensity which simplifies the exposition and has no crucial consequences on the result. Each intermediate input y_i is produced by a different firm in a monopolistic competitive market of the type studied in Sect. 9.2. The profit-maximizing price (p_i) is obtained from the condition marginal revenue = marginal cost. This condition gives $p_i = \mu w_i$, where $\mu > 0$ is the constant mark-up. The relative price of any two inputs in different industries is therefore:

$$\frac{p_S}{p_L} = \frac{w_S}{w_L}. \tag{17.21}$$

Expression (17.21) gives the Stolper-Samuelson relationship between the relative price of goods and the relative price of factors. We have already studied this relationship in Sect. 5.3 in the context of the Heckscher-Ohlin model. Here, the relationship is particularly simple because we have assumed that each input is produced with only one factor. Free entry assures zero profits and the zero profit condition determines the equilibrium size of firm output ($\bar{y}$) which turns out to be equal for all firms. Using this result, the production function of final goods may be written as:

$$Y_i = \bar{y} \, (n_i)^{\frac{\sigma_i}{\sigma_i - 1}} \tag{17.22}$$

Expression (17.22) shows the nature of economies of scale in the production of goods. As the number of intermediate inputs increases, final output Y_i expands, ceteris paribus. This property of the production function, introduced into international trade theory by Ethier (1982), captures the idea that a larger number of intermediate inputs increases the efficiency of the production process, for instance because a larger number of inputs better matches the specific needs of each production process. This property can be seen by dividing output (Y_i) by aggregate inputs (given by $\bar{y}n_i$). The result of this division is the marginal (and average) productivity of each input:

$$\frac{Y_i}{\bar{y}n_i} = (n_i)^{\frac{1}{\sigma_i-1}} \tag{17.23}$$

which shows that the marginal productivity is increasing in the number of inputs. The relationship between number of inputs and output is not the same in both industries, however. In fact, the model assumes that $\sigma_L > \sigma_S > \varepsilon$. This means that economies of scale are stronger in the skill-intensive industry ($\sigma_L > \sigma_S$) and that the elasticity of substitution between any two inputs is larger than the elasticity of substitution between the final goods ($\sigma_L > \varepsilon$; $\sigma_S > \varepsilon$). Using (17.22) the relative supply of Y_S is:

$$\frac{Y_S^s}{Y_L^s} = \frac{(n_S)^{\frac{\sigma_S}{(\sigma_S-1)}}}{(n_L)^{\frac{\sigma_L}{(\sigma_L-1)}}}. \tag{17.24}$$

where the superscript s indicates quantities supplied. Profit maximization in the final good industry requires the marginal revenue to equal the marginal cost for each intermediate input, which is:

$$P_i\,(n_i)^{\frac{1}{\sigma_i-1}} = p_i \tag{17.25}$$

Equation (17.25) is easily understood by noting that $(n_i)^{\frac{1}{\sigma_i-1}}$ is the contribution to output of each input (its marginal productivity) and each unit of such contribution is worth P_i; therefore the left-hand side is the marginal revenue while the right-hand side is the marginal cost of each input (its price). The relative price of the L-intensive good is therefore:

$$\frac{P_L}{P_S} = \frac{p_L}{p_S} \frac{(n_S)^{\frac{1}{\sigma_S-1}}}{(n_L)^{\frac{1}{\sigma_L-1}}}. \tag{17.26}$$

Using (17.20) and (17.24), the equilibrium condition in the final goods market is:

$$\frac{Y_S^d}{Y_L^d} = \frac{Y_S^s}{Y_L^s} \implies \frac{P_L}{P_S} = \frac{(n_S)^{\frac{\sigma_S}{\varepsilon(\sigma_S-1)}}}{(n_L)^{\frac{\sigma_L}{\varepsilon(\sigma_L-1)}}} \tag{17.27}$$

Combining Eqs. (17.27) and (17.26) we obtain:

$$\frac{p_S}{p_L} = \frac{(n_L)^{\frac{\sigma_L-\varepsilon}{\varepsilon(\sigma_L-1)}}}{(n_S)^{\frac{\sigma_S-\varepsilon}{\varepsilon(\sigma_S-1)}}} \tag{17.28}$$

The number of varieties is determined by the equilibrium conditions in factor markets. Let $\bar{L}$ and $\bar{S}$ be the quantity of unskilled and skilled labour existing in

the economy. By appropriate choice of parameter values, factor market equilibrium conditions are $n_S = \bar{S}$ and $n_L = \bar{L}$. Therefore $n_S/n_L = \bar{S}/\bar{L}$.

Now imagine a second identical economy and assume free trade. Then the number of intermediate inputs for each industry produced in the world economy is just twice the autarky number. Each good is therefore produced in free trade with twice as many inputs as in autarky. The ratio n_L/n_S remains unchanged in both countries, though the number of inputs in each good doubles, thanks to trade in intermediate inputs. The consequence on the skill premium can be seen by inspecting Eqs. (17.28) and (17.21). From (17.28) we see that p_S/p_L increases and from (17.21) we see that an increase in p_S/p_L drives up the skill premium.[13] A simple way of interpreting this result is that trade opening, through the availability of a larger number of intermediate inputs, increases the productivity of each input in Y_S relative to that of each input in Y_L. Therefore each intermediate input in Y_S is paid relatively more. Consequently, since the mark-up μ is constant, the skill premium is pulled upwards. It is worth mentioning that the relative price of the skill-intensive good declines due to the relative increase in its supply (see Eqs. 17.24 and 17.27). Nevertheless, the relative price of each input in Y_S increases. This is possible because, as shown by expression (17.25), the relative price of final goods depends positively on the relative price of intermediate inputs but negatively on the relative number of inputs.

17.4.2   Skill Biased Economies of Scale and Demand Elasticity

A possible additional link between trade integration and the skill premium may reside in the non-homotheticity of the production function. A production function is said to be homothetic when the factor intensity remains constant as output changes (with unchanged relative factor prices). When, on the contrary, the factor intensity depends on the size of output, the production function is said to be non-homothetic.[14] Clearly then, when the production function is non-homothetic, a change in output results in a change in the relative demand for factors at the firm level and also at the aggregate level, thereby affecting the skill premium. Dinopoulos et al. (2011) use this link to suggest that trade integration may drive up the skill premium because it induces a skill-biased expansion of output. There are two key assumptions in the model. First, the demand curve faced by each producer must become flatter (more elastic) when the economy moves from autarky to free trade. This induces imperfectly competitive producers to reduce the price and expand the

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[13]As an example, assume $\sigma_L = 4$, $\sigma_S = 3$, $\varepsilon = 2$. Let $\bar{S} = \bar{L} = 10$ so that $n_S = n_L = 10$ in autarky and $n_S = n_L = 20$ in free trade. Therefore $w_S/w_L = 10^{1/12}$ in autarky and increases to $20^{1/12}$ in free trade.

[14]See any microeconomics textbook for further details on the concept of homotheticity.

output.[15] Second, the production function must be such that factor intensity depends on the size of firm's output. We now describe a simplified version of their model.

Each firm produces a different variety of a single consumption good. The market is in monopolistic competition but, unlike the monopolistic competition model presented in Sect. 9.2, here the perceived demand elasticity increases with trade opening. Firm output, y, is obtained from the sum powered to $1/\rho$ of *effective* factor inputs (L_e and S_e), each powered to ρ, that is:

$$y = [(L_e)^\rho + (S_e)^\rho]^{\frac{1}{\rho}} \qquad 0 < \rho < 1 \qquad (17.29)$$

The *effective* factor inputs L_e and S_e are defined as:

$$L_e = y^{\phi_L} L, \qquad (17.30)$$

$$S_e = y^{\phi_S} S, \qquad (17.31)$$

where L and S are actual factor inputs and ϕ_L and ϕ_S are parameters whose value is between zero and one.

Expression (17.30) means that for every unit of labour input there is a corresponding effective unit equal to y^{ϕ_L}; it is as if the quantity of labour input was $y^{\phi_L} L$ instead of L. Likewise for the effective input of skilled labour defined by expression (17.31). To avoid confusion we emphasise that firms' output is not put back into the production process. The coefficients multiplying factor inputs do not represent physical input of the firm's output. They represent the efficiency of factors as depending on the quantity of output of the firm. As firm's output expands, factors become more productive according to a multiplicative term, y^{ϕ_L} and y^{ϕ_S}. Dinopoulos et al. (2011), assume that $\phi_S > \phi_L$; this means that non-homotheticity is skill-biased or, to put it differently, that any increase in output increases the effective relative input of skilled labour.[16] Firms maximize profits, which in equilibrium are driven to zero by the assumption of free entry (as in Sect. 9.2).

The equilibrium for the representative firm is characterized by two conditions: marginal revenue = marginal cost (profit maximization) and price = average cost (zero profit). Figure 17.7 represents the equilibrium for the representative firm in autarky (point A) and in free trade (point FT). The marginal revenue = marginal cost condition is not shown in the figure. The price = average cost condition is

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[15]This sort of pro-competitive effect may emerge, for instance, in general equilibrium oligopoly à la Neary (2009) or Neary and Tharakan (2012), or in monopolistic competition with linear demand à la Ottaviano, Tabuchi, & Thisse (2002), or in monopolistic competition with translated additive demand à la Pollak (1971). The latter is the microfoundation chosen by Dinopoulos et al. (2011). We pass over the details of the microfoundation since they are not relevant to understanding the effect of trade opening on the skill premium.

[16]As an example consider $\phi_L = 1/4$ and $\phi_S = 3/4$. Then $S_e/L_e = \sqrt[2]{y}\,(S/L)$. Any increase in output—*ceteris paribus*—will increase the effective relative input of skilled labour.

Fig. 17.7 Non homothetic
technology, trade integration
and firm output
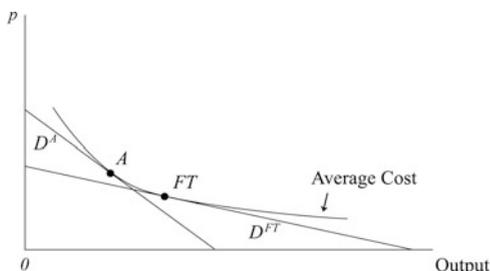
represented by the tangency point between the demand curve and the average cost
curve.[17]

Moving from autarky to free trade puts producers under competitive pressure.
The market becomes larger (the intersection between the abscissa and the demand
curve shifts to the right) but the elasticity of demand increases for any given
price (the demand curve becomes flatter). Thus, each producer reacts by lowering
the price and expanding the output. Here is where the non-homotheticity comes
into play. The expansion of firms' output makes both factors more productive as
shown by expressions (17.30)–(17.31), but under the assumption that $\phi_S > \phi_L$,
the productivity of skilled labour increases more than the productivity of unskilled
labour. Therefore, the relative demand for skilled labour increases and so does the
skill premium in all countries.

17.5   Heterogeneous Firms, and the Skill Premium

Another channel through which trade opening may give rise to inequality is
represented by the heterogeneity of firms' responses to trade opening. To study
this channel, many works abandon the two-sector Heckscher-Ohlin structure and
focus instead on wage inequality within a single industry. Models in these papers
feature heterogeneous firms and/or heterogeneous labour and assume that the most
productive firms are those that use skilled labour more intensively. Furthermore,
they assume the presence of some kind of fixed exporting cost giving rise to a
partition of firms between exporters and non-exporters. The triggering factor of
wage inequality is trade integration, which indirectly reallocates firms' revenue
from low-skill-intensive non-exporters towards the high-skill-intensive exporters.
This reallocation benefits skilled labour relative to unskilled labour. Thus, we begin
by studying the relationship between trade integration and revenues.

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[17]Figure 17.7 represent the same equilibrium as Fig. 9.2 of Sect. 9.2.1. The only difference is in the
form of the demand curve. In Sect. 9.2.1 moving from autarky to free trade induces entry of new
firms but firm's output (for existing and new firms) is the same as in autarky. Here instead, moving
from autarky to free trade induces firms to expand the output.

17.5.1   Trade Integration and Firm Revenue Inequality

The first step is to write the firm revenue as a function of output alone. This is intuitively a rather simple matter; since each firm faces a downward sloping demand curve, the price depends on the quantity the firm supplies to the market. Therefore, ultimately, revenue depends only on firm output. Let p be the price, y the output, and $R = py$ the revenue of the firm. Since some firms exports and some do not, we distinguish between domestic and foreign revenue. A firm has domestic revenue, R_d, and, if it exports, foreign revenue, R_f. The first depends on output sold domestically, y_d, and the second depends on output sold abroad, y_f. All works reviewed in this section adopt the type of monopolistic competition studied in Sect. 9.2, which allows revenue to be written as a function of output in the following simple way:

$$R = \underbrace{C_d \, (y_d)^\alpha}_{R_d} \qquad \text{if the firm does not export,} \qquad (17.32)$$

$$R = \underbrace{C_d \, (y_d)^\alpha}_{R_d} + \underbrace{C_f \left(y_f\right)^\alpha}_{R_f} \qquad \text{if the firm exports,} \qquad (17.33)$$

where $C_d, C_f > 0$ depend on variables that are not relevant for our purposes and α is a positive constant smaller than 1.[18] Exporting firms have larger revenue. Trade integration leads to an increase in revenue inequality for the reason that we now discuss. Following trade integration, foreign demand for domestic output increases because trade costs have declined. Thus, output produced for export increases and so does foreign revenue. This, obviously, only benefits exporting firms. Domestic demand for domestic output declines because some domestic expenditure is now reallocated to foreign varieties, since trade costs have declined. Output for the domestic market and domestic revenue therefore decline for all firms. It can be shown, however, that for exporting firms the increase in foreign revenue more than compensates for the decline in domestic revenue. Intuitively, the reason is that since exporting firms are also the most productive firms, they suffer less than other firms from the intensification of competition at home and benefit greatly from the improved access to the foreign market; their total sales, therefore, rise.[19] In sum, trade integration induces a reduction in y_d and an increase in y_f; domestic revenue declines for all firms, but exporting firms benefit from the increase in

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[18]This is in fact the same α as in the utility function given by expression (9.2). It is not surprising that a parameter of the utility function ends up in the revenue function: after all, the willingness to pay for the item produced by a firm depends on the utility consumers obtain from it.

[19]Here and throughout this section we use the term "competition" somewhat loosely. In fact, what takes place in the domestic market is a market-crowding effect similar to that studied in Sect. 9.2.1.3. In that case the market crowding resulted in the exit of firms; here it results in a reduction of output and revenue.

foreign revenue. For exporting firms, total revenue rises, for non-exporting firms total revenue declines. Thus, trade integration gives rise to an increase in revenue inequality.

The mechanism that links trade integration to revenue inequality is common to all the models we study in this section. The difference between them lies in the way revenue inequality translates into wage inequality. We shall study these different ways in the next subsection.

17.5.2 Quality and Heterogeneous Fixed Inputs

A very direct way in which trade integration affects wages is proposed by Manasse and Turrini (2001). In their model, skilled labour is used as fixed input and is paid a wage equal to revenue minus variable costs. Therefore, revenue inequality translates directly into wage inequality. We present a simplified version of their model.

Goods are differentiated horizontally (by brand) and vertically (by quality). Workers differ in skills measured by s. We refer to the lowest skill as unskilled labour (s_0). Production of any variety requires one unit of skilled labour (any $s > s_0$) as a fixed input and one unit of unskilled labour per unit of output. The index s therefore identifies the skill level as well as the firm using that skill level. The quality of the variety increases with the level of skills. Thus, firms employing workers with higher skills produce higher-quality varieties. The market is in monopolistic competition and therefore the price of a variety, p_s, and the marginal cost, w_0, are in a constant proportion to each other given by:

$$\frac{p_s}{\mu} = w_0, \qquad \mu > 1, \tag{17.34}$$

where μ is the mark-up already encountered in Sect. 9.2. Marginal cost does not depend on the quality of the variety, since production only requires unskilled labour. Firms wanting to export face a fixed exporting cost in terms of one unit of unskilled labour and a variable trade cost of the iceberg type already introduced in Sect. 6.3. Firm's profit goes entirely to pay the skilled labour that made it possible to produce the variety of that particular quality. Thus, after paying all costs the firm makes zero profit. This gives the wage of skilled labour, w_s, as:

$$w_s = \underbrace{p_s y_{ds}}_{\text{Revenue}} - \underbrace{w_0 y_{ds}}_{\text{Variable cost}} \qquad \text{in non exporting firms,} \tag{17.35}$$

$$w_s = \underbrace{p_s y_s}_{\text{Revenue}} - \underbrace{w_0 y_s}_{\text{Variable cost}} - \underbrace{w_0}_{\text{Fixed exp. cost}} \qquad \text{in exporting firms,} \tag{17.36}$$

where y_{ds} is the output of a non-exporting firm and $y_s = y_{ds} + y_{fs}$ is total output of an exporting firm. Using expression (17.34) to substitute for w_0 in expressions

Fig. 17.8 Heterogeneous
fixed cost and wage
inequality
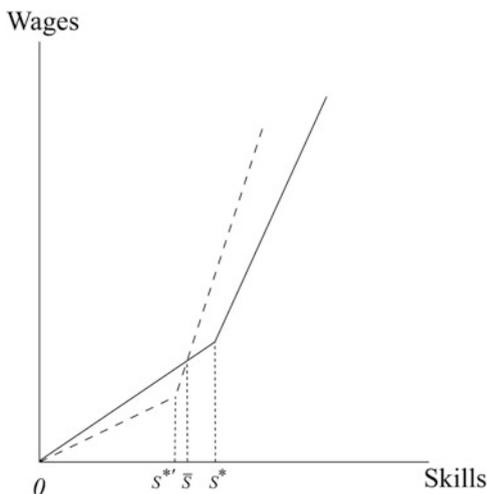
(17.35) and (17.36), we can write wages as a function of revenue as follows:

$$w_s = \frac{(\mu - 1)}{\mu} R_{ds} \qquad \text{in non exporting firms,} \qquad (17.37)$$

$$w_s = \frac{(\mu - 1)}{\mu} \left(R_{ds} + R_{fs} \right) - w_0 \qquad \text{in exporting firms,} \qquad (17.38)$$

where $R_{ds} = p_s y_{ds}, R_{fs} = p_s y_{fs}$. We can see from these two expressions that the wage increases with s since revenue increases with s (consumers like quality). The increase in wage is, however, faster for exporting firms because an increase in s increases both domestic and foreign revenues.

Turning our attention to export decisions, a firm decides to export only if it makes a non-negative profit on the foreign market. Obviously, only firms with sufficiently large revenues (high quality) find it profitable to pay the fixed exporting costs and export. Let s^* be the cut-off value of skills below which a firm decides not to export. By definition, the firm employing the worker with skill s^* makes zero profit on the foreign market. The distribution of wages among skilled workers will therefore take the shape represented by the solid line in Fig. 17.8. The wage of skilled workers increases with the level of skills, but the increase is faster for exporting firms because for these firms a marginal increase in quality increases sales at home *and* abroad.

Trade integration has two effects. First, the firm employing the worker with skill s^* is now making positive profits in the foreign market, because the reduction in trade costs has increased its foreign sales. Therefore the new cut-off value of skill, $s^{*\prime}$, will lie to the left of s^*. Second, trade integration triggers the reallocation of firms' revenues. Revenues of non-exporting firms decline because these firms suffer from stronger foreign competition. Consequently, skilled workers employed by non-exporting firms will see their wage decline. Firms which were exporters before

trade integration suffer the same intensification of competition in the domestic market, but this is more than offset by the increase in foreign revenues. The wage of skilled workers in these firms increases. New exporters make larger revenues after trade integration, but they now pay the fixed exporting costs. For some of them, the increase in revenue more than compensates for the fixed costs and therefore the wage of skilled workers increases. For the other new exporters, the increase in revenue is not sufficient to allow for an increase in the wage of skilled labour. The dashed line in Fig. 17.8 shows the situation after the reduction of variable trade costs. Comparing the solid with the dashed line, we see that wages of workers in non-exporting firms decline, wages in newly exporting firms but with skills between $s^{*\prime}$ and $\bar{s}$ decline too, wages in all other firms increase.

We can now evaluate the consequences of trade integration on the skill premium. The presence of heterogenous labour means that the concept of skill premium needs to be qualified. To this purpose, let the wage ratio between any two workers, one in an exporting and the other in a non-exporting firm, be a measure of the skill premium. Inspection of Fig. 17.8 shows that trade integration induces a rise in the skill premium. For any two workers s (in a non-exporting firm) and s' (in an exporting firm), the wage ratio $w_{s'}/w_s$ is larger after trade integration than before. The effect of trade integration on inequality can also be measured by the change in relative aggregate revenue of highly-skilled workers. Highly-skilled workers means skilled workers employed by exporting firms. Since the employment share of exporting firms increases with trade integration (s^* moves to $s^{*\prime}$), trade integration implies a redistribution of total income from unskilled workers to skilled workers.

17.5.3   Endogenous Technology Adoption with Heterogeneous Workers

Yeaple (2005) develops a model where the most productive workers endogenously match with firms adopting the best technology. He suggests that trade integration induces an increase in wage inequality because it changes the matching between firms and workers in favour of highly-skilled workers to the detriment of moderately-skilled workers. To understand the logic of his argument, we now study a simplified version of his model.

The economy produces a differentiated good, Y, and a homogeneous good Z. There are three technologies indexed by $j = Z, H, L$. Technology Z is used only to produce the homogenous good Z. Good Y is produced by use of either technology H or technology L. Workers differ in skills, measured by s which takes values from 0 to infinity. Let ϕ_s^j denote the quantity of the good a worker with skill s can produce in industry j. We adopt the convention that the least-skilled worker can produce one unit of output regardless of technology, $\phi_0^j = 1$ for any j. For all other workers, ϕ_s^j depends on the skill level and on the technology the worker is using. For any given technology, a unit of high-skill labour produces more than a unit of

low-skill labour, i.e., $\phi_{s'}^j > \phi_s^j$ for any $s' > s > 0$. For any given skill, technology H is more productive than L which, in turn, is more productive than Z, i.e., $\phi_s^H > \phi_s^L > \phi_s^Z$ for any $s > 0$. Furthermore, and crucially, highly-skilled workers have a comparative advantage in the use of the H technology relative to moderate and low-skilled workers, and moderately skilled workers have a comparative advantage in producing Y relative to low-skilled workers. Thus we have:

$$\frac{\phi_{s'}^H}{\phi_s^H} > \frac{\phi_{s'}^L}{\phi_s^L} > \frac{\phi_{s'}^Z}{\phi_s^Z} \text{ for any } s' > s > 0 \tag{17.39}$$

Good Z is produced in perfect competition, without fixed inputs, is chosen as the numéraire and its price is set to 1. Good Y is produced in monopolistic competition and requires fixed and variable inputs. Firms have to pay a fixed cost F_L to adopt technology L or a fixed cost F_H to adopt technology H. The H technology requires a higher fixed cost, $F_H > F_L$. Both fixed costs take the form of output that must be produced but cannot be sold.

Let w_s^j denote the wage of a worker with skill s using technology j. The total cost of producing y_j units of output for a firm employing workers with skill s is $\left(w_s^j / \phi_s^j \right) y_j + F_j$. Since the fixed cost takes the form of output, the unit cost (cost per unit of total output) is $\left(w_s^j / \phi_s^j \right)$. Every firm must choose one of three options: not paying any fixed cost and producing Z, paying F_L and producing Y with technology L, or paying F_H and producing Y with technology H. In equilibrium, some firms will employ low-productivity workers and produce Z, other firms will employ workers with intermediate productivity and produce Y with technology L, and the remaining firms will employ very productive workers and produce Y with technology H. The labour market is perfectly competitive, therefore wages adjust to equalize the unit cost of production for all firms using the same technology, that is:

$$\frac{w_s^j}{\phi_s^j} = \frac{w_{s'}^j}{\phi_{s'}^j} \text{ for any } s \neq s' \tag{17.40}$$

Let s_1 and s_2 be the threshold values of s above which firms adopt technology L and H respectively. A firm hiring workers of skill s_1 is indifferent between producing Z or producing Y with technology L. If it produces Y, it will have a lower unit cost but will incur fixed costs. By definition, when $s = s_1$, the lower unit cost exactly compensates for the fixed cost. Similarly, for a firm hiring workers with skill s_2, the lower unit cost of technology H exactly compensates for the higher fixed cost. Equation (17.40) characterizes the distribution of wages for any given value of s_1 and s_2.[20] The wage distribution derives from three conditions, which we now discuss in detail.

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[20]The values s_1 and s_2 are determined endogenously by the equilibrium condition in the goods market and by the zero profit conditions. Since the determination of these values is not relevant for our purposes we disregard it for the sake of simplicity.

We begin by determining wages in industry Z, which are obtained as follows:

$$1 = w_s^Z / \phi_s^Z \implies 1 = \frac{w_0^Z}{\phi_0^Z} \implies w_s^Z = \phi_s^Z, \quad \text{for } 0 \leqslant s < s_1. \tag{17.41}$$

The first equation in (17.41), $1 = w_s^Z / \phi_s^Z$, is the price $=$ marginal cost condition of perfectly competitive industry Z. Using this condition and $s' = 0$ in Eq. (17.40) gives the second of equations (17.41), which determines $w_0^Z = 1$ (recall that $\phi_0^Z = 1$). Then, substituting $w_0^Z = 1$ in (17.40) gives $w_s^Z = \phi_s^Z$ which is the third of equations (17.41). Wages in industry Y are determined by two arbitrage conditions. First, the wage of workers with skills s_1 must be the same in firms producing Z and in firms using technology L, otherwise these workers would not accept to be employed in either the production of Z or in the production of Y with technology L. Second, for the same reason, the wage of workers with skills s_2 must be the same in firms using technology H and technology L. The arbitrage conditions are therefore $w_{s_1}^Z = w_{s_1}^L$ and $w_{s_2}^L = w_{s_2}^H$. The first arbitrage condition and the third equation in (17.41) give the wage in L as follows:

$$w_s^L = \left(w_{s_1}^L / \phi_{s_1}^L \right) \phi_s^L \implies w_s^L = \frac{\phi_{s_1}^Z}{\phi_{s_1}^L} \phi_s^L, \text{ for } s_1 \leqslant s < s_2 \tag{17.42}$$

To understand Eq. (17.42), the first step is to write Eq. (17.40) using $s' = s_1$ and $j = L$, which gives the first equation in (17.42). Then using $w_{s_1}^L = w_{s_1}^Z$ and the result obtained in Eq. (17.41), where we found that $w_s^Z = \phi_s^Z$, therefore $w_{s_1}^Z = \phi_{s_1}^Z$, gives w_s^L as in the second of equations (17.42). An analogous procedure applied to the arbitrage condition $w_{s_2}^L = w_{s_2}^H$ gives the wage w_s^H as shown in Eq. (17.43):

$$w_s^H = \left(w_{s_2}^H / \phi_{s_2}^H \right) \phi_s^H \implies w_s^H = \frac{\phi_{s_1}^Z}{\phi_{s_1}^L} \frac{\phi_{s_2}^L}{\phi_{s_2}^H} \phi_s^H, \text{ for } s \geqslant s_2 \tag{17.43}$$

Figure 17.9a shows the distribution of wages resulting from Eqs. (17.41) to (17.43).

The three lines (w_Z, w_L, and w_H) represent the distribution of wages for each of the three technologies. The line w_L is steeper than the line w_Z, reflecting higher productivity, but intersects the ordinate at a lower value, reflecting the lower shadow unit cost of production for any s between 0 and s_1.[21] Likewise for w_H with respect to w_L. The bold broken line represents the wage paid by firms to workers of different skills. Workers with skills between 0 and s_1 are employed by firms in the Z industry and are paid low wages. The skills of these workers are so low that if firms in industry Y employed them they would make negative profits. Workers with skills between s_1 and s_2 are employed by L technology firms and paid intermediate wages.

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[21]The shadow unit cost is the unit cost that would obtain if the firm using technology L hired workers with skills between 0 and s_1.
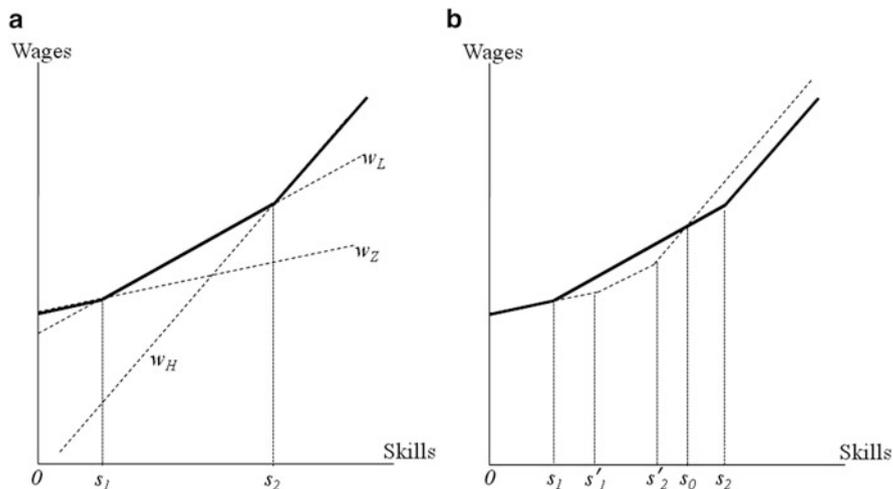
Fig. 17.9 Technology adoption and wage inequality. (**a**) Wage distribution. (**b**) Change in wage distribution

These workers are overqualified for industry Z but their skills are not high enough to give rise to non-negative profits when employed in firms using technology H. Lastly, workers with skills higher than s_2 are employed by firms adopting the most productive technology.

Consider now two identical economies opened to costly trade. Trade costs take the usual form of a fixed exporting cost F_X (for good Y only) and a variable trade cost of the iceberg type. The choice for firms in industry Y is either paying F_X and thus adding foreign sales to domestic sales, or not paying F_X and settling for domestic sales only. In the simple configurations that we discuss here, we assume that the set of firms adopting the H technology is identical to the set of firms deciding to export.[22] Therefore, in equilibrium, some firms use the L technology and do not export and the remaining firms in industry Y use the H technology and export. Since countries are identical, there is only intra-industry trade in the different varieties of Y. The consequences of trade integration on wage distribution are shown in Fig. 17.9b, where the dashed line represents a lower iceberg cost situation than the solid line.

When variable trade costs decline, the better access to foreign markets improves exporting firms' foreign revenue, while foreign competition in the domestic market deteriorates their domestic revenue. Overall, however, exporting firms' revenue increases. Therefore, the exporting firm that employed the worker with productivity s_2 is no longer indifferent between L-technology non-exporter status and H-technology exporter status; this firm will make larger profits by using the

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[22]This only requires mild conditions on fixed costs.

H technology and exporting than otherwise. This is represented in Fig. 17.9b by a leftward shift of the cut-off value from s_2 to s_2' (due to a leftward shift of the line w_H in Fig. 17.9a). Non-exporting firms face fiercer competition from foreign exporters, their revenue declines and some of them succumb. Workers laid off by these firms will be employed by the Z industry (rightward shift of the cut-off value from s_1 to s_1').[23] The final situation is one in which the most highly-skilled workers gain from trade integration. Conversely, workers who are laid off by the Y industry see their wage decline, as do workers remaining in the Y industry and continuing to use the L technology. Workers remaining in the Z industry see their wage unchanged. Finally, workers with skills between s_2' and $\bar{s}$ see their wage decline: they now use a better technology but their skills are too low for them to benefit from it.

We now evaluate the consequence of trade integration on the skill premium. Again we define the skill premium as the wage ratio between any two workers, one in an exporting and the other in a non-exporting firm. Inspection of Fig. 17.9b shows that trade integration induces a rise in the skill premium. For any two workers s (in a non-exporting firm) and s' (in an exporting firm), the wage ratio $w_{s'}/w_s$ is larger after trade integration than before. Furthermore, the aggregate revenue of highly-skilled workers increases relative to the aggregate revenue of moderately-skilled workers.

17.5.4 Heterogeneous Hiring (Fixed) Costs

Helpman et al. (2010) argue that a possible source of within-industry heterogeneity is that more productive firms have stronger incentives to search and select more productive workers in costly trade than in autarky. Conversely, less productive firms have less incentive. Thus, in costly trade more than in autarky, the more productive workers end up matching with the more productive firms. Since the wage depends on average productivity at the firm level, the wage dispersion in the industry is larger in costly trade than in autarky. We now examine a simplified version of their model.

Firm output, Y, depends positively on the productivity of the firm, ϕ, on the number of workers employed by the firm, h, and on the average productivity of workers employed by the firm, $\bar{s}$. Thus, the production function of a firm is:

$$y = \phi h^\gamma \bar{s}, \qquad 0 < \gamma < 1. \tag{17.44}$$

A characteristic of this production function is that it is supermodular in $(\phi, \bar{s})$. Supermodularity (see, for example, Amir, 2005) refers to situations where an advantage begets further advantage. In the case of the production function (17.44),

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[23]The expansion of the Y industry is consistent with the fact that the wage of workers with skills higher than $\bar{s}$ increases relative to good Y, thereby inducing an increase in the demand for this good.

supermodularity simply means that the more productive the firm is, the greater the effect of an increase in the average productivity of workers. Specifically, for any two firms with different productivity levels ϕ' and ϕ'', an equal increase in $\bar{s}$ will result in a larger output increase for the firm with higher productivity.[24]

Productivity is assigned randomly to firms, while the productivity of workers results from a search and screening activity undertaken by firms, which we now discuss.[25] Workers differ in skills measured by $s \geqslant 1$. Firms incur search and screening costs of employment. The search cost is represented by the cost of matching with workers (think of the administrative cost of opening a vacancy). To match randomly with n workers seeking a job, a firm pays bn units of the numéraire. The marginal cost of searching is therefore equal to b. The screening cost is represented by the cost of evaluating the productivity of each of the n workers sampled (think of the cost of job interviews). The screening procedure allows a firm to identify workers with skills up to a given threshold level chosen by the firm. Let $\underline{s}$ be such threshold. Screening is costly and it is assumed that screening costs are increasing in the threshold $\underline{s}$. This is plausibly justified by the need to set up more elaborate tests to identify higher skills. Specifically, it is assumed that by paying $c\underline{s}^2/2$ units of the numéraire, where $c > 0$, the firm is able to identify workers with skills lower than $\underline{s}$; the marginal cost of screening is therefore $c\underline{s}$. The number of workers actually employed by the firm, h, increases with the number of workers sampled, n, and decreases with the threshold $\underline{s}$ chosen by the firm. To be specific, assume that $h = n(1/\underline{s})^k$, $k > 1$.[26] Recall that $s \geqslant 1$, therefore the number of workers employed is simply a fraction $(1/\underline{s})^k < 1$ of the number of workers sampled. The average skill of workers employed by the firm, denoted by $\bar{s}$, turns out to be $\bar{s} = k\underline{s}/(k-1)$. Replacing $h = n(1/\underline{s})^k$ and $\bar{s} = k\underline{s}/(k-1)$ in the production function (17.44) yields:

$$y = \frac{k}{k-1}\phi n^\gamma \underline{s}^{1-\gamma k} \tag{17.45}$$

where it is assumed that $0 < \gamma k < 1$.

Firms operate in monopolistic competition and their revenue depends on output, as shown by expressions (17.32) and (17.33). Substituting (17.45) into y_d and y_f of expressions (17.32) and (17.33) shows that a firm's revenue depends positively on its productivity, ϕ, the number of workers sampled, n, and the threshold level $\bar{s}$.

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[24]Consider, for instance, two firms with the same employment $h = 1$ and with productivity levels $\phi' = 1$ and $\phi'' = 2$. Imagine they experience the same increase in average productivity of workers, $\Delta\bar{s} = 1$. The output increases are, respectively, $\phi'\Delta\bar{s}$ and $\phi''\Delta\bar{s}$ where clearly the latter is larger than the former since $\phi'' > \phi'$.

[25]The labour market is modeled along the lines of Diamond-Mortensen-Pissarides search and matching frictions.

[26]This specification is obtained by assuming that the skill distribution is Pareto with shape parameter k and lower bound equal to one. This distribution also gives rise to the expression for the average skill of workers employed by the firm specified below.
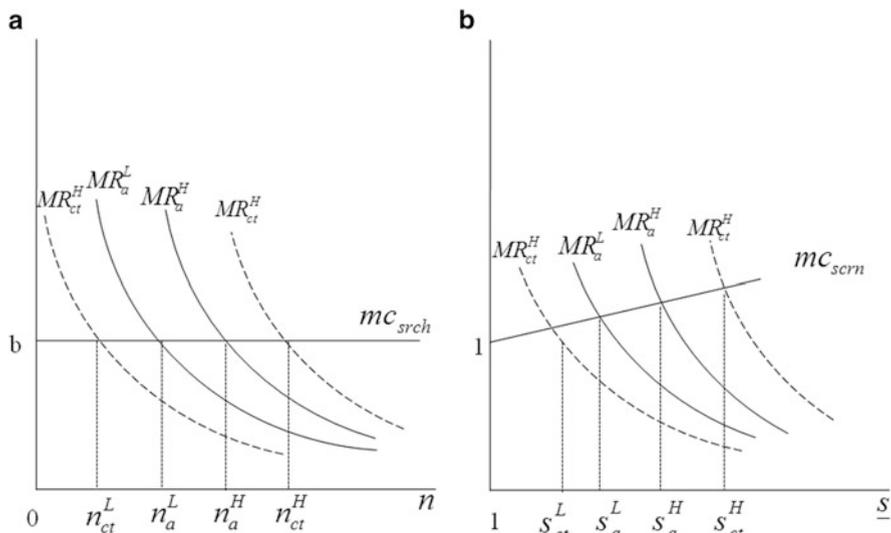
Fig. 17.10 Search and screening costs: firm's equilibrium

Figures 17.10 and 17.11 depict the autarky and costly trade equilibria. To simplify the graphical treatment, we represent the situation for only two firms: a high productivity firm, H, and a low productivity firm, L. Consider first the autarky situation represented by the solid lines. The declining solid lines in Fig. 17.10a represent the marginal revenue plotted against the number of workers sampled for the high and low productivity firms, MR_a^H and MR_a^L respectively. The H firm has a higher marginal revenue simply because it has a larger ϕ, and a worker of any given skill generates more revenue if employed by the H firm than by the L firm. Firms choose the number of workers to be sampled by equating marginal revenue to the marginal cost of searching ($mc_{srch} = b$). Thus, the equilibrium number of workers sampled is n_a^H and n_a^L with $n_a^H > n_a^L$, as shown in Fig. 17.10a. Figure 17.10b shows the marginal revenues MR_a^H and MR_a^L plotted against the threshold level of screening for any given number of workers sampled.

Supermodularity entails that a higher average productivity of workers is more valuable in firms with higher ϕ. Therefore, for any given n, the more productive firm has larger marginal revenues from screening, as represented in Fig. 17.10a. Firms choose the screening threshold $\underline{s}$ so as to equalize marginal revenue with the marginal cost of screening (mc_{scrn}).[27] The equilibrium screening thresholds are therefore $\underline{s}_a^H$ and $\underline{s}_a^L$; the more productive firm screens more severely.

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[27]It is worth mentioning that the marginal revenue lines in Fig. 17.10a are plotted for given values of $\underline{s}$. The revenue lines in Fig. 17.10b are plotted for given values of n. There is therefore a relationship between the optimal number of workers sampled and the optimal level of screening. This relationship is not relevant for understanding the model and we therefore disregard it.
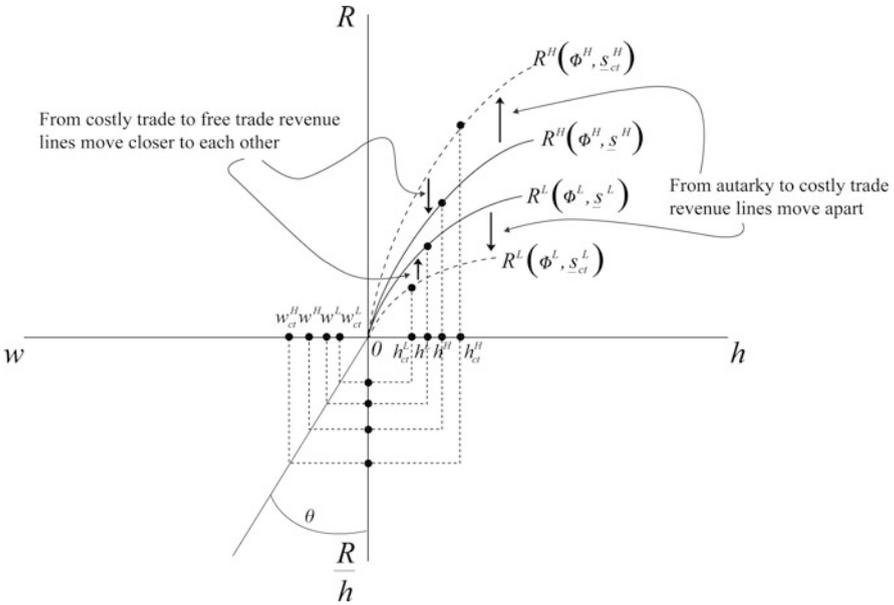
Fig. 17.11 Search and screening costs: general equilibrium

In the North-East quadrant of Fig. 17.11 we see that firm H has larger revenues for any $h > 0$. This is due to two reasons: first, H is more productive ($\phi^H > \phi^L$), and second, H has screened more severely ($\bar{s}_a^H > \bar{s}_a^L$). Although the H firm samples a larger number of workers it may end up hiring an equal or smaller number than the L firm because of more severe screening. However, under mild conditions on the parameters which we assume to hold, it turns out that $h_a^H > h_a^L$.

We now turn to wage determination. Each firm negotiates the wage with its employees. The result of this negotiation is that each party gets a constant fraction of total revenues and the individual wage is equal to the total wage bill divided by the number of workers employed in the firm. Let $\theta \in (0, 1)$ be the fraction of total revenue that goes to wages. Graphically, the revenue per worker corresponds to the size of the angle formed by a straight line emanating from the origin and reaching the dot on each of the revenue lines. For convenience of visual inspection, we plot the revenue per worker on the vertical axis of the South-East quadrant and wages on the horizontal axis of the North-West quadrant. Clearly, the H firm pays higher wages.

We can now examine the effect of trade opening from an initial situation of autarky. The costly trade situation (labelled ct) is represented by the dashed lines and is characterized by the presence of fixed and variable exporting costs. Let us assume that in costly trade, the H firm finds it profitable to export and the L firm does not. Moving from autarky to costly trade brings about a reallocation of revenues. The exporting firm loses revenue at home because of the foreign

competition but this is more than offset by foreign sales. The non-exporting firm suffers the competition of foreign firms and its revenue declines. This reallocation of sales is represented in Fig. 17.10 where the marginal revenue of firm H shifts to the right and that of firm L to the left. As a result, in costly trade, firm H samples and screens more than in autarky while firm L samples and screens less. Therefore, as we see by inspecting the expression (17.45), output (and revenue) increase in firm H and decline in firm L. Graphically this means that the revenue lines move apart when passing from autarky to free trade, as shown by the dashed lines in Fig. 17.11. The consequences on wage inequality are immediately found. Taking the wage ratio between H and L as a simple measure of wage inequality, we observe that $w_{ct}^H/w_{ct}^L > w_a^H/w_a^L$; wage inequality has increased in passing from autarky to costly trade.

In sum, the model tells the following story: a reduction in trade costs makes searching and screening more profitable for highly productive firms and less profitable for less productive firms. Average labour productivity and revenue decline in less productive firms and increase in highly productive firms. Since wages are in fixed proportions to revenues, wage inequality increases. The mechanism generating wage inequality can also be seen in a different way if we observe that when the wage negotiation and employment decisions are taken, the search and screening costs have been paid and they are not retrievable. Thus, at this stage of the firm's decision, searching and screening costs are a fixed and sunk cost. In this perspective, we could say that in this model there are fixed but adjustable costs of hiring. Trade integration magnifies revenue inequality which, in turn, heightens wage inequality through heterogeneous responses of firms concerning the optimal amount of fixed hiring costs they want to pay.

From the analysis above, one might carelessly conclude that any step forward in trade integration brings about an increase in wage inequality. This would be a wrong conclusion. Indeed, when all firms export (say, in free trade), the ratio of revenues between firm H and firm L is—ceteris paribus—the same as in autarky. There is no longer a partition between exporting and non-exporting firms. In free trade, firms return to the same sampling and screening as in autarky and the wage inequality returns to the autarky level. There is, therefore, a hump-shaped relationship between trade opening and wage inequality, first increasing then decreasing until wage inequality reaches its initial level. This relationship is depicted in Fig. 17.12.

17.5.5 *Heterogeneous Globalization Modes*

It is well known that a large and growing share of world trade is in intermediate inputs. Amiti and Davis (2011) study the effect of globalization on wages taking account of trade in intermediates in addition to trade in consumption goods. In addition to the partition of all firms into exporters and non-exporters, their model generates an endogenous partition of all firms into importers (of intermediate inputs) and non-importers. Thus, a firm may (or may not) relate to other countries in four

Fig. 17.12 Search and
screening costs: from autarky
to free trade
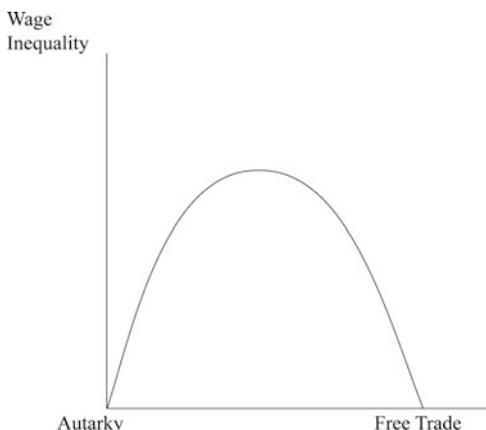
ways: by exporting and importing, by exporting and not importing, by importing and
not exporting, or by neither exporting nor importing. This choice is endogenous and
Amiti and Davis refer to it as the globalization mode chosen by the firm. They find
that when firms choose different globalization modes, trade integration affects the
skill premium because it magnifies the revenue inequality and/or the marginal cost
inequality across firms. To understand the logic of their argument, we now describe
a simplified version of their model.

Intermediate inputs are produced in each country in a fixed number of varieties.
Let n_d and n_f be the number of varieties produced domestically and abroad,
respectively. Producing one unit of intermediate input requires one unit of labour.
All intermediates are priced at marginal cost. The production of the final good
requires one unit of labour as fixed input and both labour and intermediate inputs
in the production of output. An important property of the technology of production
of final goods is that—ceteris paribus—the marginal cost declines as the number of
varieties of intermediate inputs increases.[28]

Intermediate inputs and final goods are traded internationally at an iceberg trade
cost which has two components: a component common to all firms, $\tau_X \in (0, 1)$ for
the final good and $\tau_M \in (0, 1)$ for the intermediate inputs; and a component specific
to each firm v, t_{Xv} and t_{Mv} for final goods and intermediate inputs, respectively. Let
$\tau_{Mv} \equiv \tau_M t_{Mv}$ and $\tau_{Xv} \equiv \tau_X t_{Xv}$. So, an exporting firm will see a fraction $(1 - \tau_{Xv})$
of the good exported "melting" in transit and an importing firm will see a fraction
$(1 - \tau_{Mv})$ of the intermediate good bought abroad "melting" in transit. Production,
export and import are subject to the fixed costs F, F_X, and F_M respectively.
Thus a firm which produces only for the domestic market and uses only domestic
intermediates has a fixed cost $F_v = F$, a firm which produces for the domestic and
foreign markets and uses only domestic intermediates has a fixed cost $F_v = F + F_X$,

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[28]The cost function resulting from the production function in expression (17.5) has this property.

a firm which produces for the domestic market only and uses domestic and imported intermediates has a fixed cost $F_v = F + F_M$, and a firm which produces for the domestic and foreign markets and uses domestic and foreign intermediates has a fixed cost $F_v = F + F_M + F_X$.

Firms are heterogenous in three respects: productivity, ϕ_v, unit exporting cost, $(1 - \tau_X t_{Xv})$, and unit importing cost, $(1 - \tau_M t_{Mv})$. The triplet (ϕ_v, t_{Mv}, t_{Xv}) is assigned randomly to firms. Once the triplet is assigned, firms have to make three decisions: the profit-maximizing price, whether or not to produce, and the mode of globalization (import only, export only, both, or none). The market for final goods is characterized by monopolistic competition and the profit maximizing, p_v, is therefore a multiple of the firm's marginal cost, c_v:

$$p_v = \mu c_v, \tag{17.46}$$

where $\mu > 1$ is the mark-up already encountered in Sect. 9.2. The mark-up is common to all firms but the marginal cost is different in different firms (and so is the price) because firms have different productivity levels and because they may have chosen different modes of globalization. To see this, we take a closer look at marginal cost, c_v:

$$c_v = f \left(\underbrace{\phi_v}_{-}, \underbrace{w_v}_{+}, \underbrace{n_d}_{-} \right) \qquad \text{for non importing firms,} \quad (17.47)$$

$$c_v = f \left(\underbrace{\phi_v}_{-}, \underbrace{w_v}_{+}, \underbrace{n_d + \tau_{Mv} n_f}_{-} \right) \qquad \text{for importing firms.} \quad (17.48)$$

As above in this chapter, the notation $f(.,.,.)$ simply means that the marginal cost of any firm v depends on its productivity, ϕ_v, on the wage it pays to labour, w_v, and on the number of varieties it uses, n_d or $n_d + \tau_{Mv} n_f$. As usual, the algebraic signs below each of the three variables indicate the relationship between each of them and marginal cost. Pretty intuitively, an increase in productivity reduces marginal cost, an increase in wage increases marginal cost, and an increase in the number of varieties (moving from non-importing to importing) reduces marginal cost.

Firm revenue depends on output as in expressions (17.32) and (17.33); and firm profit, π_v, may conveniently be written in terms of revenue as:

$$\pi_v = \frac{(\mu - 1)}{\mu} R_v - F_v, \tag{17.49}$$

where we keep in mind that R_v and F_v depend on the mode of globalization and on productivity. The decision on whether or not to produce and the mode of globalization depend on the productivity level drawn by the firm. The most

productive firms will find it optimal to pay $F + F_M + F_X$ in order to export and import. Slightly less productive firms will find it optimal to pay either $F + F_X$ or $F + F_M$ to be able to export or import, respectively. The other firms will produce only for the domestic market and will use only domestic inputs. Turning to wage determination, to simplify matters we assume that the wage results from a bargaining process and is equal to a constant fraction of profit:

$$w_v = \theta \pi_v, \quad 0 < \theta < 1 \tag{17.50}$$

We now turn to the effect of trade integration on wage inequalities. Consider first a trade integration in intermediate inputs (an increase in τ_M). Trade integration in intermediate inputs reduces the marginal cost of importing firms because it increases τ_{Mv} while keeping the marginal cost of the non-importing firms the same (see expression (17.47) and (17.48)). Hence the prices of the varieties produced by the importing firms decline (see expression (17.46)) and output increases. Therefore, profits and wages also increase for these firms (see expression (17.49) and (17.50)). Wage dispersion increases because the wage paid by importing firms relative to non-importing firms increases. But this is not all: the effect of trade integration is amplified because firms have different individual trade costs. An increase in the common component τ_M has a stronger impact on τ_{Mv} for firms with higher t_{Mv}. Therefore, among the importing firms, revenues, profits, and wages increase more for firms with lower import trade costs. This amplifies the wage inequality. Now let us consider trade integration in the final good (an increase in τ_X). This type of integration increases revenue inequality; the revenue of exporting firms increases and the revenue of non-exporting firms declines. Wage inequality increases because the wages paid by exporting firms increase relative to those paid by non-exporting firms. The wage dispersion is amplified by the fact that the trade cost of exports declines more for firms who have lower individual trade costs for final goods.

There is also a synergy between these two effects. To understand this synergy, consider trade integration in inputs. The revenues of importing firms increase because of the decline in the marginal cost, which makes these firms more competitive. All importing firms benefit from trade integration in inputs but the exporting firms (if there are any among the importing firms) benefit more than the non-exporters because they gain competitiveness at home and abroad.

In conclusion, both types of trade integration increase wage inequality, but they do so in different ways. A decline in output tariffs increases the wages of workers employed in exporting firms relative to those of workers employed in non-exporting firms. A decline in input tariffs raises the wages of workers employed in firms using imported inputs relative to the wages paid by firms that do not import inputs. Furthermore, there is a synergy between these effects. Lastly, wage inequality is magnified by the fact that firms have different firm-specific trade costs.

17.6 Endogenous Market Size

In the new economic geography models, trade integration may give rise to industrial agglomeration (see Chap. 16). In these models, agglomeration is often associated with wage inequality between regions. This is the case, for instance, in the core-periphery model. In this section we study the relationship between agglomeration and wage inequality by using the model developed by Krugman and Venables (1995) and studied in Sect. 16.3. In that section, the parametrization was chosen so that income inequality did not arise even in the presence of agglomeration. Here, a simple additional assumption will cause agglomeration to give rise to wage inequality. However, wage inequality arises for intermediate levels of trade costs, whereas low trade costs lead to the convergence of wages.

The basic model considers two regions, conventionally called North and South, each producing two commodities: "agricultural" goods and "manufactured" goods. Agricultural goods are produced under a constant return to scale in a perfectly competitive setting with labour as the sole input. Manufactured goods are differentiated goods produced under increasing returns to scale in a monopolistically competitive setting, using labour and a composite manufacturing intermediate good. Thus the manufacturing sector produces both final consumer goods and intermediate goods to be used as inputs.

At the beginning, no trade exists because of prohibitive transport costs, and both regions produce both kinds of goods in autarky. It is assumed that both regions are equal, in the sense that they are equally efficient in the production of both types of goods, so that neither region has any intrinsic comparative advantage in manufacturing. However, one region (say, North) has a larger manufacturing sector than the other.

Let us now assume that transport costs are gradually reduced, so that the possibility of trade in manufactured goods arises. As we know from the monopolistic competition model of international trade (see Sect. 9.2.2), there will be intra-industry trade in manufactured goods, with neither region becoming fully specialized in them. But as transport costs continue falling, a cumulative process will arise due to locational factors of the following type.

The initially larger manufacturing sector in North offers a larger market for intermediate goods, which makes this region (ceteris paribus) more advantageous for localizing the production of these goods. Such an effect is called a demand or "backward" linkage. The immediate consequence is that a greater number of intermediate goods will be produced in North than in South.

The availability of intermediate goods will then become better and better in North with respect to South, which means (again ceteris paribus) lower production costs of final goods; this effect is called a cost or "forward" linkage. Hence, further manufacturing production will be attracted to North, and so on: a trend towards the agglomeration of manufacturing in North is set in motion. There will be some critical value of transport costs below which the world economy will self-organize into a de-industrialized periphery and an industrialized core (the model thus explains

the core-periphery pattern of world development). What is important to note is that this outcome is completely spontaneous, due to the self-organizing forces of the global economy (on self-organization in general see, for example, Gandolfo, 2009, chap. 25, sect. 25.6.2).

Assume that the manufacturing sector is large enough not to fit in one country.[29] Then the higher labour demand in the industrializing region (the core) will drive up real wages, while the falling demand for labour in the de-industrializing region (the periphery) will cause a decline in real wages there. In a nutshell: *globalization leads to inequality*.

However, this is not the end of the story, since a further decline in transportation costs has striking effects. In fact, the importance of being close to suppliers of intermediate goods and to markets for final goods (the backward and forward linkages) declines in concomitance with the decline in transport costs. On the other hand, the lower wage rate in the periphery is an important factor in production-cost calculations. There will be a certain threshold of transportation costs below which the lower wage rate in the periphery more than offsets the distance factor (i.e., the disadvantage of being far from suppliers and markets). Below this threshold value, manufacturing will find it profitable to relocate to the periphery. The higher labour demand there, and the lower demand for labour in the core, will bring about convergence of real wages.

Thus, after the initial formation of a core-periphery pattern, whereby globalization (due to declining transport costs) divides the world into rich and poor nations, further integration of world markets will bring about a convergence in incomes and economic structures.

17.7   Conclusion

The models studied in this chapter offer a rich set of plausible explanations for the increase in wage inequality. One of them is the Stolper-Samuelson effect, operating both directly and through skill-biased technical change. Another plausible explanation is that economies of scale affect the relative demand for factors. A third explanation hinges on firm revenue inequality. The mechanism through which revenue inequality translates into wage inequality differs in different models, but in all the models it requires some kind of heterogeneity whereby skilled labour is used relatively more in exporting firms than in non-exporting firms (either because of a skill bias in production or because of fixed costs in terms of skilled labour). Trade integration may also trigger an increase in marginal cost inequality which in turn causes wage inequality to rise. This increase in wage inequality is heightened by the export status of the firm and by the fact that firms have heterogeneous trade costs.

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[29]This assumption is crucial and makes the difference between the parametrization of this model in this section and the parametrization in Sect. 16.3.

Lastly, trade integration unleashes agglomeration forces that may give rise to an increase in wage inequality across countries.

The literature on this topic is growing very rapidly and an exhaustive review is far beyond the scope of this chapter. The studies reviewed above, however, cover most of the explanations for the increase in wage inequality provided by the literature to date.

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