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Employment effects of innovation in developing countries: A summary

Doris A. Oberdabernig

Is technological progress causing inequality and unemployment in developing countries? In this paper we survey the literature on the effects of innovation and technological change on employment, demand for skills, and wages. We revisit theoretical arguments of the effects of innovation on labor market outcomes such as employment, skill premia, and the life span of jobs, and summarize the findings of empirical studies. We pay special attention to the empirical literature for developing countries. We also visit some arguments concerning the role of policy in this context.

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Abstract

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Keywords: Technical change, innovation, employment, demand for skills, wage premia.

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1 Introduction

Technological upgrading is often seen to be a source of economic growth in the long run (Solow, 1956; Romer, 1986, 1990; Lucas, 1988, and other contributions cited in Oberdabernig, 2015). This theoretical relationship has also been confirmed through various examples from history, as pointed out in Cahuc and Zylberberg (2004):

"In the seventeenth and eighteenth centuries, the introduction of new crops and the abandonment of the practice of fallowing land led to a strong increase in agricultural production per hectare and per worker. In the nineteenth and twentieth centuries, mastery of the powers of steam, electricity, and internal combustion made it possible greatly to increase the ratio of industrial production to the quantities of inputs used. At the end of the twentieth century, innovations in the areas of computerization and telecommunications improved productivity in the service sector. Over a span of centuries, history has been marked by technological innovations that have strongly increased the efficiency of the inputs in the rich countries." (Cahuc and Zylberberg, 2004).

The importance of technological upgrading as important driver of sustained economic growth and development has been recognized by international institutions and governments in developing countries (for a more extensive overview see Oberdabernig, 2015). Through the positive correlation of per capita income with socio-economic indicators such as health and education outcomes, and standards of living in general (e.g. Szirmai, 2015), this is likely to have important implications for improving social welfare. However, especially in the short run a country might face a painful adjustment process as its economy adapts to new production structures. This process is usually characterized with what Schumpeter (1942) calls creative destruction (see also Aghion and Howitt, 1992, 1998; Mortensen and Pissarides, 1998), in which jobs get destroyed but at the same type new employment opportunities are created. The net-effect of this mechanism of creative destruction, which is inherent in the process of technological innovation, is *a-priori* unclear (Vivarelli, 2012).

While more rapid economic growth spurs demand for new products and production activities and thus has the potential to create new employment opportunities (see also Okun's law for the negative relationship between economic growth and unemployment), this new demand might be satisfied by employing more machines rather than more workers in the production process. Especially in the short- and medium-run, when the full growth potential cannot yet be realized, the substitution of labor for machines might lead to a loss of jobs. This fear has occurred through various points in history. A famous example is the Luddite movement in nineteenth century Britain, in which textile workers destroyed weaving and spinning machines out of the fear that their jobs would be taken over by these machines. This fear is also reflected in the still ongoing, prominent debate on whether automation and technological progress lead to a destruction of jobs and makes human labor obsolete or whether it rather contributes to a higher demand for labor (see Brynjolfsson and McAfee, 2014; Autor, 2015).

In this article we review theoretical arguments and findings of the empirical literature to provide a balanced view on the effects of innovation on employment outcomes. Doing so, we pay special attention to the situation in developing countries. The article is organized as follows. In Section 2 we review theoretical arguments of the impact of innovation on labor market outcomes such as employment, wages, employment structure, and working conditions. Section 3 presents the empirical evidence of the effects based on cross-country analyses, case studies and findings for a set of developing countries. In section 4 we discuss the role of policy and institutions in shaping labor market outcomes. Finally section 5 concludes.

2 Theoretical arguments

From the theoretical side, economic models claim that there are counterbalancing effects of technological change on employment. On the one hand labor can be substituted by capital, which leads to a decrease in employment (*substitution effect*). On the other hand, due to increased productivity of labor firms can expand their production, which generates income, new demand and thus also promotes employment opportunities (*scale effect*). If this *scale effect* outweighs the *substitution effect*, labor-saving technological change can have employment enhancing effects, while otherwise the opposite is true.

Furthermore, technological change does not affect all workers the same way.

The same reasoning from above can be expanded to different skill levels of employment. Many scholars argue that most technologies that are invented nowadays are biased in favor of skilled labor, making this type of labor more productive, while replacing less skilled labor. This stems from the observation that most technologies are developed in rich, industrialized countries, in which skilled labor is the abundant factor of production. Through technology diffusion to developing economies also these countries potentially adopt skill-biased technologies, rather than technologies that are more suitable for their factor endowments.[1] The effect of technological change that is skill enhancing is, as we will see, an increase in the demand for skilled labor relative to unskilled labor, which is likely to manifest itself either in terms of higher relative wages of skilled workers, in lower unemployment rates among them, or a combination of both. In what follows we will visit each of these arguments in detail.

2.1 Innovation and employment

When investigating the impact of innovation on employment outcomes one can distinguish between product and process innovation (e.g. Katsoulacos, 1986; Stoneman, 1983; Hamermesh, 1993; Petit, 1995; Lachenmaier and Rottman, 2011; Vivarelli, 2012). While product innovation refers to the improvement of existing products or the introduction of new products in the market, process innovation leads to a decrease of production costs through improvements of production processes. Both have different theoretical effects on employment. The question of whether either type of innovation causes an increase or decrease of employment opportunities is an interplay of counterbalancing factors.

2.1.1 Product innovation

Product innovation can lead to improvements of existing products, new products that become available at the market, or the creation of new economic branches.

[1] Technological innovation and the possibility of automation of jobs does not necessarily imply that the new technology will be used everywhere. The adoption of technology depends on the one hand on absorptive capacities of a country and its firms (see studies cited in Oberdabernig, 2015) and on the other hand on relative costs of automation versus employing workers for conducting the same tasks (Zeira, 2007). In this literature review we will mainly focus on the effects of introducing new technologies and production processes—which is actively promoted in many development strategies—on labor market outcomes, abstracting from the fact that other technologies that might be available on the market are not adapted.

This can stimulate demand and contribute to the creation of new employment opportunities. In an early contribution Say (1964) recognized the positive impact of product innovation on employment, which has been confirmed by many subsequent studies (see e.g. Lachenmaier and Rottman, 2011, Vivarelli, 2012, and studies cited therein).

There are, however, also indirect effects that may counterbalance the employment generating, direct effect of product innovation. If the introduction of new products crowds out existing ones the employment effect of product innovation becomes less clear as the production of the latter contracts. Another effect that is often overlooked is that the introduction of new products can grant firms a temporary monopoly position, until other firms copy the newly introduced products. A firm might exploit its monopoly power to reduce its output in order to increase prices, which might have an adverse effect on employment (see Lachenmaier and Rottman, 2011). Thus, the impact of product innovation on employment is theoretically ambiguous.

In a developing country context, product innovation is likely to play a rather minor role in overall technological upgrading, which primarily takes the form of embodied technological change through the importation of capital goods from industrialized countries (see Vivarelli, 2012). This is because R&D expenditures on product innovation are much lower in developing countries as compared to their industrialized counterparts. The main difference between embodied and disembodied technological progress is that the former increases the productivity of new equipment only, while the latter increases the productivity of capital as a whole. This has important implications for the sources of economic growth (Cahuc and Zylberberg, 2004). Although investment in R&D is usually rather low in developing countries, there are other channels that allow them to gain access to product innovations, such as through licensing or reverse engineering. Compared to industrialized countries, the degree of licensing is rather low in developing countries, however. Also, it depends on their absorptive capacities on whether countries or firms can get access to these passive forms of innovation (see Vivarelli, 2012; Oberdabernig, 2015).

On these grounds, product innovation is likely to be more limited in developing countries than in their high-income counterparts. Combined with the empirical evidence presented in section 3 of this survey, this is likely to have important implications in terms of employment generation in a developing country context.

2.1.2 Process innovation

Also for process innovation there are counterbalancing forces at work, which determine its impact on employment outcomes. On the one hand, the direct effect of an upgrade of production technology is that labor gets substituted by machines. Through the productivity increase of labor, less workers are required to produce the same number of products. On the other hand, there exist various indirect effects of process innovation that can potentially counterbalance the negative employment impact. Vivarelli (2012) provides an excellent overview of the different compensation mechanisms put forward by the compensation theory (see Marx, 1961, 1969):

a) Automation can create demand for labor in the capital sector that produces machines (Say, 1964). A similar but broader argument is that automation does not impact to the same extent on different tasks. While some tasks are substituted by new technologies, other tasks complement these technologies or new production methods. In Autor's (2015) words:
   "Productivity improvements in one set of tasks almost necessarily increase the economic value of the remaining tasks. [...] When automation or computerization makes some steps in a work process more reliable, cheaper, or faster, this increases the value of the remaining human links in the production chain." Autor (2015).

b) The use of new technologies leads to a decrease in production costs, which can translate into lower product prices. The lower price stimulates demand, which leads to an expansion of the scale of production and thus can generate additional employment. This effect has been recognized by various scholars, dating back to Sir James Steuart (1966) (see Vivarelli, 2012, and studies cited therein). This effect is preceded, however, by an initial drop in demand due to the direct employment reducing effect of innovation, and thus it depends on the price elasticity of demand which effect prevails (as already noted by Mill, 1976, cited in Vivarelli, 2012).

c) If the decrease in production costs is not passed on to consumers through lower prices as mentioned in point b), extra-profit for entrepreneurs is created. If the additional profit is invested, this can lead to an expansion of production and generate employment (see Ricardo, 1951, and studies cited in Vivarelli, 2012).

d) The demand for labor could increase if innovation leads to lower wages. The formulation of this compensation channel dates back to Wicksell (1961), Hicks (1932), Pigou (1933) and Robbins (1934).[2]

e) Also if a sector of activity contracts as productivity increases this does not mean that jobs get destroyed in the economy as a whole. If productivity increases are passed on to workers in the form of higher wages, for example through the operations of labor unions, this generates new demand for products and thus can generate additional employment. Thus, depending on the income elasticity of demand, this process can even offset the initial job loss (see Pasinetti, 1981; Boyer, 1988, 1990, cited by Vivarelli, 2012).

Thus, from a theoretical point of view, it is ambiguous how process innovation will impact on employment. The effect depends on the interplay between job rationalization and each of the factors mentioned above.

Some of the adjustment mechanisms mentioned above are subject to critique and might work to a lesser extend in developing countries, where the work of some market forces might be impeded due to structural characteristics of their economies. Vivarelli (2012) explains these constraints in detail. Given that developing countries mostly rely on imported machines and capital goods that are used in the production process, and that technological change often takes the form of technological change embodied in imported capital, it is unlikely that employment in the capital sector will increase enough as a result of automation as to offset the decrease in employment due to the rationalization of labor (see Vivarelli, 2012). Also, as already argued above, automation and technical change is often skill biased, a point which we will take up later in this review in more detail. Innovation that complements skilled labor, which is a scarce factor in

[2]Cahuc and Zylberberg (2004) show that an increase in labor productivity due to technological upgrading can also result in higher wages of workers. This follows from the increase in workers' bargaining power as a result of a higher demand for labor. The higher labor demand is driven by the capitalization effect of technological change, which—by increasing labor productivity—increases the profit due to job creation.

many developing countries, might lead to a smaller employment generating effect than in industrialized countries, which are usually skill abundant.

Also demand constraints might exist that delay expenditure decisions and thus hinder some of the adjustment mechanisms from above to work. If lower product prices do not lead to increased demand for products, if extra-profits are not invested, or if no new workers are hired as a result of expectations of low demand, employment generation through the respective adjustment mechanisms is limited (see for example Keynes, 1973, and more recent studies cited in Vivarelli, 2012). Also a low degree of competition in developing countries can severely hinder the adjustment mechanism through lower prices, and the tendencies to invest profits abroad and to use additional income for the consumption of imported luxury goods limit domestic investment and demand (Vivarelli, 2012). Furthermore, labor unions and other workers representations are usually less prominent in developing countries and because of the often huge pool of unemployed persons labor productivity increases are not passed on to workers in form of higher wages (Szirmai, 2015).

Another mechanism, which has especially unfavorable implications in labor-abundant developing countries that are characterized through high unemployment rates, comes from the possibility of getting locked-in in labor saving technological progress. The largest part of innovation in developing countries is driven by the adoption of technologies that are developed in industrialized countries, which are usually labor saving (see Helpman, 1992; Keller, 2004). Getting locked-in in labor-saving technical change might impede "a reversal of this trend by temporary small reductions in the relative price of labor" (see Freeman and Soete, 1987, cited in Vivarelli, 2012).

To sum up, economic theory does not provide a clear-cut answer to the question of whether either type of innovation creates or destroys employment opportunities. From the above discussion it seems likely, however, that forces that are able to counterbalance the employment reducing effect of innovation might be weaker in a developing country context. Ultimately, the answer to the question of whether innovation contributes to job creation or job destruction is likely to depend on the economy of investigation, the time period analyzed and the type of labor market institutions that are in place. Before we turn to the findings of empirical studies on the effect of innovation on employment in section 3, we shortly review theoretical arguments concerning the impact on innovation on skills and the life span of jobs.

2.2 Innovation and employment quality

2.2.1 Demand for skilled and unskilled labor

Apart from its quantitative effect on employment, innovation is likely to change the demand for workers of different skill levels (see Acemoglu, 2002, for an excellent overview). A concept dating back to Griliches (1969), Nelson and Phelps (1966), and Welch (1970) that has received a great deal of attention in both the theoretical and empirical literature is capital-skill complementarity, or skill biased technological change (SBTC).[3] The effect of SBTC, which is often coupled with labor-saving process innovation, is that it increases the productivity of skilled labor. How this impacts on the demand for skilled and unskilled workers theoretically depends on the elasticity of substitution between workers of the two categories. Combined with the finding of the empirical literature that skilled and unskilled workers are substitutes,[4] the implication of the theoretical literature is that skill-biased innovation induces an increase in the demand for skilled labor. As such, skill-biased innovation replaces tasks that are traditionally carried out by low-skilled workers by new tasks that demand qualified workers (Acemoglu, 2002; Cahuc and Zylberberg, 2004; Vivarelli, 2012). Especially in developing countries that are characterized by high rates of unemployment or underemployment skilled workers may take over tasks that are traditionally performed by unskilled workers, rather than staying unemployed. Thus, skilled labor can offset unskilled labor (see Albrecht and Vroman, 2002; Cahuc and Zylberberg, 2004).[5]

Is technological change always skill biased? The recent consensus that technological developments favor skilled workers is largely driven by the experience of the past several decades, but it has not always been like that. A counterexample to this is the Luddite movement, which was mentioned in the introduction. In

[3] See e.g. Haskel and Slaughter (2002); Acemoglu (2003); Thoenig and Verdier (2003) and Zeira (2007) for theoretical models and the large empirical literature cited in Vivarelli (2012).

[4] See for example Freeman (1986); Katz and Murphy (1992); Angrist (1995); Katz and Autor (1999) and Acemoglu (2002)

[5] This has potentially also important implications for the interaction between the formal and the informal sector, as skilled labor has a higher probability of getting employed in the formal sector. This effect might be even stronger after the implementation of skill-biased technological innovations.

Britain of the earlier nineteenth century it was primarily skilled artisans that feared to lose their jobs and being replaced by machines. Their fear was not unfounded as their craft was taken over by factories that employed workers with relatively few skills. Yet, more recent empirical evidence suggests that skill-biased innovation is an important phenomenon of most of the twentieth century and that it has been accelerating in the past few decades (Acemoglu, 2002). Empirical studies also show that investments in new technologies usually come at the expense of unskilled workers.[6]

The direction of the skill-bias of newly developed technologies is determined by market forces that are at work in technologically leading economies, in which the bulk technological inventions are created. Theoretically the skill-bias of innovation is determined by two factors (see e.g. Acemoglu, 1998, 2002, 2003):

a) the *price effect*, which complements the scarce factor that is used intensively to produce the more expensive good in an economy, and

b) the *market size effect*, which is directed towards the abundant factor that is readily available in the country. Technologies directed towards the abundant factor (e.g. skilled labor) can be used by a bigger clientele and thus have larger scale effects.

Also here it depends on the elasticity of substitution between the different factors of production which effect will prevail. According to theory, if skilled and unskilled labor are substitutes, as argued before, the *market size effect* outweighs the *price effect*, thus resulting in the invention of skill-biased technologies in industrial economies that are characterized by relative abundance of skilled labor. This mechanism is also capable of explaining the shift from innovation favoring less skilled labor in nineteenth century Britain, when skilled workers were scarce, to innovation directed at skilled labor since the second half of the twentieth century when the supply of educated workers was constantly increasing.[7]

It follows from the arguments above that technologies developed in rich, industrialized countries, which are characterized by a large pool of skilled workers,

[6] See for example the evidence provided by Berman et al. (1994); Autor et al. (1998); Machin and Van Reenen (1998) and Krueger (1993), cited in Cahuc and Zylberberg (2004).

[7] The increase in the supply of skilled labor over the past seventy years in the technologically leading economy, the US, and also in other advanced economies is likely to have substantially contributed to the skill-biased nature of technical change over the second half of the twentieth century (see Acemoglu, 2002).

are likely to complement skilled labor. For developing countries, which are often abundant in unskilled labor, the opposite is true. Yet, in developing countries foreign technologies that are developed in rich countries account for a large part of domestic productivity growth (Acemoglu and Zilibotti, 2001; Acemoglu, 2002, 2003; Keller, 2004). As a result, innovation in these countries is often skill biased, creating a mismatch between the requirements of the adopted technologies and the skills of the domestic workforce. It is thus not likely to entail large beneficial effects on local labor markets, which are characterized by a huge pool of unskilled labor, and might imply low productivity levels in developing countries (Acemoglu and Zilibotti, 2001). In these countries "the scarcity of skilled labor can easily generate unemployment among the unskilled workers" (Vivarelli, 2012) .

2.2.2 Wage effects of technical change

The effect of skill-biased innovation on wages follows from its effect on the demand for workers of the two skill categories described above. It depends on the flexibility of the labor market, the rigidity of wages, and on the supply of production factors, whether a higher demand for a certain type of workers will lead to higher employment of those workers, to an increase in their wages, or a combination of both effects.

The theoretical effect of skill-biased innovation—and thus of a higher demand for skilled workers—is to increase the wages of skilled workers over the wages of their unskilled counterparts. This leads to an increase in the skill-premium.[8] Its effect on the wages of unskilled workers is ambiguous. Because of the substitution of low-skilled for high-skilled workers, the direct effect of skill-biased innovation is a fall in the demand for low-skilled workers. However, it is possible that productivity increases that stem from SBTC lead to an expansion of production, through which also the demand for unskilled workers, and therefore also their wages, might increase. Which effect outperforms the other again depends on the interplay of substitution and scale effects (Acemoglu, 2003).

[8]Indeed, a large empirical literature explains the increase in income inequality in developing countries after they opened up for international trade—a phenomenon that contradicts the predictions of the Stolper-Samuelson theorem in the Heckscher-Ohlin model of international trade—to trade induced SBTC (see e.g. Wood, 1995; Acemoglu, 2003; Thoenig and Verdier, 2003; Zeira, 2007, for theoretical models and e.g. Meschi and Vivarelli, 2009, and Görg and Strobl, 2002, for empirical studies).

Not referring explicitly to innovation that is biased towards skilled labor, the Nelson-Phelps hypothesis (Nelson and Phelps, 1966) states that skilled workers have a higher capacity to adapt to new technologies in general. Thus, according to this hypothesis, also factor neutral technological upgrading raises the demand for skilled workers and leads to an increase in the skill premium (see studies cited in Acemoglu, 2002, and Foster and Rosenzweig, 1996, for evidence from India).

2.2.3 The life span of a job

We saw from before that the impact of innovation on on the number of jobs is ambiguous from a theoretical point of view. But also if total employment (or unemployment) does not change as a result of technological upgrading, this does not mean that the same workers will stay employed. Some jobs become obsolete and get replaced by new ones.

The description of this process of creative destruction dates back to Schumpeter (1942) and was formalized by Aghion and Howitt (1992, 1998) and Mortensen and Pissarides (1998). According to this process, certain types of jobs disappear as a result of innovation when the technology they employ no longer yields a positive surplus. Hence, technological advance has an impact on the life span of jobs, which decreases as a result of technological upgrading. This results from the increase in the number of jobs that become obsolete (see Cahuc and Zylberberg, 2004). At the same time, under certain conditions the creation of new jobs can counterbalance job destruction. The extent to which old jobs benefit from innovation in terms of experiencing productivity increases is a crucial factor in determining whether job creation dominates the process of job destruction (see Aghion and Howitt, 1998; Mortensen and Pissarides, 1998; Cahuc and Zylberberg, 2004).

3 Empirical evidence

3.1 Findings for industrialized countries

3.1.1 Innovation and employment

A large number of studies in the empirical literature aim to estimate the employment impact of innovation on employment in industrialized countries. Tables 1 and 2 provide an overview of studies covering developed economies and summarize their findings.

Table 1: Employment effects in industrialized countries (firms)

authors	year	country	data	product innovation (1)	process innovation (2)	innovation (3)
Firm-level evidence						
Entorf and Pohlmeier	1990	DE	cs	+	0	
Lachenmaier and Rottmann	2007	DE	pn	+	+	
Lachenmaier and Rottmann	2011	DE	pn	+	+	
Peters	2004	DE	cs	+	-	
Rottmann and Ruschinski	1998	DE	pn	+	0	
Smolny	1998	DE	pn	+	+	
Zimmermann	1991	DE	cs			-
Bogliacino et al.	2011	EU 27	pn			+/0
Greenan and Guellec	2000	FR	pn	+	+	
Harrison et al.	2014	FR, DE, ES, UK	cs	+	+	
Hall et al	2008	IT	pn	+	0	
Piva and Vivarelli	2004	IT	pn			+
Piva and Vivarelli	2005	IT	pn			+
Vivarelli et al.	1996	IT	cs	+	-	-
Brouwer et al	1993	NL	pn	+		-
Klette and Forre	1998	NO	pn			0
Blanchflower et al.	1991	UK	cs			+
Greenhalgh et al.	2001	UK	pn			+
Machin and Wadhwani	1991	UK	cs			+
Van Reenen	1997	UK	pn	+		
Blanchflower and Burgess	1998	UK, AUS	cs		+	
Coad and Rao	2011	US	pn			+
Doms et al.	1997	US	cs			+

Note: country: ISO2 codes are reported. data: cs stands for cross-section, pn stands for panel. + stands for a positive and statistically significant effect, 0 for an insignificant effect and - for a negative and statistically significant effect.

A look at these tables makes clear that empirical studies that focus on OECD economies provide a quite heterogeneous picture on the effects of innovation on employment. While at the firm level (see Table 1) many studies find positive employment effects of innovation in general (column 3),[9] Bogliacino et al. (2011) and Klette and Forre (1998) do not find a clear cut relationship between R&D

[9]For studies finding positive employment effects of innovation at the firm level see Piva and Vivarelli (2004, 2005) for evidence form Italy, Blanchflower et al. (1991); Greenhalgh et al. (2001), and Machin and Wadhwani (1991) for the UK, and Coad and Rao (2011) and Doms et al. (1997) for evidence from the US.

expenditures and employment,[10] and Zimmermann (1991), Vivarelli et al. (1996), and Brouwer et al. (1993) provide evidence for negative employment effects.

Disentangling the effects of product and process innovation, empirical work usually shows a positive employment impact of the former type of innovation (column 1).[11] This indicates that the direct employment generating effect of product innovation dominates the indirect effects summarized in the theoretical part of this review. The results of empirical papers on the impact of process innovation on employment are less clear-cut (column 2). Some authors find positive effects of process innovation on employment (Lachenmaier and Rottman, 2007, 2011; Smolny, 1998; Greenan and Guellec, 2000; Harrison et al., 2014; Blanchflower and Burgess, 1998), some find negative effects (Peters, 2004; Vivarelli et al., 1996), and some do not find significant effects at all (Entorf and Pohlmeier, 1990; Rottmann and Ruschinski, 1998; Hall et al., 2008).

While firm-level studies are informative as to the extend that they indicate whether innovating firms are more likely to grow in terms of employment, they are unable to capture overall effects on employment at the sectoral level. Firms that innovate might expand employment through stealing market-share from other firms operating in the same sector. Thus, firm level analyses could result in too positive conclusions concerning the employment effects of technical upgrading (Vivarelli, 2012; Harrison et al., 2014). Therefore, accounting for the potential crowding out of non-innovating firms is important when investigating overall employment effects at the sectoral level (e.g. Pianta, 2000; Bogliacino and Pianta, 2010; Vivarelli, 2012).

The results of empirical studies that engage in sector-level analyses of the employment effect of innovation are summarized in Table 2. The picture that emerges is that the employment enhancing effect of product innovation is not limited to firm-level analyses, but can be found also at the sectoral level (column 1). What is striking from Table 2 is that now process innovation seems to have a consistently negative effect on employment (column 2). This indicates that

[10] In Bogliacino et al. (2011) the positive effect of R&D expenditure on employment is limited to services and high-tech manufacturing.

[11] See Entorf and Pohlmeier (1990); Lachenmaier and Rottman (2007, 2011); Peters (2004); Rottmann and Ruschinski (1998), and Smolny (1998) for evidence from Germany, Greenan and Guellec (2000) for evidence from France, Hall et al. (2008) and Vivarelli et al. (1996) for Italy, Brouwer et al. (1993) for the Netherlands, Van Reenen (1997) for the UK, and Harrison et al. (2014) for evidence from four European countries (France, Germany, Spain, and the UK).

Table 2: Employment effects in industrialized countries (sectors)

authors	year	country	data	product innovation (1)	process innovation (2)	innovation (3)
Sector-level studies						
Pianta et al.	1996	6 OECD countries	cs			+/-
Pianta	2000	5 Europ. countries	cs	+	-	-
Antonucci and Pianta	2002	7 Europ. countries	cs	0	-/0	-
Bogliacino and Pianta	2010	8 Europ. countries	pn	+	-	
Greenan and Guellec	2000	FR	pn	+	-	-
Evangelista and Savona	2002	IT	cs			+/-
Vivarelli et al.	1996	IT	cs	+	-	-
Clark	1983	UK	pn			+/-
Clark	1987	UK	pn			+/-

Note: country: ISO2 codes are reported. data: cs stands for cross-section, pn stands for panel. + stands for a positive and statistically significant effect, 0 for an insignificant effect and - for a negative and statistically significant effect.

the expansion of employment in firms that engage in process innovation, which is found in a considerable number of empirical studies, comes at the costs of stealing business (and thus employment) from other firms in the same industry. Finally, most sectoral studies find a negative effect of innovation in general on employment (column 3), although differences can arise when looking at different time periods (Clark, 1983, 1987), or different sectors of the economy (Pianta et al. 1996, cited in Vivarelli 2012; Evangelista 2000).

3.1.2 Innovation and skills

For investigating the effects of technological upgrading and innovation on the quality of employment, empirical studies often focus on the demand for workers of different skill levels. Jobs for workers with higher skill levels (or non-production, white-collar activities) are usually less dangerous and less physically demanding and usually pay higher wages than jobs for less skilled workers, as evidenced by the positive skill premium that is often found in the literature. Also other features like social protection for families, prospects for personal development, and leave options are typically positively correlated with the skill level of jobs (Gyeke-Dako et al., 2016c). Autor (2015) emphasizes this relationship by arguing that with the increase of skilled blue- and white-collar work after World War II, physically demanding, dangerous and menial employment dropped in industrialized countries.

In empirical studies covering industrialized economies a large set of controls has been used to capture the effect of technological change on the demand for skilled workers. These studies frequently apply data on R&D investments, patents, licenses, stocks of technological capital, and the use of information and communication technologies (e.g. computers, broadband internet), among others, which should allow to control for the level of technology and innovation in a rather direct way. To test whether technical change is skill biased, these studies usually focus on the effect of innovation on i) employment shares or ii) wage bill shares of different skill categories, or iii) on changes in skill premia. The argument is the following: for a given supply of workers in each skill category, an increase in demand for skilled labor should lower unemployment of skilled workers and/or raise their relative wages, thus extending their wage bill share.

As becomes visible in Table 3, most of the empirical studies focusing on OECD economies (both on the firm- and industry level) find strong evidence for the hypothesis of SBTC, which implies that technological upgrading is connected to a higher demand for high-skilled (white-collar, non-production) workers relative to workers of lower skill levels (blue-collar, production workers). In what follows, we will discuss the empirical evidence by first focusing on the American continent, and after mentioning the findings covering various OECD economies we will turn to European countries in more detail. Finally, we will discuss evidence provided by more recent studies that aim to describe the polarization of labor markets that is observed in many industrialized economies.

For the US, Dunne et al. (1997), Autor et al. (1998), Berman et al. (1994b), Lindley and Machin (2016) and Morrison Paul and Siegel (2001) find that technological improvements have a positive effect on the employment share of skilled workers.[12] While the cross-sectional results by Doms et al. (1997) are in line with the findings of these studies, the significant impact of the usage of advanced technologies on the employment of skilled labor turns statistically insignificant in their panel framework. For Canada, Betts (1997) and Gera et al. (2001) provide evidence for the presence of SBTC through a technology-induced increase in the wage bill share of skilled labor. While Gera et al. (2001) measure techno-

[12] Autor et al. (1998) also provides evidence for a technology-induced increase in the skill premium.

Table 3: Skill bias of technology in industrialized countries

authors	year	country	data	SBTC (1)	skill premium (2)	wage bill share (3)	employment share (4)
Firm/Plant-level evidence							
Falk and Seim	2001	DE	cs	+			+
Aguirregabiria and Alonso-Borrego	2001	ES	pn	+/0			+/0
Luque	2005	ES	pn	+			+
Greenan et al.	2001	FR	pn	+			+
Baccini and Cioni	2010	IT	cs	+/0			+/0
Casavola et al.	1996	IT	pn	+	+		+
Piva and Vivarelli	2001	IT	pn	+/0			+/0
Piva and Vivarelli	2002	IT	pn	+/0			+/0
Piva et al.	2005	IT	pn	+/0			+/0
Piva et al.	2006	IT	pn	0			0
Akerman et al.	2015	NO	pn	+	+		+
Haskel and Heden	1999	UK	pn	+		+	
Doms et al.	1997	US	cs, pn	+/0			+/0
Dunne et al.	1997	US	pn	+			+
Sector/Industry-level evidence							
Betts	1997	CA	pn	+		+	
Gera et al.	2001	CA	pn	+		+	
Falk and Koebel	2004	DE	pn	+/0			+/0
Goux and Maurin	2000	FR	pn	0		0	0
Lindley and Machin	2013	UK	pn	+			+
Autor et al.	1998	US	pn	+	+		+
Berman et al.	1994	US	pn	+			+
Lindley and Machin	2016	US	pn	+			+
Morrison Paul and Siegel	2001	US	pn	+			+
Machin and Van Reenen	1998	7 OECD	pn	+		+	

Note: country: ISO2 codes are reported. data: cs stands for cross-section, pn stands for panel. + stands for a positive and statistically significant effect, 0 for an insignificant effect and - for a negative and statistically significant effect.

logical change based on information on R&D, patent stock, and the age of the capital stock, Betts (1997) uses a time trend to capture technological upgrading. Also the study by Machin and Van Reenen (1998) focusing on the US, the UK, Denmark, France, Germany, Sweden, and Japan, confirms the positive impact of R&D expenditure on the demand of skilled workers, as evidenced by the increase in their wage bill share.

Turning to the European continent, Haskel and Heden (1999) and Lindley and Machin (2013) provide evidence for the SBTC hypothesis in the case of the UK. Investigating the effect of broadband internet on employment shares and skill premia in Norway, Akerman et al. (2015) confirm that this type of innovation had a positive impact on skilled labor, while wages of low-skilled workers declined. Falk and Seim (2001) and Falk and Koebel (2004) provide evidence for the existence of SBTC in West German firms and industries, respectively. Falk and Koebel (2004), however, also document that their findings are less robust in certain manufacturing industries, in contrast to the robust results found for the non-manufacturing sector. Similar results are reported for Spain by Aguirregabiria and Alonso-Borrego (2001) and Luque (2005). Aguirregabiria and Alonso-Borrego (2001) provide additional insights in noting that only the introduction of new technological capital is connected to an increase in the relative demand for skilled workers, while increasing an existing stock of technological capital does not have a statistically significant effect on the relative demand for labor of a certain skill type. The authors attribute this finding to the fact that R&D spending might not necessarily lead to successful innovations.

Turning to the case of France, Greenan et al. (2001) and Goux and Maurin (2000) find somewhat less unanimous results. While Greenan et al. (2001) show that innovation is connected to a higher relative demand for skills on the firm level, Goux and Maurin (2000) indicate that the impact of new technologies on employment shares and labor-cost shares of skilled labor is statistically insignificant at the industry level. Also in Greenan et al. (2001) only the negative relationship between innovation and employment of less-skilled workers is robust in time-series, while the relationship with the demand for high-skilled workers is not. Similarly, for Italy empirical studies usually find either positive or insignificant effects of technological innovation on the relative demand for skilled labor. Casavola et al. (1996) provide evidence for an increase of the relative demand for skilled labor (indicated by an increase in skilled employment shares and higher skill premia) but note that the rise in the skill premia was lower than in the US and the UK. Baccini and Cioni (2010) show that embodied technical change affects low-skilled workers negatively, but that a universal skill-biased effect for all occupations cannot be detected. Piva and Vivarelli (2001, 2002) and Piva et al. (2005, 2006) find that R&D alone does not have a statistically significant effect in determining skill bias, but that its effect turns statistically significant once it is interacted with organizational change (Piva and Vivarelli, 2002; Piva et al., 2005). Organizational change alone (which may in turn be linked to new technologies), by contrast, is found to have a significantly positive influence on the demand for skilled labor. Piva and Vivarelli (2002) also find a skill-biased effect of FDI, which might indicate indirect impacts though technological change.

Finally, a more recent set of studies attributes the shrinkage of the middle class and the polarization observed in many western labor markets to the availability and adoption of new technologies. Hynninen et al. (2013) show that the availability and use of the steam engine by seamen in Sweden led to an increase in demand for high-skilled engineers and unskilled engine room operators, while the demand for intermediate-skilled workers decreased. Van Reenen (2011) (for the UK and US) and Michaels et al. (2014) (for the US, Japan and 9 European countries) argue that information and communication technologies have been replacing routine tasks, leading to a fall in demand for the middle educated workers.

While the findings of the empirical studies summarized above are informative about the possible mechanisms that are in force when driving labor market outcomes in industrialized countries, they might not apply in a developing country context, due to differences in the process of technological upgrading but also due to structural characteristics and differences in labor market institutions. Thus, we revise the empirical literature for developing countries in the next section.

3.2 Findings for developing countries

While extensive analyses concerning the effects on innovation on labor market outcomes in developed countries exist, the evidence for developing economies is rather limited. Section 3.2.1 summarizes the empirical studies on innovation and employment in developing countries, while section 3.2.2 reviews the empirical literature on the impact on the demand of skilled workers.

3.2.1 Innovation and employment

Most of the scarce studies on the effect of product and process innovation on employment in developing countries focus on Latin America and are limited to firm-level data. The picture that emerges from a survey of these studies is that product innovation, like for industrialized economies, is connected to an increase in employment (see column 1 in Table 4), while the effect of process innovation is not so clear cut (column 2). Thus, also the overall effect of innovation on employment seems to be ambiguous in developing countries (column 3).

Table 4: Employment effects in developing countries

authors	year	country	data	product innovation (1)	process innovation (2)	innovation (3)
Firm-level evidence						
Castillo et al.	2014	AR	pn	+	+	
Elejalde et al.	2015	AR	pn	+	0	
Zuniga and Crespi	2013	AR, CL, UY	pn			+
Crespi and Tacsir	2013	AR, CL, CR, UY	pn	+	+/-/0	
Alvarez et al.	2011	CL	pn	+	0	+/0
Alvarez et al.	2012	CL	pn			+/-
Benavente and Lauterbach	2008	CL	pn	+	0	
Monge-González et al.	2011	CR	cs	+	+	
Aboal et al.	2015	UY	pn	+	-	
Baffour et al.	2016	GH	cs	+	0	
Gyeke-Dako et al.	2016	GH	cs	+	0	

Note: country: ISO2 codes are reported. data: cs stands for cross-section, pn stands for panel. + stands for a positive and statistically significant effect, 0 for an insignificant effect and - for a negative and statistically significant effect.

Not distinguishing between process and product innovation Zuniga and Crespi (2013) show that innovation, measured as in-house R&D and external innovation activities, is connected to higher employment in Argentina, Chile, and Uruguay. While their result is confirmed by Alvarez et al. (2011) for firms in Chile, this effect turns insignificant when limiting the analysis to small firms only. Alvarez et al. (2012) exploit information on different innovation policies and find that their effect on employment depends on the type and design of the respective policy that is aimed at encouraging innovation. The authors show that FONTEC (National Productivity and Technological Development Fund) policies had an employment increasing effect on treated firms, while FONDEF (Science and Technology Development Fund) policies had a negative impact on employment.

Distinguishing between product and process innovation, empirical studies focusing on developing countries usually find evidence for a positive impact of product innovation on employment (column 1). The findings for process innovation, by contrast, are more heterogeneous (column 2). Castillo et al. (2014) find positive effects of process innovation on employment in Argentina, while Elejalde et al. (2015) and Crespi and Tacsir (2013) do not confirm the statically significant impact. Also for Chile, Benavente and Lauterbach (2008) and Alvarez et al. (2011) do not detect evidence for a significant relationship between process innovation and employment—Crespi and Tacsir's (2013) instrumental variable (IV) results, by contrast, point towards a negative effect. Monge-González et al. (2011) report a positive relationship in Costa Rica, which is confirmed by Crespi and Tacsir's (2013) IV estimations, while their ordinary least squares (OLS) estimations yield insignificant results. For Uruguay, both Aboal et al. (2015) and Crespi and Tacsir (2013) find a negative relationship between process innovation and employment.

Twumasi Baffour et al. (2016) and Gyeke-Dako et al. (2016b) provide evidence from Ghana. Twumasi Baffour et al. (2016) do not detect statistically significant effects of process innovation on employment in their econometric analysis, but report a positive relationship between product innovation and employment. Gyeke-Dako et al. (2016b) confirm the finding of Twumasi Baffour et al. (2016), which indicate that product innovation is likely to lead to an increase in employment, while process innovation has an insignificant effect, in a qualitative case study analysis. Gyeke-Dako et al. (2016a) show that process innovation is the dominant form of innovation in the context of Ghana. The authors also provide evidence that it is usually larger firms, exporting firms, and firms whose managers have higher skill levels that are the more innovative ones. Digging deeper into what determines product and process innovation, Oduro et al. (2016) provide evidence that in the case of Ghana FDI might spur both innovation activities directed at product and process innovation. While joint ventures are more likely to stimulate process innovation, product innovation is not dependent on whether a firm is foreign or domestic owned. Also R&D activities, which are concentrated in large firms, are found to be positively connected to both innovation types, while the direct effect of firm size on innovation is statistically insignificant. The authors also show that having a website is important for product innovation.

3.2.2 Innovation and skills

In the empirical literature on innovation and the demand for skills the effects of trade openness, FDI, and technological upgrading have often been investigated simultaneously, especially in a developing country context. This is often based on the argument that new technologies are primarily developed in industrialized countries and that in developing countries innovation often takes the form of technological change that is embodied in capital equipment (ETC), which is imported from industrialized countries, or that technological spillovers occur more easily in firms with foreign ownership through technology transfers (see Keller, 2004; Oberdabernig, 2015). In what follows, we summarize the evidence from empirical studies that focus on developing countries by first providing a general overview and then consecutively moving from countries in Africa to Latin America and Asia. Finally, we concentrate on cross-country studies covering developing economies on different continents.

Empirical studies that focus on developing countries usually find that technological upgrading, either based on domestic or imported technologies (via trade or FDI), is connected to an increase in the relative demand for skilled labor (see Table 5). Exceptions are the studies by Haile et al. (2013), Twumasi Baffour et al. (2016), Pavcnik (2003), and Fajnzylber and Fernandes (2009), which do not detect robust evidence for the presence of SBTC. The significantly positive effect of foreign ownership that Haile et al. (2013) detect based on their general method of moments (GMM) estimates for Ethiopia is not robust to alternative estimation methods. OLS estimates suggest that the employment of both skilled and unskilled workers increases and for fixed effects (FE) estimates the results are statistically insignificant. Twumasi Baffour et al. (2016) distinguish between product and process innovation and show that there is evidence for SBTC connected to product innovation in Ghana, however process innovation is found to have a negative effect on the employment of high-skilled workers. Although Fajnzylber and Fernandes's (2009) results point towards the existence of SBTC in Brazil, the authors find that international economic activities foster unskilled, labor-intensive goods, rather than skill-intensive products, in China. Also the studies by Lee and Wie (2015) and Yu (2010) do not provide evidence for significant impacts of do-

Table 5: Skill bias of technology in developing countries

authors	year	country	data	SBTC (1)	skill premium (2)	wage bill share (3)	employment share (4)
Firm/Plant-level evidence							
Haile et al.	2013	ET	pn	+/0		+/0	
Görg and Strobl	2002	GA	pn	+			
Baffour et al.	2016	GA	cs	+/-		+/-	
Pavcnik	2003	CL	pn	0			
Fuentes and Gilchrist	2005	CL	pn	+			
Feenstra and Hanson	1997	MX	pn	+			+
Hanson and Harrison	1999	MX	pn	+		+	
Caselli	2014	MX	pn	+	+		
Giovanetti and Menezes-Filho	2006	BR	pn	+			
Fajnzylber and Fernandes	2009	BR/CN	cs	+/-			
Araújo et al.	2011	BR	pn	+			
Lee and Wie	2015	ID	pn	+/0		+/0	+/0
Almeida	2008	East Asia	cs	+			
Almeida	2010	East Asia	cs	+			
Meschi et al.	2011	TR	pn	+			
Srour et al.	2014	TR	pn	+		+	
Sector/Country-level evidence							
Yu	2010	CN	pn	+/0		+/0	
Mrabet and Lanouar	2013	TN	pn	+		+	
Meschi and Vivarelli	2009	65 DCs	pn	+	+		
Conte and Vivarelli	2010	23 DCs	pn	+		+	

Note: country: ISO2 codes are reported. data: cs stands for cross-section, pn stands for panel. + stands for a positive and statistically significant effect, 0 for an insignificant effect and - for a negative and statistically significant effect.

mestic R&D on the relative demand for skilled workers—their proxies for foreign technology (imports and FDI, and foreign R&D, respectively), however, show a positive and statistically significant impact on employment shares of skilled workers (and their wage bill shares in the case of Lee and Wie).

While we argued that in the firm-level study of Haile et al. (2013) the significance of the evidence for the presence of SBTC on the depends on the estimation method employed, Mrabet and Lanouar (2013) show that technology imports are connected to a higher employment share of skilled labor on a sectoral level in Tunisia. Similarly, for firm-level data in Ghana, Görg and Strobl (2002) show that investment in equipment sourced abroad is connected to a significant increase in the demand for skilled labor. Combining these findings with the results of Twumasi Baffour et al. (2016) described above, the demand-enhancing effect for skilled labor might stem from product innovation, as process innovation was found to be connected to a higher employment probability of low-skilled workers by the authors. In their qualitative firm-level study for Ghana, Gyeke-Dako et al. (2016b) provide the insight that innovating firms do have training programs in place to improve the quality of their workers and conclude that firms that train their workers might be more likely to innovate.

Turning to Latin American countries, Pavcnik (2003) does not find significant impacts of the adoption of foreign technology on the demand for skilled labor on the plant level in Chile, while Fuentes and Gilchrist (2005) report significant effects, using trade data to proxy for technology imports. For Mexico, Feenstra and Hanson (1997), Hanson and Harrison (1999) and Caselli (2014) document an increase in the relative demand for skilled labor (measured as an increase in wage-bill shares, employment shares, and skill premia of skilled labor, respectively) as a result of technology adoption. The authors proxy innovation by using information on FDI (Feenstra and Hanson, 1997), trade and tariff data (Hanson and Harrison, 1999), and tariff-induced price changes for machinery and equipment (Caselli, 2014). In the Brazilian case, Giovannetti et al. (2006), Fajnzylber and Fernandes (2009) and Araújo et al. (2011) provide evidence for the existence of SBTC. Araújo et al. (2011) uses expenditure on royalties as a direct measure of innovation, while Giovannetti et al. (2006) exploits the reduction in tariffs as proxy for imported technologies and Fajnzylber and Fernandes (2009) use intermediate inputs imports and FDI to test for the diffusion of skill-biased technologies.

Fajnzylber and Fernandes (2009) also investigate the effects in China and find that in contrast to Brazilian firms, FDI and imported inputs are connected to lower demand for skilled labor in Chinese firms. In contrast, Yu (2010) shows that on a sectoral level domestic R&D does not have a significant effect on the employment share of skilled workers, while foreign R&D significantly increases skilled labor demand. Similar to the findings of Yu (2010) for China, Lee and Wie (2015) show that in Indonesia domestic R&D does not have a significant effect on skill demand, while foreign technology diffusion (measured through imports and FDI) is connected to an increase in the employment share and wage bill share of skilled workers. Focusing on firms in different East Asian countries, Almeida (2008, 2010) finds some evidence for the presence of SBTC. In her 2008 paper (cited in Almeida, 2010) the author shows that East Asia firms that are more exposed to trade and adopt newer technologies take longer to fill job vacancies for skilled labor, which she interprets as evidence for skill-biased technological change combined with a lag in the supply of skills. Almeida (2010) provides evidence that greater trade openness and technological upgrading lead to a higher demand for skills in middle-income countries, while the same does not hold for low-income countries. The author attributes this finding to the higher absorptive capacity of middle-income countries. Meschi et al. (2011) and Srour et al. (2014) focus on firm-level data from Turkey and find that R&D expenditures (and patents in the case of Srour et al.) increase the relative demand for skilled workers. Srour et al. (2014) show that both domestic and imported technologies have a significant effect on the demand for skilled labor, but that they do not significantly affect the demand for unskilled workers.

Finally the results of the cross-country studies by Meschi and Vivarelli (2009) and Conte and Vivarelli (2011) can be interpreted as evidence for SBTC. Meschi and Vivarelli (2009) investigate the effects of trade openness on income inequality in 65 developing countries and find that inequality is rising as a result of trade openness in middle-income countries that trade with high-income countries, while the same is not true for low-income countries. The authors attribute the finding to SBTC, which is present in middle-income countries but not in low-income countries, due to the higher absorptive capacities in the former. Applying a more direct proxy for technology diffusion, Conte and Vivarelli (2011) find that SBTC through imports of embodied technology leads to an increase in the demand for skilled labor on a sectoral level in their sample of 23 low- and middle-income countries.

4 The role of policy and institutions

As becomes evident from the above insights, technological change and innovation have important implications for restructuring processes of labor markets within and across countries. Autor (2015) recognizes the important role of policy for reacting to distributional changes among others caused by such developments. Also the degree of flexibility of labor markets and the type of domestic institutions have important implications in determining how moving up the technological ladder impacts on employment outcomes. These factors also determine the way in which innovations influence labor market outcomes, as evidenced by the different experiences documented by the large empirical literature. The degree of rigidity of wages and jobs, which results from the type of labor market policies in force and the work of institutions, determines whether technological change impacts more heavily on wage differentials and thus income inequality, or employment figures (see Vivarelli, 2012).

The discussion often centers around the experiences of Anglo-Saxon countries, which observed increasing wage differentials over time, which have been attributed, in part, to advances in the level of skill biased technology, and compares them with the experiences of continental Europe. In European countries, as opposed to the experiences of the US and the UK, employment figures have been reacting stronger to technological developments than wages (Vivarelli, 2012). The smaller increase in income inequality in Europe as compared to the US over time is often attributed to European labor market institutions, which encourage wage compression (such as bargaining agreements between firms and unions, minimum wages, and higher social standards; see Acemoglu 2002 and Cahuc and Zylberberg 2004). The existence of such institutions provides greater incentives to adopt labor-complementary technologies, which in turn reinforce wage compression (Acemoglu and Pischke, 1999). In Anglo-Saxon countries, by contrast, the degree of state intervention in labor markets is much lower and wages are subject to being freely bargained over. This implies that, in contrast to the European model, unemployment and labor market tightness are independent from the factor bias of new technologies, while the relative wage of skilled to unskilled workers is not (Cahuc and Zylberberg, 2004).

The erosion of real value of minimum wages can, among others, potentially account for the increase in inequality in the US (Di Nardo et al., 1995; Lee, 1999), but according to Acemoglu (2002) this effect is likely to be only a minor factor contributing to changes in the structure of wages. The theoretical effect of minimum wages on income inequality is unclear because labor market adjustments resulting from SBTC would take place though a higher risk of unemployment of low-skilled workers. Thus, the net effect of minimum wages on the average income of unskilled persons is ambiguous from a theoretical point of view. Alvarez et al. (2011) argue that by increasing the hiring cost for less qualified workers, minimum wages may bias innovation against low-skilled labor and thus reinforce the skill-bias of technological change and its negative consequences for less-skilled workers. Apart from that, Cahuc and Zylberberg (2004) suggest that fiscal policy measures might be better suited than minimum wages to neutralize the distributional consequences of technological innovation. However, while minimum wages are often argued to lead to higher unemployment rates, in a developmental context minimum wages might have important implications on the social cost of labor (i.e. the shortfall of wages from the minimum cost of covering basic needs), by acting as important benchmark for fair remuneration that is not confined to the formal sector (see Kocer, 2015).

Also a decreasing importance of trade unions might result in increased income inequality. Unionization compresses the structure of wages and reduces skill premia, by increasing the bargaining power of low-skilled workers. The de-unionization that took place in the US is also unlikely, however, to be the major cause of the increase in income inequality that has been observed (Acemoglu, 2002). Alternatively, by linking changes in unionization with technological developments, Acemoglu et al. (2001) suggest that innovation might have been a driving factor of de-unionization, leading to lower wages of unskilled labor. The mechanism behind this could be the following: Technological change increases the productivity of skilled workers, and thus gives them more bargaining power. This, in turn, might provide incentives for them to break the cooperation with lower skilled workers that led to the foundation of trade unions in the first place

(Cahuc and Zylberberg, 2004). Cahuc and Zylberberg (2004) show that a too high bargaining power of workers might also impact on job creation in a negative way, thus leading to increased labor market tightness. The authors argue that employment protection policies might be ill-suited to counter the effects of innovation on unemployment. As an alternative subsidies to create employment might be a better option, as suggested by Caballero and Hammour (1996).

Also, more flexible labor markets facilitate the substitution of less productive workers with more productive ones and newly available technologies are embodied in a bigger number of jobs (Mortensen and Pissarides, 1998; Aghion and Howitt, 1998). When this is the case, the capitalization effect described above is stronger, and productivity increases are more likely to translate into job creation in the long run (see Cahuc and Zylberberg, 2004). However, it is also likely that there will be a painful adjustment period in the shorter run, until the full adjustment takes place. This, on the one hand, calls for the existence of social safety nets, which yield workers from adverse short-run consequences, while providing sufficient flexibility in labor markets to be able to reach a higher level of employment in the long run. On the other hand, however, such social safety nets (as for example through providing unemployment benefits) might also lead to increased unemployment and decrease the life span of jobs (see Cahuc and Zylberberg, 2004). Notwithstanding, education and training programs that are aimed at preparing workers for the use of new technologies to increase their productivity are likely to be an important ingredient of policy making in the light of a quickly changing environment.

Turning to the demand side of an economy, Pianta (2000; cited in Vivarelli, 2012) points out that policies that affect the demand for products (or sectoral demand) can act as a powerful tool to influence the employment impact of innovation. By creating new markets for products (in sectors) that use technologies with greater potential for growth and job creation, negative employment effects of technological change can be counteracted. The author also suggests such demand-oriented policies might move away from an industrial policy of 'picking winners' towards 'empowering the users'.

Apart from the above mentioned institutional characteristics and policy choices, there are many different mechanisms through which policies can influence labor market outcomes via their impact on innovation. In this respect, differences in the protection and enforcement of intellectual property rights, policies aimed at attracting FDI, trade regulations, and national policies aimed at technological upgrading can lead to different employment outcomes through their impact on innovation activity and technology diffusion, and by influencing the factor bias of technologies that are developed and implemented (see Acemoglu, 2002; Vivarelli, 2012).[13]

5 Conclusion

In this article we reviewed the theoretical effects of innovation and technological upgrading on employment, skills, and the life span of jobs. Doing so we discussed the different impacts of product and process innovation, while focusing on both the direct and the indirect effects. We paid special attention on the possible differences of these processes for developing countries. After having provided a theoretical summary we revised the empirical evidence of the relationship between different sources of innovation and employment on the one hand, and the demand for skilled labor on the other hand, both for industrialized and developing countries. We also discussed the role of institutions and policy in driving labor market outcomes.

Technological upgrading and innovation are often argued to be an important source of economic growth, which has been recognized by international organizations and domestic governments in many developing countries. Many of the development strategies that focus on innovation as a source of economic growth aim at improving the situation of developing countries in the long run. In the shorter run, however, the direct impact of innovation is an improvement in labor productivity, which makes it possible to produce the same output with less labor and thus might have an adverse impact on the number of jobs. The adjustment process until reaching potentially beneficial outcomes in the long run is characterized by a mechanism of creative destruction (Schumpeter, 1942), in which on the one hand jobs become obsolete, but on the other hand new employment is generated. Technological innovation, through accelerating this mechanism, is likely to decrease the life span of jobs.

[13] We do not cover these policies here in detail as their impact on technological upgrading is discussed in Oberdabernig (2015).

It is possible to distinguish between different sources of innovation—product innovation, which aims at improving existing products or introducing new products in the market, and process innovation, which aims at improving production processes. While the direct effect of product innovation is to increase employment through the creation of new employment opportunities, the indirect effect is a decrease of employment through the potential destruction of older, more labor intensive products or through the generation of market power of innovative firms, which might have adverse effects on employment. Process innovation, on the other hand, is characterized through a direct effect in which labor is substituted by machines (*substitution effect*), and indirect effects that have the potential to counterbalance the decrease in employment. The indirect effects arise from a potential increase in the scale of production (*scale effect*), either through the generation of new employment opportunities in the capital sector, through a stimulation of demand arising from lower product prices and/or higher wages, or through an increase of investment by entrepreneurs that yield higher profits. Whether the direct or the indirect effects are stronger is unclear from a theoretical point of view.

In developing countries product innovation is likely to play a less important role than in Western economies because technological upgrading in the former often takes the form of embodied technological change through the import of capital goods from the latter. Because of the same reason it is unlikely that the capital sector that produces machines is going to expand in developing countries as a result of technological upgrading, thus limiting the employment friendly indirect effects of process innovation. Furthermore, in many developing countries differences in institutions, like a lower degree of competition and the weaker influence of trade unions and workers representations, might enhance demand constraints that limit these indirect effects.

The importation of capital goods from industrialized countries also has important implications for employment outcomes of workers of different skill levels. Theoretically the factor bias of technology that is developed (mostly in industrialized economies) depends on the interplay of two effects—the *price effect*, which complements the scarce factor (unskilled labor in industrialized countries), and the *market size effect*, which is directed towards the abundant factor (skilled labor). The *market size effect* is likely to outweigh the *price effect*, thus leading to the development of skill-biased technologies in industrialized countries. This skill-biased innovation results in increased demand for skilled workers, and thus to a decrease in employment rates and/or an increase of wages for skilled workers relative to less skilled ones. In contrast to industrialized countries, developing economies are often characterized through an abundance of low-skilled workers and large rates of unemployment and underemployment. The importation of skill-biased technologies might exacerbate the unemployment of low-skilled workers and runs the risk of getting locked in capital and skilled-labor intensive technologies, which are little suited for the needs of developing economies.

Turning to the empirical literature, the evidence for industrialized countries suggests that for product innovation the direct, employment generating effect outweighs the indirect, negative effect on employment. This is the case on both the firm level and on the sectoral level. By contrast, the findings concerning the effect of process innovation seem to be less favorable. While firm-level studies sometimes detect positive effects of process innovation on employment, this seems to be driven by the potential of innovative firms to steal market share from non-innovative firms. Empirical studies that focus on a sectoral level usually find negative effects of process innovation on employment. Overall, which type of innovation drives the overall outcome is not entirely clear and depends on the country, sector, and time period under investigation. Thus, studies that do not distinguish between the different types of innovation find either positive, negative, or statistically insignificant effects of innovation on employment, both on the firm- and on the sectoral level. Furthermore, the empirical literature suggests that there is quite convincing evidence for the existence of skill-biased technological change, that can be detected in both firm- and sectoral level studies.

For developing countries the empirical evidence for the impact of innovation on employment is rather scarce compared to the literature on industrialized countries. Existing studies suggest that also in a developing country context product innovation has positive effects on employment on the firm level, while there is no clear-cut pattern for process innovation. While also here the findings on the firm level range from positive effects via insignificant impacts to negative effect, we are not aware of studies that focus on a sectoral level. Thus, the positive, employment generating effects of process innovation that are found in studies on Argentina, Chile, and Costa Rica, might be driven by innovative firms stealing market share from firms that do not innovate. Like for industrialized countries there is quite convincing evidence for the existence of skill-biased innovation also in developing countries. However for developing countries it is mostly technologies that are imported or that become locally available through FDI that are the main determinant of skill-biased innovation, while domestic R&D is often found to play an insignificant role on the relative demand for skilled labor.

Finally, we argued that labor market policy and institutions play an important role in determining the effects on innovation on labor market outcomes. Institutions that encourage wage compression (e.g. trade unions, minimum wages, higher social standards) are likely to avoid large increases in income inequality, however potentially on the cost of lower employment opportunities for less-skilled workers. More flexible labor markets, by contrast, facilitate the substitution of less productive workers with more productive ones (thus resulting in a shorter life-span of jobs), which leads to the adoption of new technologies in a bigger number of jobs. In the long run this is shown to be beneficial for employment creation form a theoretical point of view (Cahuc and Zylberberg, 2004).

While policies that are aimed at providing social safety nets and at avoiding income redistribution from low-skilled to high-skilled individuals imply a trade-off between rising inequality and growing unemployment, at least in the shorter run, education and training programs aimed at balancing the supply and demand for high-skilled workers seems to be an important policy reaction to the increased pace of technological innovation. Especially in a developing country context educating individuals and providing them with the necessary skills to operate machines and to make use of new technologies makes it possible to bridge the skill-mismatch that arises by the implementation of skill-biased technologies and increases the potential to realize the positive scale effects of technological innovation. Also guided policy intervention aimed at creating demand for products that use technologies with higher potential for growth and job creation can counteract the negative employment effects of technological change (Pianta, 2000). Finally, employment generating product innovation (potentially complementing process innovation) should be actively encouraged.

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