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TECHNOLOGICAL CHANGE IN DEVELOPING COUNTRIES: TRADE-OFFS BETWEEN ECONOMIC, SOCIAL, AND ENVIRONMENTAL SUSTAINABILITY

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Technological change in developing countries: Trade-offs between economic, social, and environmental sustainability

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Technological change in developing countries:

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Abstract

Over the past years, the manufacturing sector has gone through a period of significant technological change. Technological innovation may bring significant socio-economic benefits and improve the environmental prospects, but it may also pose severe challenges to the economy, human well-being, and the environment. The aim of this paper is to review and discuss the existing literature on the economic/social, social/environmental, and environmental/economic trade-offs stemming from technological change in the manufacturing sector, with a focus on developing countries. The policy designs proposed in the literature to minimise the trade-offs arising from technological innovation and to achieve technology-driven sustained economic growth, social inclusiveness and environmental sustainability are also examined.

JEL Codes: O11, O13, O14, O15, O33, O38

Keywords: technological change; developing countries; manufacturing; trade-offs; growth; social inclusiveness; environmental sustainability.

1. Introduction

In the past years, the manufacturing sector has gone through a period of significant technological change, and this trend is expected to continue in the coming decades (McKinsey Global Institute 2012; UNIDO 2013). Technological advancements have been made at both the product and production process level. A comprehensive description of recent innovations in the manufacturing sector is beyond the scope of this paper, but in the context of our analysis it is worth mentioning some advances in which developing countries have become active players.

A few developing economies have recently engaged in industrial *biotechnology* by starting to use enzymes and micro-organisms in order to produce bio-based products in different manufacturing industries. A report by UNCTAD (2004) shows that biotechnology industry is picking up in several developing countries and regions, although it is important to highlight that it remains moderate compared to developed countries. In India, for example, Biocon has become a major player in the field of modern biotechnology developing new fermentation platforms and enzymes, and it is currently a major supplier of food enzymes to the United States and European markets. Cuba has also fully embraced biotechnology, which at the national level was placed just behind tourism, nickel production and tobacco in terms of export earnings. African countries have also been the centre of origin of some biotechnology technologies. Think about the Biox process in South Africa, or the experimental solvent extraction electro-wining (SXEW) in Zambia (Juma and Konde 2002). In Kenya and Zambia, biotechnology has also spurred the horticultural industry. Moreover, an increasing number of developing countries are producing transgenic crops. James (2013) reports that in 2013 genetically modified crops (mainly soy, maize, cotton, and canola) were grown in 27 countries, of which 19 were developing and 8 were industrial economies. Moreover, in 2013 for the second consecutive year developing countries grew more biotech crops (54%) than developed economies (46%), and Brazil, Argentina and India were among the global top-5 countries planting transgenic crops. In Africa, Burkina Faso and Sudan increased their bacillus thuringiensis (Bt) cotton hectarage by an impressive 50% and 300%, respectively, in 2013.

The *biofuel* industry, which makes use of biofuel technologies, is also flourishing in developing economies. Biofuel technologies can be classified into two groups: first and second generation biofuels. The former utilise the sugar or starch portion of plants (e.g. sugarcane, cassava, etc.) as well as oilseed crops (e.g. sunflower, palm oil, etc.) as feedstock to produce ethanol and biodiesel respectively. The latter, instead, produce fuels from biomass (agricultural and forest residues) or advanced feedstock (e.g. Jatropha). According to the OECD-FAO Agricultural Outlook 2013, biofuel production in developing countries is expected to increase over time. The ethanol production, for example, is projected to rise from 42 billion in 2012 to 72 billion in 2022, with Brazil accounting for the biggest share of such increase followed by China. African countries, India, and other South

American economies such as Argentina are also increasing their ethanol production. In Africa, ethanol production is estimated to grow from 1.6 billion in 2011 to more than 3 billion in 2021, with South Africa, Ethiopia and Nigeria being the main producing countries (OECD-FAO 2011). Moreover, biodiesel production in developing countries is expected to increase from about 10 billion in 2013 to 14 billion in 2022, with Brazil, Indonesia, Thailand and Malaysia already playing an important role (OECD-FAO 2013). In Africa, biodiesel production is concentrated in South Africa, Mozambique, Tanzania and Ghana, and it is projected to increase from less than 0.3 billion in 2011 to about 0.4 billion in 2021 (OECD-FAO 2011).

Developing countries are also slowly but steadily increasing their role in the *renewable energy* industry. Renewable energy sources are inexhaustible energy resources which include solar, wind, and hydropower energies, among others. Chinese solar manufacturing industries are the leaders in the production of solar photovoltaic (PV) systems, producing 67% of the world total (REN21 2014; China New Energy Chamber of Commerce 2014). China is also a leading producer of solar thermal collectors and hydropower turbine-generators (REN21 2014). Manufacturers of solar PV systems are also spreading in Africa, with Ethiopia opening its first manufacturing facility in 2013 (REN21 2014). On the other hand, India is among the most promising countries for wind power development (Panwar et al. 2011), while China dominates the wind turbine supplier market with eight out of the top 15 major vendors being Chinese[1].

Besides this, the developing world has become an increasingly important player in the *computer and electronic product* manufacturing sector. Asian countries, in particular, are now home to some of the world's largest electronic manufacturers. China is one of the largest producers of information and communication technology (ICT) goods, and is also the largest exporter of ICT goods accounting for 37% of world exports (OECD-WTO 2013). According to the International Data Corp (IDC), the Chinese giant maker of telecoms equipment Huawei sold 10.8 million mobile phones around the world in the fourth quarter of 2012, placing the brand amongst the worldwide top three smartphone manufacturers, just behind Samsung and Apple[2]. Other Asian countries such as Thailand, Malaysia, and Philippines have also become major ICT manufacturers (OECD-WTO 2013). In Africa, the South African company Seemahale Telecoms has also started to manufacture home-grown smartphones tailored to African needs[3]. Moreover, Mexico is the world's leading exporter of flat-screen TVs, surpassing South Korea and China. Its largest domestic electronics company, LANIX, makes

[1] See http://www.evwind.es/2014/03/27/top-10-wind-turbines-suppliers/44405

[2] See http://www.marketwatch.com/story/how-chinas-huawei-became-a-mobile-phone-giant-2013-01-30

[3] See http://mg.co.za/article/2013-10-23-smartphones-to-be-made-in-south-africa

desktops, laptops, netbooks, tablets, LCD and LED TV, monitors, and smartphones for a range of brand names[4].

In addition to the increasing role they are playing in advanced manufacturing industries, developing countries continue to dominate some traditional manufacturing sectors such as the *textile and clothing* industry. According to UNCTAD (2005a), the developing world accounts for half of the world textile exports and almost three-quarters of the world clothing exports. Asia is the biggest exporter in the sectors, and in 2004 it accounted for about 45% of world textiles exports and 47% of world clothing exports (UNCTAD 2005a). At the country level, the 2014 WTO statistics show that in 2013 China, India, Turkey, Pakistan, Indonesia, Thailand, Vietnam and Mexico ranked among the top 15 textile exporters, while China, Turkey, Mexico, India, Indonesia, Bangladesh, Thailand, Vietnam, Cambodia, Malaysia, Pakistan and Sri Lanka featured among the top 15 clothing exporters. Various technological changes occurred in both the textile and clothing industries over time. In the textile industry, high-speed spinning frames and looms were developed in the 1950s and early 1960s, and during the 1970s rotor spinning and shuttleless looms were introduced (UNIDO 1993). Microelectronics based technology and automation of industrial processes were introduced in the developed world from the late 1970s onwards, but they are still limited in developing countries. Indeed, countries such as India, Pakistan, Bangladesh, Malaysia, Vietnam, and Indonesia, still heavily rely on huge labour force for textile weaving process (Fibre2fashion.com 2014). Moreover, an increased use of second hand weaving machines in the textile sector has also been observed in developing countries. One of the reasons why the spread of automation is still limited in the developing world is that the machines are costlier than the labour, due to costs associated to maintenance, import fees and norms, as well as to work place structure. In the garment industry, the major technological changes took place in the 1980s with the introduction of computer-aided design (CAD), computer numerical control (CNC) cutting systems, computer-aided manufacturing (CAM), and microelectronic control units (UNIDO 1993). CAD and/or CAM systems have spread in developing countries such as Thailand and Sri Lanka (UNIDO 1993; Wijayasiri and Dissanayake 2008). Other recent technological advances in the clothing industry especially in developed countries include (Madsen et al. 2007): smart fibres (i.e. clothing with integrated electronics as a main feature), fibre surface coatings (i.e. coatings applied to make clothing flame retardant, water resistant, antimicrobial, etc.), radio frequency identification chips (i.e. tags applied to clothing to improve stock accuracy and product availability, and that might become useful as a tool for theft prevention or anti-counterfeiting), and biodegradable clothing (i.e. clothing produced from banana leaves, corn and bamboo), among others. Both the textile and clothing industries also use technological innovations generated in the chemicals industry, such as complex man-made fibres (OECD 2004).

[4] See http://geo-mexico.com/?p=7949

Developing countries are also playing an increasingly important role in the *steel industry*. Indeed, steel production in developing countries, and in particular in Asian economies, has experienced a significant rise in the early 2000s; and in 2005 Asia produced over 50% of the world's total crude steel (Sato 2009). China and India are key players in the sector: China increased its share of global crude steel production from roughly 23% in 2003 to 49% in 2013; India has also experienced a huge increase in steel production, becoming the fourth largest crude steel producer, just behind China, Japan and the US (World Steel Association 2014). The production technology in the steel industry is rather outdated but a few technological innovations such as Carbon Capture and Storage (CCS) technologies (environmental friendly technologies) are starting to replace old technologies also in developing economies such as China and India.

All the above-mentioned technological changes in the manufacturing sector are a double-edged sword since they can bring enormous benefits but at the same time pose serious challenges to developing countries. The aim of this paper is to analyse the trade-offs originating from innovation in the manufacturing sector in developing countries, looking at the economic, social and environmental dimensions. In particular, the economic / social, social / environmental, and environmental / economic trade-offs will be examined according to the following scheme:

Economic vs. Social Trade-offs

Positive effects of technological change in the ***economic*** domain vs. ***Negative*** effects in the ***social*** domain
Negative effects of technological change in the ***economic*** domain vs. ***Positive*** effects in the ***social*** domain

Social vs. Environmental Trade-offs

Positive effects of technological change in the ***social*** domain vs. ***Negative*** effects in the ***environmental*** domain
Negative effects of technological change in the ***social*** domain vs. ***Positive*** effects in the ***environmental*** domain

Environmental vs. Economic Trade-offs

Positive effects of technological change in the ***environmental*** domain vs. ***Negative*** effects in the ***economic*** domain
Negative effects of technological change in the ***environmental*** domain vs. ***Positive*** effects in the ***economic*** domain

Understanding the trade-offs across the economic, social and environmental dimensions is vital for developing adequate policies to achieve sustainable development, the objective of which is to reconcile economic efficiency, social progress and the preservation of the ecosystem.

The analysis is conducted relying on an extensive number of examples gathered through a survey of the literature. Source papers include professional journal articles, refereed research studies, empirical reports, institutional reports, policy briefs, and country case studies where available. A number of decision rules in choosing articles are used. First, given the focus on the developing world, we include mostly papers dealing with developing countries specifically. Where information is scarce or not available at all with respect to those countries, evidence is drawn from the experience of emerging economies or developed countries. Second, since technological change in the manufacturing sector is changing fast in today's environment, we use mostly sources published over the last decade, except where articles are needed specifically for their historical relevance and perspective on broad issues relating to trade-offs stemming from innovation in the manufacturing sector. Third, given that innovation is a very broad domain, we decide to narrow down the focus of the analysis to a selected sample of relatively recent technological advances in which developing countries are becoming increasingly active players (i.e. biotechnology, renewable energy, biofuel, computer and electronic product innovation, and technological advances in the textile and clothing industry as well as in the steel industry).

The paper is structured as follows. Section 2 describes the economic/social, social/environmental, and environmental/economic trade-offs stemming from technical change in the manufacturing sector in developing countries. Section 3 discusses some of the policy designs proposed to minimise the trade-offs and achieve technology-driven sustained economic growth, social inclusiveness and environmental sustainability. Section 4 concludes.

2. Trade-off analysis

Innovation in the manufacturing sector in developing countries is a double-edged sword. On one hand, it may bring new socio-economic benefits and opportunities and improve the environmental prospects. On the other hand, it may pose serious challenges to the economy, and cause significant harm to human well-being and the environment. These trade-offs are discussed below focusing on the economic, social and environmental impacts of a number of recent innovations in the manufacturing sector in developing economies.

2.1 Economic/social trade-off of technological change

2.1.1 Economic pros vs. Social cons

A key trade-off generated by innovation in the manufacturing sector is the one between enhanced productivity on the economic side and increased unemployment on the social side. In what follows, this trade-off is analysed looking at the theoretical and empirical literature, as well as at specific developing country examples.

The manufacturing industry is the engine of economic growth. According to the first Kaldor's law, indeed, the growth of GDP is positively related to the growth of manufacturing output (Kaldor 1966, 1967; Thirlwall 1983). Even though we are living in an era where more and more the services sector seems to be the main driver of growth, for the developing world the Kaldor's law seems to hold. Wells and Thirlwall (2003), indeed, found evidence supporting the Kaldor's law(s) across African countries. Moreover, a study by Zalk (2014) focuses on the role of manufacturing in boosting South Africa's economic growth, and suggests that manufacturing plays an *irreplaceable* role in driving growth and economic development. Therefore, a dynamic manufacturing sector is essential for promoting economic growth in developing countries. Technological innovation plays a crucial role in enhancing the productivity of the manufacturing industry. The literature has shown that technological advances, both in products and processes, can lead to superior firm economic performance (Loof and Heshmati 2002; Loof et al. 2003; Janz et al. 2004). Furthermore, the correlation between product innovation and productivity is often higher for larger firms, with the effect of product innovation being stronger in the manufacturing sector (OECD 2009).

The importance of technological innovation in boosting productivity and output is confirmed by a number of empirical studies focusing on specific types of innovation. Chien and Hu (2007, 2008) used structural equation modelling to study the effects of the use of renewable energy on GDP. Their results suggest that there is a positive relationship between the two and the relationship comes through increasing capital formation. The authors also analysed the possible effects of the use of renewable energies on technical efficiency. Their findings show that increasing the use of renewable energies actually improves the overall economy's technical efficiency, while increasing the input of traditional energy sources decreases technical efficiency. Abanda et al. (2012), instead, investigated the relationship between renewable energy production and economic growth looking at the African continent. Their findings suggest a positive correlation between renewable energy production and GDP except in the Southern Africa Block in which the correlation is negative. Biotechnology is also found to have direct impacts on productivity. James (2013) suggests that from 1996 to 2012, biotech crops contributed to increased crop production valued at US$116.9 billion. Moreover, a study commissioned by the European Parliament (2013) analysing the impacts of biotechnology on developing countries found that biotech crops generally improve yields. For example, India witnessed a 54.8% yield increase since the introduction in 2002 of biotech (Bt) cotton. Argentina also registered a 28.6% increase since Bt cotton introduction in 1998, while the Philippines and South Africa saw an increase of 24.1 and 24.3% respectively since its introduction in 1998 and 2000 respectfully. South Africa also introduced biotech corn in 2000 and gained a 15.3% increase in yields. According to OECD (2004), huge productivity gains were also achieved through innovation in the textile industry.

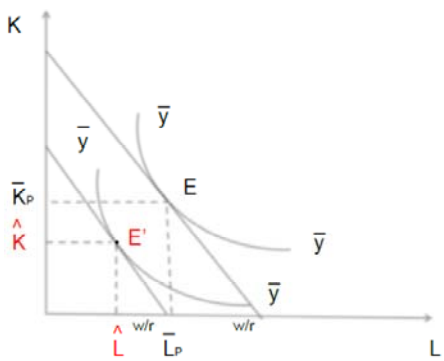
On the social side, technological innovation has a direct and indirect impact on employment and skills. In particular, technological change allows producing the same amount of goods with a lower quantity of inputs (namely labour and capital). So, one by-product of technological innovation is intrinsically technological unemployment. In the last century, Keynes (1963) warned of a potential new disease, that he called technological unemployment. According to Keynes, if the discovery of means of economising the use of labour outpaces the speed at which we can find new uses for labour, then we will end up with a gap that will result in temporary or permanent unemployment.

Box 1 shows that employment in absolute terms always decreases as a direct consequence of technological innovation (mainly due to process innovation).

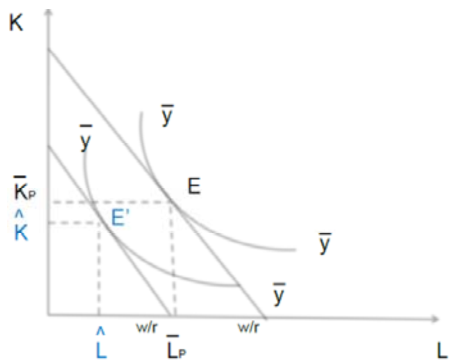
Box 1. The impact of technological change on employment

If we start at a given equilibrium E, where a given amount of output $\bar{y}$ is produced by the full potential levels of capital and labour ($\bar{K}_p$, $\bar{L}_p$), and then allow technological change to shift the isoquant towards the origin (keeping the same level of wages *w* and interest rates *r*), then the new equilibrium will shift to E', which will require the new levels of inputs $\hat{K}$ and $\hat{L}$. From the figures below, it is clear that $\hat{L}$ will always be lower than $\bar{L}_p$, regardless of the innovation being neutral, labour saving or capital saving.

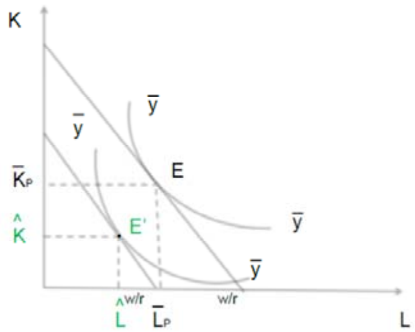
A. Neutral Technological Change



B. Labour-saving Technological Change



C. Capital-saving Technological Change



Source: Vivarelli (2012).

However, as Vivarelli (2012) points out, there are 6 different market compensation mechanisms, activated by technical change, which are able to counterbalance labour saving impacts that ensued from process innovations (the so-called 'compensation theory' put forward by Marx (1961; 1969)):

1) Compensation mechanisms through additional employment in the capital goods sector:
   The same process innovation that made workers redundant in one sector/industry will create new jobs in the capital sectors where the new machines are produced.

2) Compensation mechanism through decrease in price:
   Process innovations lead to the displacement of workers, but can lead also to a decrease in unit costs of production, which in turn can translate into lower prices, stimulating new demand for products, thus leading to additional production and consequently more employment.

3) Compensation mechanism through new investments:
   As mentioned previously, a reduction in production costs can lead to a price decrease. However, this effect is not necessarily automatic, it may well take some time, and during that time gap innovative entrepreneurs will accumulate extra profits. If entrepreneurs decide to invest these profits, then this could lead to new production and new jobs.

4) Compensation mechanism through decreases in wages:
   One direct effect of labour-saving technologies can be a decrease in wages. This decrease in wages consequently could lead to additional demand for labour.

5) Compensation mechanism through increases in incomes:
   This mechanism suggests that a portion of the costs savings result of technological innovation can be translated into higher incomes and therefore higher consumption. Therefore, the increase in demand through consumption will lead to increased employment, compensating for the initial losses as a consequence of process innovations.

6) Compensation mechanism through new products:
   As mentioned before technological innovation not necessarily comes in the form of new processes, it can also come in the form of a new product. If this is the case, then the new product would lead to new economic branches and additional jobs.

It is this latest compensation mechanism that finds most support amongst economists (Freeman et al. 1982; Vivarelli and Pianta 2000; Edquist et al. 2001). Product innovations, therefore, can have a positive impact on employment, given that new products allow for the development of new goods or the main differentiation of mature goods.

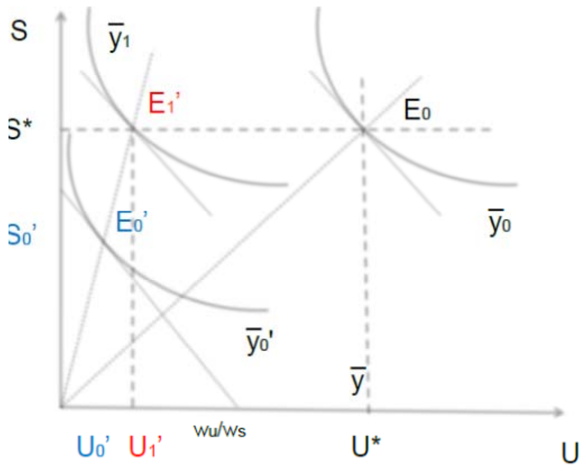
Nevertheless, the debate on the employment effects of process and product innovation is far from settled. Indeed, the two types of innovations tend to be, in most cases, rather complementary. Therefore, the final effect on employment is still an open empirical question. The relationship between employment and innovation is determined by the interactions of all the previous forces: the labour-saving effect from process innovation, the compensation mechanisms, the various drawbacks that can prevent or weaken the compensation mechanisms, and the positive effects derived from product innovation. All these forces and their interactions can lead to very diverse outcomes. Thus, so far, economic theory is unable to provide certainty on the final outcome on employment from technological innovation.

Furthermore, technological innovation not only affects jobs from a numeric point of view. It also has effects from a qualitative perspective, having a direct impact on worker's skills. The replacement of tasks traditionally done by unskilled workers with new jobs requiring more qualified labour due to technological innovation is known as the skill-biased technological change hypothesis.

Box 2. Skill-biased technological change

From a theoretical angle, skilled biased technological change is closely related to labour saving process innovations. If a skilled biased technological change takes place, the equilibrium will go from point E_0 to E_0' . Afterwards, assuming that the counterbalancing compensation effects discussed previously in the main text are able to transmit their full effects on the economy, thus limiting job losses, the economy could only rise to the new equilibrium E_1'. In the best scenario, market compensation forces can guarantee full employment of the skilled workers (S), while unskilled workers (U) will still suffer from a sharp decrease in their employment (going from U* to U_1').

Technological Change, Skilled, and Unskilled Workers



Source: Vivarelli (2012).

The notion was first proposed by Griliches (1969) and later by Welch (1970), with the main idea being that new technologies, in order to be implemented effectively, need suitable and qualified workers. Insufficient numbers of qualified workers will translate into a constraint, which will limit the diffusion and adoption of the new technology, and contribute to unemployment. Vivarelli (2012) provides a clear example of the interaction between innovation, skilled and unskilled labour. Box 2 (above) shows how technological change is related to the demand of skilled and unskilled workers, and highlights that if the economy faces a labour saving skilled biased process shock, the subsequent scarcity of skilled labour will inevitably end up with an increase of unemployment amongst unskilled workers.

But what is the empirical evidence on the impact of technological change on employment in particular for developing countries? Behar (2013) analyses the skill bias of technical change in developing economies. His findings suggest that developing countries are experiencing technical change that is mainly skill-biased, a direct consequence of skill-biased technologies becoming relatively cheaper. Furthermore, it is found that increased skill supply further biases technical change in favour of skilled labour. On the other hand, free trade induces technology that favours skilled workers mainly in skill-abundant developing countries and also favours unskilled workers in skill-scarce developing countries, amplifying the predicted wage effects of trade liberalisation. The study by Behar (2013) suggests that the above is mainly the case for the Middle East and North Africa region, given its recent increase in trade openness and an astonishing rise in educational levels. Therefore, skill-biased technical change is an important contributor to the higher inequality observed in developing countries. Behar (2013) also reckons that the pervasive increasing wage inequality within developing countries can be re-conducted to the fact that technologies available to developing economies increasingly favour skilled workers even if these countries are skill-scarce. Finally, the study highlights that access to foreign technology, and increases in human capital and trade openness are certainly important determinants of productivity and economic growth. However, they may not necessarily be inclusive, especially in middle-income countries.

Ugur and Mitra (2014) conduct a systematic literature review on the potential effects of technological change on employment in low-income countries. By conducting meta-analysis on 53 studies, they find that technological innovation impacts on employment are more susceptible to be positive when the evidence is related to skilled-labour employment, employment in the manufacturing sector, and employment in South Asian countries. Furthermore, technological innovation impacts on employment are prone to be negative when the effect is measured at sector rather than firm/farm level, and the skill category is unskilled labour.

Lundin and Sjöholm (2007) analyse how technology can contribute to job creation in the Chinese manufacturing sector. Their findings suggest that technology innovations can be expected to have both positive and negative effects on employment. On one hand, new technology might increase competitiveness and enable Chinese firms to expand their labour force. On the other hand, however, new technology might be labour-saving, thus enabling Chinese firms to produce more output with fewer employees. So, based on a large sample of manufacturing firms in China between 1998 and 2004, their study shows that technological innovation had no tangible effect on job creation.

Diop et al. (2013) note that in the case of bio-energy production, especially if we focus on small-scale production, technological innovation seems to generate more employment for the poor. This is not necessarily the case for large-scale production, which is certainly more capital intensive and labour saving. The authors also note that although small-scale production might be better at creating jobs, its ability to compete with large-scale bio-energy producers is limited and consequently any increase in employment might be just temporary. However, if the bio-energy production is used to enhance access to energy in small villages with poor and deficient infrastructure, then direct competition with large-scale firms is not necessarily a key issue and employment might become more stable and sustainable in the long-run.

In addition to the trade-off between increased productivity and unemployment, technological change in the manufacturing sector may also lead to other important economic/social trade-offs. The technological features of the textile and clothing industry (i.e. relatively simple machines at low investment costs), for example, play a major role in the economic development and poverty alleviation process of developing countries. Indeed, the textile and clothing sector is a catalyst for industrialisation in poor economies since it provides a base upon which to build capital for more technologically demanding activities in other sectors (Nordas 2004, Brenton and Hoppe 2007). The textile and clothing sector has been at the hearth of the economic success of many East Asian countries as well as of Mauritius and Vietnam, among others. The role of the textile and clothing industry in poverty reduction is recognised in the case of India (Madsen et al. 2007). On the social side, however, technological change in textile and clothing industries may pose a number of challenges in developing countries. First, the introduction of machines, CAD systems, and automation systems in the sectors not only may result in loss of employment due to decreased need of manual labour, but it may also enhance discrimination of women, that indeed compared to men are already found to occupy lower job categories (women typically sew, finish and pack clothes, while men have roles as machine operators and technicians), and earn less (Gardetti and Torres 2013). Second, the introduction of automation in production processes may worsen working conditions in textile and garments industries. Challa (2010) reported cases of extremely poor working conditions due to health and safety issues in working place, which add to forced overtime work, sexual harassment of female workers, and violation of rights to join trade unions. Health and safety issues may include workplace accidents, high noise levels from continuous operation of machinery (especially in wool production), and respiratory diseases from exposure to fibre dust (in particular in cotton, silk and wool production which involve high speed spinning) (Madsen et al. 2007). Repetitive strain injury is also increasingly recognised as a phenomenon associated with the over-engineered labour in clothing industries (Byrne 2000). Moreover, Choudhury (2014) offers a detailed description of health problems that may arise from the use of several new substances in the production process of the textile industry. Just to provide a few examples, heavy metals such as cadmium and lead may cause cancer, while chromium and nickel are skin irritant. On the other hand, volatile organic compounds may cause eye, nose, and throat irritation, headache, damage to the liver, to the central nervous system, etc. Conventional solvents such as tetrachloroethylene, which is widely used for dry-cleaning of fabrics and for metal-degreasing operations, may even be responsible of adverse reproductive effects such as spontaneous abortions. Other substances such as phenol derivatives used in cleaning and dyeing processes may be endocrine disruptors. A number of case studies have identified significant health and safety issues in the textile and clothing industry in India, China, as well as in Africa (Madsen et al. 2007).

Moving to the computer and electronic products industry, the manufacturing of electronics goods has been a major contributor to the rapid economic growth of many Asian developing countries. In the Philippines, for example, export earnings from the electronics industry were one of the main drivers of the accelerated GDP growth in the 2000s, which reached an average of 4.9% over the period 2000-10 (Mitra 2013). In a similar way, in Thailand, over the last four decades, the electronics industry played a crucial role in the growth of manufactured exports which in turn contributed significantly to the rapid economic growth of the country. In 2002, for example, computers, computer parts and integrated circuits were the top two major export items, accounting for 11% and 5% of total export value respectively (UNCTAD 2005b). Besides being an engine of economic growth, innovations in the computer and electronic products industry enable the development of new tools and functions that enhance the economic performance of other industries. For example, the electronics industry has made possible the creation of numerical machine tools, textile looms, and computer-aided design systems which have revolutionised the performance of the textile and clothing industry. Moreover, technological change in the computer and electronic products industry allows the development of information and communication technology (ICT) which in the literature have been recognised as a catalyst for economic growth and firm productivity in developing countries. Just to provide some examples, Waverman et al. (2005) argued that mobile phones have a positive and significant impact on growth in developing countries, which is twice as large as their impacts in developed economies. A similar result is found by Dimelis and Papaioannou (2010) who highlighted that the impact of ICT is stronger in developing than in developed countries. An empirical paper by Andrianaivo and Kpodar (2011) also found that ICT contribute significantly to economic growth in African countries. In a similar way, Lee et al. (2009) studied the effects of mobile phones on economic growth in sub-Saharan Africa, and found that mobile phone expansion is an important determinant of the rate of economic growth in the region. Focusing on India, Kathuria et al. (2009) found that higher mobile penetration rates lead to faster growth, and the growth impact is larger beyond a penetration rate of 25%. Moving to micro-level studies, Commander et al. (2011) found that there exists a positive relationship between ICT capital and the productivity of firms in Brazil and India. Qualitative research by Samuel et al. (2005) suggested that in South Africa and Egypt, mobile phones were associated with increased profits, significant time savings and improved communication with suppliers for small-scale firms. A positive impact of ICT on firm outcomes was also found in different Latin American countries. Indeed, the empirical evidence gathered in the book by Balboni et al. (2011) pointed to a positive impact of ICT on firm profitability in Peru, as well as on labour productivity in firms in Colombia, Argentina, and Uruguay. Notwithstanding its economic benefits, the computer and electronic products industry poses a number of social challenges. As discussed by Qasim (2011), working conditions in computer industries in developing countries are often extremely poor. There is, indeed, empirical evidence of inappropriate safety equipment in hard drive manufacturing plants in Thailand with consequent exposure of workers to harmful chemicals involved in production processes which may have serious health implications such as cancer and birth defects (Schipper and Haan 2007, Williams 2003). Health concerns also arise in Chinese plants because of the use of large quantities of formaldehyde and metals such as copper, silver, tin, lead and chromium used in the production of printed circuit boards (Williams 2003). These issues add to other social concerns arising from violations of working hours as well as from limited freedom of workers to organise unions and to collectively bargain. In Malaysia, Thailand, and China, for example, the practice of working beyond the legal limit in computer industries has led to an increasing trend of stress-related illnesses (Qasim 2011).

2.1.2 Economic cons vs. Social pros

In the literature, technological innovation is also found to exert negative economic impacts against positive social impacts. For example, looking at biotechnology innovations, there is evidence that the introduction of these technologies in developing countries may lead to a contraction of their exports (DEVE 2013). This may happen if trade partners decide to impose import bans or restrictions on biotech crops because of consumer preferences. This was the case of the EU which in 2003 introduced strict labelling regulations on biotech imports, thus negatively affecting the exports of those developing countries that did not have an adequate institutional capacity and financial ability to set up the required regulatory standards. Notwithstanding these negative economic externalities, biotechnology innovation may be an important source of new jobs. A study by Abuduxike (2014), indeed, reports that in Malaysia over the period 2005-2020, the biotechnology industry is expected to generate 280,000 jobs. Biotechnology is also recognised as a source of employment opportunities at different levels of expertise in South Africa (Cloete et al. 2006).

Moving to renewable energy industry, anecdotal evidence shows that many governments in developing countries are encouraging investments in the production of renewable energy via special tax exemptions, duty exemptions, subsidies, etc. A report by KPMG (2013) provides a description of these forms of support for a number of countries around the world, including developing and emerging countries such as Argentina, Brazil, China, India, Mexico, Peru, South Africa, Turkey, and Uruguay. These financial incentives, although useful to encourage the development of the industry, may have important opportunity costs in the form of forgone government revenues, which in developing countries are key to respond to social and infrastructure needs[5]. This negative economic effect contrasts with the social benefits that may arise from the renewable energy innovations in terms of employment creation. UNEP et al. (2008) and Wei et al. (2010) show that the solar photovoltaic (PV) technology has the potential to generate a significant number of jobs. Indeed, it is expected that the amount of jobs in the PV sector will rise from 170,000 in 2006 to 6.3 million in 2030 (UNEP et al. 2008). The overall employment in wind and solar sectors, instead, is projected to grow from 1.2 million in 2011 to two million in 2020 (UNEP Collaborating Centre et al. 2012). By looking at a country-specific experience, a recent study by Omri et al. (2015) shows that the PROSOL (Programme Solaire) project in Tunisia has created about 3,000 jobs, which can generate income and improve living conditions of local people.

The textile and clothing industry offers another good example of trade-offs between negative economic impacts and positive social impacts. On the economic side, technological change has allowed several developing countries to experience high output growth rate in the textile and garment industry and as a consequence to rely heavily on exports from the sector as shown by their high export concentration ratios. In Bangladesh and Cambodia, for example, clothing and textiles account for more than 80% of total exports (Gardetti and Torres 2013). In some economies, high export concentration ratios are also flanked by a relatively limited export market. In the case of Cambodia, for instance, the textile and clothing industry has just five main destination markets: the United States, the European Union, Singapore, Thailand, and Malaysia. As a consequence of the high dependence on textile and clothing exports, developing economies are highly vulnerable to external shocks. An example of this vulnerability is offered by what happened in Cambodia during the 2008-09 global economic slowdown: garment exports fell by almost 20%, and economic growth slowed to 6.7% in 2008 and contracted by 1.9% in 2009 (UNDP 2011). Notwithstanding these negative economic impacts, the textile and clothing industry provides important social benefits in terms of employment, women empowerment, and poverty reduction. The textile and garment industry in developing countries, indeed, is intensive and therefore, it is a key source of jobs (especially for unskilled labour). Textile and garments sectors account for a very high share of total manufacturing jobs in Cambodia (80.1%), Mauritius (72.8%), Sri Lanka (49.2%), Madagascar (45%), Pakistan (42.9%), Bangladesh (35%), Turkey (34.3%), Morocco (27.3%), Guatemala (27.1%), Romania (25.3%), India (21.9%) and China (18.9%) (McNamara 2008; Keane and te Velde 2008). Significant indirect jobs are also

[5] Note that the same issue applies to the biofuel industry in countries such as Tanzania and Brazil (Diope et al. 2013).

generated by textile and clothing sectors in related industries: in India, for example, it is estimated that every direct textile industry job means another 1.2 jobs in industries such as machinery, design or transport (Gugnami and Mishra 2012). Job creation in the textile and clothing industry is particularly strong for women. In Bangladesh and Cambodia, for example, 90% of garment workers are young female (Keane and te Velde 2008; Mlachila and Yang 2004). This contributes significantly to women empowerment. Zohir (2001) argues that employment in the garment industry in Bangladesh empowered women, increased their mobility, and expanded their individual choice. Kabeer (2002), and Hewett and Amin (2000), also found that in Bangladesh working in the textile industry leads to higher female status and better quality of life measures. Sivasankaran (2014) reached similar results in the context of India, and showed that women working in the textile sector reached higher degrees of empowerment and autonomy, which translated into delaying the age of marriage and lower desired fertility. Textile and garment industries provide also an important opportunity to women and other workers in the sectors to receive a formal wage, which is higher than that paid to agricultural workers and also higher than that paid in several other manufacturing industries such as dairy, wood processing, and leather, among others. This is found to be the case in countries such as Cambodia, Madagascar, Pakistan, India, El Salvador, Guatemala, Dominican Republic, China, and Mexico (Keane and te Velde 2008). In addition to the above, there is also empirical evidence that textile and clothing industries have the potential to lift individuals out of poverty. Studies of the textile industry in Madagascar by Nicita and Razzaz (2004) and Nicita (2008), for example, showed that moving from inconsistent, subsistence, or marginal employment to a job in the textile and garment sector could increase an individual's purchasing power by 24% on average, which is considered to be a change sufficient to lift people out of poverty.

2.2 Social/environmental trade-off of technological change

2.2.1 Social pros vs. Environmental cons

There is evidence that technological innovations may bring social benefits, while producing negative effects on the environment. For example, the spread of biotechnology in developing economies may lead to significant social improvements. Indeed, biotech crops have the potential to alleviate poverty of small farmers by increasing their incomes. In countries such as the Philippines, India, and South Africa, for example, it has been found that Bt cotton has led to important increases in yields and as a consequence to higher farm-level incomes (Popp et al. 2012). Moreover, the reduced use of pesticides deriving from the use of biotech crops may have positive health effects by reducing the exposure of small-farmers to poisoning because of faulty equipment (DEVE 2013). Nevertheless, the adoption of genetically modified crops may also have a number of adverse consequences on the environment. First, the presence of living modified organisms may pose serious challenges to biodiversity (DEVE 2013). Second, transgenic crops may negatively affect the soil and soil organisms

(DEVE 2013). Third, the development of an increasing resistance to pesticides and herbicides targeted to biotech crops may lead to an even higher use of pesticides. For example, Wang et al (2009) argue that in China the use of Bt cotton and the associated lower level of insecticide spraying has led to secondary insect infestations and therefore to an increased use of pesticides for combating these insects.

In a similar way, the development of renewable energy industries may lead to some social benefits at the expense of a certain degree of environmental deterioration. On one hand, renewable energy technologies can alleviate poverty in developing countries by providing to poor people access to affordable energy which is needed for basic domestic uses such as cooking, heating, and lighting (Odeku 2013). In Nepal, for example, renewable energy technologies have become the most promising and widely adopted technologies to provide electricity to remote rural areas where people cannot access energy because of their low income levels as well as distance from the national electricity grid (Gurung et al. 2011). Hydroelectric plants and wind turbines have also been used to power poor people in the isolated mountainous regions in Cuba (Cherni and Hill 2009). In addition to the above, renewable energy technologies may promote education in rural areas by making possible to power schools and by reducing the time children spend out of school collecting firewood (Cabraal et al. 2005). The renewable energy industry may also improve public health by reducing respiratory diseases deriving from inhalation of wood smoke, as well as by providing energy to refrigerate medicines (Odeku 2013). On the other hand, innovations in the field of renewable energy may be dangerous for the environment. Leung and Yang (2012), for example, report that wind turbines can cause substantial mortality of birds through collision. Moreover, offshore wind turbines also represent a threat for sea creatures in coastal areas. Thomsen et al. (2006) highlight that noise produced during the construction and operation of wind turbines can affect the behaviour of mammals and fishes such as dabs and salmons that can perceive pile-driving pulses at a considerable distance. There is also evidence that wind turbines may cause changes in local climates. For example, a study by Chen (2010) finds that in Mongolia since 2005 there has been an unprecedented drought which developed much faster in turbine areas. Moreover, it has been reckoned that the turbulence in the wake of wind turbines may cause changes in local climates by mixing the air up and down and changing the direction of the high-speed wind at the surface thus enhancing local moisture evaporation (Leung and Yang 2012).

Moving to the biofuel industry, the existing literature points out that biofuel production can lead to the creation of rural employment, even though the magnitude of this effect depends on the type of feedstock grown as well as on the degree of agricultural mechanisation (Diop et al. 2013). Indeed, new employment is created by biofuel production if the biofuel feedstock is grown in a previously unused land or is more labour-intensive than the crops previously planted. Moreover, the employment benefits are higher in the case of low degree of mechanisation of biofuel crops. Therefore, the production of sugarcane in Brazil which is highly mechanised creates much less jobs than the production of oil palm which can never be fully mechanised or the production of cassava which may be mechanised just to a limited extent. It is also worth highlighting that beside to direct employment, biofuel industries can generate significant indirect jobs within the economy (e.g. in commercial activities). In Mali, for example, the Markala Sugar Project is expected to create 20,000 indirect jobs in addition to the 5,000 direct jobs (Gerlach and Liu 2010). The replacement of fossil fuels with biofuels may also lead to important public health benefits by improving the quality of air. Indeed, biodiesel and ethanol significantly reduce greenhouse gas (GHG) emissions, sulphur emissions, as well as emissions of carbon monoxide (CO_2) (USAID 2009; EPA 2002). Notwithstanding these new employment opportunities and health advantages, biofuels may lead to a series of adverse environmental impacts as reported by Timilsina and Shrestha (2010). The conversion of natural landscapes into biofuel plantations, indeed, may have negative effects on biodiversity. The risk of the loss of biodiversity is faced by countries such as Indonesia and Malaysia where oil palm plantations have replaced natural forests (Koh and Wilcove 2008), or Brazil where an increasing part of the Mata Atlantica region (a biodiversity hotspot) and the Cerrado (the world's most biodiverse savannah) are being converted into sugarcane and soybean plantations (Timilsina and Shrestha 2010). Biodiversity is also threatened in African wetlands in countries such as Nigeria, Ivory Coast, Democratic Republic of Congo, Uganda, Kenya and Tanzania (Diop et al. 2013). The production of biofuels has also led to several deforestations. For example, Diop et al. (2013) report that over the last few years, in Indonesia and Malaysia the production of biodiesel from oil palm has been responsible for up to 2.8% and 6.5% of direct deforestation respectively, while in Brazil biodiesel production from soybean has been responsible for up to 5.9% of the direct annual deforestation. Dry secondary forests in sub-Saharan Africa have also been affected by the production of Jatropha. This process of deforestation may lead to the loss of soil carbon and reduce the positive impact of biofuels on GHG reduction described in sub-section 2.3.2. Biofuels production is also likely to have adverse impacts on water resources. In fact, groundwater and surface water may be polluted by the application of fertilisers, and water supply may be strained by the production of feedstocks such as maize, oil palm and sugarcane that have relatively high water requirements. In Kenya, for example, there is evidence that the production of biofuels pollutes the Tana River Delta[6].

Finally, innovation in the computer and electronic product manufacturing sector may lead to significant social benefits, at an environmental cost. Advances in the mobile-phone technologies, for example, have contributed to enhance financial inclusion in the developing world, which is a determining factor in alleviating poverty and promoting social cohesion (Thouraya and Faye 2013). Indeed, the spread of mobile-phones has made possible successful initiatives such as M-PESA in Kenya or Mzansi and WIZZIT in South Africa. Moreover, a 2014 study by UNESCO conducted on

[6] See http://glopolis.org/en/articles/impacts-biofuel-production-developing-countries/

seven developing countries (Ethiopia, Ghana, India, Nigeria, Pakistan, Uganda and Zimbabwe) shows that mobile technology can improve literacy in developing countries[7]. Mobile-phone technologies have also contributed to improve health in several developing countries. Looking at Africa, Aker and Mbiti (2010) report that mobile-phone were used for monitoring measles outbreaks in Zambia; to support diagnosis and treatment by health workers in Mozambique; to send health education messages in Benin, Malawi, and Uganda; to send reminders to HIV-positive patients about their therapy in Kenya, Malawi, and South Africa; and to create a hotline for mothers looking for information about the health status of their children in the Democratic Republic of Congo. However, the computer and electronic product industry may pose a number of environmental challenges ranging from energy consumption, to the use of hazardous materials in the production processes, and electronic waste (e-waste), among others. E-waste is a significant environmental threat at the global level. Focusing on the developing world, domestic e-waste generation has increased significantly in China and Latin America, and in Africa at least half of Africa's electronic waste comes from within the continent (Lundgren 2012)[8]. This trend is expected to continue to increase and presents severe environmental challenges. Indeed, e-waste contains high amounts of hazardous substances ranging from mercury to chromium, lead and several others. Leakages and evaporation of these substances at the e-waste dumping sites may result in the contamination of soil, crops, water, livestock and fish. Empirical evidence shows that in Nigeria lead, mercury, cadmium, arsenic, selenium, chromium and cobalt contents, among others, have been found in soil samples (Olowu 2012). Moreover, in China, there is evidence that e-waste has already led to contaminated soil and surface water (Lundgren 2012).

2.2.2 Social cons vs. Environmental pros

Although the above analysis has shown that biotechnology may bring social benefits and negatively affect the environment, the opposite is also possible. Biotechnology innovation, indeed, can increase the vulnerability of poorest smallholder farmers who are encouraged to move from growing a wide variety of crops to monocultures of biotech crops thus increasing the risk of worsen their already precarious socio-economic situation in the case of a failed harvest. This was the case in South Africa, where the introduction of Bt cotton has contributed to increase the vulnerability of poor farmers as well as socio-economic inequality (Witt et al. 2006). Nevertheless, biotechnology may contribute to a better environment since it allows reducing the amount of pesticides used. There is evidence, for example, that in Argentina, China, and India, among other countries, the introduction of Bt cotton has led to decreases of up to 75% in the amount of insecticides (Carpenter 2011). Moreover,

[7] See http://www.unesco.org/new/en/education/resources/online-materials/single-view/news/unesco_study_shows_effectiveness_of_mobile_phones_in_promoting_reading_and_literacy_in_developing_countries/#.VM48Oy7LIrg

[8] See also http://ifixit.org/ewaste

James (2013) reports that in the period 1996-2012, biotech crops have allowed to save 497 million kg a.i. of pesticides.

A trade-off between positive environmental impacts and negative social impacts may also be observed in the context of the renewable energy industry. At the social level, indeed, the latter poses a number of challenges in terms of public health. The noise caused by operating wind turbines, for example, may cause headaches, sleep disturbances, hearing loss, and even hurt the vestibular system of people (Pedersen 2011; Punch et al. 2010). Moreover, people's lives may be annoyed by the visual impact of onshore wind turbines (Leung and Yang 2012). On the other hand, at the environmental level renewable energy industries allow to reduce the climate change issue by decreasing greenhouse gases (GHG) emissions (Panwar et al. 2011). There is a rather extensive literature focusing on the ability of renewable energy to reduce GHG emissions, with a number of papers concentrating specifically on developing countries. For example, Bilen et al. (2008), among others, discuss the necessity of using renewable energy in Turkey to reduce GHG emissions and therefore limit the extent of climate change. Sapkota et al. (2014) look at the case of Nepal and by using a Long-range Energy Alternative Planning (LEAP) model show that the implementation of micro-hydro for the next 20 years will reduce CO_2 emissions by 2.553 million tons (Mt). Solar power, biogas and improved cooking stoves are also found to have the potential to significantly reduce CO_2 emissions. Yadoo and Cruickshank (2012) find that renewable energy mini-grids can help mitigate climate change in Nepal, Peru, and Kenya. An extensive review conducted by Amponsah et al. (2014), instead, found that offshore wind technologies are sources of the lowest GHG emissions.

In a similar way, a number of negative social externalities as well as positive environmental externalities are associated to biofuel industries. On the negative side, it is widely recognised in the literature that biofuel production leads to the displacement of local poor people (Diop et al. 2013). In fact, the conversion of lands to plantations for biofuels production often causes the displacement of local smallholders who therefore become low-paid seasonal workers and encounter increasing difficulties in terms of food provision and security. Anecdotal evidence shows that in the Gambella region in Ethiopia, thousands of people were displaced due to the creation of biofuel plantations[9]. A similar phenomenon has also been observed in Indonesia, Guatemala, South Sudan and Honduras[10]. A study by FAO (2008) also highlights that women are among the most affected by displacement, thus suggesting that biofuel industry may also lead to gender issues. The bio-fuel industry is also a source of social inequality. Diop et al. (2013), indeed, find that in Africa skilled workers in the industry get good salaries, while the majority of unskilled workers are poorly paid. In Ghana, for example, people working for the Solar Harvest SA earn between 30 USD and 50 USD per month, which is below the country's official minimum and well below the World Bank's poverty line of 2 USD per day. On the

[9] See http://glopolis.org/en/articles/impacts-biofuel-production-developing-countries/

[10] Ibid.

positive side, biofuel production may have a few positive environmental impacts (Timilsina and Shrestha 2010). For example, it can positively affect the ecosystem when degraded lands are restored for growing biofuel feedstock. Furthermore, growing perennials such as oil palm and sugarcane rather than annuals crops may increase soil cover and organic carbon levels.

Technological advances in the computer and electronic products industry may also generate a trade-off between negative social impacts and positive environmental impacts. On the negative side, the development of ICTs made possible thanks to technological change in the computer and electronic products industry, may lead to the social issue of digital divide *within* developing countries. In other words, the development and diffusion of ICTs within a poor country may create a gap between individuals of different gender, age, education level, geographic location, etc. A study by Acilar (2011) found that in Turkey the spread of ICTs has led to a huge gap between younger and older individuals in terms of computer and Internet use. A gap in computer and Internet usage was also found between males and females (with the percentage of males using these technologies being higher than that of females); between people with different levels of education (i.e. as the education level increases, the rate of computer and internet use also increases); as well as between residents in urban and rural areas (with the percentage of urban residents using computer and internet being higher than that of rural residents, probably due to differences in education and income levels). Moolman et al. (2007) argued that the gender digital divide is one of the most significant inequalities amplified by the ICTs revolution. This is confirmed by Hilbert (2011) who analysed a sample of 12 Latin American and 13 African countries and found that women access and use ICTs less than men, because of poorer conditions in terms of employment, income, and education[11]. On the positive side, the development and diffusion of ICTs may have some positive environmental impacts (Houghton 2009). For example, the process of *de*-materialisation made possible by the development of ICTs allows to reduce waste as well as the amount of energy and resources used in the production, storage and delivery processes of physical products. Moreover, ICTs lead to a reduction of transportation with consequent positive implications in terms of GHG emissions reductions. ICTs, indeed, have made possible advances such as e-commerce, tele-work, e-work, tele-conferencing, and video-conferencing which allow reducing long distance travel and therefore the demand for transport. Finally, ICTs also contribute to improve resource and energy efficiency of many physical products and production processes. For instance, automotive electronics in the form of ignition chips have improved the energy efficiency of motor vehicles. The so-called smart technologies have also helped to improve control of resource and energy use, as well as emissions. Smart buildings, for example, are building management systems that maximise energy efficiency in building by running heating and cooling systems according to

[11] The interested reader may refer to Antonio and Tuffley (2014) for further references on the literature on the gender digital divide.

occupants' needs. In a similar way, smart logistics enable fuel reductions and energy efficiency through better route and load planning.

2.3 Environmental/economic trade-off of technological change

2.3.1 Environmental cons vs. Economic pros

Technological change in the manufacturing sector may produce economic benefits but at the same time affect negatively the environment. Indeed, while increasing productivity as explained in Section 2.1, some types of technological innovation may intensify environmental pressures by increasing demand for natural resources (both material and energy inputs used in production). Indeed, Dincer (2000) shows that a massive use of fossil fuels leads to dangerous effects on the environment including acid rain, deterioration of the ozone layer, and the greenhouse effect. Technological change in the manufacturing industry may also have negative environmental impacts by increasing the magnitude of waste and pollution (see sub-section 2.2.1).

Even clean technologies such as renewable energy and biofuels can lead to important adverse environmental effects as reported in sub-section 2.2.1. Nevertheless, the negative impacts on the environment of these technologies contrast with the significant economic advantage that they can bring, which is an improvement of a country trade balance. Indeed, on one hand, green technologies lead to increased exports to satisfy the worldwide increasing demand of alternative sources of energy. On the other hand, they reduce a country's dependence on fuel and as a consequence fuel imports (for non-oil rich countries) decline. As a result, the trade balance improves. Tunisia is an example of a country that experienced significant export increases thanks to a solar thermal energy innovative project (PROSOL). In fact, the value of exports of the country increased from 25,334 TND in 2006 to 495,917 TND in 2010 (Omri et al. 2015).

A similar example of trade-off between economic benefits and environmental negative impacts is offered by technological change in the textiles and clothing sectors. Indeed, innovation in the textile and garment industries has led to huge productivity gains and in some developing economies, in particular in low and middle income countries, the textile and clothing sectors have become a key source of exports. Keane and te Velde (2008) report that clothing is a key manufacturing export for Haiti, Bangladesh, Cambodia, Lesotho, China, Madagascar, and Mauritius. Textile exports, instead, are dominant in countries such as Pakistan and Nepal. Notwithstanding their central economic role and given their technological features, textile and garment industries are associated with serious environmental issues, including: the use of harmful chemicals; high consumption of water and energy; generation of large quantities of solid, liquid, and gaseous wastes; air emissions; and animal exploitation. A massive amount of chemicals are used in the textile industry for fibre production as well as for dyeing and finishing processes. Indeed, an intensive use of pesticides or synthetic fertilisers characterises the production process of fibres (even natural fibres such as cotton) causing soil degradation and the loss of biodiversity (Gardetti and Torres 2013). Moreover, persistent, bio-accumulating, and toxic chemicals are used in the textile processing (Karthik and Gopalakrishnan 2014; Choudhury 2014). Some of these chemicals are evaporated into the air, some are dissolved in treatment water which is discharged into the environment, and some are retained in the fabrics that when washed release a significant percentage of the chemicals thus polluting the environment. The textile industry is also the second biggest consumer and polluter of clean water (a finite resource which is becoming scarce) next to agriculture (Oecotextiles 2012). A significant amount of water is used for example in cotton production. Indeed, there is evidence that the Aral Sea in Central Asia has halved its original size due to the extensive water use in cotton production (Madsen et al. 2007). Moreover, water is contaminated in dyeing and finishing operations. Moore and Wentz (2009) estimate that 1 ton of fabric could result in the pollution of up to 200 tons of water, and in the process it consumes large amounts of hot water. IPE (2012) also found that in China, in 2009, textile industry ranked third among major industries in terms of total wastewater discharge, emitting 2.5 billion tonnes primarily through the dyeing and finishing processes. Bello et al. (2013) highlighted that in Nigeria the textile industry is a major source of pollution for water with severe consequence on fish, plants and other aquatic organisms. The textile industry is also a major consumer of energy. Choudhury (2014) reports that 38% of the total energy used is consumed in chemical processing, 34% in spinning, 23% in weaving, and 5% for miscellaneous purposes. It is worth noting that a huge amount of water and energy is consumed not only in the process of textile production but also in subsequent laundering processes during consumer use. Sherburne (2009) argues that consumer use can explain about 75-95% of the total environmental impact of textiles and garments. In addition to the above, a huge amount of wastes (liquids, solids, and gases) are generated during textile manufacturing with important environmental consequences (Karthik and Gopalakrishnanan 2014, Table 3, p. 168-169). Non-biodegradable fibre and packaging waste, for example, may severely affect the environment. Significant air emissions are also generated in the textile industry through fossil-fuel-heated boilers, drying ovens, storage tanks, and cleaning activities. Likewise, transportation of finished products from factories in developing countries to consumers in developed economies is responsible of significant air emissions. Animal exploitation is another important environmental issue associated to the clothing industry. The latter, indeed, makes use of several animal products such as leather, fur, silk, and wool that are obtained by killing different types of animals. Draper et al. (2007) reported that 50 million animals die worldwide every year in order to provide their fur to the fashion industry. This means that 130,000 animals are killed every day because of the clothing industry.

Similarly to the textile and clothing industries, the steel industry plays a significant role in the economic growth of developing countries and represents the basis for industrialisation by supplying basic products to several other industries such as building and construction, machinery and equipment, the manufacturing of transport vehicles, and railways. Nevertheless, production technologies used in the steel industry have considerable adverse environmental impacts. The World Bank (1991) reports that huge quantities of wastewater and air emissions are generated in the course of iron and steel production in blast furnaces, open hearth furnaces, or basic oxygen furnaces. Direct reduction furnaces and electric arc furnaces are less polluting than blast furnaces, but they still produce significant emissions of dust and carbon monoxide. The iron and steel industry is also one of the largest industrial energy consumers. Ahmad and Patel (2012) report that the iron and steel industry account for 20-45% of total industrial energy demand in many countries.

2.3.2 Environmental pros vs. Economic cons

The trade-off between positive environmental impacts and negative economic impacts of technological change in the manufacturing sector can be easily illustrated by considering the environmental and economic effects of biofuel technologies. In fact, biofuels may yield to significant GHG emission reductions compared to fossil fuels, although the impact is heterogeneous across types of biofuels. A study by the OECD (2008) highlights that sugar cane ethanol reduces GHG emissions by 90% compared to an equivalent amount of gasoline. Second-generation biofuels, instead, lead to GHG reductions in the range of 70-90% relative to gasoline or diesel (IEA 2006). On the other hand, biodiesel from palm oil yields GHG reductions in the range of 50-80% (FAO 2008), while biodiesel from rapeseed leads to GHG savings in the range of 40-60% (IEA 2006). On the negative side, biofuel production may exert an upward pressure on food prices with a consequent negative impact on food security (FAO et al. 2011; Flammini 2008). Several studies have analysed the impact of biofuel production on food prices, and Timilsina and Shrestha (2010) provide an extensive review of them. Just to mention an example in the context of the developing world, Baier et al. (2009) find that in Brazil, the increase of the price of sugar over the two years ending in June 2008 was due to the growth of sugar-based ethanol production. However, it is important to note that although individual crop prices are affected by biofuels production, the impact of the latter on global food prices are rather small. Baier et al. (2009), indeed, argue that over the considered period of time, about 88% of the rise in global food prices was caused by factors other than biofuels. Moreover, the magnitude of estimates of biofuel impacts on food prices are highly sensitive to the models used for the assessment, with partial equilibrium models leading to higher estimated impacts than general equilibrium models (Timilsina and Shrestha 2010).

The innovative Carbon Capture and Storage (CCS) technologies introduced in the iron and steel industry offer another good example of trade-off between positive environmental impacts and negative economic impacts. CCS technologies aim at reducing CO_2 emissions originated in the course of the iron making process by using technical solutions for cleaning the gas and transporting it through pipes into storage sites. Storage options include saline aquifers and, marginally, exhausted gas fields. Various CCS technologies are currently available for use in the iron and steel industry and have been adopted in developing countries such as China and India. A list of these technologies is provided by Hasanbeigi and Price (2013), and includes pilot technologies such as top-gas recycling in blast furnaces with carbon capture storage, technologies at the development stage such as post-combustion carbon capture using chemical absorption technologies, as well as technologies which are still under research such as integrating steel production with mineral sequestration, among others. According to Hasanbeigi and Price (2013), these technologies have the potential to contribute to a sharp reduction in CO_2 emissions, in some cases as much as 80% (UNIDO 2010; EPA 2010). In such a way, they may contribute to reduce the environmental impacts of the iron and steel sectors and lead to greener industries. However, Doc Choi (2013) highlights that CCS technologies may have an adverse economic impact in terms of enhanced economic costs. Indeed, although the CCS technologies do have a clear advantage in reducing CO_2 emissions, the CCS process *per se* requires the use of additional infrastructures (as well as additional chemicals and a high use of energy), which in turn could lead to additional economic costs (and an increase in chemicals and energy consumption), offsetting the benefits from reductions in emissions. A joint study by IEA and UNIDO (2011), indeed, reckons that an overall global investment of USD 256 billion would be necessary for the implementation of CCS technologies between 2010 and 2030. Developing countries alone would need to disburse USD 172 billion to implement the technology. These costs do act as barriers to the adequate implementation and use of CCS technologies.

3. Policy designs to promote social inclusiveness, economic and environmental sustainability

As we have seen in the previous sections, technological change in the manufacturing sector can and has delivered enormous advantages to society. Nevertheless, these benefits may come at a cost, thus leading to significant trade-offs. If the costs are outweighed (or not) by the benefits brought by technological innovation has to do directly with the (or lack of) policies enacted by each country. So, the main issue is to develop adequate policies to minimise the trade-offs inherent to technological innovation in order to obtain win/win/win gains from an economic, environmental and social point of view. National policies have failed to achieve this objective so far. This is due to the fact that governments have been unable to develop integrative approaches to the full range of consequences of technological change, partly because of *knowledge* and *implementation* gaps. According to OECD (2001), several factors contribute to the implementation gap. First, for common resources such as climate or biodiversity, a country has few incentives to take unilateral actions since it would bear the costs, while other countries would get the benefits. Second, implementation is often delayed by concerns about short-term consequences of environmental policies on the distribution of household income, on employment, and on the competitiveness of individual firms and sectors. Third, governments are often not well-equipped to deal with the cross-cutting and long-term nature of many of the economic, environmental or social challenges.

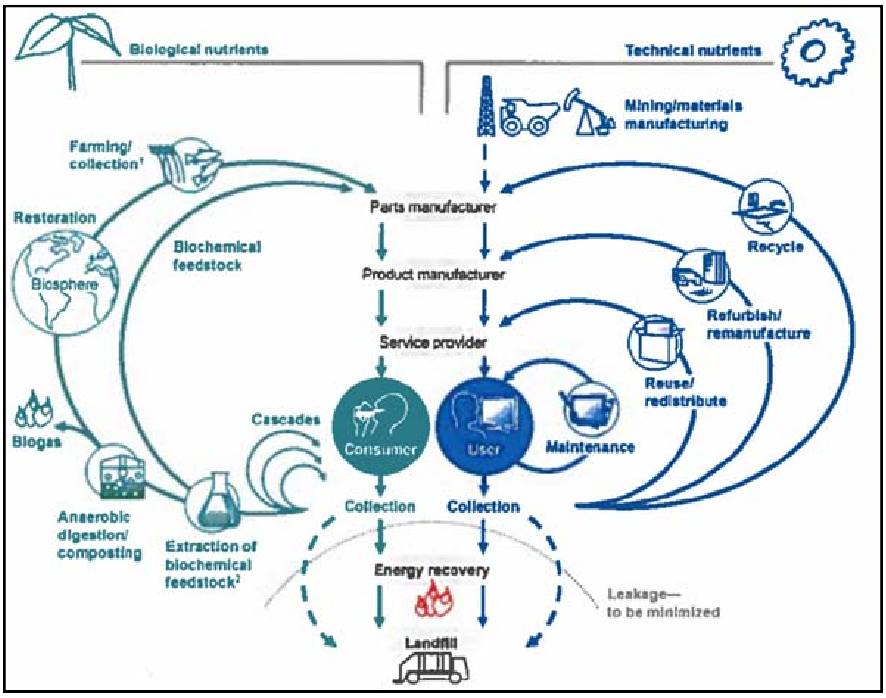
The aim of this section is to review and discuss some of the policy designs proposed in the existing literature that may be used to curtail the trade-offs arising from technological change in the manufacturing sector and to achieve technology-driven sustained economic growth, social inclusiveness and environmental sustainability.

Focusing on the economic/social trade-offs, a number of policy instruments may be used to address the issue of technological unemployment. Investing in education, for example, may prove to be useful to build the skills of workers (especially unskilled workers) thus enabling them to move up the value chain and compete for higher-paying and more highly skilled jobs in times of technological innovation in the manufacturing sector which leads to changing skills needs. Training programmes have been found to be quite effective, in particular work-based programmes rather than programmes that are classroom-based or deliver basic education (OECD 2014). Adequate social protection systems may help cushion the effects of unemployment on household income. However, in order to encourage unemployed people to return to work, the development of social protection systems should go along with the implementation of effective employment services. Furthermore, employment protection regulations are an important tool to protect workers from arbitrary actions and have firms internalise at least some of the social costs of labour turnover. Nevertheless, these rules should not be excessively strict since this may risk limiting firms' incentive to innovate with adverse consequences in terms of productivity and output growth. Investing in public unemployment insurance schemes may also be an effective policy instrument to protect workers against the risk of unemployment, while promoting social dialogue may be useful to address not only the unemployment issue but also other social issues related to economically beneficial manufacturing innovations such as health and safety issues.

Moving to the social/environmental trade-offs, social policies may play a key role in addressing social impacts of manufacturing innovations that aim to protect the environment (e.g. biofuels). To be effective, these policies should be developed on the basis of a clear understanding of the social impacts of technological change. Therefore, social and eco-social metrics and indicators are needed (UNRISD 2012). In the case of innovations such as biofuels and renewable energy, these may include indicators of the distributional effects of energy prices and green taxes on different income groups, indicators of working conditions in green jobs, indicators of the impacts on rights of rural population of green technologies, and many others. Two main tools may be used by eco-social policies to address the social dimensions of environmental friendly manufacturing innovations: safeguards protecting vulnerable people, and benefit-sharing arrangements for poor local people. Some types of safeguard are: the protection of local food systems; local consultation; mechanisms for fair arbitration, appeal, participation, and empowerment; accountability mechanisms; and the institutionalisation of basic rights and freedoms. Vermeulen (2008) reported a number of examples of safeguards that have been implemented in developing countries to respond to the social impacts of biofuels. In Southeast Asia, in order to protect small holders from the social externalities of the spread of palm oil plantations, local people have been allowed to keep as much land as they like for food production. Moreover, in Mozambique a process for consultation with local communities has been recognised by the national law. The benefit-sharing arrangements should replace the one-off compensation mechanisms, and in the case of biofuels threating the land rights of local people, they may include land-leases, land management agreements, outgrower schemes, and joint equity models. In Mali, for example, local farmers are allowed to lease their land to a collective land holding to produce Jatropha, and they can also rent out their land at the ongoing market rate (Vermeulen 2008). Land rental agreements are also used in Guatemala to produce biodiesel (Lopez 2008) and in Brazil to produce ethanol from sugar cane (Vermeulen 2008). In Brazil, land rental agreements are particularly sophisticated since they imply that the land is rented from small-scale farmers to large-scale sugar cane producers, and then it is leased back to small farmers for nut production in the off-season. Outgrower schemes are used in Brazil, while joint-equity arrangements have been implemented in Malaysia and Guatemala (Vermeulen 2008; Lopez 2008). In addition to the above, government support for social science research and multi-actor collaboration involving the state, the private sector, civil societies, and community actors, are other tools that may prove to be useful to incentivise the development of new solutions to address the social/environmental trade-offs stemming from technological change in the manufacturing sector.

Finally, looking at the economic/environmental trade-offs, the ‘circular economy’ business model may be used to maximise the productivity of technological innovations in industries such as the biofuel ones or those producing computers and electronic products, and to minimise their environmental impacts (Figure 1). The model is divided into four phases: (1) the design of products taking into account their entire life cycle; (2) the maximisation of product life cycles; (3) the recycling of materials from end-of-life products; and (4) the reuse of materials across diverse industries and value chains. Life cycle assessment (LCA) is a tool that may prove to be extremely helpful in phase (1) of the model. LCA, indeed, is used for the systematic evaluation of the environmental aspects of a product through all stages of its life cycle (Box 3).

Figure 1. The circular economy business model



Source: McKinsey Global Institute (2012).

Box 3. Life Cycle Assessment

A Life Cycle Assessment (LCA) consists of three steps:

- *Goal and scope definition*: the product(s) to be assessed is (are) defined, and a functional basis for comparison is chosen.
- *Life cycle inventory assessment*: the raw materials, energy, and water that are used as well as the emissions and other environmental releases that occur during the life of the product(s) are quantified and related to the functional basis.
- *Life cycle impact assessment*: the impacts of emissions and raw material depletions are assessed.
- *Interpretation*: the results are reported and interpreted to suggest improvements.

In the literature, LCAs have already been used to evaluate the environmental impacts of a number of manufacturing products produced in developing countries including computers (Grzesik-Wojtysiak and Kuklinski 2013), cotton fibres (PE international AG 2014a, PE International AG 2014b), biodiesel (Hidayatno et al. 2011), and ethanol (Restianti and Gheewala 2012), among several others.

A number of tools may also be used by governments to reduce the economic/environmental trade-offs of technological change in the manufacturing sector. For instance, the implementation of *ad hoc* standards and/or regulations may be used to mitigate the adverse impacts of certain technologies. The

Indian government has made an important step in this direction[12]. Indeed, in 2012 new rules on e-waste management have come into effect. These rules recognise the liability of computers and electronic products manufacturers for recycling and reducing e-waste in the country, and state that producers have a period of one year to establish e-waste collection centres or introduce 'take back' systems. Producers are also required to provide to consumers instructions for handling the equipment after its use. Government may also minimise the economic/environmental trade-offs by fostering collaboration among business leaders, technologists, researchers, and investors to promote information sharing with the objective of reducing the risks associated to certain technological innovations. Financial incentives such as tax breaks have also been used by governments in some developing countries to promote the development of environmental friendly technologies (e.g. Brazil, India, Mexico, and Peru, among others, in the case of the renewable energy industry), but as seen in sub-section 2.1.2, these policy instruments risk to be ineffective in minimising the economic/environmental trade-offs if they lead to a significant decline in government revenues, thus limiting availability of the latter to respond to social and infrastructure needs.

Innovation policy may also play a key role in guaranteeing that technological change in the manufacturing sector foster economic growth, as well as social inclusiveness and environmental sustainability. How to design an effective, equitable and sustainable innovation policy is still a big challenge for the international community. Researchers and international organisations have advanced a number of proposals that are described below. From these proposals, the main message that emerges is that innovation policy should be coherent. This means that it should be *coordinated* and *synergistic* at multiple levels (economic, social, and environmental) and between multiple actors (state, market, civil society, and community).

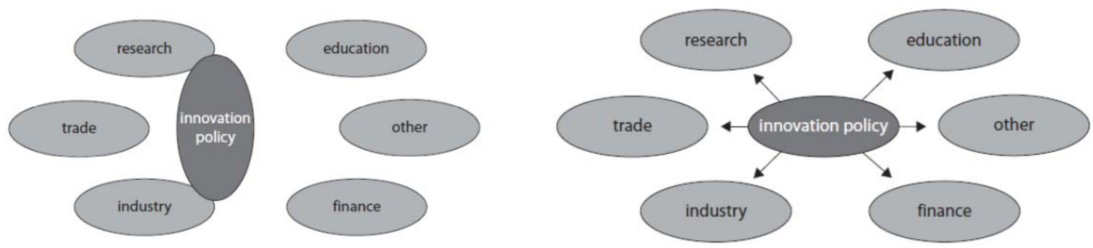
The importance of coordination in the design process of innovation policy has been stressed in several proposals. The World Bank (2010) highlights that successful innovation policies should be developed according to two principles: coordination, and adaptation. First, adequate innovation policies need horizontal and interdepartmental coordination within the government. This is due to the fact that innovation policy should not be seen as a separate entity but as a fully integrated body within all relevant areas of the economy (see Figure 2). A simple analogy with gardening can exemplify the main reasoning behind this idea. Watering can be seen as the provision of adequate finance and support to innovators within the country. Removing weeds can be understood as deregulation or the implementation of new rules and regulations that foster competition and innovation. Nurturing the soil can be translated into the provision of the right incentives to promote research as well as access and diffusion of information. Finally, preparing the ground can be associated to education. An effective

[12] See http://www.business-standard.com/article/economy-policy/india-gets-first-e-waste-management-rules-111060900037_1.html

innovation policy, indeed, requires preparing the workforce through education to be able to innovate, create, as well as adapt and use successfully any new technology in the market.

Figure 2. Traditional layout of innovation policy vs. comprehensive layout of innovation policy

Traditional layout of innovation policy *Comprehensive layout of innovation policy*



Source: World Bank (2010).

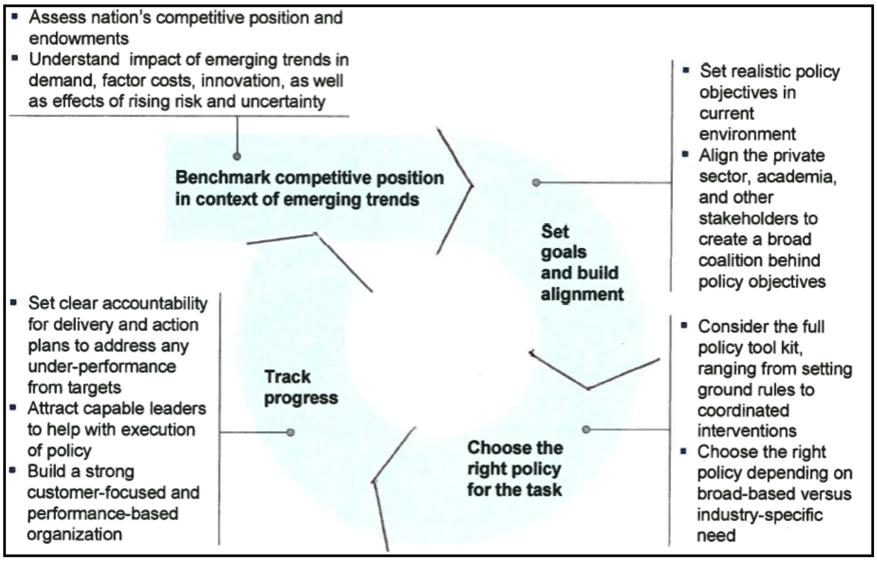
Second, the other area that needs special attention when designing innovation policies is adaptation. This is particularly relevant for developing countries. The idea is that innovation policies should take into account country-specific characteristics, at both the economic and social levels. So, in order to design country-specific adequate innovation policies, the following issues should be taken into account:

- *Implementing an adequate technology strategy*. For low-income countries the focus should be in adapting technologies to local needs. Furthermore, priority should be given to the creation of adequate structures and mechanisms that may facilitate the dissemination and adoption of new technologies amongst the poorest segments of society.
- *Institutions*. Developing countries and in particular low-income countries tend to have weak governance, very limited infrastructure, and poor education systems. So, in this adverse context, there is a clear need to setup a strong body or agency capable of developing adequate polices and mechanisms to foster innovation.
- *Legal framework*. A successful innovation policy requires a set of rules and regulations that can provide legal certainty. This is crucial when dealing with new technologies. Developing countries should make an effort to create a solid infrastructure for norms, standards and quality control that can guarantee the proper commercialisation of new products in their markets.
- *Policy focus*. Developing countries should take into account their specific needs and assets when designing their innovation policies. Any policy should take into account any potential trade-offs that new technologies might have on a particular sector or segment of the population and make the necessary amendments to maximise its beneficial impacts and reduce its potential costs.

- *Agents of change*. Developing countries sometimes are affected by inertias or lack of local support to embrace change and adequate innovations policies. In this context, developing countries should exploit any connections, networks or arguments to promote change in domestic markets. Understanding that a country is totally dependent on foreign technology or subject to third parties to access global markets may help galvanise a support base to promote the necessary changes to fully support local innovation.
- *Reform approach*. In the same lines, instead of engaging in full nation-wide reforms, sometimes a more local and regional approach may pave the way to future more comprehensive and nation-wide reforms. Indeed, in developing countries it may be advisable to focus first on small scale projects and then, when a certain representative number of successes have been attained, proceed to scale up reforms to national level.
- *Cultural and behavioural characteristics*. Cultural differences and specificities not only vary from country to country, but also within a country we can find differences from one city or region to another. Understanding this is key to the successful design and implementation of innovation policies. Acknowledging these differences and preparing tailored set of reforms, norms and regulations may guarantee success, while the one-size fits all approach may be detrimental and slow down or impede progress at all.

The importance of coordination and adaptation in designing innovation policies is also recognised by the McKinsey Global Institute (2012). According to the model reported in Figure 3, innovation policies should be designed through a four-step process. The first step consists in assessing the comparative advantages of a country by looking at its endowments (i.e. natural resources, quality of labour force, energy, etc.). This is important to understand which technology may be competitive (e.g. countries endowed with competitive labour costs may have a competitive advantage in labour-intensive technologies), and to properly inform the decision about which type of policy interventions is more adequate given certain country-specific characteristics. The next step is to define realistic policy objectives through a coordinated process which involves several actors including governments, industries, and educational institutions. In the third step, the right policy is identified taking into account both industry-specific and broad-based needs. The final step of the process consists in the careful execution of the selected policy.

Figure 3. Design process of innovation policy



Source: McKinsey Global Institute (2012).

The OECD (2001) also stresses the importance of coordination between the economic, social, and environmental dimensions as well as between multiple actors in developing innovation policies. Indeed, according to the OECD (2001), adequate, equitable and sustainable innovation policies should be designed according to the following criteria [OECD 2001]:

- *Provide permanent incentives to innovate and diffuse technologies that support sustainable development objectives, by expanding the use of market-based approaches in environmental policy. When market-based instruments are not appropriate, use performance standards in preference to measures that prescribe and support specific technologies.*
- *Support long term basic research through funding and efforts to build capacity (e.g. development of centres of excellence). Increase research on ecosystems, the value of the services they provide, the long term impact of human activity on the environment, and the employment effects of new technologies.*
- *Address unintended environmental and social consequences of technology, by separating technology promotion responsibilities from those on health, safety, and environmental protection within governments*
- *Support applied research activities when they are clearly in the public interest (e.g. protection of public health and environment) and unlikely to be provided by the private sector by:*
  - *Co-operating with the private sector to develop and diffuse new technologies.*
  - *Facilitating public-private and inter-firm collaboration with the innovators of cleaner technologies and practices.*

- *Seeking out opportunities for greater international collaboration on research, especially on issues critical for sustainable development.*
- *Allowing competition among technologies that can meet the same policy objective, and equal access to "learning opportunities" (e.g. protected niche markets and similar schemes) by foreign as well as domestic investors.*

Matus et al. (2013) endorse the idea of coordinated innovation policies by suggesting that innovation policy should be designed taking a *systemic* perspective. In other words, innovation policy needs to be defined in the context of a fair and socially just economic system that truly meets the needs of all people while maintaining what they called the Earth's life support systems. In order to do so, it is crucial to first understand the innovation process. Matus et al. (2013) schematise the process encompassing a set of interconnected and interacting elements:

(i) Invention

Mechanisms that drive invention include targeted search, accidental discovery, and repurposing of one technology or process for a different use.

(ii) Selection

This element is particularly relevant for manufacturing. It refers to the process of choosing among the universe of possible technologies available by looking over the landscape and choosing a technology for use. In the manufacturing sector the mechanisms for selection include laws and regulations which mandate environmental, health and safety standards and/or national pride. One example is governments investing in the manufacture of particular "green" technology products. The selection may also be influenced by other national policies such as tax breaks, subsidies, and other types of friendly regulations that incentive a particular innovation and which support national competitiveness.

(iii) Production

The production of technologies includes the processes and methods used to transform tangible inputs (resources, energy) into goods or services.

(iv) Initial adoption

Here end-users are trying the invented and produced technology over a short or longer period of time. Market factors, such as price, have a major impact in this sector. Demand, due to cultural factors and marketing, can also play a significant role in this phase.

(v) Widespread / sustained use

Sustained use includes the processes by which technologies move from an initial decision to be used, and end up being adopted on a wide scale by a population of potential end-users.

(vi) Adaptation and redesign

Adaptation involves adjustments made to a technology itself and/or to the practices surrounding the use of a technology. Many manufactured products and processes require adjustments to both the technology itself and the regulatory environment in order to be modified for local conditions, such as mechanical adaptations of technological products to suit local electrical grids. Consumer products such as apparel and personal care products often require more adaptation not just because of their physical attributes but because of the psychological features, including colour, size, design, brand and price, which may require redesign to adapt to cultural contexts.

(vii) Retirement

Many technologies do not provide permanent solutions to problems, but rather undergo lifecycles, at the end of which they eventually become less effective or useful, and may be replaced by newer or better technologies, or simply discarded. This retirement is driven by a number of factors including by the search for novelty, fashion and trends, improved functionality, pricing and changing context which can make a particular product or process obsolete.

Once the innovation process is understood, the next step towards a sound and comprehensive technological innovation policy consists in understanding the weaknesses of the above process. After careful analysis, the authors conclude that, in the manufacturing sector, the weaknesses in the global innovation system can be considered as a nested system of barriers, exacerbated by a system-wide economic paradigm. An industrial paradigm that does not account for ecological and social externalities is indeed the fundamental barrier to advancing sustainable and inclusive manufacturing processes.

One possible solution towards a better innovation policy comes in the form of *industrial symbiosis* (IS). IS involves the establishment of relationships between organisations in order to manage resources more effectively and efficiently. Industrial symbiosis mimics natural systems, and attempts to move industry towards a *circular* or non-linear economy, where waste-to-input linkages and goal-oriented inter-firm relationships substitute the current manufacturing structure. An IS network requires sharing natural resources (materials, energy, water, waste by products), as well as social technologies (use of assets, logistics, contracting, expertise) within an industrial cluster and/or along a supply chain. This brings benefits in the form of better resource and energy efficient processes and sustainable livelihoods for workers (Chertow and Ehrenfeld 2012).

Industrial symbiosis programs are being piloted in Australia, Brazil, China, Mexico, South Korea, and the United Kingdom. The National Industrial Symbiosis Programme in the UK originated as three pilot schemes in Scotland, West Midlands, and Yorkshire and Humberside in 2003. It is a business-led programme with over 15,000 participating industry members, which through the network identify mutually profitable transactions, allowing underused or undervalued resources to come back into productive use. This Industrial Symbiosis Programme permitted the UK to divert 47 million tonnes of industrial waste from landfill, to generate £1 billion in new sales, reduce carbon emissions by 42 million tonnes, cut costs by £1 billion by reducing disposal, storage, transport & purchasing costs; reuse 1.8 million tonnes of hazardous waste, create and safeguard over 10,000 jobs, save 60 million tonnes of virgin material, and save 73 million tonnes of industrial water[13].

Coordination is not enough to guarantee successful, sustainable, and equitable innovation policies. Synergies are crucial and have to be taken into account when designing and implementing innovation policy. The relevance of synergies in the design process of innovation policy has been recognised by UNEP (2009), which prepared a reference manual to provide guidance on what is defined as 'integrated policymaking' with the main goal of promoting sustainable development taking into account the economic, social and environmental dimensions. The main objectives of integrated policymaking are as follows:

1. To ensure that any policy decision is acceptable with regards to each of the three dimensions (economic, social and environmental);
2. To identify innovative policy solutions that will draw on synergies among the three dimensions;
3. To identify any trade-offs, and propose corrective measures;
4. To increase the transparency and accountability of the different stakeholders' attitudes towards the different dimensions of sustainable development.

Under UNEP's (2009) conceptual framework, integrated policymaking consists of a five steps policy cycle with three levels of integration. The first level of integration focuses on significant interactions or synergies of the economic, social and environmental (ESE) dimensions associated to a particular problem and its potential solutions. The main idea is to analyse and understand all the possible complementarities and reduce any trade-offs that may arise among the ESE dimensions. Box 4 offers some insights on how the various trade-offs may be treated or minimised when designing innovation policies. The second level of integration tries to introduce

[13] Interested readers can refer to the following link for more information: http://www.international-synergies.com/projects/national-industrial-symbiosis-programme-nisp

the previous considerations into the policy cycle, so that any potential policy solution is reasonable, feasible and above all sustainable. Finally, the third level of integration addresses any policy constraints in terms of political support, as well as administrative and analytical capacity within the policy process. Political support is crucial to guarantee the necessary sustenance to enact policies, while administrative and analytical capacity refers to the government's ability to formulate and carry out the required policies.

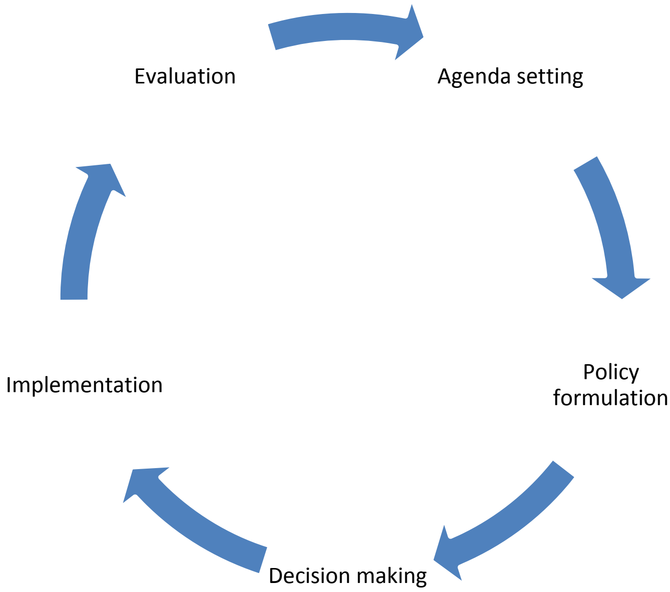
Box 4. Rules on addressing trade-offs

- Any trade-off must deliver maximum net gains.
- The burden of argument for trade-off should be on the trade-off proponent.
- Significant adverse effects must be avoided.
- The future should be given at least the same weight as the present.
- All trade-offs must be accompanied by explicit justifications.
- Decision on trade-offs must be made through an open process.

Source: Gibson et al. (2005).

As shown in Figure 4, the policy cycle starts with a problem that arises due to previous inadequate policies or the lack of policies which require government intervention. This is referred as 'agenda setting'. Once the problem has been identified, it is necessary to find potential solutions in the form of adequate/relevant policies (policy formulation). The third stage of the cycle requires action by policy makers in the form of 'decision making'. At this stage policy makers have to decide which course of action to follow and which potential policies should be adopted to address the problem. In the fourth stage the policies enter into force (implementation) and, to conclude, the fifth stage consists of monitoring and evaluating the results of the policies put into place. This stage also allows making any adjustment to the policies enacted in order to maintain or improve their effectiveness.

Figure 4. Innovation policy cycle



Source: UNEP (2009).

Agenda setting

The agenda has to be framed in sustainable terms, i.e. defining any issues related to society's sustainable development context, including priorities, risks and opportunities. Special attention needs to be paid to harmonising the interests of different stakeholders in order to avoid sectorial or institutional biases, as well as establishing horizontal and vertical linkages within the government and society to ensure the successful entry of relevant items into the agenda.

Policy formulation

When working on policy formulation it is essential to organise inter-agency committees or taskforces to formulate policy collectively or independently as appropriate. Furthermore, it is advisable to involve senior officials and opinion leaders as well as potential policy implementers, monitors and evaluators. It is important to establish a limited number of objectives for the potential policy solutions, taking care of making objectives SMART (specific, measurable, acceptable, realistic, and time-bound).

Decision making

When taking a particular decision it is important to highlight win-win opportunities, as well as inevitable trade-offs. It is also important to propose additional measures to strengthen synergies and/or minimise trade-offs. In this context, the ideal outcome is to choose a policy option that maximises synergies and minimises trade-offs. For example, investing in basic health care not only contributes to poverty reduction, but also raises labour productivity.

Implementation

This is the stage where a selected policy option is translated into action, and it is certainly the most difficult and demanding stage of the policy process. Successful implementation relies on adequate designation of an inter-sectorial, inter-agency mechanism to be responsible for the task, clarifying roles and mandates for all participants involved. Furthermore, it is essential to mobilise resources proactively and managing stakeholders' dynamics, for example by considering different stakeholders' interests, resources, and capabilities.

Evaluation

Integrated evaluation focuses on monitoring and determining the success of a policy from a sustainable development perspective. Adequate evaluation first specifies the type, scope and criteria of evaluation. It also ensures that environmental, social and economic indicators are included in order to guide the monitoring and assessment of the policy. An adequate evaluation system also engages stakeholders in the monitoring activities, in order for them to share the control over the content, process and the results of the assessment activities.

Overall, the main challenge in designing innovation policy remains the need to identify the right balance between the three dimensions of sustainable development, taking into account all the possible synergies and striving to reduce the inherent trade-offs that may arise. Furthermore, it is crucial to raise enough public support and awareness, involving as much sectors of society as possible, since any potential policy solution will undoubtedly modify the status quo, creating frictions and resistance from several groups and stakeholders. So, the only way to ensure that adequate and sustainable innovation policies are put into place is to convince the majority of society that the final outcome will benefit all in the long-term.

4. Conclusions

Technological change is a double-edged sword. On one hand, it may bring socio-economic benefits and improve the environmental prospects. On the other hand, it can pose serious challenges to the economy, and cause significant harm to human well-being and the environment. This paper surveys the literature on the economic/social, social/environmental, and environmental/economic trade-offs of innovation in the manufacturing sector, with a focus on developing countries.

The survey reveals that recent technological advances in the manufacturing industry may lead to important economic advantages such as increased productivity and improved trade balance, but also to social (e.g. new jobs, women empowerment, poverty reduction, financial inclusion, etc.) and environmental (e.g. reduced greenhouse gas emissions, improved air quality, reduced use of pesticides, etc.) benefits. At the same time, these innovations may have negative economic impacts (e.g. upward pressure on prices) or adverse social (e.g. unemployment, harmful impacts on public health, gender inequality, increased vulnerability of the poorest, digital divide, etc.) and environmental (e.g. negative impacts on ecosystems and biodiversity, contamination of soil and water, deforestation, changes in local climates, etc.) effects.

Therefore, in order to obtain win/win/win gains (i.e. economic/social/environmental gains) from technological change, it is necessary to develop integrative policy approaches that take into account the full range of positive and negative consequences of innovation. National governments have failed to achieve this objective so far, mainly due to knowledge and implementation gaps.

A number of policy tools may be used to address the individual trade-offs arising from technological change in the manufacturing sector. For example, investing in education, creating social protection systems, implementing effective employment services, developing adequate employment protection regulations, and investing in public unemployment insurance schemes, may be useful policy responses to the economic/social trade-offs between increased productivity/output and unemployment arising from technological innovation. Moreover, eco-social metrics and indicators, as well as safeguards and benefit-sharing arrangements may allow minimising the social/environmental trade-offs of green technologies. In order to respond to the economic/environmental trade-offs, the circular economy business model, the implementation of *ad hoc* standards and/or regulations, and the collaboration among different actors ranging from business leaders to technologists, researchers, and investors may be suitable for reducing the environmental risks associated to certain economically beneficial manufacturing technologies.

Innovation policy may also play a key role in guaranteeing that technological change in the manufacturing sector foster economic growth, as well as social inclusiveness and environmental sustainability. In order to be effective, equitable and sustainable, innovation policy should be coherent, which means that it should be coordinated and synergistic at multiple levels and between multiple actors. Designing a coherent innovation policy is still a big challenge for the international community, but a number of international organisations and researchers have advanced proposals to address this issue. Some key features of the proposed policy designs are the fact that innovation policy should aim to promote interactions between all the actors and sectors of the economy, to provide incentives to innovate and diffuse technologies that support sustainable development objectives, to promote capacity building, to maximise synergies and to minimise trade-offs among the economic, social and environmental dimensions.

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