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Technology and productivity in developing countries: A survey of the literature

Doris A. Oberdabernig

This paper aims to survey the literature on technological change and mechanisms of technology diffusion, with a special focus on developing countries. We investigate theoretical models of technology spillovers, discuss possible forms of measuring diffusion, and summarize the findings of empirical studies. The picture that emerges is a heterogeneous one, with weak evidence for the existence of automatic technology diffusion in developing countries. National policies aimed at increasing human capital, providing adequate infrastructure, and enhancing technology transfers might be necessary for technological spillovers to materialize.

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Abstract

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Keywords: Technological upgrading, knowledge transfer, trade, FDI, developing countries

*World Trade Institute (WTI), University Bern, Hallerstrasse 6, 3012 Bern, e-mail: doris.oberdabernig@wti.org

Contents

Abbreviations

ADB	...	Asian Development Bank
CES	...	Constant elasticity of substitution
DACST	...	Department of Arts, Culture, Science and Technology
DST	...	Department of Science and Technology
EPO	...	European Patent Office
ECA	...	Economic Commission for Africa
FDI	...	Foreign direct investment
FMOLS	...	Fully Modified Ordinary Least Squares
GDP	...	Gross domestic product
GLS	...	Generalized Least Squares
GMM	...	Generalized Method of Moments
ICT	...	Information and communication technology
IDB	...	Inter-American Development Bank
MNC	...	Multinational company
NDPC	...	National Development Planning Commission
OECD	...	Organisation for Economic Co-operation and Development
OLS	...	Ordinary Least Squares
PPP	...	Purchasing Power Parity
PWT	...	Penn World Table
R&D	...	Research and development
TFP	...	Total factor productivity
TLS	...	Telecommunication apparatus
UNCTAD	...	United Nations Conference on Trade and Development
WDI	...	World Development Indicators
WLS	...	Weighted Least Sqares

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1 Introduction

Economic growth is important for the development process of poor countries, allowing them to catch up with richer economies in the world such that the world as a whole becomes more equal in terms of income and living standards. Early models of economic growth (see Solow, 1956, and exogenous growth theory building on Solow's model) indicate the role played by technological upgrading as a primary source of sustained economic growth. While in exogenous growth models technological change remains unexplained and acts as an external source of economic growth, endogenous growth theory explains technological progress as an endogenous outcome of policy decisions such as investments in human capital formation, research and development (R&D) and knowledge-intensive industries (see Todaro and Smith, 2015). Building on the work of Romer (1986, 1990) and Lucas Jr. (1988), these endogenous growth models emphasize the role of differences in country specific technology levels for explaining differences in rates of economic growth and therefore act as a source of economic convergence or divergence (Quah, 1997; Howitt, 2000; Kumar and Russell, 2002). Other authors attribute moderate levels of convergence to the slow speed of technology diffusion (see Barro and Sala-I-Martin, 1995; Mankiew et al., 1992).[1]

Against this background, technological upgrading seems to be an important means of developing countries to catch-up, or keep pace with industrialized countries. The importance of technology adoption and innovation for economic development is recognized by national governments and development agencies, which actively focus on improving and accelerating technological upgrading and innovation. These institutions highlight the positive influence of technological progress not only on economic growth but mention a big number of areas in which technological upgrading can have beneficial socio-economic effects such as increased competitiveness, investment, efficiency, export performance, and entrepreneurship, and favorable effects on poverty alleviation, sanitation, health, and nutritional, energy and communication needs among others. Technological progress, thus, acts as an important means that helps achieve the sustainable development goals agreed upon by the member states of the United Nations (see ADB,

[1]The endogenous growth literature also allows for technological spillovers leading to productivity gains of one industry translating into productivity increases also in other industries (see Romer, 1986).

2010, 2015; Harrigan, 2007; IDB, 2015; UNCTAD, 2013; ECA, 2013, 2015; World Bank, 2014, among others). Also governments of developing countries adopt policies targeted at technological upgrading in their agenda, like in the Perspective Plan of Bangladesh (Government of Bangladesh, 2012), in the Growth and Transformation Plan in Ethiopia (Federal Democratic Republic of Ethiopia, 2013), in Ghana's Vision 2020 and Shared Growth and Development Agenda (Government of Ghana, 1995; NDPC, 2010), in the Madagascar Action Plan (Government of Madagascar, 2006), in South Africa's White Paper on Science and Technology and National Research and Development Strategy (DACST, 1996; DST, 2002), or in the Socio-Economic Development Plan of Vietnam (Socialist Republic of Vietnam, 2006; Socialist Republic of Vientam, 2011) for example.

Notwithstanding the importance of technological upgrading especially for developing countries in order to be able to catch-up with industrialized countries, only a small number of rich countries account for the majority of technological innovations. Thus, in most countries foreign sources of technology account for the biggest part of domestic productivity growth, what makes technology diffusion especially important for small and relatively poor countries (see Grossman and Helpman, 1991; Keller, 2004). There is also good news, however. The pace of technology diffusion seems to have accelerated with globalization in recent decades caused by lower transfer costs and an increased rate of technological spillovers. The increased openness of developing countries through recent trade liberalizations, their increased interconnectedness with international markets and rising inflows of foreign direct investment (FDI) lead us to hope that they can benefit from technology diffusion to the same extent as was found for industrialized nations. International trade and FDI are often mentioned as the most important channels of technology diffusion (see for example Grossman and Helpman, 1990; Rivera-Batiz and Romer, 1991; Xu, 2000; Keller, 2004; Tang and Koveos, 2008). Foreign technology embodied in a country's imports becomes implicitly available domestically. The presence of foreign firms and multinational companies (MNCs) in local markets increases the number of technologies available in a country as these firms potentially have access to and use the technologies of their home countries. Also increased interaction between local agents with international actors leads to knowledge diffusion concerning the availability of technologies and might incentivize firms to invest in new technologies in order to serve the needs of foreign markets. In the light of rapidly declining trade barriers, reductions in transport costs and larger volumes of international trade flows, together with the higher interconnectedness of the world through rapidly expanding information and communication technology (ICT) and higher shares of FDI, technology is supposed to be able to expand more rapidly across national boarders. This opens opportunities especially for developing countries to more rapidly catch-up with technologically more advanced nations by leapfrogging stages of technology development. On the downside these opportunities are by no means automatic but depend on the potential of developing countries to absorb the newly available pool of technologies through increased globalization, which poses a challenge for many developing countries (see Grossman and Helpman, 1990; Keller, 2004; Seck, 2012; ECA, 2014)

In this survey we aim to provide an overview of the diffusion of technology and productivity with special focus on developing countries. We start by a short discussion of how technology transfers take place. Section 3 reviews the most influential theoretical models of technology diffusion through trade and FDI, while section 4 discusses problems connected to the measurement of technological upgrading and technology spillovers and summarizes some of the available proxies for measuring technology levels. Section 5 summarizes the evidence provided by empirical studies and discusses their implications for policy making. Section 6 concludes.

2 How technology transfer takes place

There are different channels trough which technology diffusion can take place, which we will summarize here shortly before considering theoretical models and empirical applications investigating their validity. Transfers of technology might occur explicitly via licensing agreements or implicitly by the interaction of individuals from different countries that potentially have access to different technologies. They might exchange information and ideas and learn from others about alternative technologies. Such interactions can take place via different channels like communication, trade, and the presence of foreign companies in domestic markets. Technology usually has two important aspects, giving it a public good character: it is non-rival in the sense that it can be employed in different places at the same time, and private and public returns to investing in technology differ because it is often difficult to prevent others from its usage. This gives rise to externalities and technological spillovers (see Grossman and Helpman, 1991; Helpman, 1992; Keller, 2004).

Licensing agreements provide a direct form of transmission of technology to other parties. The decision of which technology to transmit usually reflects profit maximization behavior and it might be more beneficial for firms to transfer technologies via licensing agreements that are not the most recent ones (see Mansfield and Romeo, 1980).[2] In this survey we will focus on indirect transmission channels, however, thus discussing them in more detail while not focusing too much on explicit transfers of technology through licensing.

Trade is often argue to be an important means of indirect technology spillovers. Imports can act as a channel of technology diffusion to the extent that foreign technology is embodied in imported intermediates and capital goods, which can become domestically available or not (Grossman and Helpman, 1991; Rivera-Batiz and Romer, 1991; Coe et al., 1997; Eaton and Kortum, 2002). More advanced foreign technology becomes domestically available and thereby increases the local knowledge stock for example through reverse engineering or merely from the use of these goods (see Grossman and Helpman, 1991). On the other hand, imports of intermediate inputs can raise domestic productivity without contributing to the local knowledge stock through lowering input prices if imported intermediates are cheaper than if they were domestically produced. In contrast to reverse engineering the technology embodied in imports is not automatically domestically available via this channel. Also, increased access to a wider variety of intermediate inputs might be beneficial for increasing productivity as the available inputs can be of higher quality (see Grossman and Helpman, 1991; Eaton and Kortum, 2002).

Not only imports of intermediate goods but also exports can lead to technology diffusion, especially to low- and middle-income countries. The interaction of domestic firms with foreign competitors and customers who impose higher product quality standards exporting can make them learn about the availability of new technologies and products for example through providing technical assistance (Grossman and Helpman, 1991; Keller, 2004). The increased competition on in-

[2]Mansfield and Romeo (1980) finds that multinational companies transfer much newer technology to their affiliates than the technology sold via licensing agreements.

ternational markets has the potential to raise productivity by encouraging firms to invest in new technologies and become more efficient. Indeed, the empirical literature provides evidence that exporting firms are more productive than firms that operate only in domestic markets. Also technological upgrading is found to occur more quickly in firms that enter the export market than in firms that only serve the domestic market. Exporting firms have excess to a larger market than the domestic one and can thus realize economies of scale by increasing their production. The resulting productivity gains of these companies induce investment in new technologies (see Bustos, 2011).

The diffusion of technologies that are not commercially available may be enhanced by FDI. Usually foreign firms that locate in countries other than their home country have access to more advanced technologies than local firms. This makes them able to compete against domestic firms which have better knowledge of local markets, consumer preferences, and business practices (see Blomström and Sjöholm, 1999). Foreign affiliates of MNCs might adopt the same business practices and production processes that are common in its headquarters in the foreign country. Usually MNCs also transfer technology to their foreign affiliates explicitly by choosing the technology level that maximizes their expected profits. It is reasonable to assume that the degree of foreign ownership has an effect on the technologies that are transferred to the foreign affiliate and thus also on the degree of spillovers that can materialize. In which direction ownership patterns affect the quality of technology that is transferred is a priori ambiguous, however. If, on the one hand, foreign firms are characterized through a high degree of local participation, technologies might get transferred faster to domestic markets because local partners get closer contact with the foreign technology. On the other hand, forcing MNCs into equity sharing with local partners might have negative effects on the technologies that are transferred to the affiliates. This can be explained by the risk of MNCs of loosing their intangible assets to the local partner, or alternatively the bigger incentive to transfer new technologies if the MNC is able to capture the resulting profits (see Findlay, 1978; Blomström and Sjöholm, 1999). MNCs often invest in increasing the labor productivity of local workers employed in their subsidiary by making them take part in training programs and teaching them operation processes and management methods. This knowledge can spread to domestic firms via labor turnover with employees of MNCs moving to domestic companies, but also by doing business with MNCs and observing their business practices (see Haddad and Harrison, 1993; Kinda, 2012). Thus, productivity diffusion can take place in the foreign affiliate's own industry or through upstream and downstream linkages also in other industries. Apart from that the entry of foreign firms can lead to increased competition in the domestic market. This might stimulates technological upgrading, particularly in firms that are shielded from competition at international markets and which did not have the incentive to operate as efficiently as possible before. All these practices, although operating via different diffusion channels, have the potential to raise productivity in domestic firms.

An alternative channel of technology diffusion is international interconnectedness through improved communication and information technologies and internet usage. Technologies that are freely available in one country can codified and made available through books or through the internet. Information on them might also be exchanged on conferences or over the telephone. The degree of technology diffusion via this channel depends of course on the complexity of the technology and its tacit or codifiable character. The more tacit know-how a certain technology embodies, the more difficult and costly it is to transfer the technology and it might be diffused only by face-to-face contact and training. This implies that the stronger the tacit character of a technology, the more geographically localized the technology will be because the cost of moving people generally increases with distance (see Keller, 2004).

As mentioned in the introduction, technology spillovers are neither inevitable nor automatic. While some forms of technology diffusion arise naturally because current researchers can use the knowledge that has been created by previous research over a long period of time (see Helpman, 1992; Keller, 2004), there are also other ways of technology transfers that depend on local conditions for spillovers to occur. For this type of technological transfer to take place countries have to meet certain requirements to be able to make use of these new technologies. Such prerequisites include education and skill development, what is necessary for using new technologies like operating new machines or having the required skills to using computer programs (see Nelson and Phelps, 1966; Findlay, 1978; Xu, 2000; Seck, 2012). If new technologies incorporate a big share of non-codifiable tacit knowledge costly training programs for using the new technology might be necessary. This is especially true for more advanced products (see Wang and Blomström, 1992; Thoenig and Verdier, 2003). For the adoption of new technologies financial resources might be requried in order to adapt thechnologies that are invented somewhere else to local needs. Many new technologies that are invented by technologically advanced countries might not be of use in developing countries directly, for example due to their skill bias (see Barro and Sala-I-Martin, 1997; Zeira, 2007). Also the protection of property rights plays an important role in the decision of MNCs on which technologies to transfer to their affiliates, as without property rights protection only old technologies might get transferred (see Seck, 2012, for empirical evidence). Also it might be necessary to actively screen for newly available technologies and to provide technical support for potential users of new technologies for technological upgrading to take place (see ECA, 2013, 2014). All of this highlights the importance of policies that complement measures aimed at fostering technology transfers in order to increase the potential to benefit from newly available technologies.

3 Theoretical models

3.1 Technological catch-up and convergence

In an early study, Nelson and Phelps (1966) develop a theoretical model which endogenizes the speed of technology adoption of technologically less advanced regions. In their model human capital and the technology level prevalent in a society are interrelated. The authors assume an exogenously given best practice technology level, which they define as the theoretical technology level prevalent if all technologies spread and get adopted immediately by all economies. This theoretical technology level is supposed to grow at an exogenous constant exponential rate. The authors model technology adoption as an endogenous process that depends on the level of human capital and the gap between the theoretical technology level and the prevalent level of technology in a country. As a result higher educational attainment levels speed up technological catch-up through the adoption of new technologies. However, as the technology gap narrows, the speed of technology adoption decreases. In steady state the level of technology adoption equals the exogenous growth rate of the theoretical technology level. Interpreting this model in the light of a industrialized country being the technological leader operating at the theoretical technology level and developing countries whose technological level is lower than the one of the industrialized country, this implies that the speed of technology adoption could be improved and the technology gap between developing and developed countries could be reduced by investing in education in the developing country. Thus, policies aiming at skill upgrading are important for technological catch-up.

Barro and Sala-I-Martin (1997) endogenize the decision to adopt existing technologies or invent new technologies by making it dependent on the costs of learning. In their theoretical model the authors link endogenous growth models with the neoclassical growth model, and long-run growth depends on the innovations of technologically advanced countries. While the invention of new technologies is limited to a relatively small number of countries, most countries adopt technologies developed by the technological leaders due to the relatively lower cost of copying existing technologies (see also Keller, 2004). In the model the invention of a new technology, or product, is connected to a country specific constant fixed innovation cost. Copying an existing product that is invented in another country is connected to a fixed cost that is an increasing function of the number of goods that are copied. Thus, initially adopting already existing technology is cheaper. The difference in the constant nature of the fixed cost of innovation and imitation is that the number of products that can be invented is infinite, while the number of products that can be copied is bound by the number of products available in the market. During the transition to steady state the adoption of existing products is faster than the invention of new products, thus a catch-up process occurs. However, the higher technological growth rate of the technological less advanced region diminishes over time due to the increasing costs of imitation. In steady state the number of products grows at the same rate in both countries, so does production and consumption. Thus, the model by Barro and Sala-I-Martin implies conditional convergence.[3]

Zeira (2007) provides a theoretical model in which not every country decides to adopt foreign technologies. In his model the endogenous decission on to adopt technologies depends on the relative wages of skilled to unskilled workers. The author assumes that new technology is skill-enhancing and allows to substitute less skilled workers in the production process by a smaller number of skilled

[3] The authors acknowledge that government policies, infrastructure, tax rates, property rights, and the rule of law are subsumed in the technology parameter in their theoretical model.

workers. The new technology is adopted only if the productivity gains by the new technology outweigh the relatively higher costs that arise due to the higher wages of skilled labor in comparison to unskilled labor which was used under the old technology. This implies that countries with a relatively high wage ratio between skilled and unskilled labor are less likely to adopt new technologies than countries with a lower wage ratio. This usually applies to countries that are relatively abundant in unskilled labor, which is commonly the case in developing economies. Thus, Zeira's model implies that developing countries have limited capacities for technological catch-up due to technologies that are not suited to local needs because of their skill-complementary nature.

3.2 Channels of technology diffusion

The above mentioned literature does not model the channel through which technology transfers take place explicitly, a issue that we will look at in this section. An early contribution by Findlay (1978) argues that the presence of multinational corporations in a technologically less advanced economy facilitates technology diffusion. Motivated by the lack of explicit analytical models of technological diffusion at the time the paper was written,[4] Findlay develops a dynamic model of how technology diffusion takes place. He explicitly includes the role of FDI in his model. In the model technological progress in the advanced region is exogenously defined, while technological progress in the less advanced region is endogenously determined as a function of the technology levels in both regions and the presence of foreign firms in the local economy. The influence of foreign firms in the less advanced region is proxied by the ratio of the foreign to the domestic capital stock. It is assumed that the bigger the foreign capital stock in the economy is, the faster the new technology is diffused. Higher profits realized by the affiliates of MNCs as a result of technological upgrading lead to a rise in tax payments, which finally accrue to domestic firms increasing their capital stock and inducing technological catch-up. If technological upgrading is faster in the less advanced region, the foreign sector's profit rate and thus its capital growth rate will fall. This decrease in foreign profits impacts also on the domestic capital stock via its effect on tax revenues that also decline. The long-run steady state is reached when both, the rates of technological progress and the the rates of capital accumula-

[4]The author mentions Mansfield (1961) and Nelson (1968) as two notable exceptions.

tion coincide in the domestic and the foreign sector. It indicates the equilibrium level of technological disparities between the regions and dependence of the less advanced region on foreign capital stock.

The implication of this model is that the less advanced region will never reach the technology level of the technological leader but rather approach an equilibrium gap. This gap can be influenced according to Findlay (1978), however, by an educated labor force, management quality, and other parameters such as market structure, patent laws, and licensing arrangements and royalties. The author also analyses potential scenarios and their impact on the technology gap and foreign capital dependence. He finds that the faster the growth rate of technology in the advanced region, the larger the technology gap and the higher the dependence on foreign capital in the less advanced region. The more favorable opposite can be achieved by increasing the educational level in the less advanced region. According to the model a rise in the tax rate on foreign profits has a similar effect on technological efficiency and foreign capital dependence as a rising propensity to save in the less advanced region—both lead to a reduction of the share of foreign capital in the less advanced region but a larger technological gap. Alternatively, the author argues that it would be possible to allow for a higher savings rate to lead to a higher capability of technology adoption, which would further reduce foreign capital dependence while offsetting the unfavorable effect on technological efficiency. Finally, Findlay acknowledges that although the presented model relies on the assumption that the inflow of foreign capital into a technologically less advanced economy leads to technological spillovers, one could alternatively argue that technological upgrading is reinforced in self-reliant economies.

While Findlay's (1978) model implicitly assumes that foreign affiliates of MNCs operate with the same higher technology level like their headquarters, Wang and Blomström (1992) endogenize the process of technology transfer from multinational companies (MNCs) to their affiliates in the host country, and from these to domestic firms, in a game theoretical model. In contrast to earlier studies, the authors allow the competition of domestic firms to affect the rate at which MNCs transfer technology via FDI. In their model R&D aimed at creating new technologies takes place only in the headquarters of the MNC in the foreign country. The transfer of technology to the MNCs affiliate, which is already established in the host country, incurs a transfer cost. The authors incorporate the age of transferred technology in their model by assuming that the cost of technology transfer decrease with the transfer frequency, what makes it cheaper to transfer old technologies. The demand for investment in technology is derived from the profit maximizing behavior of firms, taking into account that more advanced technology makes the differentiated product of a firm more attractive for consumers. The domestic firm chooses its learning investment to maximize the present value of profits. The foreign affiliate takes into account the decision of the domestic firm when maximizing its own profits, leading to a joint determination of technology investment of both firms.[5] For the domestic firm the learning investment is also an increasing function of the technological proximity. Departing from a relatively large initial technology gap, the investment of domestic companies in learning leads to a technological catch-up process. As reaction to the catch-up of the domestic firm the foreign affiliate raises its investment in technology transfers in order to keep its market share.

The model suggests that the rate of technology transfers of MNCs to their affiliates could be increased by improving the learning efforts of domestic firms to upgrade their technology. If this occurs, foreign affiliates will face higher competition from domestic firms and invest more in technology adoption themselves. Furthermore, learning efficiency and the amount of resources devoted to learning positively impact on the speed of technology transfers. Higher learning investment makes catch-up with more advanced countries more likely. In a short extension of the model for a market with more than two firms Wang and Blomström (1992) allow for positive externalities of learning. In the presence of externalities the equilibrium learning investment of domestic firms is lower than the social optimum. This stresses the need for policies aimed at coordinating learning investment in order to speed up technology transfers via FDI. As technological upgrading leads to an improvement of the products produced by both types of firms while holding the firms profit streams constant, the authors argue that policies leading to faster technology transfer could be welfare enhancing if the benefits outweigh the costs connected to the implementation of such policies.

[5] In order to account for the potentially better access of foreign firms to international capital market, and to allow for a risk premium of the foreign firm to operate in the domestic market, discount rates of future profits of the foreign and domestic firm are allowed to differ. Lower discount rates are connected to higher investment in technology adoption (and thus faster technological upgrading) and depend negatively on the operation risk of the foreign firm in the domestic market and positively on better access to international capital markets.

Finally, Wang and Blomström (1992) do not preclude the possibility of catch-up of the less advanced region, which happens as technological imitation of domestic firms occurs at a faster rate than technology creation through R&D by the MNC headquarters.

Trade can also act as a channel of technology diffusion. It is often argued that trade in intermediate goods leads to productivity improvements through the lower price of foreign intermediates in the production of final goods. Helpman (1992) provides an overview of theoretical models on technology diffusion through intermediate inputs, while Grossman and Helpman (1991) discuss the role of trade as a channel of technology diffusion in these models in more detail. The models are build on a Solow growth model and allow for intermediate inputs in the production function. In the absence of technological progress growth can only be sustained by an sufficiently high marginal product of capital, which in certain situations is, however, not a sufficient condition for long-run growth. Allowing for technological progress in the model either exogenously, or endogenously by making it dependent on capital accumulation, does lead to sustained long-run growth. Technological progress can be introduced by allowing for horizontal or vertical product differentiation through the availability of different product varieties. In the model of horizontal product differentiation investment in R&D leads to the development of additional varieties of inputs. The more intermediate inputs are available to an economy, the more efficient it can use available factor inputs to produce output. Vertical differentiation, in contrast, takes into account different qualities of products. Here, R&D spending aims at improving product quality, which increases total factor productivity. Alternatively, R&D might increase production efficiency also through a reduction of production costs. With increasing experience in R&D (and thus an increasing knowledge capital stock) the productivity enhancing effect of R&D rises. R&D is conducted by using skilled labor, which is no longer available to the production of final goods. The decision to innovate is endogenous and depends on the economy's resource base, the degree of market power and time preferences.

What happens if countries open up to trade? Let us consider the case without international knowledge spillovers first. As mentioned above, R&D activities compete with the manufacturing sector for human capital. Trade liberalization leads to a contraction of the sector that produces the good that uses the economy's relatively scarce factor intensively, as this good can be imported to a lower price. This implies that skill-intensive sectors in a relatively unskilled-labor abundant country contract, and wages of skilled workers decrease according to the Stopler Samuelson theorem. At the same time, this leads to a decrease in the cost of R&D, which uses skilled workers whose wage is now lower and thus spurs innovation. The opposite is true for economies that are net-exporters of the good that uses human capital intensively. Now, what happens if we account for technology spillovers? Technology might spread across boarders in the presence of international trade because of interaction with foreign customers or alternatively because intermediate imports provide access to foreign technology adding to the domestic stock of knowledge. Technology diffusion is assumed to increase with the degree of interaction between the two economies and thus with trade volumes. Unless there are no technology spillovers, the model suggests that an increase in trade flows leads to a higher transfer rate of technologies from abroad, thus raising domestic productivity and accelerating economic growth.

To sum up, in innovation-based growth theories trade has the potential to facilitate the transmission of technological knowledge across international boarders, leading to an increase in a country's total factor productivity and spurring innovation. This effect can be even stronger if trade leads to falling wages of skilled workers, which are employed in the R&D sector. However, through its effect on factor markets trade might also have the opposite effect by drawing away human capital from research activities in cases in which a country exports goods intensive in skilled-labor (see Grossman and Helpman, 1991). For developing countries, which are usually exporters of goods with lower skill-intensity, the first effect seems to be the prevalent one. Thus the theories presented in Grossman and Helpman (1991) and Helpman (1992) point toward productivity enhancing effects of international trade liberalization in these countries.

Eaton and Kortum (2002) focus on imports as a diffusion channel of foreign technology and incorporate geographic distance in their model. The authors depart from the Dornbusch et al. (1977) Ricardian model of international trade, which they append with differences in technology between countries that are separated by geographic barriers. A country's efficiency level is drawn as a random parameter from a country-specific probability distribution. With trade, consumers have access to the goods sold by producers in different countries to different prices, where the price of a good depends on the technology level, input costs, and trade barriers. Foreign technology is accessed through the purchase of cheaper foreign goods and trade augments the production possibilities of a country in this way. Through specialization output can be produced more efficiently by purchasing cheaper foreign inputs. A counterfactual analysis conducted by Eaton and Kortum suggests that technological progress is spread via trade, leading to welfare improvements in all countries if labor is mobile between sectors. With immobile labor lower wages induced by shifting production patterns might lead to a negative income effect, thus leading to a lower overall welfare effect.

The authors conclude that spillovers of foreign technological upgrading on domestic productivity can be potentially high between geographically close countries (or countries with low bilateral trade barriers), and countries with flexible labor markets which allow labor to reallocate to other sectors of production.

3.3 Trade induced technical change

Apart from the role of trade as transmission channel of technology, trade can also stimulate technology creation. In his paper Wood (1995) explains that trade is likely to contribute to technological progress *per se*. He argues that trade liberalization leads to higher competition on world markets, which is especially severe in import competing industries. Industrialized countries that are usually abundant in skilled labor relative to developing countries where the opposite applies, have the incentive to invest in new (unskilled-labor saving) technologies in order to stay competitive, a development that Wood calls defensive innovation.

Thoenig and Verdier (2003) formalize the process described by Wood (1995) in a theoretical model and allow trade to influence the factor bias of innovation. Thoenig and Verdier argue that globalization might not only increase competition but might also make it possible for foreign forms to copy more advanced technology from domestic firms, causing a thread of technological leapfrogging. Thus, in order to reduce the extent of potential technological spillovers to firms in other countries, domestic firms have the incentive to invest in new technologies that are more difficult to copy. These newly invented technologies are likely to embody a big share of tacit knowledge in order to avoid technology spillovers to others because non-codifiable technologies are harder to transfer. These less imitable technologies are usually more skill-intensive than older technologies that are subject to being replicated by others. The authors show that it does not depend on who industrialized countries trade with in order to have the incentive to invest in new skill-biased technologies, as their results similarly apply to North-North and North-South trade.

Apart from the before mentioned mechanisms of trade impacting on technology creation, trade might also lead to an increase in average productivity of a sector as increased competition drives out less productive firms. This idea is formalized by Melitz (2003) who introduces firm heterogeneity into a international trade model. Entry into the market is connected to incurring a fixed cost. Only firms which are more productive than a productivity threshold stay in the market. After trade liberalization every firm can enter the export market conditional on paying an additional fixed cost and incurring an iceberg transport cost. Thus, only the most productive firms choose to export. Exporting firms also expand their production and hire away labor from other firms with lower productivity levels. In the open economy expected profits for potential entrants in the market are larger, due to the possibility to export. This leads to the entry of more firms with more heterogeneous productivity levels. As now there are also potentially more firms with relatively higher productivity levels in the market, the threshold for staying and producing in the domestic market rises. As a result average productivity increases.

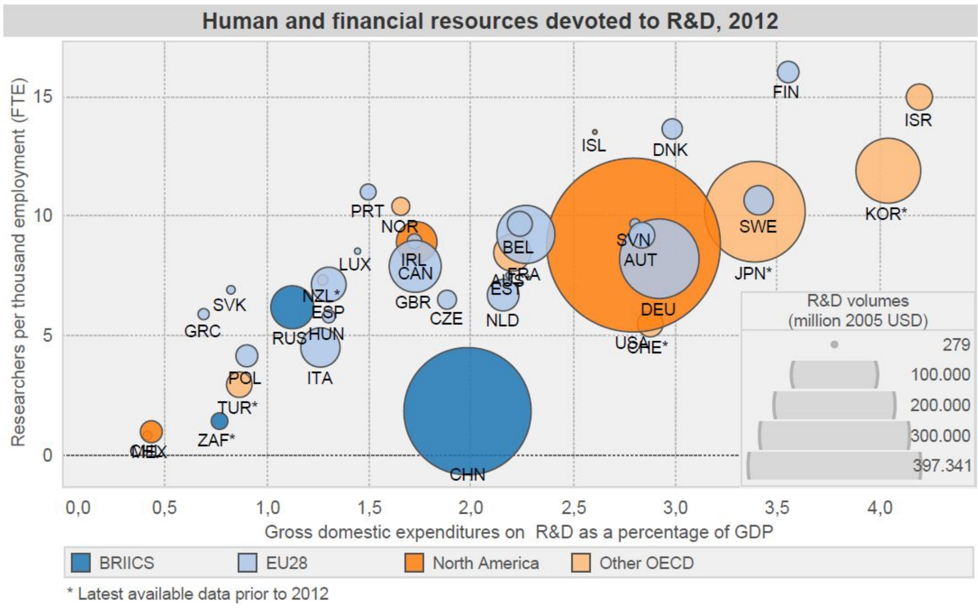
While in the Melitz (2003) model productivity gains occur independent of investment in new technologies, Bustos (2011) appends the model of heterogeneous firms with international trade to incorporate technological upgrading. Like in the Melitz model only the most productive firms enter the export market. Also, it is only the most productive firms that invest into new technologies, which is connected to a fixed cost, because the benefits of technological upgrading are proportional to revenues. Thus, the model implies that trade liberalization leads to technological upgrading that is induced by the rising revenues of exporting firms after opening up the economy.

These examples make clear that trade does not only have an important role as a transfer mechanism of technology but also as a means of spurring innovation.

4 Measurement of technological upgrading and spillovers

Popular proxies for measuring technology are R&D expenditure, the use of patents, or productivity, all of which are connected to advantages and disadvantages. R&D expenditure is widely used as proxy for measuring technology, due to the availability of internationally comparable data for a relatively long time period. Data on R&D are for example available from the OECD for a wide range of countries starting in 1981 (OECD, 2014a, 2015a), and from the World Development Indicators database of the World Bank (World Bank, 2015), starting in 1996. Figure 1 and 2 depict some of the available data from the two databases for the most recent year available per country.

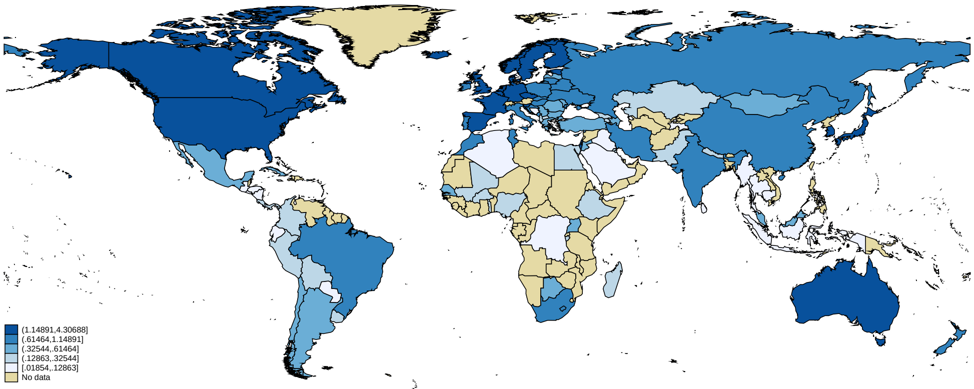
Figure 1: Research and development indicators



Source: OECD, 2015. Available from `www.oecd.org/sti/rds`

As can be seen in the figures industrialized countries account for the biggest part of R&D expenditure as a percentage of their gross domestic product (GDP), while R&D expenditures in developing countries are quite low. There is also a strong positive relation between R&D expenditures and researchers employed, as shown in figure 1. As only a small number of countries account for the largest R&D expenditures, whereas small and relatively poor countries rely relatively

Figure 2: Research and development expenditure (% of GDP)

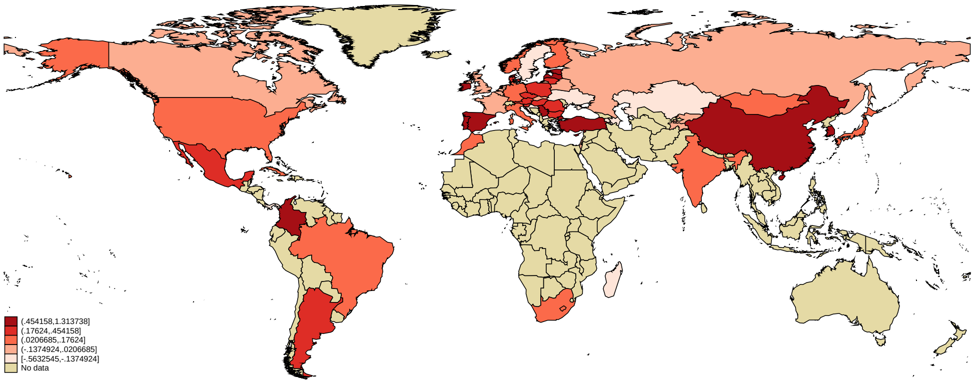


Source: World Development Indicators, 2015. Most recent year available.

heavily on the use of foreign technologies the justification for using R&D expenditure as proxy for technology in developing countries is limited. Technologically less advanced regions primarily invest in imitation and technology adoption rather than technological innovation (see Helpman, 1992; Keller, 2004). The OECD definition, which is usually applied to R&D measurement, comprises only resources spent on increasing the stock of knowledge and innovation and not on technology adoption (see OECD, 2002). Another drawback of using R&D data as a proxy of technology levels is its flow nature, while technology levels are usually related to stock data. Data on R&D expenditure do not take into account previous R&D spending of a country and might be very volatile between years. Thus, many researchers use the perpetual inventory method to calculate R&D capital stocks as a proxy for technology levels. Over time we see an increase in the growth rate of R&D expenditures in developing countries, like indicated in figure 3, which might eventually indicate a catch-up process of these countries. As the main R&D statistics from the OECD are measured at a geographic basis and do not reflect ownership patterns, this development might, however, be connected with the increase in FDI and research conducted in affiliates of MNCs (see Keller, 2004; UNCTAD, 2014).

Another proxy that is commonly used for technology is patent data. Patents give the holder "a temporary legal monopoly to use an innovation in a specific market at the price of public disclosure of technical information in the patent description" (Keller, 2004). In general the use of patent data as a proxy of tech-

Figure 3: Growth rate of research and development expenditure (% of GDP)

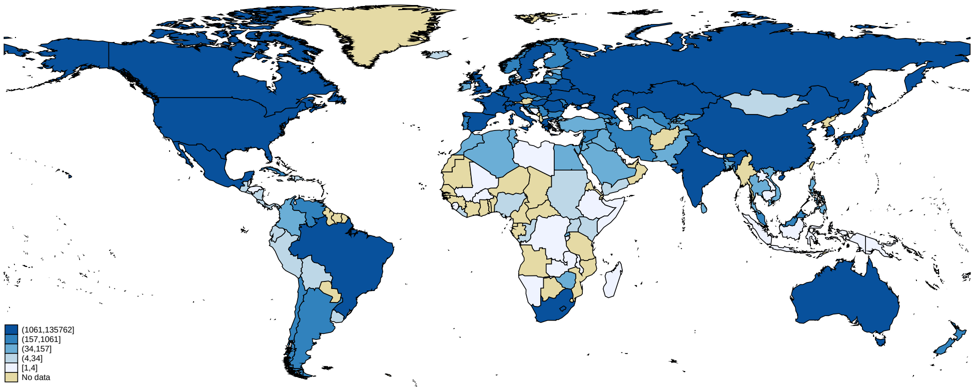


Source: World Development Indicators, 2015. Growth rate between 2001 and 2010.

nology levels is more adecuate in the case of developing countries, as they usually have a substantial number of patents. Data on patents are for example available from the OECD patent databases (OECD, 2015b), the European Patent Office's (EPO) Worldwide Patent Statistical Database (PATSTAT) (European Patent Office, 2013) and the WDI database (World Bank, 2015). For some countries patent data goes even back more than 150 years (see Keller, 2004). Figure 4 displays the number of patent applications by residents in countries for which data is available from the WDI database. As can be seen in the figure, also developing countries make use of patents quite extensively (as compared to R&D expenditures) with an exception of countries in Africa and the Middle East and some countries in Latin America. Figure 5 shows the growth rate of patent applications between 2000 and 2010, also providing some evidence that the application for patents has been growing more strongly in some developing as compared to developed countries.

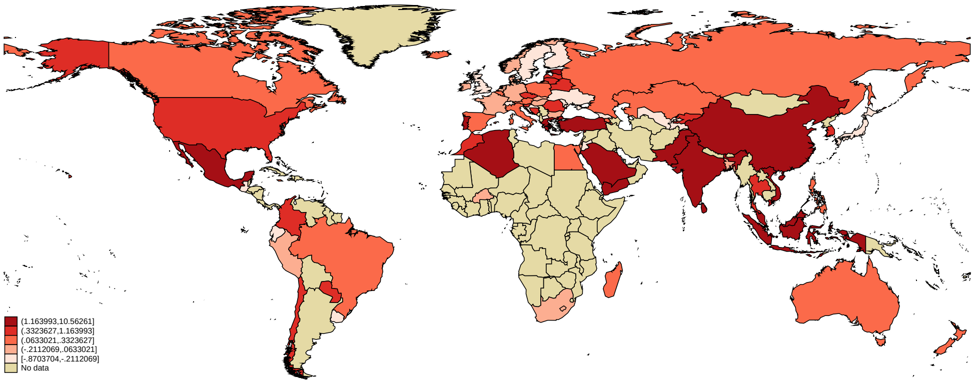
The use of patent data as a proxy for technology levels is problematic as well because not every patent has the same impact on a country's technology stock. Indeed, the biggest part of the value of patents is accounted for by a small number of patents. Thus, simply counting the number of patent applications might be misleading (Keller, 2004). As an answer to that problem, citation-weighted patent data have been used by some authors (see for example Bloom and Van Reenen, 2002; Aghion et al., 2005; Hashmi, 2013). A problem that is more difficult to address is that technology is not always patented, be it based on a firm's decision or the impossibility to codify technology due to its tacit character.

Figure 4: Patent applications, residents



Source: World Development Indicators, 2015. Most recent year available.

Figure 5: Growth rate of patent applications, residents

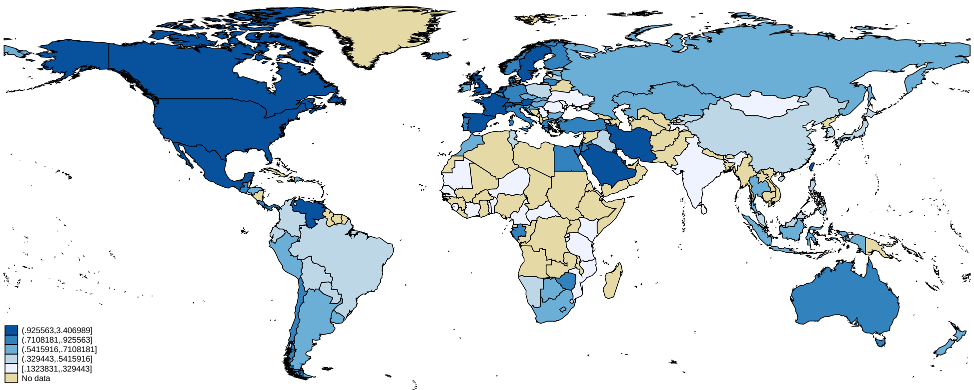


Source: World Development Indicators, 2015. Growth rate between 2000 and 2010.

Also an outcome of the usage of technology, namely productivity, is commonly used by empirical studies. Some of them measure productivity as labor productivity, which is defined as output per worker (and available on a country level for example from OECD, 2014b), while others use total factor productivity (TFP) that is obtained by estimating a Cobb-Douglas production function in which output is related to inputs of production. Because TFP is usually measured as a "residual", that is output that cannot be explained by physical inputs, it might be subject to measurement error as it potentially captures additional factors such as institutions, infrastructure, and other things that are not included in the estimation. Often even data on physical quantities of output and inputs might not be available leading researchers to use data on revenues and expenditures instead.

This might, however, lead to the wrong interpretation of higher mark-ups as an increase in productivity (see Keller, 2004). In order to get rid of the influence of time-invariant institutions in the measurement of TFP, many authors use first differences in order to construct TFP changes which they use instead of TFP levels. Using such method does not get rid, however, of time-variant factors that contaminate TFP estimates. Sometimes TFP measures are therefore used together with data on R&D in order to decrease the likelihood of inappropriately measuring changes in technology (Keller, 2004).

Figure 6: Total factor productivity level at current PPPs

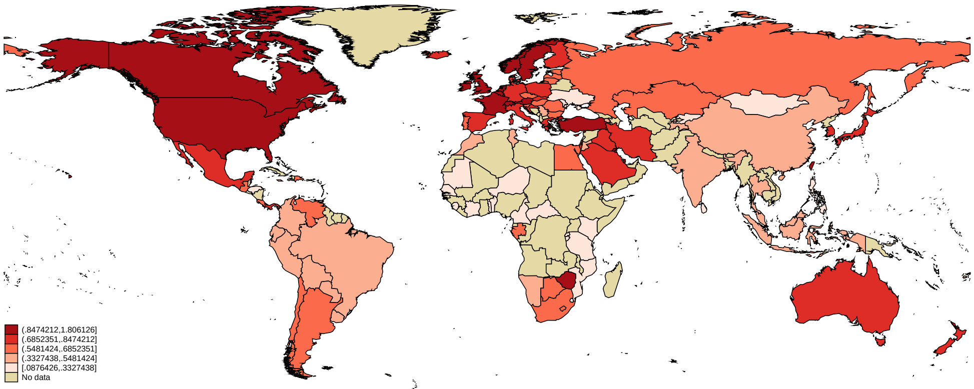


Source: Penn World Table 8.0. Most recent year available.

TFP can be calculated based on sector-level or more aggregated data, but is also available on a national level from the Penn World Table (PWT, Feenstra et al., 2013) for example. Figure 6 depicts the data for all countries in the world for which data is available from the PWT. The pattern that emerges from this picture is similar to the one obtained when looking at R&D expenditure or patent applications—developing countries seem to have lower levels of productivity than technologically more advanced nations. When looking at growth rates in TFP in figure 7, however, developing countries do not seem to have experienced a stronger growth rate of productivity as compared to industrialized nations. The evidence for catch-up based on TFP measures seems to be limited.

There exist attempts to decompose productivity measures into several components, including technological change and technological catch-up. The study by Kumar and Russell (2002) is an example that analyses the distribution of labor-productivity across countries. The authors investigate the driving factors

Figure 7: Growth rate of TFP level at current PPPs

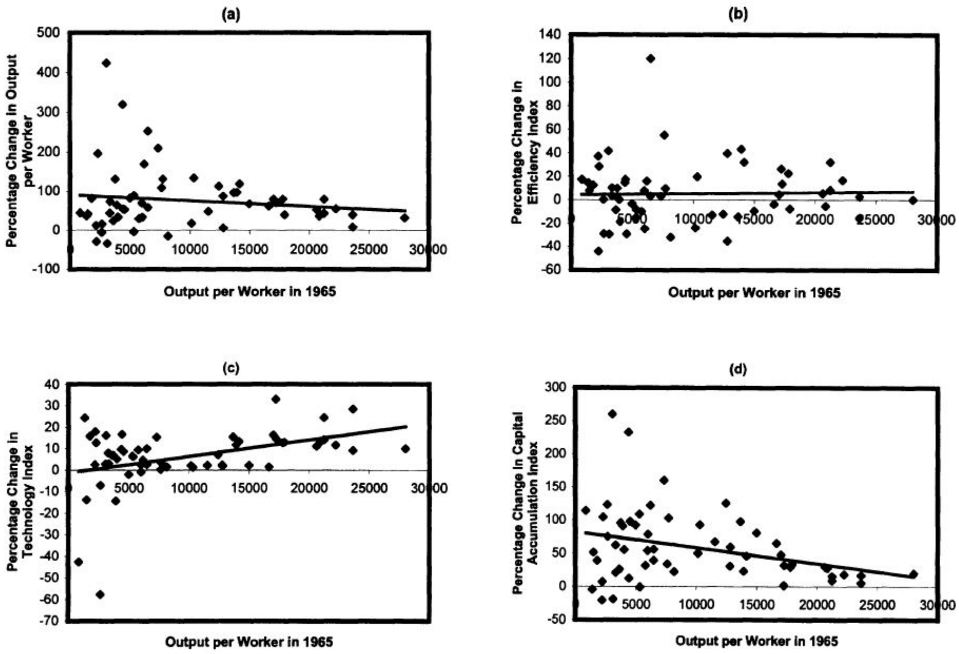


Source: Penn World Table 8.0. Growth rate between 1990 and 2010.

of shifts in the distribution over time. For this, the authors decompose national labor-productivity growth for 57 countries in the 1965–1990 period into three components: technological changes, technological catch-up and capital accumulation. With non-parametric techniques the authors estimate a global production frontier by data envelopment techniques, which represents the state-of-the-art technology level available at a certain point in time to the world. The relative efficiency level of each country is then expressed by the distance to the technology frontier. Some countries operate at this efficient technology level, which can potentially be transferred as well to other countries with lower technology levels. Over time, technological improvements and innovation shifts the state-of-the-art technology level, resulting in shifts in the technology frontier. Also, some countries are closer to the frontier than others, and over time their position relative to the frontier can change. The move toward the technology frontier represents technological catch-up, which reduces technical and allocative inefficiencies. Finally, the degree of capital accumulation can change over time, leading countries to improve their capital-labor ratios which is represented by movements along the technology frontier. A mayor advantage of the non-parametric estimation technique used by the authors in comparison to earlier decomposition analyses is that it does not require any functional form, and does not assume a particular market structure or market imperfections. Thus, it is also more flexible in that it allows technological change to be non-neutral.

The analysis of Kumar and Russell (2002) reveals that on average countries

Figure 8: Percentage changes between 1965 and 1990 in output per worker

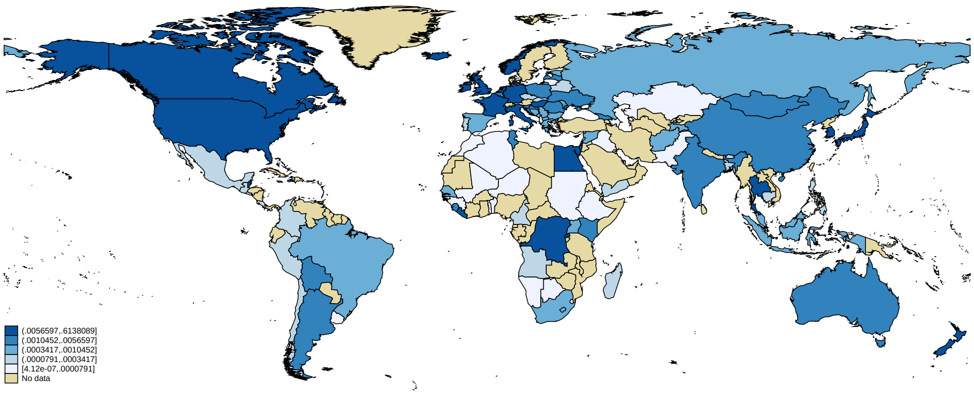


Source: Figure 4 in Kumar and Russell (2002). Note: Percentage changes between 1965 and 1990 in output per worker and three decomposition indexes plotted against 1965 output per worker. Each panel contains a generalized least squares (GLS) regression line.

have moved toward the global production frontier, indicating that there was substantial technological catch-up between 1965 and 1990. Their results however show that this catch-up did not especially benefit poor countries, as rich and poor countries seem to have equally benefited from technology transfer (see panel (b) in figure 8). The authors find that although technological change has positively contributed to growth in most countries in their sample, the benefits from technological change were very unevenly distributed with technological regress in some countries with very low capital-labor ratios and very pronounced technological progress in relatively rich countries (see panel (c)). Thus, technological change decidedly non-neutral in this sense, what indicates that earlier contributions which assume neutral technological change might have led to erroneous results. Capital accumulation turns out to have been the main contributor to increased labor productivity, accounting for on average three quarters of overall productivity gains and therefore seems to be the main driver of observed growth patterns (see panel (d)).[6]

Alternative measure that can be used as proxies for technology include charges from the use of intellectual property rights, trademark applications, high technology exports as a percentage of manufactured exports, and the number of scientific and technical journal articles, all available from the WDI database (World Bank, 2015, see figures 9 to 12).[7]

Figure 9: Charges for the use of intellectual property, receipts (% of GDP)



Source: World Development Indicators, 2015. Most recent year available.

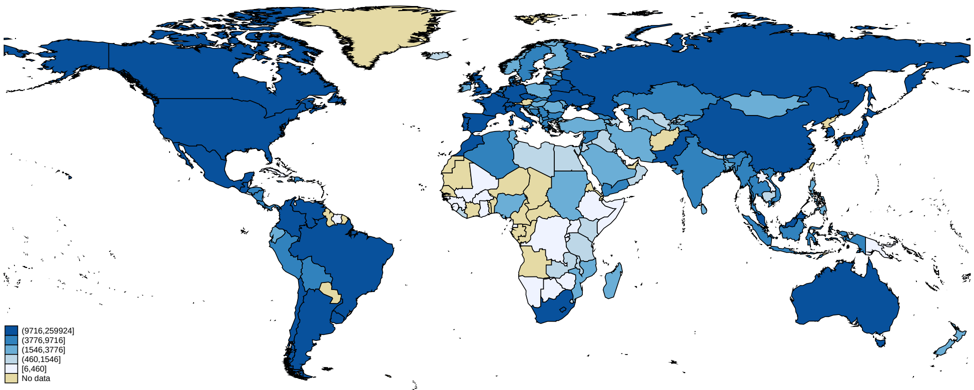
The United Nations Conference on Trade and Development (UNCTAD) provides, among others, statistics on the proportion of businesses using computers and the internet (UNCTAD, 2015). The country coverage of these indicators is limited, however, as is visible in figures 13 and 14.

Also the World Bank Enterprise Surveys (World Bank, 2015) include indicators related to technology, such as for example the percentage of firms using e-mail to interact with clients and suppliers or the percentage of firms having their own website (see figures 15 and 16). These indicators are however usually not available in panel format but are reported only for some points in time.

[6]The authors acknowledge that the finding of the big influence of capital deepening for observed growth patterns can potentially be attributed to them measuring capital deepening by using capital-labor ratios, while other authors that rely on capital-output ratios find a lower influence of capital deepening on economic growth. Growth driven by technological progress could lead to a rising capital-labor ratio—thus the effect of technological progress would be attributed to capital deepening—while the capital-output measure would remain constant. Thus, the analysis presented by the authors potentially underestimates the importance of technological progress for labor productivity and growth.

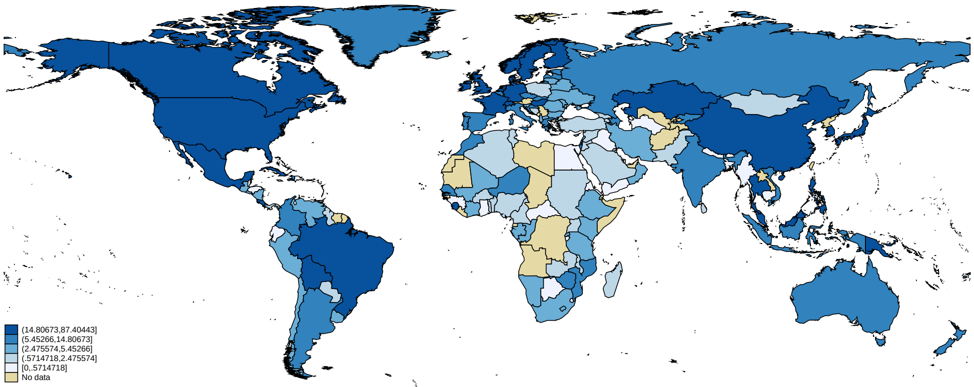
[7]Figures showing the growth rates of the variables showed in figures 9 to 12 can be found in the appendix.

Figure 10: Trademark applications, total



Source: World Development Indicators, 2015. Most recent year available.

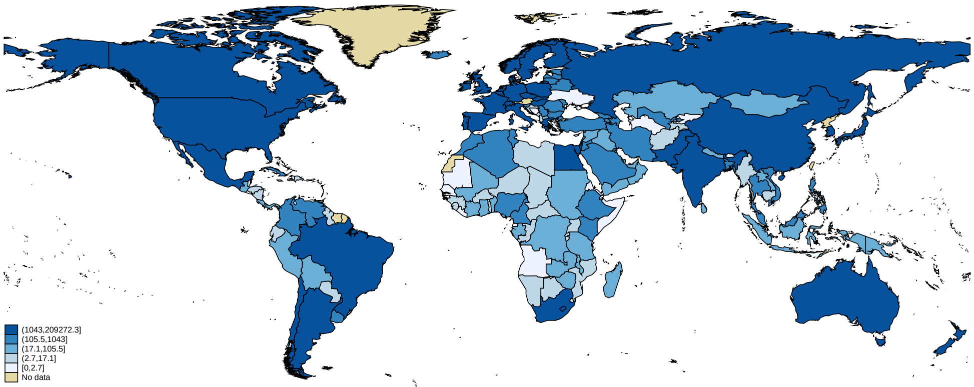
Figure 11: High technology exports (% of manufactured exports)



Source: World Development Indicators, 2015. Most recent year available.

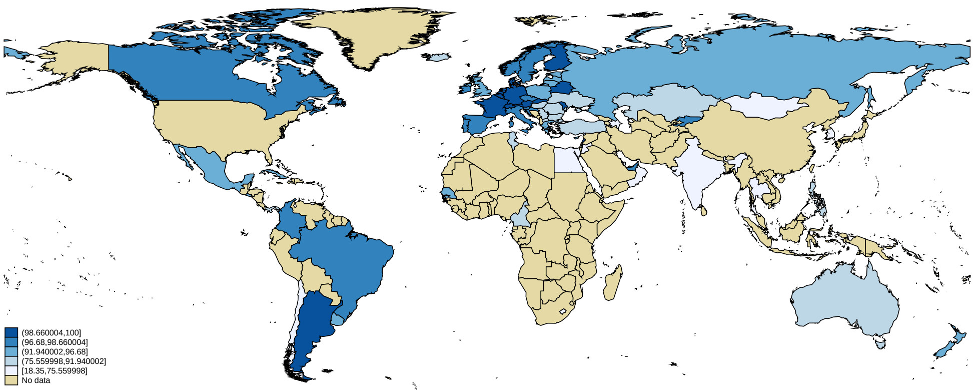
Some studies also use the data on investment in computers and other machinery and technical equipment, or ICT capital goods in order to proxy for technology levels (see Haskel and Slaughter, 2002; Conte and Vivarelli, 2011). Such information is available for example from the OECD (OECD, 2014b, 2015a).

Figure 12: Scientific and technical journal articles



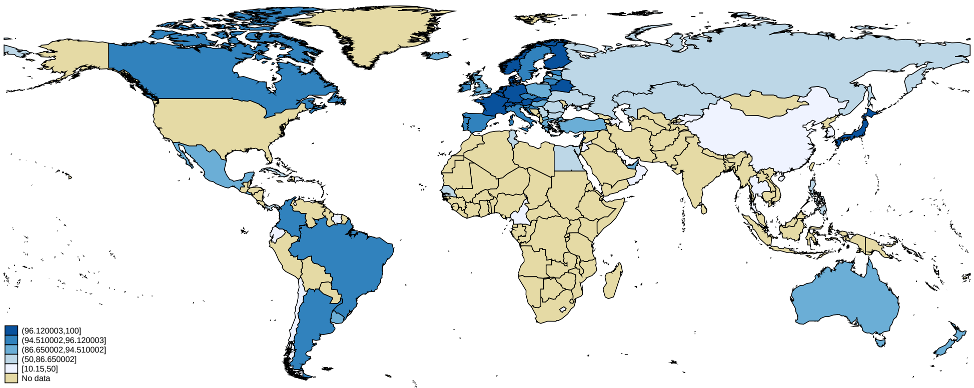
Source: World Development Indicators, 2015. Most recent year available.

Figure 13: Proportion of businesses using computers



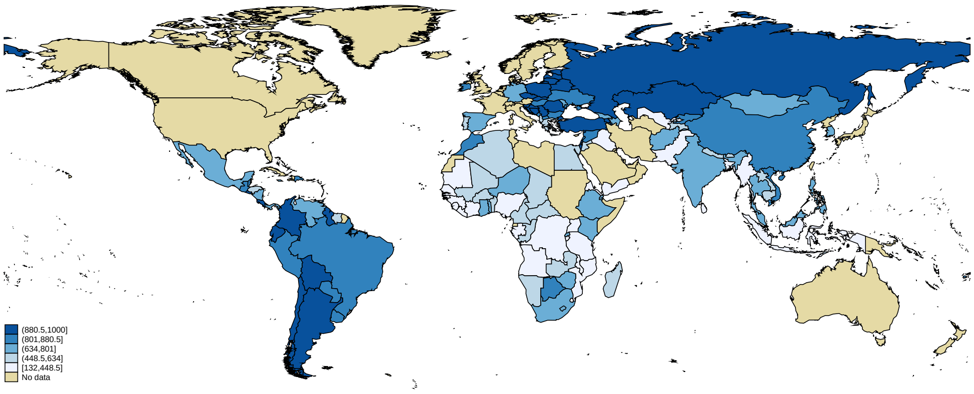
Source: UNCTADstat. Most recent year available.

Figure 14: Proportion of businesses using the internet



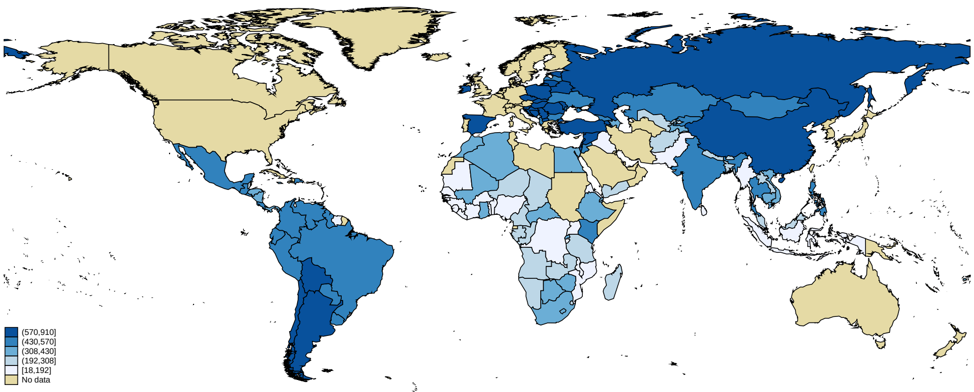
Source: UNCTADstat. Most recent year available.

Figure 15: Percent of firms using e-mail to interact with clients and suppliers



Source: World Bank Enterprise Surveys. Most recent year available

Figure 16: Percent of firms having their own website



Source: World Bank Enterprise Surveys. Most recent year available

Against the background of the above mentioned problems connected to the measurement of technology levels it is evident that the measurement of technology spillovers is even more challenging. While technology transfers can be measured using data on copyrights, patents and licenses, data on the externalities of technology such as technology spillovers do not exist (see Keller, 2004). Empirical studies intend to identify technology spillovers often by estimating R&D spillover regressions, in which TFP (or another proxy of technology) is regressed on a foreign R&D variable. The foreign R&D stock is often weighted by import shares of a country with its trading partners or by other weights that aim to capture the channel of technology transfer (see for example Coe and Helpman, 1995; Lichtenberg and van Pottelsberghe de la Potterie, 1998; Keller, 1998; Tang and Koveos, 2008). Alternatively to basing the evidence of technology spillovers on foreign R&D, also other measures of foreign activity, such as FDI, can be used (see for example Haddad and Harrison, 1993; Blomström and Sjöholm, 1999; Aitken and Harrison, 1999; Waldkirch and Ofosu, 2010; Kinda, 2012). Empirical studies that aim to analyze the extent of such spillovers have to be careful, however in identifying causal effects rather than mere correlations (Keller, 2004). We will summarize some of these studies in what follows. Doing so we concentrate on econometric studies that focus on developing countries or provide important insights in the topic.[8]

5 Empirical evidence

5.1 Foreign direct investment

Haddad and Harrison (1993) investigate the impact of FDI on productivity in the manufacturing sector in Morocco for the 1985–1989 period. Using panel data on individual firms the authors are able to control for firm-specific characteristics such as firm size and to account for the endogeneity emerging from the potential selection of foreign firms into more productive sectors of production. In order to empirically evaluate technology spillovers of foreign to domestic firms, the authors follow two identification strategies: one focuses on productivity levels, while the other one looks at productivity growth. For the first strategy the authors estimate

[8] A summary table including the studies under investigation can be found in the appendix.

an equation of the form

$$u_{ijt} = \alpha + \beta_1 FDI\_firm_{ijt} + \beta_2 FDI\_sector_{jt} + \beta_3 SIZE_{ijt} + \epsilon_{ijt} \tag{1}$$

where u_{ijt} is the deviation of productivity of the firm i from the sector's j best-practice productivity frontier in year t, and FDI_firm_{ijt} and FDI_sector_{jt} are the proportion of a firm's foreign assets in total assets and the share of foreign firms in the sector, and $SIZE_{ijt}$ stands for firm size measured as a firm's sales relative to sales of the largest firm in the sector. The results based on equation (1) suggest that foreign ownership and firm size are connected to higher productivity levels. There is also evidence for a higher productivity level of firms in sectors that are characterized by a higher share of foreign firms. The authors interpret this finding as greater competition through the presence of foreign firms in a sector that leads firms with low productivity levels leave the market.

Turning to productivity growth, the authors specify their empirical model as

$$\begin{aligned} dln(Y_{ijt}) =& \beta_1 FDI\_firm_{ijt} + \beta_2 FDI\_sector_{jt} \\ &+ \beta_4 dln(L_{ijt}) + \beta_5 dln(K_{ijt}) + \gamma_1 D_t + \gamma_2 I_j + \epsilon_{ijt} \end{aligned} \tag{2}$$

where d stands for first differences, $ln(Y_{ijt})$ is the natural logarithm of the value added of firm i in sector j and time t, D_t and I_j are a set of sector and time dummies, $ln(L_{ijt})$ and $ln(K_{ijt})$ are the logarithm of labor and capital respectively. The results of the estimation of equation (2) indicate that the coefficients of both FDI measures are statistically insignificant (and negative), thus providing no evidence for the existence of higher productivity growth in foreign firms or spillovers of productivity growth to firms operating in sectors characterized by a high share of foreign firms. The authors argue that the results could be driven by different technology gaps between domestic and foreign owned firms and include a variable measuring this gap at the beginning of the sample among their regressors. While the above mentioned results on the previously included variables do not change qualitatively, the technology gap variable turns out to be positive and statistically significant in sectors characterized by high import protection. Thus, the productivity of domestic firms that are operative in protected sectors seem to grow faster when there is a large productivity gap to foreign firms. This catch-up is, however, not driven by the presence of foreign firms in the sector.

Haddad and Harrison (1993) estimate a big number of additional specifications to check the robustness of their results and conclude that the found patterns are not affected by variations in trade protection and other factors. They conclude that in Morocco joint ventures benefited from FDI, while the efficiency increase of domestic firms attributable to FDI was a one-time phenomenon. Moroccan firms seem to have not benefited from FDI in terms of rising productivity in the second half of the 1980s.

Blomström and Sjöholm (1999) focus on the case of Indonesia. They investigate whether Indonesian firms realize productivity gains induced by technology transfer and spillovers from foreign firms using firm-level data from 1991. In contrast to Haddad and Harrison the authors rely on data for one year, which impedes them to take into account the impact of time-invariant firm characteristics. Blomström and Sjöholm focus on the ownership pattern of foreign firms in more detail, investigating whether different productivity effects are observed for firms that are or are not majority foreign owned (majority ownership is defined as foreign ownership higher than 50%, while minority ownership is defined as foreign ownership equal or up to 50%). The hypothesis that the authors want to test is whether a higher share of foreign ownership leads to newer technology being transferred and thus higher productivity levels of majority owned foreign companies. Concerning productivity spillovers induced through the presence of foreign companies in a sector the authors expect to observe larger productivity spillovers in sectors characterized by a large presence of minority owned foreign firms in contrast to majority owned foreign firms, because local partners might capture new technologies faster when they work with foreign technologies.

In their empirical setup the authors first investigate whether foreign companies are more or less productive than their domestic counterparts by estimating

$$\begin{aligned}\frac{Y_{ij}}{L_{ij}} =& \alpha + \beta_1 FDI\_firm_{ij} + \beta_2 \frac{K_{ij}}{L_{ij}} \\ &+ \beta_3 skill_{ij} + \beta_4 capacity_{ij} + \beta_5 scale_{ij} + \gamma I_j + \epsilon_{ij}\end{aligned} \tag{3}$$

where, as before, Y_{ij} represents value added of firm i in sector j, L_{ij} and K_{ij} stand for labor and capital stock, $skill_{ij}$ is measured as the ratio of white to blue collar workers, $capacity_{ij}$ is the share of actual to potential output as reported in the dataset, $scale_{ij}$ is the firm's output relative to average output in the industry, and I_j is a set of industry dummies. Here, FDI_firm_{ij} is a dummy variable equal to one if an establishment is partly foreign owned. This indicator is substituted by two dummy variables measuring minority ($\leq 50\%$) and majority ($> 50\%$) foreign ownership in an alternative specification. The results of the authors suggest that the capital-labor ratio, skill level, capacity utilization, and scale of operation are positively related to labor productivity. Furthermore, foreign firms (either majority or minority owned) are more productive than their domestic counterparts.

In the second part of their analysis Blomström and Sjöholm (1999) investigate whether FDI spillovers to domestic firms, indicated by the superscript d, are present in Indonesia by estimating

$$\begin{aligned}\frac{Y_{ij}^d}{L_{ij}^d} =& \alpha + \beta_1 FDI\_sector_j + \beta_2 \frac{K_{ij}^d}{L_{ij}^d} \\ &+ \beta_3 skill_{ij}^d + \beta_4 capacity_{ij}^d + \beta_5 scale_{ij}^d + \gamma I_j + \epsilon_{ij}\end{aligned} \tag{4}$$

where FDI_sector_j stands for the share of output produced in foreign firms at the 5-digit industry level. This variable is replaced in an alternative specification by two variables measuring the share of industry output produced by majority and minority owned firms respectively. The results of estimation of equation (4) provide evidence for productivity spillovers in sectors that are characterized by a high value-added share of foreign firms. There are no statistically significant differences in the effect of the presence of minority and majority owned firms in a sector. The results for the other variables that enter the specification remain the same as before. The results suggest that domestic firms benefit from the presence of foreign firms in a sector in terms of increased labor productivity, while the degree of foreign ownership does not play a role for the strength of productivity spillovers.

Finally, Blomström and Sjöholm (1999) investigate whether the results are driven by increased competition through the entry of foreign firms in domestic markets, which enhance the labor productivity of domestic firms. By doing so the authors split their sample in exporting and non-exporting firms arguing that exporters are already exposed to foreign competition at world markets, while non-exporters might experience an increase in competition and are forced to increase their productivity. Indeed, the results of this analysis suggest that productivity spillovers are restricted to the non-exporter sample, giving support for increased competition driving the results of increased labor productivity.[9]

The authors conclude that the degree of foreign ownership of firms does not have a significant effect on FDI spillovers in Indonesia. They argue that policies that aim to restrict foreign ownership and force MNCs into joint venture agreements seem not to have a productivity-enhancing effect on Indonesian firms.

Turning to the case of Venezuela, Aitken and Harrison (1999) test the hypothesis that inward FDI encourages technology spillovers from foreign to domestic firms. The rich data from the Encuestra Indisturial allows them to track a large number of firms during the 1976 to 1989 period. As each plant can be observed over time, Aitken and Harrison (1999) are able to account for potential endogeneity emerging from non-random selection of firms into sectors. Their results are based on the estimation of a log-linear production function at the firm level by ordinary least squares (OLS) with heteroscedasticity corrected standard errors, which is specified as

$$\begin{aligned} ln(Y_{ijt}) =& \alpha + \beta_1 FDI\_firm_{ijt} + \beta_2 FDI\_sector_{jt} \\ &+ \beta_3 FDI\_firm_{ijt} * FDI\_sector_{jt} \\ &+ \beta_4 ln(X_{ijt}) + \gamma_1 D_t + \gamma_2 I_j + \epsilon_{ijt} \end{aligned} \tag{5}$$

$ln(Y_{ijt})$ is the natural logarithm of output of firm i in sector j and time t, FDI_firm_{ijt} is the share of foreign ownership at the plant level, FDI_sector_{jt} is the average of foreign ownership at the industry level, and X_{ijt} is a vector of plant level inputs including skilled and unskilled labor, materials and capital. D_t and I_j are year and industry dummies and ϵ_{ijt} is a random error term. The authors also estimate variations of equation (5) by weighted least squares (WLS) estimations with employment weights, and by first (and longer) differencing in order to account for firm fixed-effects. Furthermore, they estimate specifications omitting the industry dummies or adding variables measuring local productivity

[9] Exporters might already have access to improved technology through the trade-channel as explained above.

spillovers of FDI, and conduct estimations based on subsamples of different firm sizes.

While Aitken and Harrison (1999) find positive effects of FDI on own plant production, their results do not support the hypothesis that FDI leads to productivity spillovers from foreign to domestic firms. Indeed, these spillovers turn out to be even negative. The authors attribute this finding to a market stealing effect that emerges as higher productivity foreign firms expand and make domestic firms cut their production. Because domestic firms as a result cannot make use of scale economies their productivity declines. However, the authors find some weaker evidence for positive productivity spillovers of FDI to other firms with foreign equity participation. Repeating their estimations for different subsamples based on firm size Aitken and Harrison (1999) find that the results are especially robust for small firms with less than 50 employees, while for larger firms the results depend to a large degree on the specification used.

The results based on first and longer difference transformations of the data strongly confirm the negative productivity spillovers from foreign to domestic firms, while productivity spillovers to other foreign plants are statistically less often significant and own plant effects turn insignificant in each specification. The authors interpret these findings as indication for the preference of foreign investors to invest in the most productive firms *a priori*. Not accounting for firm-level fixed effects would wrongly attribute this behavior to own-plant productivity effects of FDI. Also, these results suggest that foreign firms benefit from FDI in sectors with a already high FDI share. Aitken and Harrison find little evidence for locally concentrated productivity spillovers to domestic firms. However, their results indicate that although at the country level foreign firms benefit from FDI, the opposite is true for geographically close foreign firms, pointing towards a market stealing effect also in this context.

Finally, Aitken and Harrison (1999) also evaluate the overall impact of FDI on productivity at the sectoral level. They use the coefficient estimates of their regressions together with the data to determine the net effect of FDI for each firm. The net effect at the country level is obtained by summing over all firms applying weights that are proportional to the firms output level. This analysis shows that the net impact of FDI on productivity at the country level is quite small and its sign depends on the model specification used.

Although many previous authors—like Blomström and Sjöholm (1999) for Indonesia, found evidence for productivity spillovers from foreign to domestic firms arising from FDI inflows—Aitken and Harrison (1999) provide evidence that in Venezuela the opposite is true. The authors argue that many previous studies, especially cross-country studies, fail to account for the potentially higher investment inflows into sectors with already high productivity levels and therefore mistakenly attribute the higher productivity to capital inflows in these industries. Omitting industry dummies in their regressions, Aitken and Harrison obtain findings similar to those of former cross-country studies, what points towards endogeneity problems in previous research.

In an empirical study on Ghana, Waldkirch and Ofosu (2010) investigate whether there are positive productivity spillovers of FDI on both domestic and foreign firms in the manufacturing sector in the 1991–1997 period. They also look at the effect of FDI on domestic wages. Furthermore, the authors test the hypothesis that although foreign presence might lead to a decline in productivity levels of domestic firms in the short run due to required investments in machinery, tools, and training programs in order to be able to realize the benefits from new technologies, this effect might be offset in the longer run when gains from using new technologies materialize (see also Liu, 2008). Making use of the panel structure of firm-level data from surveys of the Ghanaian manufacturing sector, in their empirical model the authors take into account both observable as well as unobservable firm characteristics in order to avoid spurious results that are subject omitted variable bias and endogeneity issues. The authors base their estimations on measures of total factor productivity, labor productivity and wages, which they subsequently use as dependent variable in their analysis.

The empirical strategy of the authors consists in subsequently estimating the equations

$$
\begin{aligned}
ln(TFP_{ijt}) =& \alpha + \beta_1 FDI\_firm_{ijt} + \beta_2 FDI\_sector_{jt} \\
&+ \beta_3 FDI\_firm_{ijt} * FDI\_sector_{jt} \\
&+ \beta_4 SL_{ijt} + \gamma_1 D_t + \gamma_2 I_{i/j} + \epsilon_{ijt}
\end{aligned}
\tag{6}
$$

$$
\begin{aligned}
ln(TFP_{ijt}) =& \alpha + \beta_1 FDI\_firm_{ijt} + \beta_2 FDI\_sector_{jt} \\
&+ \beta_3 FDI\_sector_{jt} * time + \beta_4 time \\
&+ \beta_5 SL_{ijt} + \gamma_1 D_t + \gamma_2 I_{i/j} + \epsilon_{ijt}
\end{aligned} \tag{7}
$$

$$
\begin{aligned}
ln(LP_{ijt}) =& \alpha + \beta_1 FDI\_firm_{ijt} + \beta_2 FDI\_sector_{jt} \\
&+ \beta_3 FDI\_firm_{ijt} * FDI\_sector_{jt} + \beta_4 ln(kl_{ijt}) + \beta_5 ln(k_{ijt}) \\
&+ \beta_6 SL_{ijt} + \gamma_1 D_t + \gamma_2 I_{i/j} + \epsilon_{ijt}
\end{aligned} \tag{8}
$$

where $ln(TFP_{ijt})$ is the natural logarithm of total factor productivity of firm i in sector j and time t, FDI_firm_{ijt} represents the foreign ownership share of the firm, FDI_sector_{jt} is defined as the output-share-weighted average of foreign ownership in a sector, SL_{ijt} is the share of non-production workers (excluding apprentices and technical workers), D_t and $I_{i/j}$ are a set of time and respectively firm or sector dummies, and ϵ_{ijt} is the error term. In equation (7) $time$ stands for a time trend, which is introduced to test the hypothesis of falling labor-productivity in the short-run and its interaction term with FDI_sector_{ijt} should capture the potentially positive long-run effect on productivity. In equation (8), $ln(TFP_{ijt})$ is substituted by $ln(LP_{ijt})$, which is the natural logarithm of labor productivity (defined by value added per worker) and the logarithm of the capital-labor ratio $ln(kl_{ijt})$ and of capital itself $ln(k_{ijt})$ are included in the specification.

In order to calculate total factor productivity from a production function of the form $Y_{it} = A_{it} K_{it}^{\alpha_1} L_{it}^{\alpha_2}$ to estimate equation (6), where Y_{it} is value added, A_{it} total factor productivity and K_{it} and L_{it} stand for capital and labor, the authors follow three distinct approaches in order to test for the robustness of their results. The authors estimate the production function by OLS and system GMM (generalized method of moments) (see Arellano and Bover, 1995; Blundell and Bond, 1998) and introduce an investment function in an alternative specification of the production function using the Levinsohn and Petrin (2003) methodology to take into account the potential simultaneity between variable inputs and TFP.

The results of estimations of equations (6) to (8) suggest that foreign ownership has a statistically significant positive effect on TFPuctivity of foreign firms especially in sectors that are characterized by a high presence of foreign firms. In contrast, in sectors with a very low presence of foreign firms the effect of foreign ownership on TFP of foreign firms with minority foreign ownership is negative but the statistically significance depends on the model specifications. Domestic firms, in contrast, are always negatively affected by a high share of foreign firms in the same industry. Like in Aitken and Harrison (1999) this result might be explained by negative competition effects as foreign firms crowd out domestic firms by reducing their scale and productivity. This cannot be outweighed by potential positive technology effects. Estimations for a subsample of domestic firms and the results for labor-productivity as dependent variable as in equation (8) reinforce this result. Also, the evidence for positive long-run effects of FDI on domestic firms' productivity from equation (7) is limited. While the short-run effect of FDI is a statistically significant decrease in domestic firms' productivity, the positive long-run effects are either statistically insignificant, or so small that it would take at least 10 years before the negative short-run effects are offset.

Waldkirch and Ofosu (2010) also investigate the effect of FDI on wages in foreign and domestic firms under the hypothesis that foreign firms potentially pay higher wages based on their higher marginal product of labor, while wages paid by domestic firms might contract as a result of increased competition or an on average lower ability level of workers in domestic firms after more able workers are contracted by foreign companies. In order to test whether this is the case in Ghana, the authors estimate an equation similar to equation (8), where they substitute labor productivity by the natural logarithm of wages per worker as dependent variable. The results of this analysis suggest that FDI does not have a statistically significant impact on wages paid by neither foreign nor domestic firms. The authors attribute this finding to rigid labor markets in Ghana, which preclude wage effects stemming from the presence of foreign companies in the domestic market.

The authors conclude that empirical studies focusing on the same question in different countries have resulted in very distinct findings concerning the effects of FDI on the productivity of domestic firms. They point out that results found for one country should not be extrapolated to another country, as country characteristics such as the technology gap between the origin and the host country of FDI, intellectual property rights enforcement, the level of competition in the market, as well as economic size are important determinants of the occurrence of productivity spillovers. They emphasize that especially Sub-Saharan Africa is quite distinct from many Asian and Latin American countries in terms of trade and investment policies (see also Asiedu, 2002).

A cross-country study by Xu (2000) distinguishes between the technology diffusion effect and other productivity-enhancing effects of the presence of U.S. MNCs in a panel of 20 developing and 20 developed countries for the 1966–1994 period. The author uses data on technology transfers to the MNCs' affiliates, which he measures by the royalty and license fee payments of the MNCs' affiliates to their parents as a share of their value added. Under the assumption that higher spending on this kind of technology transfers leads to a bigger degree of technology diffusion to the host country of the affiliate, the author is able to separate the effect of technology transfers from other productivity enhancing effects of the presence of MNCs such as productivity and efficiency gains through increased competition. In an empirical specification the author regresses the growth rate of TFP on the technology gap measured as the ratio of a country's TFP to the TFP of the US, on education measured as the average years of male secondary school attainment, and consecutively on the value added of the MNCs' affiliates as a share of the GDP of the host country, the spending on technology transfers of MNCs' affiliates as a share of their value added, and the share of technology transfer spending of MNC affiliates in the host country's GDP. Each estimation includes country and time fixed effects. The author takes into account potential endogeneities of the MNC measures by instrumenting the value added share of GDP by MNCs' affiliates and the technology transfer spending of MNC affiliates as a share of their value added. The author finds a statistically significant positive coefficient of each of the three MNC variables in the full sample, indicating that there are productivity and technology gains associated with the presence of MNCs' affiliates. Splitting the sample and repeating the same estimations for developing and developed countries separately, the author finds evidence for a productivity increase due to the presence of MNCs in both groups, while the effect of technology transfer (measured as share of value added or host country's GDP) turns out to be statistically significant only in the sample of OECD countries. The author interprets this finding as evidence for technology diffusion taking place only in developed countries, which he explains by the higher level of human capital in this group of countries as compared to developing countries. He concludes that especially in developing countries human capital plays an important role in attracting technology from MNCs.

Another cross-country study by Kinda (2012) investigates the presence of vertical productivity spillovers via backward linkages using information on the share of a company's sales to MNCs in the country, employing firm level data for Brazil, Morocco, Pakistan, South Africa, and Vietnam in the mid 2000 period. The author uses one-step stochastic frontier analysis, accounting for the effect of the investment climate faced by domestic and foreign firms. In her model the production function, the determinants of firm inefficiency, and an error term consisting of a technological inefficiency part and a random external shock, are estimated simultaneously (see Kinda, 2012). The one-step stochastic frontier model can be written as

$$\begin{aligned} ln(Y_{cijt}) = ln(f(L_{cijt}, K_{cijt}, D_t, I_c, I_j, \beta)) + V_{cijt} - U_{cijt} \\ \text{where } U_{cijt} = Z'_{cji}\delta + \eta_{cijt} \end{aligned} \tag{9}$$

where $ln(Y_{cijt})$ stands for the natural logarithm of the value added of firm i in sector j and country c at time t, L_{cijt} and K_{cijt} stand for capital stock and labor, D_t, I_c, and I_j are a set of time, country, and industry dummies, β is the coefficient vector, V_{cijt} is the part of the error capturing composite shocks, and U measures technical inefficiency. U_{cijt} can be expressed as a function of the investment climate and firm specific characteristics, which are summarized in the vector Z_{cij}. η_{cijt} is a random error term.

The results provide evidence that firm productivity is strongly influenced by investment climate constraints, which are lower for foreign firms. This is because in contrast to local firms, foreign firms seem to use their capacity to influence their own investment climate via for example generating their own electricity using power generating units, or by their decision to locate in areas with more favorable investment climate. The only factor that turns out to undermine the productivity of foreign firms is the time they have to spend in dealing with government regulations because their knowledge of local markets in comparison to domestic firms is limited.

In order to investigate to what degree vertical productivity spillovers to domestic firms are present in the countries under investigation, Kinda (2012) uses information on the share of a firm's sales to MNCs located in the respective country. This allows him to identify spillovers through backward linkages. The results of Kinda's analysis indicate higher productivity levels of (especially small) local firms that sell a higher share of their production to MNCs. The author mentions various explanations for this finding for which formal tests are not possible due to data constraints. The diffusion of higher technology to domestic suppliers of MNCs is one potential explanation of the results. Alternatively, the demand from MNCs could increase competition among local suppliers, which leads to improvement in efficiency while driving the least productive firms out of the market. The author acknowledges that her results could also be affected by endogeneity bias as foreign firms could choose the most productive domestic firms as their suppliers. In this respect the results on spillovers to local firms via backward linkages are inconclusive and further investigation is needed.

Given the very heterogeneous findings on whether the presence of MNCs affect domestic firms' productivity, Görg and Strobl (2001) conduct a meta analysis in order to find out whether differences in study design drive the results. Their analysis covers 21 papers focusing on both on developing and on developed countries for different time periods. Both cross-section and panel data studies are included in their analysis, which are using either industry or firm level data. Furthermore, the included papers differ in their definition of the foreign presence variable used (employment share, output share, or other) and the dependent variable (output per worker, growth of output, or other). Görg and Strobl (2001) perform a formal test on whether either of these differences could be responsible for driving the heterogeneity of findings in the various studies. Additional to controlling for the above mentioned differences, the authors also include a measure for sample size (the square root of the degrees of freedom) among their variables. Görg and Strobl provide evidence that the results of cross-sectional studies usually point towards a significantly higher (positive) effect of foreign presence on domestic firms productivity, in contrast to panel-data studies that usually find insignificant or even negative productivity spillovers. The same explanation applies to the different findings of the studies on developing countries that we summarized above. The authors attribute this result to time invariant firm or sector specific characteristics that cannot be controlled for in cross-section studies in contrast to panel data studies, a point also mentioned by Aitken and Harrison (1999).

If foreign firms are attracted by sectors with high productivity, the coefficient of the presence of MNCs on domestic firms productivity would be positive and mistakenly overstated (see Aitken and Harrison, 1999; Görg and Strobl, 2001). Görg and Strobl do not find any of the other controls having an impact on the results of the underlying studies, thus not providing evidence for the hypothesis of Haddad and Harrison (1993), Kokko et al. (1996), and Xu (2000) that positive technology spillovers from foreign to domestic firms might not be present in developing countries due to their lower level of human capital and lower absorptive capacity as the technology gap between domestic and foreign firms is potentially bigger. Finally, Görg and Strobl (2001) point out that the empirical literature in this field might be subject to publication bias and studies that find insignificant effects of MNCs on domestic firms' productivity might not be published.

Summing up, there exist very limited evidence that FDI has a positive (and statistically significant) effect on the productivity of local firms in developing countries. Studies that find evidence for positive spillovers usually rely on cross-sectional datasets which impede them to take into account endogeneity due to the decision of foreign firms to locate in sectors that have a higher productivity level on average. Against this background, the question emerges whether expensive national investment promotion policies that are aimed at attracting FDI inflows—such as fiscal or financial incentives like for example investment grants or subsidized credits—are justified. Often, such policies are criticized for being economically inefficient and for leading to misallocations of public funds (UNCTAD, 2014). A study by Haskel et al. (2007) attempts to quantify the productivity gains of domestic firms through FDI in the U.K. and relates these gains to the cost of government incentives granted to attract FDI. The authors use plant level data covering the manufacturing sector in the 1973–1992 period and account for endogeneity and selection bias in their production function estimates. Haskel et al. find evidence for positive productivity spillovers from foreign to domestic firms, which are typically small, however. Their results indicate that a 10 percentage point increase in foreign presence in an industry raises domestic plants' productivity by about 0.5 percent. This suggests an additional annual £2,440 (in 2000 prices) generated by one additional foreign job. The authors conclude that this is much less than per-job incentives granted by the government to attract FDI and therefore question the effectiveness of such government incentives.

Especially in the light of negative effects of FDI on domestic firms' productivity that are sometimes found in the literature (like found by Aitken and Harrison, 1999, for Venezuela or Waldkirch and Ofosu, 2010, for Ghana), also investment incentives that are not costly for the government like for example investment liberalization or simplified business registration might not be beneficial if indeed there is a market stealing effect of foreign firms. Although foreign firms may experience productivity increases, these benefits might not accrue to the domestic economy. As a reaction to potentially unfavorable effects of FDI on the domestic economy some countries introduce new FDI restrictions like Indonesia, Sri Lanka, or India for example (see UNCTAD, 2014). However, although the presence of foreign firms might not have positive impacts on the productivity of domestic firms, the presence of MNCs might still have other beneficial affects for developing countries' domestic economies as they might create additional employment opportunities or because foreign firms might pay higher wages or provide better labor standards. Also these factors should be taken into account when evaluating the implications of FDI on welfare.

5.2 Trade

In this section we focus on the role of international trade as a channel for technology diffusion. In an influential study, Coe and Helpman (1995) investigate the existence of international R&D spillovers embodied in international trade flows for a sample of 21 OECD countries and Israel in the 1971–1990 period.[10] The authors depart from theoretical models of innovation-driven endogenous growth, which we summarized in section 3, in which expenditures on R&D lead to either an increase in the number of available inputs in the production function (horizontal differentiation) or inputs of higher quality (vertical differentiation), both of which increase productivity (see Helpman, 1992; Grossman and Helpman, 1991). Taking into account the extent of globalization reflected by the large observed trade volumes, the authors account for the possibility of using inputs for production that are produced by an economy's trade partners. Their hypothesis is that imports of goods and services embody technological knowledge of the exporter that is directly related to its R&D capital stock, what might enhance

[10] Although the authors do not focus on developing countries we summarize the paper because it has been indicatory for a whole strand of following research.

domestic productivity. The authors measure productivity as the natural logarithm of TFP, which they regress on the domestic R&D capital stock and the import-share weighted average R&D stock of a country's trading partners. The empirical specification that Coe and Helpman (1995) estimate is the following:

$$ln(TFP_{it}) = \alpha_i^0 + \alpha^d ln(S_{it}^d) + \alpha^f ln(S_{it}^f) + \epsilon_{it} \tag{10}$$

where $ln(TFP_{it})$ is the natural logarithm of total factor productivity (in local currency units) in country i and year t, S_{it}^d is the domestic R&D capital stock (in constant U.S. dollars), and S_{it}^f is the import-share weighted foreign capital stock, which takes the form

$$S_{it}^f = \sum_{j \neq i} \frac{m_{ijt}}{m_{it}} S_{jt}^d \tag{11}$$

m_{ij} measures imports of country i from country j, and m_i are the total imports of country i. Thus, a country potentially benefits more from foreign R&D if it imports more from countries with a relatively high R&D stock. In order to take into account that TFP is measured in local currency units, while data on R&D is measured in constant U.S. dollars, the authors transform their data into index numbers, what leads to the absorption of the denominators that are used to index country specific R&D stocks in the country fixed effects α_i (see Lichtenberg and van Pottelsberghe de la Potterie, 1998). A version of equation (10) that takes into account also the volumes of trade flows and not just their relative importance is

$$ln(TFP_{it}) = \alpha_i^0 + \alpha^d ln(S_{it}^d) + \alpha^f \frac{m_{it}}{y_{it}} ln(S_{it}^f) + \epsilon_{it} \tag{12}$$

where the import-share weighted foreign capital stock is scaled by the share of imports as a proportion of GDP (y_{it}). Coe and Helpman allow the coefficient of domestic R&D expenditure to be different for the the seven largest economies (G7) from the coefficient estimate for the rest of the countries in the sample.[11]

Their results suggest that domestic R&D is an important driver of domestic productivity. This effect turns out to be more pronounced in G7 countries, for which the elasticity of productivity with respect to domestic R&D is higher than compared to the rest of the sample. Furthermore, the authors find international

[11]The authors take into account the cointegration relationship between total factor productivity and domestic and foreign R&D capital stocks which they use in their empirical analysis.

R&D spillovers to be important contributors to domestic productivity. While in G7 countries domestic R&D seems to affect TFP more strongly than foreign R&D, the reverse is true for small countries which are in general more open to international trade and can therefore profit more from international R&D spillovers. The impact of foreign R&D is stronger the more open the economy of a country is to international trade.[12]

Coe et al. (1997) performs a similar analysis to that in Coe and Helpman (1995), expanding their sample to include 77 developing countries in the 1971–1990 period in order to investigate whether developing countries are equally able to benefit from international R&D spillovers like their industrialized counterparts. The authors slightly modify their estimation equation, taking into account the diversity of the countries in their sample in terms of human capital and the fact that these countries virtually do not invest significant proportions of their income in R&D. Their model takes the form

$$dln(TFP_{it}) = \alpha_i^0 + \alpha_i^f dln(S_{it}^f) + \alpha_i^m dM_{it} + \alpha_i^e dE_{it} + \alpha^t time + \epsilon_{it} \tag{13}$$

d stands for first differences, $ln(TFP_{it})$ is the natural logarithm of total factor productivity in country i and year t, S_{it}^f is the import-share weighted foreign R&D capital stock, which is based on import shares of machinery and equipment from industrial countries, M_{it} is the share of machinery and equipment imports from the 22 industrial countries in the sample, E_{it} is a measure for eduction, proxied by secondary school enrollment, $time$ is a time trend and ϵ_{it} is the error term. In this specification the coefficients α_i are allowed to differ between countries. The authors also allow for an interaction of M_{it} and E_{it} with S_{it}^f in an alternative specification.

The results of the the authors suggest that there exist positive spillovers of foreign R&D on domestic TFP in developing countries, and that imports of machinery and equipment reinforce this effect.[13] Although the share of secondary

[12]Coe and Helpman (1995) also calculate a measure of the rate of return on investment in R&D by using information on the ratio of output to R&D capital stocks and on the elasticities of TFP with respect to R&D estimated before. The results of this analysis suggest that the rate of return on R&D capital is very high.

[13]For very low levels of import-share weighted foreign R&D capital stocks imports of machinery and equipment turn out to have a negative effect on TFP.

school enrollment has a positive effect on domestic TFP, it seems not to affect the degree of R&D spillovers. Because developing countries usually do not invest significant proportions of their income in R&D as compared to industrialized countries, the spillover effects of foreign R&D are particularly important for them. Coe et al. (1997) conclude that R&D spillovers from the North to the South are also of quantitative importance.

Lichtenberg and van Pottelsberghe de la Potterie (1998) re-examine the empirical model of Coe and Helpman (1995) and point out some methodological problems connected to it. They show that the weighting scheme used by the authors to compute foreign R&D capital stocks in their empirical estimation is influenced by the level of data aggregation used and suggest an alternative weighting scheme for foreign R&D, which takes into account the intensity as well as the direction of international R&D spillovers. It is defined as

$$S_{it}^{f-alt} = \sum_j \frac{m_{ijt}}{y_{jt}} S_{jt}^d \tag{14}$$

The authors also improve upon the estimation framework of Coe and Helpman (1995) by noting that the transformation of variables into index numbers leads to a misspecification of equation (12). They re-estimate the same specification using levels instead of index numbers. Finally, Lichtenberg and van Pottelsberghe de la Potterie (1998) emphasizes that the equations estimated by Coe and Helpman (1995) can be written as a special case of the more flexible form

$$ln(TFP_{it}) = \alpha_i^0 + \alpha^d ln(S_{it}^d) + \alpha^f \left[\frac{m_{it}}{y_{it}}\right]^{\theta_1} ln\left[\sum_j \frac{m_{ijt} S_{jt}^d}{m_{it}^{\theta_2} y_{jt}^{\theta_3}}\right] + \epsilon_{it} \tag{15}$$

for which θ_1, θ_2, and θ_3 are parameters that can take the values of 0, 1, or some other value. Based on this equation the authors show that the share of imports from a country to its GDP, like in equation (14), is a more appropriate weight than the share of imports from a country to total imports of the recipient country, as in equation (11). Furthermore, when taking into account the erroneous use of indexes by Coe and Helpman (1995) the finding that countries that are more open to international trade benefit more from foreign R&D spillovers than countries that trade less turns statistically insignificant. By adding the import share and its interaction with foreign R&D among the regressors, the results indicate that increased openness reduces TFP unless the foreign R&D capital stock is very large. This indicates that the country of origin of imports rather than import volumes alone drives the domestic productivity enhancing effect of foreign R&D.

Keller (1998) also revisits the analysis in Coe and Helpman (1995) in order to assess whether the international R&D spillovers found by Coe and Helpman are driven by international trade patterns. The authors perform a Monte-Carlo based analysis that generates randomly matched trade partners in order to compare the results of these random trade patterns with the results using actual trade patterns that are observed in reality. The motivation of Keller (1998) is that if the estimates based on the exposure to foreign R&D measured by randomly created trade links are similar or even outperform the estimates based on real trade patterns, this would cast doubt on the claim that trade patterns are important in driving R&D spillovers.

Keller (1998) substitutes the import measures m_{ijt} in the construction of the import-share weighted foreign R&D capital stock in equation (11) with randomly created values. He also treats m_{it} in the estimation of equation (12) similar. Keller's results indicate that also these randomly created import flows give rise to positive spillovers of foreign R&D. They even outperform the ones based on actual trade flows—they are often larger and explain more of the cross-country variation in TFP. In a second exercise Keller (1998) abstracts from trade flows completely by substituting the import-share weighted foreign R&D capital stock in equation (11) by a unweighted sum of foreign R&D capital stocks.

$$S_{it}^{f-uw} = \sum_{j \neq i} S_{jt}^{d} \tag{16}$$

In this setting R&D spillovers on TFP do not depend on trade patterns at all. The results based on this specification indicate positive international R&D spillovers that are larger than the ones found by Coe and Helpman (1995) and explain more of national TFP. Thus, the results of the analyses conducted by Keller (1998) cast serious doubt on the importance of a country's import composition for impacting its productivity via R&D spillovers.

The author points out that his results seem unsurprising in the light of the data aggregation and data quality, the uncertainty connected to the data generating process and the complicated nature of the problem. He concludes by highlighting that factors that are unrelated to trade might be important for explaining international technology diffusion.

Trade might, however, still be an important channel for technology diffusion. The analysis of Keller (1998) is incomplete in the sense that it does not take into account the interconnectedness of the world trading system and indirect spillovers of R&D embodied in imports via third countries, which should ideally also be included in the investigation. Lumenga-Neso et al. (2005) account for such indirect spillovers of foreign R&D through third countries using the same dataset as Coe and Helpman (1995) and appending it by trade flows of 92 additional countries. The authors decompose foreign R&D that is imported into a direct component as in Coe and Helpman (1995) and an indirect component that arises from indirect imports via third countries. For their estimation the authors use the same specification as Coe and Helpman (1995) and Keller (1998) (equation (10)) where S^f can stand alternatively for the definition of Coe and Helpman (see equation (11)), the definition of Keller (see equation (14)) or the import weighted sum of foreign R&D available in each trading partner (see Lumenga-Neso et al., 2005) where

$$S^{f-total} = S^f + S^{f-indirect} \tag{17}$$

and

$$S^{f-indirect} = \left[(I + \rho M)^{-1} - I - \rho M\right] S^d \tag{18}$$

S^f is defined as in equation (11), S^d is the domestic R&D capital stock, and $S^{f-indirect}$ accounts for indirect trade-related R&D spillovers. I is the identity matrix, and M is the matrix of bilateral import shares.

The result of the authors suggest that indirect R&D spillovers are much larger than the direct ones used by Coe and Helpman (1995). There is evidence that trade acts as an important transmission channel of technology, once indirect spillovers through third countries are taken into account. The result found by Keller (1998) is likely to arise because bilateral trade patterns do not account for the much larger indirect R&D content that is embodied in the total foreign R&D capital stock. The authors conclude that trade volumes are more important than trade patterns for technology transmissions.

Focusing on developing countries, Conte and Vivarelli (2011) investigate the existence of imported skill-biased technological change for a group of 23 developing countries over the 1980–1991 period. The authors apply a more direct measure of technology transfer via imports than previous studies. Their technology transfer indicator measures the value of imports of capital goods from high-income countries that are likely to incorporate advanced technologies. The authors define those products as industrial machinery and equipment, power-generating machinery, electrical machinery and apparatus, and ICT capital goods such as office machines, automatic data-processing equipment, and telecommunication apparatus (TLC). The hypothesis of the authors is that technology imports are skill enhancing and thus should lead to widening skill-based employment differentials in the countries of their sample. Conte and Vivarelli base their empirical analysis on the first-order profit-maximization condition for labor obtained from a constant elasticity of substitution (CES) production function. Their empirical model, which they estimate in a system GMM framework (see Arellano and Bover, 1995; Blundell and Bond, 1998) takes the form

$$\begin{aligned} ln(L_{cjt}) =& \alpha + \beta_1 ln(L_{cjt-1}) + \beta_2 ln(Y_{cjt}) + \beta_3 ln(wL_{cjt}) \\ &+ \beta_4 ln(K_{cjt}) + \beta_5 ln(TI_{cjt}) + \gamma_1 D_t + \gamma_2 I_{c/j} + \epsilon_{cjt} \end{aligned} \tag{19}$$

where $ln(L_{cjt})$ stands consecutively for the natural logarithm of blue and white collar workers in sector j in country c and year t, $ln(Y_{cjt})$ represents the logarithm of value added, $ln(wL_{cjt})$ is consecutively the wage of blue and white collar workers, $ln(K_{cjt})$ measures capital deepening as the ratio of gross fixed capital formation to value added, $ln(TI_{cjt})$ stands for technological import deepening which is defined as the ratio of technology imports to value added. D_t and $I_{c/j}$ are set of time dummies and successively country and sector dummies, and ϵ_{cjt} is the random error term.

Their results indicate that the deepening of technology imports significantly raises the demand for white-collar workers, while it has no statistically significant effect on the number of blue-collar workers. The authors interpret this result as being in line with the intuition that technology imports are skill-enhancing and thus impact on the skill-bias of employment.

The effect of international telephone traffic as transmission channel of foreign R&D is investigated by Tang and Koveos (2008). The authors adopt a similar approach to the one of Coe and Helpman (1995) by estimating a variant of equation (10) in which they add an interaction term of the domestic R&D variable with a dummy variable for OECD countries, a measure for openness and a human capital measure among the explanatory variables. Their study comprises of 22 OECD and 21 developing countries in the 1983–1997 period. The authors subsequently use three different weighting methods for the stock of foreign R&D. One is based on equation (11) in Coe and Helpman (1995), while the other two substitute import shares by the inward FDI shares from G7 countries in total inward FDI from G7 countries and the share of a country's outgoing telephone traffic to G7 countries in total outgoing telephone traffic to G7 countries. In an alternative specification the authors subsequently include two of the three measures together in their estimations. The results indicate that technology diffusion, especially via trade and international telephone traffic have significant positive impacts on total factor productivity, while the effects of FDI as transmission channel are smaller in size. The spillover effects for trade and telephone traffic are higher in developing countries, while there does not exist a significant different effect for FDI as transmission channel.

The results of Tang and Koveos (2008) have to be interpreted with caution. The authors modify the weights for measuring the influence of the foreign R&D capital stock on domestic TFP and draw conclusions from this analysis. However, Keller (1998) showed that the weighting based on trade patterns used by Coe and Helpman (1995) does not play any particular role in measuring the extent of R&D spillovers and derives an even better fit of the observed productivity patterns by randomly generated weights. Thus, the results of Tang and Koveos (2008) could be influenced in a similar way and should be interpreted against this background. The authors do not account for indirect trade linkages as in Lumenga-Neso et al. (2005). Also, apart from their last model in which they look at two transmission channels at the same time, their estimates might be driven by omitted variable bias—the transmission channel modeled is likely to pick up the effect of other transmission channels, given the relatively high correlation between the three alternative transmission measures the authors use. Although it is an interesting research question whether FDI and telephone traffic act as transmission channels of foreign technology, the results of Tang and Koveos are inconclusive due to the problems connected to their estimation framework.

Another study that looks not only on imports but also on FDI as transmission channel for technology diffusion is the one by Seck (2012). The author focuses on a panel of 55 developing countries from 1980–2006 and identifies factors that enhance the capacity to absorb new technologies. The empirical specificication is build upon the model by Coe and Helpman (1995), appending it by allowing for R&D spillovers through FDI and adding controls for human capital and institutional quality and their interactions with the foreign R&D variables among the regressors. The specificiation is defined as

$$\begin{aligned} ln(TFP_{it}) =& \alpha^0 + \alpha^m ln(S^m_{it}) + \alpha^{fdi} ln(S^{fdi}_{it}) + \alpha^e E_{it} \\ &+ \alpha^{mz}(Z_{it} ln(S^m_{it})) + \alpha^{fdiz}(Z_{it} ln(S^{fdi}_{it})) + \alpha^z Z_{it} + \alpha^t D_t + \epsilon_{it} \end{aligned} \tag{20}$$

where $ln(TFP_{it})$ stands for the natural logarithm of TFP in country i and year t, S^m_{it} is the import-share weighted foreign capital stock based on imports of machinery and equipment (following Coe et al., 1997), and S^{fdi}_{it} is the foreign capital stock that is FDI-share weighted. E_{it} measures human capital as the average years of schooling, Z_{it} captures institutional quality (as the ease of doing buisness, property rights protection, and origins of legal systems), D_t is a set of time dummies and ϵ_{it} is the error term. S^m_{it} is constructed like S^f_{it} in equation (11), and S^{fdi}_{it} is similarly defined as

$$S^{fdi}_{it} = \sum_{j \neq i} \frac{FDI_{ijt}}{I_{ijt}} S^d_{jt} \tag{21}$$

FDI_{ijt} is inward FDI from country j to country i in year t, I_{ijt} is total physical investment and S^d_{jt} is the domestic R&D capital stock of country j.

Seck finds evidence for substantial positive spillovers from import-share weighted foreign R&D and positive but smaller spillovers from FDI-share weighted foreign knowledge. The degree of spillovers is found to increase with the level of human capital and the quality of institutions, as mesaured by the ease of doing business, intellectual property rights protection, and in legel systems originating from British law. Spillovers from the import-share weighted foreign capital stock are substantially bigger than the ones found by Coe et al. (1997), accounting for a two percent increase in domestic FDI due to a ten percent increase in the foreign capital stock. These North-South spillovers to developing countries are, however, still quantitatively lower than spillovers found by trade between industrialized nations.

The estimates reveal beneficial effects of not only trade openness but also openness to FDI of a country. This partially contradicts recent evidence of sometimes even negative effects of the presence of foreign firms on domestic productivity like found some of the studies summarized above. The contradiction in findings potentially stems from the fact that in Seck's empirical model FDI acts as a transmission channel for the foreign R&D capital stock, while the studies cited in section 5.1 do not directly account for the degree of technological knowledge of the origin country of foreign firms. While in Seck's model only spillovers from inward FDI from the G7 countries are taken into account, this is usually not the case in studies that relate the presence of foreign owned firms to domestic productivity levels. In contrast to Tang and Koveos (2008) who also found that FDI has a conducive effect on domestic productivity Seck includes both transmission channels simultaneously in the model specificiation in order to avoid omitted variable bias. The results of spillovers via imports potentially do not account for the entire spillover effects of foreign knowledge, however, because they do not take into account indirect spillovers through imports, such as in Lumenga-Neso et al. (2005).

The evidence that emerges from studies that focus on the effect of imports as a transmission channel of foreign technolgy points toward a positive effect on domestic productivity levels. Usually studies find that trade patterns and especially trade volumes are important in accounting for technology diffusion. There is evidence that this is true not only in developed countries but also for North-South trade, making developing countries benefit from foreign stock of knowledge. However, spillovers are usually found to be smaller for developing than for developed countries. This can be attributed to the more favorable local conditions in developed countries, which usually have better institutions and infrastructure and higher levels of human capital. These factors are found to be important as well for rising the absorptive capacity of developing countries (see Seck, 2012).

6 Conclusion

In this survey we investigated theoretical models and empirical evidence for the role of technological upgrading and technology diffusion for economic growth, as well as the channels through which technology spillovers can occur. Endogenous growth models make clear that technological upgrading is an important mechanism for sustaining long-run growth, which is especially important for the catch-up process of developing countries. Given the empirical evidence that the biggest part of R&D aimed at the creation of new technologies takes place in a small number of industrialized countries and that foreign technologies account for the largest share of the technologies that are used in many, especially small and relatively poor countries, technology diffusion is an important means of convergence between poor and rich economies. While most theoretical models on technology and growth imply a catch-up process of technologically less advanced countries, convergence is not achieved in all models thus impeding technologically less advanced countries to reach the technology level of the technological leader (see for example Wang and Blomström 1992; Barro and Sala-I-Martin 1997 for models implying convergence and Findlay 1978 for a model implying an equilibrium technology gap).

Some theoretical models provide explanations of how to speed up the catch-up process of technologically less advanced countries making them able to adopt newly available technologies more efficiently. These mechanisms include education and training (see Nelson and Phelps, 1966; Findlay, 1978; Wang and Blomström, 1992; Seck, 2012), the provision of suitable infrastructure and institutions (see Findlay, 1978; Seck, 2012) or imply the need of investment to adapt technologies developed abroad to local needs as otherwise the adoption of such technologies remains unprofitable (see Zeira, 2007). Theoretical models that include the role of trade and FDI as transmission channels of technology diffusion suggest that opening up economies to international markets has beneficial effects on technology transfers from technologically more advanced to less advanced economies. This is often explained by increased interaction with individuals that have access to foreign technologies, by the implicit access to foreign technologies embodied in imports, by learning effects from exporting through technical assistance of customers, or also by competition effects that make firms become more efficient and improve their productivity, what might occur also through investment in more advanced technologies. Thus, trade as such does not only have the potential to act as a means of technology diffusion but also as a means of technology creation via increasing competition and the incentive of firms to innovate (see Wood, 1995; Thoenig and Verdier, 2003; Melitz, 2003; Bustos, 2011).

Furthermore, we discussed problems connected to the measurement of technology and technology diffusion and mentioned some data sources on commonly used proxies for technology. The most popular proxies include expenditure on R&D, the use of patents, and measures of labor or total factor productivity or some variants of them. There are studies that also proxy technology levels by high-technology exports, or imports of computers, machinery and technical equipment, or information on ICT capital goods.

There exist serious data constraints for some of the indicators, especially for developing countries as data on porxies of technology do not exist for a long period of time or are even missing for some countries altogether. Some proxies that are usually used in industrialized countries are less suitable for developing countries, such as domestic R&D expenditure. This has to be taken into account in empirical studies. However, with new data becoming more readily available over time there is hope that the situation is going to improve in the long-run thus providing potential pathways for future research.

Empirical studies on technology diffusion in developing countries through international trade and FDI provide a heterogeneous picture. There is no strong evidence for the existence of positive productivity spillovers through FDI to domestic firms. Usually studies that find such domestic productivity enhancing effects rely on cross-sectional datasets and are unable to account for selection and endogeneity problems. Research that relies on panel datasets is usually able to take these issues into account. Their results usually suggest insignificant effects of the presence of foreign firms on the productivity of domestic companies, or even significantly negative ones (see Aitken and Harrison, 1999; Waldkirch and Ofosu, 2010). This raises the concern of whether policies that aim at increasing FDI inflows are justified. Although foreign firms are usually more productive than domestic firms and positive productivity spillovers to other foreign firms seem to exist (see Aitken and Harrison, 1999), the benefits from this are likely not to accrue to the host-country of these companies but to the MNCs that are usually locating in other countries. However, also employment, wage and labor standard effects have to be taken into account when evaluating the desirability of FDI in an economy.

The validity of imports as a channel of technology diffusion is confirmed by many studies, pointing towards a positive impact of the foreign R&D stock on domestic productivity. Although based on the study by Keller (1998) the impression emerged that trade does not act as a transfer channel of technologies, this result was attenuated by Lumenga-Neso et al. (2005) who demonstrated that indirect technology spillovers via third countries have to be accounted for. Their result emphasized the role of trade openness as they found that trade volumes rather than the composition of trade matters for technology diffusion. Coe et al.'s (1997) results suggest that positive spillovers of foreign R&D via trade also exist in developing countries, a result which is confirmed by Conte and Vivarelli (2011) who base their estimations on a different empirical setup.

The summarized literature reveals that policies aimed at enhancing technology diffusion should not be conducted in isolation but should be backed-up with accompanying measures that aim to provide the human capital that is needed in order to make use of newly available technologies through education, training programs and technical support. Also necessary infrastructure and institutions have to be provided in order for technology diffusion to materialize. Policies that prevent investment climate constraints to domestic firms, which might not have the same capacity as foreign firms to influence their own investment climate, are likely to have a positive impact on domestic firms' productivity (see Kinda, 2012). Additionally, active screening for new technologies, and investment in the adaptation of foreign technologies to local needs are actions conducive for faster technology adoption ECA (see 2014).

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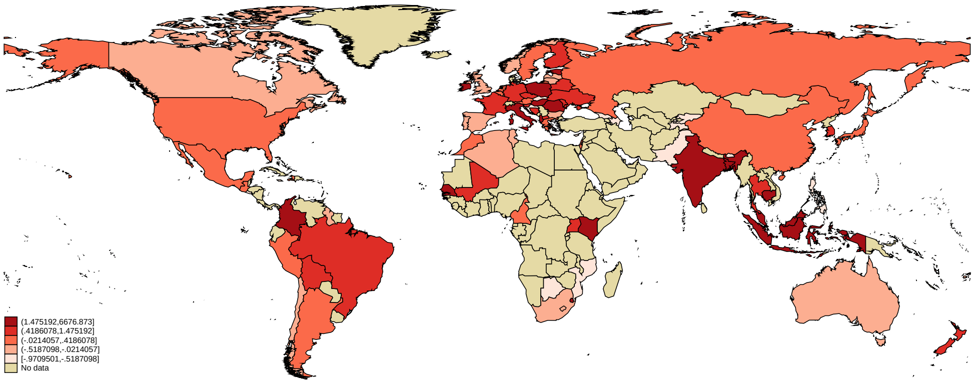
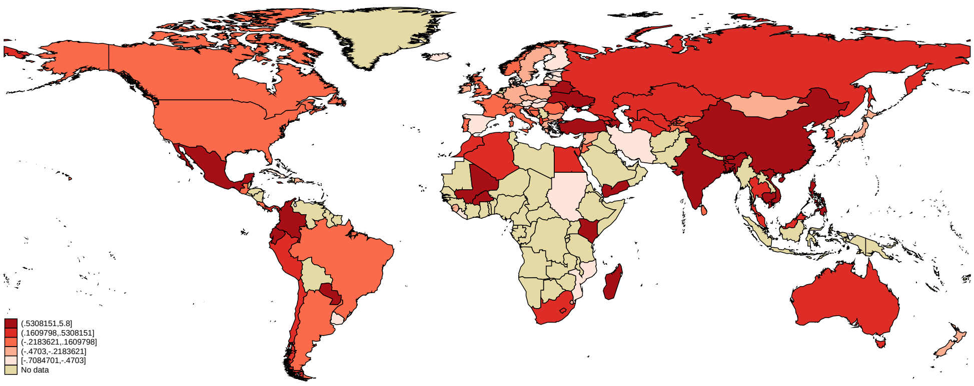
7 Appendix

Figure 17: Growth rate of charges for the use of intellectual property, receipts (% of GDP)



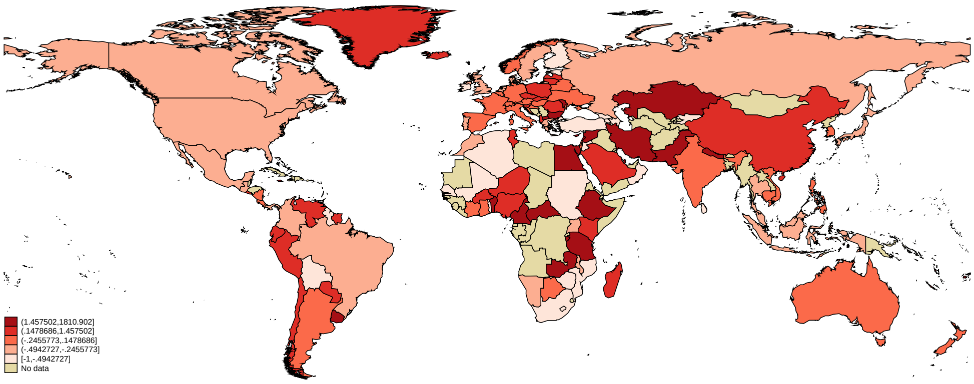
Source: World Development Indicators, 2015. Growth rate between 2006 and 2011.

Figure 18: Growth rate of trademark applications, total



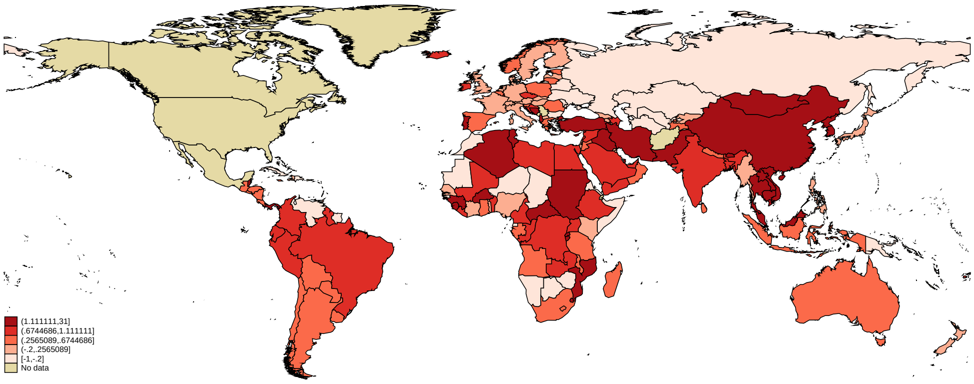
Source: World Development Indicators, 2015. Growth rate between 2000 and 2010.

Figure 19: Growth rate of high technology exports (% of manufactured exports)



Source: World Development Indicators, 2015. Growth rate between 2000 and 2010.

Figure 20: Growth rate of scientific and technical journal articles



Source: World Development Indicators, 2015. Growth rate between 2000 and 2010.

Table 1: Overview of country case studies on FDI spillovers to domestic firms in developing countries

Study	Country & Period	Data sources	Findings	Methodology
Haddad and Harrison (1993)	Morocco, 1985–1989	Moroccan manufacturing census	Insignificant (positive) spillovers on productivity growth rates (levels).	OLS
Blomström and Sjöholm (1999)	Indonesia, 1991	Central Bureau of Statistics	Positive spillovers to domestic firms, independent of degree of foreign ownership.	OLS
Aitken and Harrison (1999)	Venezuela, 1976–1989	Encuestra Industrial	Negative (positive) spillover to domestic (foreign) firms.	OLS, WLS, FE
Waldkirch and Ofosu (2010)	Ghana, 1991–1997	Surveys of the Ghanaian manufacturing sector	Negative (positive) spillover to domestic (foreign) firms.	OLS, GMM, Levinsohn and Petrin (2003)
Kinda (2012)	Brazil, 2003; Morocco, 2004; Pakistan, 2002; South Africa, 2003; Vietnam, 2005	World Bank enterprise surveys	Positive vertical spillovers to domestic suppliers of MNCs through backward linkages.	One-step stochastic frontier analysis

Table 2: Overview of the impact of trade induced productivity spillovers of foreign R&D

Study	Country & Period	Data sources	Findings	Methodology
Coe and Helpman (1995)	21 OECD countries and Israel, 1971–1990	OECD Analytical Data Base, OECD Main Science and Technology Indicators, Monthly Labor Review (U.S), Monthly Labor Survey (Japan), Monthly Bulletin of Statistics and Bank of Israel (Israel), IMF's Direction of Trade, IMF's World Economic Outlook	Positive effect of domestic and foreign R&D. Effects of domestic (foreign) R&D are bigger in larger (smaller) countries. Countries that are more open to trade benefit more from foreign R&D	OLS, FE (error correction models)
Coe et al. (1997)	77 developing countries and 22 industrial countries, 1971–1990 (5 year periods)	IMF's World Economic Outlook, World Bank's DEC Analytical Database, UNCTAD's Handbook of International Trade and Development Statistics, OECD's Main Science and Technology Indicators, UNESCO Statistical Yearbooks	Positive spillovers of R&D on developing countries' productivity, especially in countries that are more open to machinery and equipment imports.	WLS, FE
Lichtenberg and van Pottelsberghe de la Potterie (1998)	21 OECD countries and Israel, 1971–1990	Same as in Coe and Helpman (1995) except for data on trade flows: UN International Trade Statistics Yearbooks, OECD's Main Economic Indicators, IMF's Statistical Yearbook (Israel)	Greater trade openness leads to productivity gains through foreign R&D if the R&D capital stock of a country's trading partners is large.	OLS, FE
Keller (1998)	21 OECD countries and Israel, 1971–1990	Same as in Coe and Helpman (1995)	Trade patterns do not play a particular role for international R&D spillovers.	OLS, FE
Tang and Koveos (2008)	22 OECD and 21 non-OECD countries, 1983–1997	World Development Indicators, OECD Main Science and Technology Indicators, OECD International Direct Investment Statistics Yearbook, World Trade Flow CD-ROM (2000) by Robert Feenstra, Direction of Traffic by the International Telecommunications Union, Barro and Lee (1993)	International R&D spillovers through trade and international telephone traffic have higher impacts on TFP in developed countries. Trade and telephone traffic are more effective channels for technology diffusion than FDI. Telephone traffic (FDI) is a more (equally) important transmission channel for developing as compared to developed countries.	OLS, FE
Lumenga-Neso et al. (2005)	21 OECD countries and Israel, 1971–1990	Same as in Coe and Helpman (1995) plus trade for 92 non-OECD countries from the is IMF's Direction of Trade Statistics	Indirect R&D spillovers through trade are more important than direct ones. Trade matters for technology diffusion	OLS, FE, non-linear least squares
Seck (2012)	55 developing countries and G7 countries, 1980–2006	OECD, Barro and Lee (2000), World Bank ease of doing business, index of patent protection of Park (2008)	Positive spillovers from imports and FDI (smaller for the latter). Positive effects increase with education and institutional quality.	FMOLS, panel cointegration