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Why some countries are slow in acquiring new technologies? A model of trade-led diffusion and absorption ☆

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Abstract

Drawing on the stylized facts and evidences, in a computable general equilibrium (CGE) model, this paper examines the impact on TFP of North–South, North–North trade-related triangular R&D spillovers. By constructing different technology appropriation parameters based on embodied and disembodied R&D, absorption and learning effects, it shows: (i) North–South R&D flows have a positive impact on TFP; (ii) human capital-induced skill facilitates North–South R&D flows; (iii) socio-institutional and technology adoption parameters do play roles for knowledge flows, its capture, and transmission. Such technology diffusion and assimilation counters the adverse impact of North–South geographical distance on productivity dynamics.

JEL classification: J24; O33; O43; F43; D58

Keywords: Technology diffusion; Trade; Syndromes; Capture; R&D

> *"In all the cases of sustained, high growth, the [developing] economies have rapidly absorbed knowhow, technology, and, more generally, knowledge from the rest of the world.*

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These economies did not have to originate much of this knowledge, but they did have to assimilate it at a tremendous pace. That we know. What we do not know—at least not as well as we would like—is precisely how they did it, and how policy makers can hurry the process along. This is an obvious priority for research. [Economies] can learn faster than they can invent. Knowledge acquired from the global economy is thus the fundamental basis of economic catch-up and sustained growth."—Michael Spence, Spence Commission on Growth and Development, World Bank (2008), p. 41.

1. Introduction and motivation

Drawing on the idiosyncratic regional growth experiences and historical trajectories of development episodes, Spence (2011), and World Bank (2008) highlighted, *inter alia*, the importance of pursuing context- and case-specific policies—as emphasized in the quote that opened this article—related to trade and industry development, education, knowledge creation, technological improvement, inequality, etc.; in particular, it emphasized the preponderant role of engagement in the global economy as well as extending the knowledge frontier via investment in human capital, institutional quality, R&D, and the educative effect of trade to achieve Millennium Development Goals. In particular, Goals 2, 8A and 8F emphasize the roles of not only global partnership for technological access to reduce disparities in ICT diffusion and usage, but also on the importance of good governance and institutions (United Nations, October 2010). In a constantly evolving world of ideas, science, technology, and innovation policy aims at dispensing with the growth inertia by sparking mankind's innate 'lack of patience with status quo, or *sitzfleisch*' (Griliches, 2000). Government policy plays role for orchestration of knowledge, entrepreneurial know-how, *cross-fertilization* of ideas to enrich the knowledge-capital, and institutional innovation. The important visionary role that the state could play as enabling transformer of an economy through innovation-oriented policy trajectory is widely evidenced in the literature. Mazzucato (2013) has emphasized the role played by state—like Prometheus, not Leviathan—in undertaking investments in innovation via policy instruments to create an innovation ecosystems, where symbiotic coexistence of public–private investments, and other supportive policies like education policy, industrial policy work concurrently. Szirmai, Gebreeyesus, Guadagno, and Verspagen (2013) has discussed in the context of Africa that wide range of policies related to trade, sectoral innovation, population, employment, and labor market are important for productive employment. Bengoa and Sanchez-Robles (2005) and Bluedorn, Duttagupta, Guajardo, and Mwase (2014) have discussed the importance of favorable economic policies conducive for structural reforms, institutions, and domestic factors causing take-off and sustained growth of the less-developed countries' (LDCs). In particular, proper region-specific investment climate via policy instruments influencing infrastructure, governance features, scarcity of tertiary human capital, weak institutional capacity, and other pertinent socio-institutional factors in the LDCs matter.[1]

Why, despite the State-Prometheus having a visionary role to undertake strategic policy instruments, the things are not taking shape? In this paper, we ask this policy-guided research question grounded upon theoretical rationale. We enunciate the role of host of factors underlying seizure of the potential knowledge-diffusion. Lack of education, skill mismatch, inappropriate structural change, educational bottlenecks, inadequate innovation, and lack of attention to SMEs with growth

[1] World Bank's 'Doing Business Project', benchmarking different indicators for regulatory regime for 130 countries, offered Investment Climate Surveys conducted at the firm level for 26,000 firms in 53 developing nations.

potentials, all balk the growth spurt for the LDCs. Interestingly, Jones and Romer (2010) offered stylized facts based on the interactions between increased market integration (via trade) and *four state variables*, namely: ideas, human capital, population and institutions. LDCs' growth and development in the long-term depends on their capabilities, for effectively identifying, procuring, assimilating it (absorptive capacity, AC) and applying the state-of-the-art (Cohen & Levinthal, 1989; Das, 2002, 2010), and structural congruence, socio-institutional features like governance, corruption, domestic circumstances. World Bank (2010) has stressed the importance of innovation lying in the core of economic progress of the developing nations and Southern engines. Recently, Asian Development Bank Report (2014a, 2014b) has constructed the Creative Productivity Index (CPI), by ranking developing countries like Indonesia, China, India, Bangladesh, Cambodia, according to creative inputs and outputs such as skill, education, R&D, infrastructure, etc., and urged for 'strong, coordinated government policies' for tertiary education, skill-enhancement, ICT investment, innovation and favorable institution so as to develop a knowledge-based economy.

In LDCs, policymakers have focused on these factors in their policy agenda for inclusive growth and development, and policy instruments for accumulation of human and physical capital, innovation, and institution-building are prioritized. In the current paper's taxonomy, lack of these makes deleterious *syndromes* to occur and inhibit the growth process. Policy shocks inducing those factors could be a source of endogenous growth, and this paper considers role of technology shocks and trade in intermediates (Salvatore, 2007). This paper elicits a mechanism of North–North–South triangular knowledge diffusion for reducing the technological gap via synergistic spillover capture, and how all these country-specific factors create a conducive policy climate for nourishing and nurturing the innovation potential. For unraveling the interlinkages, we employ multi-sectoral, multi-regional computable general equilibrium (CGE) Global Trade Analysis Project's (GTAP) model tailored to formalize a stylized mechanism. This paper adds value to the literature by: (i) offering an analysis of interplay between trade, technology dissemination and highlighting the importance of enabling factors for such absorption factors affecting its assimilation; (ii) making a contribution to the mechanism underlying adoption of trade-mediated technology diffusion; and (iii) thus, expounding theoretical underpinning for growth-oriented public policy. As the paper unfolds, Sections 2 and 3 outlines the literature, and considers the data, and Section 4 offers the model. Simulation design and principal findings are discussed in Section 5. Section 6 summarizes with policy discussion.

2. North–south trade-led technology flows and adoption factors: a bird's eye (re-) view

The important issues of creation of new technology, its diffusion and actual adoption have been discussed on both theoretical and empirical planes. Conscious efforts by policy-makers around the developing world for embracing globalization, and investment in human capital, innovation, and macroeconomic policy has led to the emergence of dynamic emerging economies like Brazil, China, India, Korea, and others, making a New Economic Order conspicuous by 2020. The reconfiguration of the world economy via such transformation of the dynamic economies (contrary to the next tier laggards)—as discussed by Duval and de la Maisonneuve (2010), Jorgenson and Vu (2011, 2013), OECD (2010a, 2010b, 2014), Klein and Salvatore (2013)—are attributed generally to: global integration, ICT and non-ICT capital, total factor productivity (TFP), technology transfer, human and non-human capital accumulation, and institutional qualities. However, we observe differences in technology assimilation across countries.

Growth-spillover benefits the trade-partners so long as different countries engage in trade. Spence (2011, p. 5) has talked highly about this aspect of dissemination and its benefits to the developing world, by mentioning 'two parallel revolutions': *industrial revolution* in advanced world and *inclusive revolution*, spreading to the south for its quantum leap. For current evidences of such trade-mediated technology diffusion *in the developing world*, plethora of empirical supports are available—see, *Global Economic Prospects* (World Bank, 2008), Hoekman and Javorcik (2006), World Bank (1998, 2010). Despite debates about relative efficacies of different channels, it is well-established in the literature that trade (especially, imports and to some extent, exports) is significant channel of technology diffusion (Eaton & Kortum, 1996; Keller, 2004).[2] Considering a panel of 101 developing and developed countries, Arora and Vamvakidis (2004, 2005) have explored the importance of growth spillover via trade. Additionally, with intermediate trade representing 56% of trade in goods and 73% of trade in services in OECD and emerging engines being well-integrated into production networks, this diffusion improves productive efficiency of the recipients via intermediate goods and services (OECD, 2010b). The interest in exploring the North–South trade-mediated '*indirect*' *spillover* has drawn attention of researchers, which culminated into papers analyzing the relative merits of *indirect* technology flows via trade-embodiment, FDI and '*direct*' disembodied flows via technological proximity such as internet technology, telephone, or effective teledensity (Lee, 2005; Tang & Koveos, 2008). Schiff and Wang (2006) considered direct and indirect North–South R&D spillovers between 15 OECD and 24 developing nations across 16 manufacturing industries. We consider domestic R&D as well as foreign sourced R&D in DCs as well as in LDCs, along with heterogeneities in assimilation rates.

Additionally, even with global integration *localized nature* of technology makes domestic investments in enabling factors such as indigenous innovative capabilities, absorptive capacity, sound macroeconomic policies, human capital and creating better institutions are necessary for effective dissemination (Caselli & Coleman, 2006; Cosar, 2011; Keller, 2004; Lall, 2001; López-Puyeo & Mancebón, 2010; Lucas, 2009a, 2009b; Onyeiwu, 2011; Schiff & Wang, 2006, to name a few). Quantifying absorptive capacity (AC) by human capital, in the context of Sub-Saharan African (SSA) manufacturing firms Foster-McGregor, Isaksson, and Kaulich (2014) has shown that AC is instrumental for importer firms to have positive productivity spillover. Clark, Highfille, de Oliveira, and Rehman (2011) have surveyed FDI-related technological spillovers and growth impact; however, they emphasized the importance of trade channel and the role of AC, mentioning the lacunae in the literature in incorporating these aspects operationally. Onyeiuw (March 2011) has shown that for 31 Sub-Saharan African countries apart from political stability and good governance, absorptive capability to utilize new technology matter much for development. Role of adoption for using a specific set of ICT skills for teacher trainers is discussed in the context of Cambodia by Richardson (2011). World Bank (p. 2, 2010) reports that: "Innovation depends significantly on overall conditions in the economy, governance, education, and infrastructure. Such framework conditions are particularly problematic in developing countries, but experience shows not only those proactive innovation policies are possible and effective but also that they help create an environment for broader reforms. "Spence (2011, p. 109) has mentioned about '*key internal ingredients'* for sustained high-growth and the recipes involve factors such as infrastructure, good institutions, governance, education, and facilitating structural change. The negative impacts of corruption, instability, '*internal snags*' like 'bad' rule of law, and bad governance are highlighted (Collier, 2009). In what follows, we offer some pertinent stylized data.

[2] Keller (2004: p. 769) has mentioned that: "[A] number of surveys have recently concluded that there is no evidence for substantial FDI spillover." Amiti and Konings (2007) studied the positive effects on productivity of a tariff-cut in trade in intermediates for Indonesian manufacturing.

3. Database and stylized facts: a macro lens view

3.1. Sectoral and regional dimensions

Quoting Lucas (2009a, p. 1): "a study of economic growth in the *world as a whole* must be a study of the diffusion of the industrial revolution across economies, a study of the cross-country flows of production-related knowledge from the successful economies to the unsuccessful ones." Literatures abound with information and communication technology's (ICT) role as a general-purpose-technology (GPT) for facilitating growth via impacts on nanotechnology and biotechnology (OECD, 2006a). Following Qiang (2007) and Grace, Kenny, and Qiang (2004), 'informatization' is a complex process for achieving 'critical development goals' via 'ICT-driven economic and social transformation', and investment in social and economic infrastructure.

In the technology diffusion literature, the *dynamism and persistence* of technological competitiveness *across industrial clusters* are quite common. In this paper, we divide the entire global economy into composite regions—broadly into two groups, the North (N) and the South (S), according to their status of development. Based on *variation of diffusion and adoption* of new technologies across geographical regions, there has been considerable evidence on differences in technology transfer between the North and the South. OECD nations account for largest of total world R&D and within them, 7 largest (G7) account for major share (Coe, Helpman, & Hoffmaister, 2008). UNESCO (2009) has shown that the number of researchers in developing countries has increased by 45% as compared to 9% in the DCs; however, in America, Europe and Oceania researchers per million inhabitants were still far higher than the world average. Considering R&D intensity (i.e., R&D expenditure as a percentage of the GDP), the Americas accounted for 37.6% of World R&D expenditure (mainly attributed to R&D spending in USA and Canada) followed by Europe and Asia. Rapid globalization of science and technological invention has been accompanied not only by concentration of such activities in only OECD regions, but non-OECD economies also have exhibited fastest growth and sizable contribution to global R&D.[3] However, Asia's increasing R&D intensity is largely dominated by China's contribution—registering increase from 1.1% in 2002 to 1.5% in 2007, thus, accounting for 39% of R&D expenditure and 53% of researchers in the LDCs; but in case of India, it is about 0.8%. In Sub-Saharan Africa (SSA), the intensity is much less, about 0.3%, whereas South Africa invested almost 1% of GDP for R&D. On the world as a whole, R&D expenditure has increased (1.7% of world GDP). Thus, we see that G7 countries have the significant share of R&D and still developing countries need to make significant strides in their innovative skills. G7 countries' '*technological readiness' index* score is far higher than those in Asia and Africa (Global Competitiveness Report 2009–2010).

For our model, we categorize the whole range of 57 product categories in the GTAP database into 7 broad R&D-intensive technology clusters—namely, ICT, Transport Equipment, Materials, Consumption goods, Fabrication and Services (Das, 2002). We follow OECD (2003a, 2005) classification of manufacturing activities according to technological intensity. Based on Hatzichronoglou (1997), using ISIC Rev.3 OECD (2003a, 2005) methodology considers both 'technology-producer' and 'technology-user' aspects based on three technological intensity indicators, namely, R&D expenditures as proportion to value-added, production and R&D plus technology embodied in capital goods and intermediates as proportion of production, to determine

[3] According to OECD (2006a), compared to 7% in 1995 China, Israel, Russia, and South Africa contribute combined 17% of R&D expenditure of OECD nations in 2004.

Table 1
Technology clusters and industries.

Technology clusters	Industries
Information and Communications Technology	Computers and related equipment, Telecommunication and Semiconductor Equipment, Electrical Machinery, Audio and Video Equipment, Instruments
Transport Technology	Shipbuilding, Aircraft, Motor Vehicles, Other Transportation
Consumer goods Technology	Food, Beverages and Tobacco, Textiles, Apparel and Footwear
Materials Technology	Agriculture, Construction, Mining, Paper and Printing, Wood
Fabrication Technology	Fabricated Metal Products, Other non-electrical machinery, Others

Source: OECD (1997), Science, Technology and Industry – Scoreboard of Indicators. pp. 40–41. Taken from Das (2008).

'technological criteria'. By adopting a narrow definition (ISIC Rev 3.) and based on idea of embodied technology flows estimated from input-output tables, market service activities like 'Finance and Insurance (Divn 65–67)', 'Business activities (71–74)', 'Post and telecommunications (Divn 64)' are considered knowledge-intensive. Table 1 presents the taxonomy of grouping industries into *technology clusters* (OECD, 2004).[4] IT cluster belongs to the hi-tech cluster. Consumer goods and Fabrication are in the medium-low and low technology categories, respectively. We consider *technology clusters*—'industries sharing a number of common characteristics' (OECD, 2000).

Table 2 presents the regional concordance and geographical matching of regions/nations. OECD Outlook (2004) identifies five broad categories of ICT goods. ICT services, based on industry-based definition and ISIC, Rev 3., are *grouped together in the 'services' cluster* comprising mainly telecommunications, IT-enabled and related services facilitate trade.

3.2. Stylized facts

The GTAP database (Version 7) divides the world economy into 113 regions, 57 sectors and 2 labor classes. Based on SITC, Revision 3, and Commodity Product Classification and Harmonised System (HS, Rev 2.), WPIIS, OECD (2003a) has developed a classification of ICT-goods separately from ICT-services.[5] Tables 3 and 4 present annual growth rates of global and regional trade in the clusters over 1965–2004. As per OECD (2003a), high-technology industries like electronic equipment and computers represent about 25% of total OECD trade and registered highest growth rates in manufacturing trade. Together with Medium high-technology (transportation cluster, chemicals, machinery and equipment), the share is 65% of manufactures trade.[6] This is attributed to rise in investment in knowledge (i.e., R&D expenditures, software investment, human resources via higher education) especially in ICT sector accounting for 5.2% of GDP in the OECD economies in 2002. However, this has also been accompanied by closer integration of OECD and non-OECD countries leading to increase in *internationalization of* R&D activities. A cursory look confirms that although the some regions have higher chances of enrichment via trade, the lower bilateral technology achievement indexes, *relative to G7* composite region, could reduce the *chance*; on the contrary, the emerging southern engines of growth with higher bilateral technology appropriation factor and inventive capabilities have better scope of enrichment in contrast with the regions with lower R&D (for example, SSA, MENA, other South Asia, South

[4] OECD (1997), *Science, Technology and Industry Scoreboard of Indicators*, pp. 40–41.
[5] Working Party on Indicators for the Information Society (WPIIS, OECD, 2003a).
[6] OECD (2003b), p. 147.

Table 2
Sectoral and regional aggregations adopted for the simulation.

	Regions and elements			Sectors and descriptions	
1	G7	G7-North Developed	1	ConsumerGood	Sugar cane, sugar beet, Plant-based fibers, Cattle, sheep, goats, horses
2	OtherEU	EU minus G7 4 members			Animal products nec, Raw milk, Wool, silk-worm cocoons
3	Brazil	Brazil			Fishing, Meat: cattle, sheep, goats, horse, Meat products nec
4	Russia	Russian Federation			Dairy products, Processed rice, Sugar, Food products nec
5	India	India.			Beverages and tobacco products, Textiles, Wearing apparel
6	China	China.			Leather products, Wood products, Paper products, publishing
7	Hkg_Twn	HongKong Taiwan	2	AgBioTech	Paddy rice, Wheat, Cereal grains nec, Vegetables, fruit, nuts
8	SouthKorea	South Korea			Oil seeds, Crops nec, Forestry, Vegetable oils and fats
9	SouthEAsia	Developing Asia	3	ElectronicIT	Electronic equipment, Machinery and equipment nec
10	RSA	Rest of South Asia			Manufactures nec
11	ECA	Europe and Central Asia	4	Nano_Matrls	Coal, Oil, Gas, Minerals nec, Petroleum, coal products
12	SouthAfrica	South Africa			Chemical, rubber, plastic prods
13	LAC	LatinAmerica&Caribbean	5	TransportTec	Motor vehicles and parts, Transport equipment nec
14	Mexico	Mexico	6	Metal_MedTec	Mineral products nec, Ferrous metals
15	OthrOECD	OECD minus G7 minus EU			Metals nec, Metal products
16	MENA	MiddleEastNorthAfrica	7	Svces	Electricity, Gas manufacture, distribution
17	SSA	Sub-Saharan Africa			Water, Construction, Trade, Transport nec
18	ROW	All other regions			Sea transport, Air transport, Communication
					Financial services nec, Insurance, Business services nec
					Recreation and other services, PubAdmin/Defence/Health/Educat Dwellings

Source: This is based on 18 × 7 Aggmap.Txt file based on author's aggregation of augmented GTAP Version 7 database.

Table 3
Average annual growth rates for global trade in technology clusters, 1965–2004.

Technology clusters	Average annual growth rates (%)
Information and communication technology	12
Consumer goods	9.1
Biotechnology Cluster	6.1
Nanotechnology Cluster	10.4
Transport Equipment	11.2
Fabrication	9.1

Source: Calculated from the time-series trade data for the aggregated GTAP Database.

Table 4
Average annual growth rates for global trade in technology clusters, 1992–2006.

Technology clusters	Average annual growth (%) in trade from		
Source region	G7	Other EU	Other OECD
ICT	5.3	6.9	4.9
Consumer goods	3.8	3.8	4.0
Biotechnology Cluster	2.4	4.1	4.9
Nanotechnology Cluster	8.3	10.2	8.9
Transport Equipment	6.4	6.8	7.7
Fabrication	5.8	5.9	7.2

Source: Author's calculations as above.

East Asia).[7] Why? That is explained in the model in Section 4. Global integration has led to technology flows—*indirectly* via *embodied* traded intermediate inputs and/or, *directly* via *disembodied* through IT-enabled services. Thus, *effectiveness* of trans-border technology diffusion are contingent on several factors that, *amongst a tall order*, we identify as: *recipient's (any region 'r' specific)* own domestic R&D ($R\&D^d$), foreign-trade induced R&D flows via imported intermediates ($R\&D^f$) connectivity with advanced world via superior network (disembodied, $R\&D^{disemb}$), human development (HDI, a broad multidimensional concept incorporating literacy, health, education), human-capital induced skill-intensity proxying learning capacity (AC), latest technology (TA), socio-institutional parameter (SIP) encompassing Governance (GP), transparency (T), and competitiveness indicator (C). Apart from that, the role of geographical proximity and contiguity in facilitating trade flows between regions is important.[8] Krugman (1991, 1995) has emphasized the role of geography and locational choices in formation of trade blocs (termed 'natural' blocs). Frankel (1997), Diao, Rattso, and Stokke (2005) have focused on the role of adjacency in promoting trade between neighboring countries. In Asia and Latin America's context, the importance of physical (hard) and institutional (soft) infrastructure (institutional bottlenecks like legal, administrative, regulatory, rent-seeking behavior, human capital and customs clearance) along with complementary structural reforms and investments in productive capacity for trading linkages are emphasized. As geographical clustering benefits easy transmission of technology—either via trade-embodiment, disembodied channel and/or, cultural proximity—between the trade partners, we also consider the role of bilateral distance (D_{ns}) between North ('n', G7 here) and other client regions ('s'). In a single framework we consider the roles of these parameters and relative performance of DCs vis-à-vis LDCs in harnessing technology vehicled via domestic R&D as well as foreign sourced R&D.

4. Technology spillover and effective assimilation

4.1. Core model

The pattern and magnitude of the trans-border flows can be discerned by constellation of the conducive parameters that enable superseding the 'barriers to riches' (Parente and Prescott,

[7] Emerging Southern Giants are new economic center of gravity and hence, recently scope of South-South, South-North cooperation in a declining North-South trend is often explored (see OECD, 2010a; Santos-Paulino and Wan, 2010). In this paper, for parsimony we do not consider such scheme.
[8] Proximity is proxied by physical distance between two members or margins of trade.

1994). Acquisition of state-of-the-art technologies from the industrialized nations (North) to the developing economies (South) is a dominant mode of fostering productivity growth via knowledge propagation (Coe et al., 2008; Eaton & Kortum, 1996; Lucas, 2009a, 2009b; Spence, 2011). As Tang and Koveos (2008) has shown that *both trade-embodied* and *dis-embodied information technology-induced knowledge spillovers* have larger impact than FDI effect, I consider conjoint impacts of both channels of diffusion. In fact, Tang and Koveos (2008) and Bitzer and Kerekes (2008) have shown that ICT cluster and trade, *as compared to FDI*, has larger impact on technology spillover from G7 to other destination nations. Vita (2013), Jorgenson and Vu (2013), López-Puyeo and Mancebón (2010), and Bayraktar-Sağlam and Yetkiner (2014) has mentioned the necessity of policies for innovation, capital accumulation and spillover assimilation for labor-productivity growth in ICT industry as a leading sector.

Contrasting performances across countries in seizure of the potential benefits of trans-boundary technology spillovers has been ascribed, inter alia, to their heterogeneous assimilation and idiosyncratic features related to enabling ‘systems of learning and diffusion’, like governance, learning, indigenous technological and absorptive capability (AC), geographical distance, technological and structural congruence. On the contrary, lack of such factors or bottlenecks will aggravate the syndromes, impede absorption and effective utilization of ideas, and make development disorderly. All these are encapsulated into a *learning effect and adoption parameter* (*LeAP*).

Regarding the source region (generically, North), we consider G7 as the *major* progenitor of technological change. Typically, destination regions comprise the amalgam of heterogeneous nations, viz., other ‘Norths’ (like other EU and other OECD nations), dynamic adopters or emerging economies, as well as the relatively laggards encapsulated into generic ‘South’. We reserve ‘r’ for all regions (say, REG) where $r \in \{n, k, u\}$ where ‘n’ is the source (unique), ‘k’ and ‘u’ are other northern and southern recipients of technological change respectively. Thus, $s \in [k, u]$ represents generic ‘destinations’. One pertinent point to note is that we will use ‘r’ to represent all regions and then, as per the requirements of specification we will use the moving subscripts/superscripts viz., ‘n’, ‘s’, ‘k’ and ‘u’ ($s \subset r$ and $n \neq k$, $u \neq k$).

Investment in skill helps unlocking the potential of technological capability and technology absorption, diffusion of ideas and innovation-entrepreneurship (Caselli & Coleman, 2006; Cosar, 2011; Goldberg, Branstetter, Goddard, & Kuriakose, 2008; Herrerias & Orts, 2013; Jones, 2008; Kosempel, 2007). Destinations’ growth depends on the extent of technology propagation as well as on skill intensity-induced absorptive capacity (AC). AC_r index is region ‘r’ specific $0 \leq \text{AC}_r \leq 1$. Following Sen (2004), this ‘capability’ translates into important *functioning* of accessing technological improvement, and converting into *well-defined action* via productivity.

As successful adoption depends on a combination of factors such as, educational attainment, intensity of R&D activity, knowledge creation, we need to consider a broader aggregative multi-dimensional ‘Innovation Capability Index’ ($0 < \text{ICC}_r < 1$) as developed by the World Investment Report (2005). Not only that, technology availability to a region ($0 < \text{TA}_r < 7$) is also crucial for technology acquisition, derived from scores of such measure from Global Competitiveness Report (2009–2010). Kosempel (2007) has shown that elasticity of human capital acquisition in response to technology, a measure of learning propensity, determines TFP. Thus, productivity of skill depends on availability of learning scope or technology (TA_r) R&D, ICC and AC, determining regional 'Technology Absorption Parameter (TAP_r)'.[9] Thus, we write:

$$\mathrm{TAP}_r = \mathrm{AC}_r \cdot \mathrm{TA}_r \cdot \mathrm{ICC}_r \tag{1}$$

Bi-lateral, with respect to TAP of G7 (n = North) is defined as:

$$\mathrm{TAP}_{ns} = \min\left[1, \frac{\mathrm{TAP}_s}{\mathrm{TAP}_n}\right], \quad \text{where } r = n,\ s = k, u \tag{2}$$

Here, also $\mathrm{TAP}_{ns} \in [0,1]$ with zero implying further away from the technological absorption capacity of the relatively advanced nation/s and unity implying closer to innovating partners.

Keller (2004) mentions, 'speeding up the diffusion of technology [will] depend on the distribution of human capital and R&D across countries (pp. 774–775).' As 96% of world's R&D expenditure flows take place in the developed North, abstracting from Southern R&D does not necessarily undermine our primary emphasis. I here consider domestic R&D expenditure data (as % of GDP) as flow variable measure. For own R&D ($\mathrm{R\&D}_r^d$), we combine data—domestic R&D expenditure as percentage of GDP (GERD) from UNESCO (2008) and Human Development Report (2008, 2009) for the base year of Gtap data (i.e., 2004)—to match the single region and derive for composite regions a simple average of their component-wise figures. We take GTAP database's regional imports, exports and bi-lateral intermediate import shares in total imports in the destination to get foreign R&D flows ($\mathrm{R\&D}_r^f$) according to the formula:

$$\mathrm{R\&D}_s^f = \mathrm{R\&D}_n^d \cdot \mathrm{TFP}_n \cdot \Psi_{ns}, \quad \text{where } r = n \text{ and } s = k,\ u \tag{3}$$

where n = G7 and 's' is destination. Ψ_{ns} = bilateral intermediate import shares in value-added.

As there are substantial inter- and intra-regional trade flows among the composite North and their partners, we adopt the same formula to *derive intra-regional* flows. Thus, total R&D for a particular region 'r' is:

$$\mathrm{R\&D}_r = \mathrm{R\&D}_r^d + \mathrm{R\&D}_r^f \quad \forall r = n,\ k,\ u \tag{4}$$

Therefore, bi-lateral, with respect to R&D of G7 (n = North), is defined as:

$$\mathrm{R\&D}_{ns} = \min\left[1, \frac{\mathrm{R\&D}_s}{\mathrm{R\&D}_n}\right], \quad \text{here } r = n \tag{5}$$

Here, also $\mathrm{R\&D}_{ns} \in [0,1]$ with zero implying further away from the invention frontier.

A measure of foreign R&D flow that transmits across borders directly (*disembodied*, DISEMB_r) via *effective teledensity*—international telephone traffic, broadband penetration, cellular subscription encapsulated in *telecommunications infrastructure penetration per 100 inhabitants in a region*—is also computed to measure bilateral technological proximity. Ours coverage of disembodied flows is derived as:

$$\text{between source '}n\text{' and destination '}s\text{'}: \ \mathrm{DISEMB}_{ns} = \mathrm{R\&D}_n^d \cdot d_n \cdot d_s \tag{6a}$$

$$\text{between norths}: \text{'}n\text{' and '}k\text{'}: \mathrm{DISEMB}_n = \sum_{k \neq n} \mathrm{R\&D}_n^d \cdot d_n \cdot d_k \tag{6b}$$

9 Wang (2007) has measured the elasticity of AC wrt Human capital as quite high for South—3.3 whereas elasticity of TFP wrt Human capital is 1.1 for almost all the regions. Das (2002) explores relationships between AC and TFP.

Here, d_r ($\forall r$) is a composite measure for the development of teledensity such as telephone and internet subscribers penetration obtained from Telecommunications Database (World Telecommunications ICT Indicator, International Telecommunications Union, ITCU 2008).

Therefore, bi-lateral, with respect to R&D of G7 (n = North) is defined as:

$$\text{DISEMB}_{ns} = \min\left[1, \frac{\text{DISEMB}_{ns}}{\text{DISEMB}_{n}}\right], \quad (\text{where } r = n) \tag{7}$$

Thus, from earlier discussion and specification we infer that foreign R&D gives scope for cross-border learning, and subsequent innovations build on cumulative R&D experience. As regards the bilateral trade intensity, following Bergstrand (1985) & Linnemann (1966), we calculate the bilateral distance between 'n' and 's' (D_{ns}) using a simple specification as below:

$$D_{ns} = \exp\left[-\left|\frac{d_{ns}}{d_{ns}^{\max}}\right|\right] \tag{8}$$

where d_{ns} = distance between 'n' and 's' and $d_{ns}^{\max}$ is the largest absolute distance between all pairs of regions. This formulation scales the differences in binary distances on the unit interval so that the function takes the *value 'unity' if two countries are nearest*, whereas declines exponentially to '*zero*' *if they are farthest*. Thus, the lower values indicate farther distant whereas higher values imply geographical proximity.

The cross-country heterogeneity in the perceived effect of technology transfer depends, inter alia, on factors encapsulated in Socio-Institutional Parameter (SIP_r), such as rule of law, regulatory constraints, violence, corruption, transparency, labor strikes, governance and social capital. These are important *policy-syndrome variables* affecting growth and causing reversal of fortunes in LDCs in Asia, Latin America or Africa (Lee and Kim: World Development 2010, Lucas 2009). However, acceptance of 'foreign technology' depends also on social capital, social cohesion and cultural affinity based on network and trust (Dasgupta, 2009). We construct such measure by the UN's human development index (HDI) embracing multi-faceted nature of social acceptance via factors influencing human capital as well as income characteristics. This is specified via bi-lateral proximity parameter HD ($0 \le \text{HD}_{rs} \le 1$):

$$\text{HD}_{rs} = \min\left[1, \frac{\text{HD}_{s}}{\text{HD}_{r}}\right] \tag{9}$$

Domestic invention and foreign-sourced technological spillovers depend, inter alia, on domestic institutional setting based on political dimensions and good governance, institutional factors like legal side protecting intellectual property rights (IPRs), habits and even languages. Dasgupta (p. 3, 2009) argues that "that a natural place to look for the worth of social capital in macro-economic statistics is "total factor productivity" (TFP). TFP is an amalgam of technology and institutions." We incorporate these socio-institutional factors via a *binary* parameter of the index of governance (Kaufmann, Kraay, & Mastruzzi, 2009), (GP_{rs}, $-1 \le \text{GP}_{rs} \le 1$) as comparative measure of institutional quality indicator between partners as:

$$\text{GP}_{rs} = \min\left[1, \frac{\text{GP}_{s}}{\text{GP}_{r}}\right] \tag{10}$$

If destination 's' has higher GP_s than that of source 'r' i.e., $\text{GP}_s > \text{GP}_r$, then it is conducive governance structure for 's'. Otherwise, if the client region lags in institutional quality behind the advanced source [i.e., $\text{GP}_s < \text{GP}_r$], then it poses hindrance in 's' even with high TAP. Regarding corruption or transparency, we take Transparency International's (2008/9) Global Corruption Barometer data on Corruption perception Index ($0 < T_r < 10$). Also, a composite indicator of national competitiveness ($1 < C_r < 7$) which encapsulates different aspects of a nation's technological readiness in terms of socio-economic variables is taken from *Global Competitiveness Report* (World Economic forum 2008/09). Hence, the socio-institutional parameter (SIP_r) is defined as:

$$\mathrm{SIP}_r = T_r \cdot C_r \cdot \mathrm{GP}_r \tag{11}$$

As before, we convert it into a binary parameter [$0 < \mathrm{SIP}_{ns} < 1$] w.r.t. $n = \mathrm{G7}$ as below:

$$\mathrm{SIP}_{ns} = \min\left[1, \frac{\mathrm{SIP}_s}{\mathrm{SIP}_n}\right] \tag{12}$$

Having described the arrays of 'barriers to adoption and diffusion' parameters, we specify a binary *Learning effects and Distance Function* ($LeAD_{ns}$) between 'n' and 's' as:

$$LeAD_{ns} = \mathrm{R\&D}_{ns}^{\beta_{ns}} \cdot \mathrm{HD}_{ns}^{\phi_{ns}} \cdot \mathrm{Disemb}_{ns} \cdot D_{ns} \quad \forall s = k, u \text{ and } n = G7\text{(unique)} \tag{13}$$

where Φ_s = elasticity of TFP/R&D with human capital or education is taken from prior study (Wang, 2007, World Bank) and β_s = elasticity of TFP with foreign R&D. We set $\Phi_s = 1$ (Wang, 2007 estimates it 0.99–1.06) and $\beta_s = 0.12$ (for advanced economies based on CHH 1995) and $\beta_s = 0.3$ for all emerging and dynamic adopters (Wang, 2007), and $\beta_s = 0.04$ for least developed ones.

For laggards the values will be lower than the dynamic adopters or advanced northern recipients (i.e., $\mathrm{LeAD}_{nk} > \mathrm{LeAD}_{nu}$). Now, we define the structural congruence index ($0 < \mathrm{SCI}_{ns} < 1$) and Technological congruence Index ($0 < \mathrm{TCI}_{ns} < 1$) parameters between '$n$' and '$s$' as:

$$\mathrm{SCI}_{ns} = LeAD_{ns} \cdot \mathrm{SIP}_{ns} \tag{14}$$

and

$$\mathrm{TCI}_{ns} = LeAD_{ns} \cdot \mathrm{TAP}_{ns} \tag{15}$$

For the advanced North (here G7 composite), the major source of knowledge or current vintage technology, we define a function *representing its invention capability*. We call it '*Indigenous, Disembodied and Embodied R&D, and Schooling* parameter ($IDEAS_r$) where

$$IDEAS_r = \mathrm{R\&D}_r \cdot \mathrm{HDI}_r \cdot \mathrm{DISEMB}_r$$

This is, in fact, related to $LeAD_r$ variables. This is, in fact, related and isomorphic to $LeAD_r$ variables. Next we discuss the crucial parameters for technology capture and assimilation—*Learning-enabled Absorption Parameter* ($LeAP$)—for North ($LeAP_n$) and north vis-à-vis recipients 's' ($LeAP_{ns}$) as follows:

$$LeAP_n = \mathrm{AC}_n \cdot \mathrm{ICC}_n \cdot \mathrm{TA}_n \cdot \mathrm{GP}_n \cdot C_n \cdot T_n \cdot IDEAS_n \tag{16}$$

and

$$\begin{aligned} LeAP_{ns} &= \mathrm{AC}_s \cdot \mathrm{ICC}_{ns} \cdot \mathrm{TA}_{ns} \cdot \mathrm{GP}_{ns} \cdot C_{ns} \cdot T_{ns} \cdot LeAD_{ns}, \quad \forall s = k, u \\ &= \mathrm{TAP}_{ns} \cdot LeAD_{ns} \cdot \mathrm{SIP}_{ns} \end{aligned} \tag{17}$$

It is different from (13) as the dimensions of *Syndrome-variables* enter into (13) to determine the extent of capture from accessible technology spectrum, failing which emerges the development and growth disorder. Following an exogenous Hicks-neutral technological improvement in one sector of a region (i.e., the ICT sector in the North), all other sectors in the source and destinations experience trade-induced endogenous TFP improvement. We define embodiment index [E_{ijrs}] as the flow of imported intermediate in sector 'i' in source region 'r' and exported to firms in sector 'j' in recipient 's', [F_{irjs}], per unit of composite intermediate input (domestic as well as composite imported inputs) of 'i' used by 'j' in 's', [M_{ijs}]. Thus,

$$E_{irjs} = \frac{F_{ijrs}}{M_{ijs}} \tag{18}$$

Spillover coefficient for 'j' in destination 's' (γ_{ijrs}) is:

$$\gamma_{ijrs}(E_{ijrs}, \theta_s) = E_{ijrs}^{1-\theta_s} \quad (s \in \{k, u\}) \tag{19}$$

$$\gamma_s(0) = 0,\ \gamma_s(1) = 1,\ \gamma_s' = (1-\theta) \cdot E_{rs}^{-\theta_s} > 0,\ \gamma_s'' = \left[\frac{-\theta_s(1-\theta_s)}{E_{rs}^{1+\theta_s}}\right] < 0$$

where $\theta = LeAP\ \forall\ r \in \{n, s\}$ and $s \in \{k, u\}$. The realized productivity level from the potential flows of 'current technology' depends on $LeAP_{ns} \in [0, 1]$, $LeAP_{ns} = 1$ implies full appropriation. For the destination region 's', θ_s and E_{rs} jointly determine the value of the '*Spillover Coefficient*' γ_s (E_{rs}, θ_s), where primes indicate the first ($'$) and the second ($''$) derivatives with respect to E_{rs}. Thus, if F_{irjs} indicates usage in region 's' by 'j' of imported intermediate 'i' from 'r', we assume that the share of imported input 'i' from source 'r' in receiving region 's' holds for all industries 'j' in 's' using imported input 'i':

$$\frac{F_{irjs}}{F_{ijs}} = \frac{F_{irs}}{F_{is}} \tag{20}$$

where F_{is} is the aggregate imports of tradeable commodity 'i' in region 's' from all source regions.

Source 'r' reaps technological spillover via inputs embodying technology so that:

$$E_{ijn} = \frac{D_{ijn}}{M_{jn}}, \quad i \neq j \tag{21}$$

where D_{ijn} is the domestic tradeable 'i' used by j of '$r = n$'. M_{jr} represents domestic production of 'j' in '$r = n$'. Given constellation of parameters, higher $IDEAS_n$ and $LeAP_n$ induce knowledge-spillover via:

$$\gamma_{ijn}(E_{ijn}, LeAP_n) = E_{ijn}^{1-LeAP_n} \tag{22}$$

θ_n has one-to-one correspondence with $LeAP_n$, $0 \leq LeAP_n \leq 1$. TFP transmission equation for 's' is:

$$a_{js} = E_{ijns}^{1-LeAP_{ns}} a_{in} \tag{23}$$

where a_{in} – an exogenous TFP improvement in sector 'i' (IT-cluster) of 'r' ($r = n$) – induces endogenous TFP changes a_{js}, translating into induced-innovation in user-clusters. Such a mechanism is invoked via:

$$af_{ijs} = E_{ijns}^{1-LeAP_{ns}} af_{ijn} \tag{24}$$

where af_{ijn} is ith (unique$'i'$) input-augmenting technical change in 'j' sector in 'n'.

4.2. Construction of parameters

Tables 5 and 6 show the *Technology appropriation parameters* for each region as well as the binary values vis-à-vis G7 (North = n). Look at the pattern in the Table/s: compare BRIC, although TA is almost similar in the range of 4.1–5.5, but as AC is highest in Brazil and ICC_r is higher its TAP parameter value is higher than other 3 in the group. Thus, although 'available tech' is comparable, differences in Innovative Capability and Absorptive Capacity make the difference. It shows the *Socio-institutional parameters* as described in Section 3. R&D-expenditures data are from published sources (for example, ANBERD or STAN or OECD's Main Science and Technology Indicators). However, we use UNESCO (2008) and UN's Human Development Report (2008) (see Tables 5 and 6). Table 7 gives the measures of structural and technological congruence between the north (G7 here) and other destinations, showing that relatively advanced nations and dynamic adopters (Hong Kong, South Korea, BRIC) have higher TCI and SCI values compared to the followers or laggards, for example, MENA, RSA or SSA.

Comparing TCI_{ns} and TAP_{ns}, we see that they are not equal also the ranking is preserved more or less. This is because magnitude of $LeAD_{ns}$ values—encapsulating learning, human development, research efforts and spillover—impact on the technology appropriability and magnitude of those factors for technology assimilation. In case of structural symmetry, we see that G7 is more congruent to EU and other OECD, as compared to, for example, SSA, India, China, RSA, LAC or MENA. Typically, rapidly industrializing economies, like South Korea and Hong Kong-Taiwan, have higher bilateral SIP values (and hence, SCI) with G7 because of higher indices for the constituent parameters like GP, transparency, and lower Corruption perception index. Thus, the constituents of the learning and distance function (via Eq. (13)) determine the extent of congruence—*either institutional or technological*—between north and the southern recipients.

From Table 7, we observe that usually countries/regions with better enabling factors have higher bi-lateral *LeAP* and *LeAD* values, for example, dynamic Asian economies like S. Korea, other OECD and EU vis-à-vis G7. Comparing India among BRIC and LAC, the values for the embodied and disembodied spillover are lower. With low values for HDI, she registers *low magnitude for 'Ideas'* parameter. But, if we compare India with developing South East Asia and Latin America, disembodied spillover is lower in India. HDI values are lower, too. Thus, even with higher embodied spillover *LeAD and IDEAS* for India are lower than these emerging economies. It confirms our conjecture that disembodied spillover and better governance and institutions are crucial factor for 'IDEAS' to develop.

4.3. Illustrative simulation design: productivity experiment

The model is a special tailor-made version of a CGE trade model-GTAP (Hertel, 1997). For capturing direct and indirect intersectoral effects based on well-defined production and demand structure, the CGE model scores over the simplistic input-output specification and the Social Accounting Matrix (SAM) based models, and enable us to account for behavioral responses of each representative economic agent in response to relative price changes following policy changes. Because of our enhancement of theory via technology spillover mechanism, an augmented version of the comparative static multi-regional, multi-sectoral model is solved using General Equilibrium Modeling Package (GEMPACK) (Harrison & Pearson, 1996). We just consider 5% Total factor productivity shock in the north, G7. From the current literature on TFP, we see that sources of TFP growth are mainly governed by ICT growth in most sectors (see EUKLEMS database, release March 2008 and Groningen Growth and Development Center (GGDC 2006), and OECD

Table 5
Region-wise Technology Absorption and Socio-institutional Parameter derived from Eqs. (1), (2), (11) and (12) in the text.

GTAP code	GTAP regions	T_r, CPI_r	C_r, GCI_r	GP_r	SIP_{ns}	TA_r	AC_r	ICC_r	TAP_r	TAP_{ns}
G7	G7-North Developed	7.228571	5.184509	1.31564	1	6.128571	0.724223	0.870286	3.862724	1
OtherEU	EU minus G7 4 members	7.745455	4.979621	1.528518	1	6.054545	0.705468	0.853545	3.64574	0.94
Brazil	Brazil	3.5	4.227963	0.75	0.22	5.3	0.561541	0.529	1.574394	0.41
Russia	Russian Federation	2.1	4.152973	0.28	0.05	4.1	0.466861	0.79	1.512162	0.39
India	India	3.4	4.303131	0.59	0.18	5.5	0.314229	0.29	0.501195	0.13
China	China	3.6	4.736538	0.38	0.13	4.3	0.279342	0.358	0.430019	0.11
Hkg_Twn	HongKong Taiwan	6.9	5.211573	1.128491	0.82	6	0.720604	0.714	3.087069	0.8
SouthKorea	South Korea	5.6	5.003964	1.42	0.8	5.9	0.447592	0.839	2.215624	0.57
SouthEAsia	Developing Asia	3.27	4.168391	0.49	0.14	4.75	0.353306	0.3612	0.606166	0.16
RSA	Rest of South Asia	2.7125	3.645467	0.18	0.04	3.75	0.346921	0.17375	0.226041	0.06
ECA	Europe and Central Asia	4.004667	4.068955	0.86	0.28	4.513542	0.426924	0.60328	1.162483	0.3
SouthAfrica	South Africa	4.9	4.340151	1.16	0.5	5.5	0.564539	0.55	1.707731	0.44
LAC	LatinAmerica&Caribbean	3.640686	3.857779	0.62	0.18	4.138125	0.430442	0.373625	0.665509	0.17
Mexico	Mexico	3.6	4.189043	0.76	0.23	4.6	0.617532	0.47	1.335103	0.35
OthrOECD	OECD minus G7 minus EU	8.7	5.13939	1.732302	1	6.38	0.698383	0.896	3.992294	1
MENA	MiddleEastNorthAfrica	3.356944	4.177408	0.47	0.13	4.995833	0.481806	0.3715	0.89421	0.23
SSA	Sub-Saharan Africa	2.984375	3.48093	0.28	0.06	4.207639	0.276345	0.146813	0.170708	0.04

Source: Author's calculation by matching with GTAP Regions based on external Datasources; AC (from GTAP), ICC (World Investment Report 2005), TA (Global Competitiveness Report 2008/2009), T (transparency international), GFI (Global competitiveness Report 2009), GP (World Bank 2009). See text.

Table 6
R&D flows comprising own R&D and Trade-mediated flows (via Eqs. (3)–(5)) with Intra-Regional flows in 3 Composite Norths n1, n2, and n3.

	GTAP regions	n1 = G7 TRDFn1s	n2 = Other EU TRDFn2s	n3 = Other OECD TRDFn3s	Total foreign R&D spillover Aggr R&D_f	Own R&D R&D_d	Total R&D_f + R&D_d Total R&D_r	Own Domestic Bi-lateral R&D_{ns}	North–South Bi-lateral R&D_{ns}
1	G7	0.818344	0.248468	0.040196	1.107009	2.234765	3.341774	1	1
2	OtherEU	1.013433	0.341471	0.035673	1.390577	1.923093	3.31367	0.86	1
3	Brazil	0.917653	0.182791	0.030486	1.130929	0.968866	2.099795	0.43	0.63
4	Russia	0.815808	0.244339	0.020218	1.080364	1.067194	2.147559	0.477542	0.64
5	India	0.499535	0.149897	0.08031	0.729742	0.80374	1.533481	0.359653	0.46
6	China	0.762083	0.076567	0.026729	0.865379	1.44	2.305379	0.644363	0.69
7	Hkg_Twn	0.907377	0.069333	0.039655	1.016365	0.694976	1.711341	0.310984	0.51
8	SouthKorea	0.925408	0.060453	0.046127	1.031989	2.6	3.631989	1	1
9	SouthEAsia	0.73246	0.099003	0.033905	0.865368	0.394665	1.260033	0.176603	0.38
10	RSA	0.528673	0.106296	0.036234	0.671203	0.366886	1.038089	0.164172	0.31
11	ECA	0.831126	0.251604	0.02322	1.10595	0.576384	1.682335	0.257917	0.5
12	SouthAfrica	0.882286	0.166564	0.035765	1.084616	0.919225	2.003841	0.41133	0.6
13	LAC	0.87102	0.141309	0.018794	1.031123	0.270354	1.301478	0.120977	0.39
14	Mexico	1.52725	0.077711	0.011637	1.616598	0.504215	2.120814	0.225623	0.63
15	OthrOECD	1.01026	0.300632	0.042889	1.353781	1.873612	3.227393	0.838393	0.97
16	MENA	0.865824	0.200827	0.037445	1.104097	0.541462	1.645558	0.24229	0.49
17	SSA	0.692301	0.218337	0.019576	0.930214	0.243271	1.173484	0.108857	0.35

Source: Author's calculations based on R&D data sources, UNESCO (2009) and UN's HDR 2008/2009, and Trade shares derived from GTAP Version 7 database.

Table 7
Values of binary Structural and Technological Congruence Indices, LeAP, LeAD, Disembodied R&D and the elasticity values based on Eqs. (5)–(7), (9), (13)–(16).

GTAP regions	HDI_r	HDI_{rs}	$IDEAS_r = RD_r \cdot HD_r \cdot DISEMB_r$	$LEAD_{rs}$	$TCI_{rs} = LEAD_{rs} \cdot TAP_{rs}$	$SCI_{rs} = LEAD_{rs} \cdot SIP_{rs}$	$TCI_r = IDEAS_r \cdot TAP_r$	$SCI_r = IDEAS_r \cdot SIP_r$	$LeAP_{ns}$	$DISEMB_{ns}$	D_{ns}	Φrs	βrs
G7-North	0.948429	1	0.035614	1						1	1	1	0.12
OtherEU	0.943545	0.99	0.038248	0.617547	0.580494	0.617547	0.139441	2.254848	0.580494	1	0.623784	1	0.12
Brazil	0.8	0.84	0.027024	0.162527	0.066636	0.035756	0.042546	0.006573	0.01466	0.526977	0.421747	1	0.3
Russia	0.802	0.84	0.030121	0.249959	0.097484	0.012498	0.045548	0.073555	0.004874	0.572885	0.593837	1	0.3
India	0.62	0.65	0.011277	0.093653	0.012175	0.016858	0.005643	0.097184	0.002191	0.388527	0.468125	1	0.3
China	0.777	0.82	0.026815	0.184067	0.020247	0.023929	0.011531	0.173747	0.002632	0.490363	0.511669	1	0.3
Hkg_Twn	0.937	0.98	0.029296	0.229298	0.183439	0.188025	0.090438	1.188829	0.15042	0.598465	0.478481	1	0.3
SouthKorea	0.921	0.97	0.058989	0.295867	0.168644	0.236694	0.130697	1.130771	0.134915	0.577664	0.52802	1	0.3
SouthEAsia	0.7232	0.76	0.01258	0.107272	0.017163	0.015018	0.007626	0.084021	0.002403	0.452218	0.417243	1	0.3
RSA	0.59525	0.62	0.007731	0.118231	0.007094	0.004729	0.001748	0.013761	0.000284	0.409845	0.487601	1	0.04
ECA	0.82825	0.87	0.023019	0.225121	0.067536	0.063034	0.026759	0.045981	0.01891	0.541157	0.588685	1	0.3
SouthAfrica	0.674	0.71	0.020776	0.112919	0.049684	0.05646	0.03548	0.183865	0.024842	0.503916	0.367879	1	0.3
LAC	0.777063	0.8	0.015994	0.149407	0.025399	0.026893	0.010644	0.139272	0.004572	0.518048	0.47818	1	0.3
Mexico	0.829	0.87	0.027162	0.220763	0.077267	0.050775	0.036263	0.007975	0.017771	0.506068	0.575964	1	0.3
OthrOECD	0.9582	1	0.03819	0.376426	0.376426	0.376426	0.152465	2.958018	0.376426	1	0.377804	1	0.12
MENA	0.7415	0.78	0.018966	0.208292	0.047907	0.027078	0.01696	0.125007	0.006228	0.509182	0.539631	1	0.04
SSA	0.497625	0.52	0.00677	0.087011	0.00348	0.005221	0.001156	0.019691	0.000209	0.379742	0.459537	1	0.04

Source: Author's computations based on data constructed as described in the text and in other tables.

Productivity Database 2008). For simulation, however, we consider GGDC (2006)'s Productivity monitor to get estimated TFP growth in ICT (Table 12, GGDC 2006).

5. Selective simulation results

5.1. Macroeconomic impacts

Macroeconomic impacts show that following the TFP-led endogenous spillover via trade-embodiment in all traded sectors (both domestically and abroad), all the regions register higher TFP improvement—although magnitudes differ across regions—owing to differential embodied knowledge-spillover via intermediates (Table 8). We see the largest beneficiary is the other two developed regions, namely, other EU and OECD. They have higher embodiment and spillover coefficients (see Table 9). LDCs like MENA, Mexico, SSA have highest region-wide trade-embodiment index (E_{irs}). Nevertheless, higher capture-parameter ($LeAP_{nk} > LeAP_{nu}$) magnifies E_{irs} to higher spillover-coefficient, 0.52 and 0.42 by more than 100% compared to Low and middle income economies (LMIE) (varying on an average between 0.01% in case of SSA, MENA, Mexico, India to 25% in case of S Korea, Hong Kong Taiwan).

Despite having low $LeAP(\theta_{nu})$, with post-simulation technological benefits higher, γ_{irs} and E_{irs} result into higher TFP, exports and GDP growth in LMIE. In G7, principal beneficiary of technological change, highest value of $LeAP(\theta_n)$ amplifies spillover γ_{ir} reflected in highest GDP and TFP-growth (rows 1, 2 and 3, Table 8). North, thus, reaps the maximum productivity growth by sourcing relatively high proportion of its own 'technological improvement-bearing' input. TFP-growth acts as an export supply shifter for each generic commodity so that output and global trade increases (rows 4 and 5, Table 8).

Regional differences are explained in terms of differences in the economy-wide embodiment index and spillover coefficient (Table 9). As conjectured, G7, EU, other OECD and dynamic adopters of foreign-improvement in technology, like Korea, Taiwan, China, Hkg have registered much higher regional index of technical change as opposed to the relatively laggard, viz., Rest of South Asia, Africa and most of the Latin American countries experiencing modest region-wide TFP performance. This is attributed not only to lower embodiment index, but also to lower capture-parameter thanks to higher R&D-enabled flows, as well as the better institutional set up facilitating higher learning effect and assimilation by these emerging economies.

However, for MENA and SSA, although being outliers in case of having low *LeAP* values or SIP, Technology Appropriation Parameters, they show better performance in terms of almost all macroeconomic variables reported in Tables 8 and 9. This is due to higher values of trade-led embodiment via traded intermediates. USA, EU, Canada and Japan in G7-being more structurally congruent and hence, along with trade-embodiment-reaped most of the benefits of own and foreign induced spillover because of highest values of socio-economic parameters, viz., GP, HDI, R&D flows and ICC (see the values in Tables 5–7). On the contrary, for India, SSA, MENA, Rest of Africa, and South Africa, these values are considerably low. In fact, for GP values showing poor governance quality, the capture parameter drives the magnitude of structural-congruence (SCI_{rs}) to low (see Tables 5 and 7). Table 9 shows that BRIC has lower SCI_{rs} values than those in S. Korea, HKG_Twn, and other North; lower SIP_{ns} and $LeAD_{ns}$ caused lower capture values ($LeAP_{ns}$) so that they were unable to tap the potential spillover in foreign-technology. As conjectured, regions with higher AC_s, HD_{rs}, $R\&D_{rs}$, $DISEMB_{rs}$, GP_{rs} and ICC_{rs} had higher absorption and adoption of technology vehicle via trade, for example, the case of South Korea, Other OECD, Hkg_Twn, ECA, etc. In case of G7, the more pronounced TFP-enhancement is attributed to the fact that most

Table 8
Simulated macroeconomic impact of 5% TFP shock in G7 (North) in ICT sectors and its repercussions in destinations for some selected macroeconomic variables.

	Variables (% change)	G7	OtherEU	Brazil	Russia	India	China	Hkg_Twn	SKorea	SE Asia	ECA	SAfrica	LAC	Mexico	OthrOECD	MENA	SSA
1	Region-wide Tec Change	5.79	4.11	0.53	0.88	0.52	0.59	2.41	1.13	1.40	1.66	1.13	1.28	1.45	3.05	1.92	2.08
2	Regional Income (real)	5.00	3.11	0.34	0.87	0.42	0.66	2.20	1.03	1.48	1.45	0.99	1.20	1.48	2.56	1.85	2.02
3	Real GDP	4.44	2.79	0.36	0.79	0.51	0.64	2.08	1.07	1.29	1.31	0.89	1.10	1.33	2.30	1.61	1.76
4	Regional exports (volume)	1.71	3.22	5.55	1.96	5.64	3.33	2.33	3.63	2.16	2.76	3.12	3.61	3.42	3.59	2.55	2.85
5	Regional imports (volume)	4.11	2.38	−1.30	0.21	−0.82	0.24	1.19	0.75	0.82	0.70	−0.10	0.42	1.38	1.64	0.64	1.05
6	Regional export Price Index	−3.31	−3.44	−3.90	−3.26	−3.89	−3.51	−3.51	−3.74	−3.41	−3.43	−3.48	−3.48	−3.42	−3.49	−3.33	−3.34
7	Regional import Price Index	−3.41	−3.37	−3.39	−3.39	−3.37	−3.43	−3.40	−3.35	−3.41	−3.37	−3.42	−3.44	−3.38	−3.39	−3.41	−3.41
8	Terms-of-Trade	0.11	−0.07	−0.53	0.14	−0.54	−0.09	−0.11	−0.40	−0.01	−0.06	−0.06	−0.04	−0.05	−0.10	0.08	0.07
9	Welfare (in US $ million)	1,154,495	99,822	1839	4719	2483	9938	9397	6163	10,072	15,709	2342	9283	8938	30,764	18,471	4510
10	Change in trade Balance ($Usmln)	−99,537	11,322	5414	1310	6892	17,044	1960	5980	5844	12,650	2510	6812	3614	6491	7531	1746
11	Per capita real income (HHLD)	5.00	3.11	0.34	0.87	0.42	0.66	2.20	1.03	1.46	1.45	0.99	1.20	1.48	2.56	1.85	2.01
12	Regional investment demand	5.12	3.16	0.33	0.90	0.57	0.69	2.22	1.06	1.55	1.54	0.99	1.22	1.86	2.57	1.91	2.10

Source: Author's simulation results. Except welfare and change in trade balance, figures present post-simulation %-deviation from base case scenario.

Table 9
Values of economy-wide spillover, embodiment indexes and constituents of learning and effective capture parameters.

	G7	OtherEU	Brazil	Russia	India	China	Hkg_Twn	SKorea	SEAsia	ECA	SAfrica	LAC	Mexico	OthrOECD	MENA	SSA
Aggregate Embodiment	0.092662	0.241771	0.076912	0.138281	0.093122	0.108811	0.326736	0.146455	0.244025	0.249281	0.173661	0.220713	0.24376	0.268228	0.294053	0.323586
Aggregate Spillover	0.803137	0.515655	0.079615	0.139549	0.093516	0.109389	0.381974	0.184688	0.244789	0.255421	0.180978	0.222078	0.248918	0.421236	0.29607	0.323653
$LeAD_{ns}$	1	0.617547	0.162527	0.249959	0.093653	0.184067	0.229298	0.295867	0.107272	0.225121	0.112919	0.149407	0.220763	0.376426	0.208292	0.087011
$LeAP_{ns} = \theta$	0.95559	0.580494	0.01466	0.004874	0.002191	0.002632	0.15042	0.134915	0.002403	0.01891	0.024842	0.004572	0.017771	0.376426	0.006228	0.000209
SIP_{ns}	1	1	0.22	0.05	0.18	0.13	0.82	0.8	0.14	0.28	0.5	0.18	0.23	1	0.13	0.06
TCI_{rs}		0.580494	0.066636	0.097484	0.012175	0.020247	0.183439	0.168644	0.017163	0.067536	0.049684	0.025399	0.077267	0.376426	0.039797	0.002649
AC_r	0.724223	0.705468	0.561541	0.466861	0.314229	0.279342	0.720604	0.447592	0.353306	0.426924	0.564539	0.430442	0.617532	0.698383	0.481806	0.276345

Source: Author's calculation based on databases and adapted for GTAP databases regional aggregation as documented in the text.

of the spillover is domestically sourced with indirect spillover with the trading partners, namely, EU, Japan, High-income Asia and Canada (a NAFTA member). Table 8 (3rd item) shows that, region by region, the overall technical change translates into approximately similar percentage increase in real GDP at factor cost. As the shock is factor-neutral, with fixity of regional supplies of all the components of value-added, the percentage deviation in real GDP at factor cost is almost equal to the respective region-wide TFP changes.

Real income increases in all the scenarios in all regions, caused by relatively pronounced TFP-gains (row 2, Table 8). More predominant effect occurs in USA, Canada, LAEEX, EU, Brazil and high-income Asia as they experience higher doses of trade-induced spillovers. For Canada and Mexico, since they belong to NAFTA with USA as the hub, the induced spillover is more dominant. However, in case of South Korea, the trade-induced spillover is high due to higher trade in ICT, biotech intermediates and higher AC and $LeAP_{rs}$, SCI_{rs}. After the technology shocks, there are changes in price relativities across regions which induce changes in regional TOT (row 8, Table 8), perturbing the pattern of inter-regional competition. This indicates that due to technological benefits there is substantial cost reductions leading to decline in export price indexes in all the regions—the extent of fall depending on the magnitude of technology transmission and its actual capture by the sectors in destinations. From Tables 8 and 10, we observe that aggregate regional export price indexes fall in almost all the regions with more fall observed in the major beneficiaries of such spillover and its higher capture such as Canada, Argentina, Japan, China, Brazil, India, and EU, compared to SSA, RoAFR, MENA and RoSAsia, benefiting from cost-reduction technological inventions. This resulted in increase in volume of regional exports (trade as a whole)—see rows 4 and 5 in Table 8. In case of Brazil, India, other Asian countries considered, and Africa, regional imports shrank a bit due to increase in own production via TFP-gains, acting as an export-supply shifter for each generic commodity. Not surprisingly, all the countries have a positive change in trade balance, with degrees differing owing to differences in realization of trade-induced benefits. Regional investment demand, following the technological benefits augmented with lowest impact in India and China—this is surprising, but given the base period data (2004), it could be attributed to the post-simulation lesser TFP growth benefits accrual—caused by lower sets of host of parameter values. The aggregate spillover index gives us an average *overall* magnitude of technology appropriated by all user sectors in G7 as well as host regions from the ICT sector via intermediate inputs. From Table 9, it is evident that the aggregate spillover index in G7 is highest and domestic spillover is higher than the LDCs. The capture-parameter (θ_n) in G7 is higher than θ_s in all the destinations, so that it reaps the maximum spillover (γ_{ir}) compared to most of the LDCs and other EU, and OECD. For EU, Japan and BRIC, although the values of E_{irs} are of the same order of magnitude, the aggregate spillover coefficient (γ_{irs}) for EU and OECD is of much higher magnitude than in most of the LDCs in South America and South Asia and the composite African regions. This is because the higher value of the capture parameter (θ_r) magnifies the value of the embodiment index and hence enables them to record a much higher rate of TFP improvement. From Tables 8 and 9, it is evident that in conformity with our theory the relatively laggard and less congruous regions like Argentina, Brazil, South Asia, Mexico and Africa register moderate growth effects. Note that the ordering of the spillover coefficient in Table 9 matches the ordering of the real GDP results in Table 8. Regarding Welfare effects, in all the simulations it leads to welfare-augmentation with much higher welfare improvement in case of concomitant productivity improvement of ICT. It is true in most of the regions exception being South Asia, Africa and Thailand capturing less trade-induced benefits due to lower capture (Table 8, Row 9).

Table 10
Simulated impact on output supply and supply prices of selected sectors under the designated scenario along with the embodied spillover coefficients, TFP and sectors' total exports.

	G7	OtherEU	Brazil	Russia	India	China	Hkg_Twn	SKorea	SEAsia	SAfrica	LAC	Mexico	OthrOECD	MENA	SSA
Output supply															
ElectronicIT	1.684141	1.564169	1.515986	−0.06163	0.914797	1.363866	0.660896	3.082189	1.464043	−0.70159	0.750626	1.719393	2.792393	1.13524	1.07523
Nano_Matrls	3.486675	3.827113	2.294131	1.293233	1.626885	1.362416	2.092595	1.837482	1.840176	2.31871	2.912059	1.925469	3.197725	1.94574	2.669626
TransportTec	4.08713	2.127445	0.868632	−0.17769	−0.96964	−0.31345	1.074714	0.806255	−0.45266	−1.05208	−0.53035	1.440262	0.83883	0.026598	0.984384
Svces	4.507883	2.846243	−0.13396	0.576299	0.256751	−0.00123	2.231367	0.577624	1.038605	0.737413	0.678662	1.322104	2.154094	1.530571	1.408554
CGDS	4.165318	0.199055	−5.53456	−2.4364	−3.6582	−2.41853	−2.20215	−3.30653	−3.91163	−5.67351	−3.58932	−1.87392	−1.14356	−2.79036	−2.56045
Supply prices															
ps															
AgBioTech	−3.46632	−3.50879	−3.61378	−3.31781	−3.21403	−2.99942	−3.36392	−2.85037	−3.41872	−3.5853	−3.51019	−3.47396	−3.4925	−3.51044	−3.56526
ElectronicIT	−3.38304	−3.47757	−4.34954	−3.50561	−4.11489	−3.62464	−3.47068	−3.89258	−3.54901	−3.46891	−3.63969	−3.50858	−3.70436	−3.55024	−3.42163
Nano_Matrls	−3.16046	−3.38083	−3.7189	−3.16953	−3.63847	−3.43692	−3.31602	−3.38402	−3.27029	−3.41994	−3.49844	−3.47162	−3.30856	−3.19095	−3.3089
TransportTec	−3.75058	−3.58604	−3.96537	−3.59393	−4.19491	−3.57907	−3.4815	−3.69962	−3.41774	−3.44339	−3.52202	−3.67894	−3.52518	−3.68159	−3.51473
Svces	−3.09876	−3.42432	−4.10873	−3.36418	−4.24096	−3.58843	−3.61997	−3.8152	−3.40628	−3.47987	−3.33115	−2.73285	−3.52303	−3.66381	−3.27985
CGDS	−3.24948	−3.4566	−4.05061	−3.40775	−4.10306	−3.57985	−3.56683	−3.78003	−3.4578	−3.49012	−3.42108	−3.36055	−3.52785	−3.60615	−3.38989
Commodity-wise regional exports															
qxw															
ElectronicIT	0.314352	1.417106	8.093122	0.149507	6.742657	2.98725	0.724954	4.358434	1.658072	0.305252	2.508863	2.736252	3.459097	1.626718	1.181503
Nano_Matrls	2.101226	4.264537	5.842737	1.895737	5.000992	4.255849	2.012942	2.800885	2.286862	4.045146	4.795204	5.313208	3.677576	2.120432	2.949326
TransportTec	3.179523	2.315035	3.54658	−0.51263	4.721197	1.838908	1.065863	2.003881	−0.57672	0.658994	0.214333	4.160388	0.843385	0.981344	1.226547
Metal_MedTec	1.925837	2.837139	6.54308	1.870188	5.442841	2.861921	2.299726	2.719613	1.959651	2.747458	1.260477	−0.44785	2.761592	1.932792	1.183893
Svces	2.104148	3.455882	6.058083	3.066243	6.488312	4.012369	3.902191	4.149473	3.303499	3.776216	3.069859	1.319321	3.790215	4.471451	2.984968
Sectoral TFP (%) changes															
avaall															
AgBioTech	4.127485	2.875599	0.329549	0.671444	0.000666	0.182098	1.594373	0.236366	1.468324	1.17698	1.389678	1.457524	2.199038	1.490045	1.819754
ElectronicIT	5	3.071155	1.350795	1.025996	1.208258	0.996439	1.865391	1.745403	1.721374	0.878606	1.720621	2.250799	2.84877	1.6564	1.957118
Nano_Matrls	4.11206	2.957302	0.334545	0.73672	0.323689	0.611827	1.67186	0.464999	1.225114	1.120991	1.722745	2.108583	2.290256	1.422197	2.113146
TransportTec	4.460036	2.896465	0.353648	1.374397	1.020911	0.554007	1.687535	0.820315	1.05413	0.449754	1.007364	1.56859	2.137932	1.849614	1.975464
Metal_MedTec	4.296549	2.705159	0.343764	0.749156	0.251708	0.295329	1.921561	0.68097	1.420476	1.010909	0.544202	0.291073	2.295599	1.520918	2.022779
Svces	4.19724	2.827511	0.416733	0.725229	0.768205	0.65467	2.143546	1.047371	1.294663	0.894721	0.936262	0.776027	2.285038	1.811285	1.624791
Sectoral spillover coefficients															
SPLCOEFFT															
AgBioTech	0.733227	0.581898	0.068558	0.137671	0.000139	0.037548	0.325582	0.048799	0.30032	0.240755	0.284831	0.297628	0.447308	0.304668	0.370944
ElectronicIT	0.922728	0.620871	0.278202	0.209972	0.248436	0.204484	0.380441	0.356643	0.351606	0.179986	0.352006	0.457731	0.577265	0.338383	0.398692
Nano_Matrls	0.802921	0.59819	0.069593	0.151003	0.067142	0.125839	0.341281	0.095857	0.250898	0.229365	0.352437	0.429125	0.465615	0.2909	0.430166
TransportTec	0.859164	0.58606	0.073554	0.280754	0.210304	0.113985	0.344455	0.168696	0.216078	0.09233	0.206916	0.320123	0.435033	0.377467	0.402395
Metal_MedTec	0.828311	0.547869	0.071505	0.153542	0.052249	0.060856	0.391794	0.140173	0.290607	0.206954	0.112074	0.0598	0.466687	0.310929	0.411942
Svces	0.912772	0.572303	0.086621	0.148657	0.158644	0.134617	0.436601	0.215054	0.265044	0.183273	0.192389	0.159029	0.464569	0.36972	0.331502
CGDS	0.937794	0.609238	0.277299	0.312476	0.116009	0.185398	0.435001	0.296036	0.335883	0.275088	0.373101	0.158793	0.541632	0.439147	0.487766

Source: Author's simulations. Except spillover coefficients, the induced productivity effects are post-shock % changes from base-case.

5.2. Sector-wise effects

It is evident that spillover indexes depend on the source and user sector-specific trade-embodiment index via the Equations (Section 3). The spillover coefficients for ICT, heavy manufacturing and services are higher in G7 and other DCs than those in the less developed host for these industries (Table 10). These technological improvements translate into productivity gains leading to increased supply in all regions except for MENA, some LAC and SSA. As discussed before, this is attributed to lower technological spillover, lower capture and lack of R&D causing less-pronounced TFP-effects (Tables 7 and 10).

However, in all scenarios productivity gains and capture has larger impact on supply prices to go down—the impact differentials being caused by disparate TFP-augmentation and its assimilation. The changes in price relativities coupled with the Armington (1969) specification of commodity substitution triggers inter-regional competition. For the global economy as a whole, in all the scenarios there has been an increase in the quantity index of world trade by almost 2.6%. In effect, supply prices for all the commodities fall in USA and other developed economies whereas for those experiencing lesser transmitted spillover benefits the gains are limited. Concomitantly, output response is strongly positive in all the regions except very few negligible negative impacts due to general equilibrium competition among regions and sectors. Not surprisingly, India, Rest of South Asia, Vietnam, SSA, ROAFR, MENA, being laggard in technology capture and lower transmission, register modest increase in supply. As expected, we see that this has been governed by the magnitude of the embodiment and spillover coefficients and uneven distribution of productivity enhancements across sectors. A glance at Table 10 reveals that the impact of the technological improvement is not as uniform across sectors and other regions although the direction of change matches expectation, largely governed by the magnitude of the sector-wise spillover coefficients—influencing differentials in commodity-wise regional export performances. This can be ascribed-one-to-one correspondence—to the differentials in the bi-lateral sectoral embodiment indexes [E_{irjs}]. Largest beneficiaries among the developing economies are South Korea, Hkg_Twn, South Africa, Mexico with BRIC being relatively unsuccessful due to lower spillover. As expected, cost-reducing spillovers cause rise in regional exports (Tables 8 and 10).

6. Conclusion and policy insights

Empirical growth literature—based on Solovian and endogenous Lucas-Romer theoretical paradigms—has embarked upon policy-recommendations for catching-up and convergence of economies with per capita income differences, and brings into light the role of economic policy mix for successful transition to growth. Complementarities between economic policy and structural features such as institutions, financial development, infrastructure, governance as well as R&D-policy, education are crucial for growth process (Calderón & Fuentes, 2012). Hence, the public policies to stimulate structural change toward investments in R&D, human capital, infrastructure, as well as trans-border technology diffusions are necessary for growth and avoiding middle-income trap (MIT). According to the New Growth Theory framework (Barro & Sala-I-Martin, 1995; Lucas, 1998), the key requirements of technology-driven development are not simply global integration and new knowledge as economic development requires education, combinations of technical skills, and a whole series of institutions, networks, and capabilities that enable the effective use of existing knowledge, all of which must be part of, or even precede, any serious effort to create new knowledge (Das, 2002, 2010; World Bank, 2010).

Along this maintained hypothesis, in this paper, we construct an empirical general equilibrium model (CGE) to highlight the role of skill, institutions, innovation policy for assimilating transferred technology, and avoiding middle-income trap via catch-up. The paper designs a model where a change in policy facilitating trade, technology, different propensities and heterogeneous assimilation to adopt frontier technology cause relative convergence and divergence of regions to the world technology frontier. Based on evidences of North–South and South–South trade patterns, the results well accord with our a priori expectations: (i) in general, North–South and South–South technology diffusion embodied in traded goods have a positive impact on TFP; (ii) conducive economic policies make the emerging economies superior in the league in acquisition of spillover benefits, while the policy bottlenecks roadblock further development of the poor economies in Africa or Asia; (iii) trade and associated enabling factors are crucial for enrichment of recipients. The result supports the conjecture that learning and effective assimilation—attributed to governance, R&D, institutions, technological capability, human capital, skill—are important for harnessing North–South transmission of knowledge. The model shows that policies targeting investments in R&D, human and non-human capital, structural diversification are important for closing the differences in income gap, but for economies lacking resources for such allocation policy makers should also enable technology dissemination and assimilation for conditional convergence.

Thus, as expected, a proper combination of local technology, socio-institutional structure and human capital-induced skill intensity, and indigenous inventive capability (R&D) is sine-qua-non for effective absorption of current vintage technology. For jumpstarting take-off, the LDCs need appropriate economic policies focusing on these factors that can initiate the take-off into sustained growth, without reversal of fortunes (Bluedorn et al., 2014). It depends not only on trade potential, but also importantly on other factors like human capital, research capability or inventive capacity, and institutions. These depend also on nurturing domestic usability and absorption capacity to harness foreign-improvement in technology, which is couched in terms of socio-structural features. According to OECD (2006b), ICT has an important role for facilitating interconnectedness and convergence of diverse technological applications via spin-off effects, skills and competencies requisite for appropriating the benefits from ICT-use. Several evidences—for example, in case of South Korea, Taiwan, Singapore, Japan and lately, the BRIC—exist supporting the role of integrated economic policy in promoting these candidate factors for trade-led technology assimilation and thus, avoiding MIT (Lee, 2013; Ojha, Pradhan, & Ghosh, 2013; Vivarelli, 2014).

The policy lesson is that boosting long-term investments in the spheres of human capital, skill formation, technological infrastructure, better governance, institutions, science and technology policy for innovation capture, and global trade and financial linkages matter immensely for catching-up (Salvatore, 2004, 2007). The CGE result elicits the importance for catalyzing TFP-improvement via R&D, education, enhancing better governance and development of logistics infrastructure for making transition to a syndrome-free, policy regime. A comprehensive package of policy response beyond trade policy is required. Innovation policy goes beyond the science and technology policy per se, as with global trade, these domestic factors could work aplomb for output and employment growth, and improving welfare. Thus, the model provides a conceptual framework for public support policies in the evolution of international competitiveness, technological innovativeness, and inclusiveness for economic development.

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