Information age to genetic revolution: Embodied technology transfer and assimilation — A tale of two technologies

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Information Age to Genetic Revolution: Embodied Technology Transfer in Agriculture and its Assimilation—A Tale of Two Technologies*

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ABSTRACT

In this paper, a fifteen regions-fifteen sectors global Computable General Equilibrium (CGE) model is calibrated. It offers quantitative enumeration of 5% *exogenous* biotechnological invention in USA in genetically modified crops namely, maize grains and soybean. Consequently, it results in endogenously transmitted productivity gains via traded intermediates in user sectors in donor and recipient regions. Sustained absorption and domestic usability of transgenic varieties depend on constellation of: human capital-induced absorptive capacity, governance, and structural congruence between source and recipients contingent on technology infrastructure and socio-institutional parameters. Such innovations result in higher production, welfare and global trade. Also, concomitant 4% *exogenous* productivity shock in information technology along with 5% productivity growth in the agro-biotech sectors further enhances such simulated impacts on global production and welfare. Regions with larger extent of technology capture aided by higher human capital, better governance, conducive institutional-structural features, and superior technological expertise perform better.

Keywords: Agricultural Biotechnology, Information technology, Embodied spillover, Structural congruence, Absorptive Capacity, Welfare.

JEL Classification: C68, D58, F13, O3, Q17, Q18.

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ABSTRACT

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1. Introduction

Genomics and proteomics based on genetic algorithms, genetic engineering, gene mapping and cellular automata shows that information technology (IT) and biotechnology (BT) are 'coupled interlinked systems' with gradual convergence of boundaries between the two (Linstone, 2004).[2] Needless to say, advances in genetic engineering techniques are built on the development of cutting-edge research in IT so that we find concomitant development in both technologies (Meyer and Davis, 2003). According to Linstone (2004), "the convergence of information and molecular technologies may well revolutionize the innovation process and transform not only the role of forecasting, but also the process of foresight and planning." Rapid evolution of IT as a general purpose technology (GPT) gives access to rapid information network (for example, via gene bank), faster execution of experimental scientific revolution and bio-chemical synthesis and thus, facilitates rapid adaptability of new lines of inventions. In fact, Office of Technical Assessment (OTA), Congress of the US (1989) identified potential areas of application of IT in plant agriculture like in integrated pest management (IPM), irrigation control systems, control of rate of application of fertilizers, pesticides, other agricultural chemicals, and farm management. Therefore, BT developments, aided by simultaneous maturing of IT cluster are bound to deliver immense benefits to the society at large. The economic impacts of such inventions and their inter-cluster and inter-regional diffusion are best evaluated in a framework of '*social system agent-based simulation models*' (Linstone, 2004).

Of late, plant-biotechnology and use of genetically modified (GM) plants has grown into a $4.5 billion-a-year sector with most of the developments centered on food crops, particularly soybeans and oilseeds, maize grains, corn and canola. According to International Society for the Acquisition of Agri-biotech Applications (ISAAA, 2003) the total extent of world coverage under GM-varieties showed remarkable double-digit increase around 167.3 million acres in 2003, a 15% escalation from previous year. Of this, developing regions accounted for 33% (compared to 25% in 2002) and the US tops the list with 66% of world aggregated acreage whereas EU accounts for 0.5% of the

[2] Growth of IT, BT and Nanotechnology are studied as evolved through simulations based on computer simulation of complex, non-linear system, adaptive systems (CAS).

world's total. It is projected that by 2009 the forecast growth of acreage and number of GM-variety adopters would increase by another 33%. Also, GM crops will evolve along new paths in providing necessary ingredients for non-food usages like alternatives for fuel, chemicals and health (e.g., bio-pharming in pharmaceuticals, chemical and material sectors).

Given this background, we offer a quantitative enumeration of potential economic benefits of leading BT crops namely, soybeans and maize corns, wheat and also rice.[3] In particular, the analysis focuses on (exogenously specified) invention of transgenic varieties in the GM crops and the induced productivity escalation via dissemination of technological improvements through multi-sectoral and multi-country interlinkages. As IT development enhances BT activities by genome mapping and programming, the information revolution facilitates gene revolution which in turn, induces scope of cumulative productivity gains and cost advantages in the modern varieties of high yielding crop inaccessible by conventional breeding techniques. Thus, 'gene revolution' and 'green revolution' are congruous, reinforcing one another in complementary relationship (Evenson, December 2003). Also, diffusion and adoption of modern plant varieties depend on constellation of technological, economic, and social factors proxied by absorption capacity (AC), social acceptance (SA) and structural congruence (SC). We attribute 'AC' to the human capital endowment and skills. 'SC' between the origin of technology creation and the recipients depend on governance indicator, factor proportions and technological distance between partners. Also, 'SA' based on human development index determine domestication of such genetic varieties for harnessing the benefits. These three parameterize and hence, conjointly influence the magnitude of technology capture.

Technological change in the GM crops and in the IT sector occurs exogenously in the source USA. It induces *endogenous* productivity spillovers to other client sectors and regions via intermediate inputs embodying technological development. In other words, we specify a total factor productivity (TFP) improvement in the GM crops and IT sector and trace the ensuing changes in the recipients. In the spillover mechanism, traded

[3] Soybeans (Oilseeds), Corn, Canola and Cotton are major leaders in biotech inventions and innovations. Corn, Soybeans (Oilseeds), Canola and Cotton are major biotech crops. Wheat and Rice are also germane potential crops with rice has already been developed as 'golden' and other varieties. However, we do not make any specific distinction between GM and non-GM types to trace the differential impacts.

intermediates ferry the current state-of-the-art embedded in the imported intermediate. For IT sector, induced intermediate-input augmenting technical change in the chemicals sector impacts on the productivity in the biotech sectors and gives rise to technical change. A modified 15 regions-15 sectors Computable General Equilibrium (CGE) model with the global trade analysis project's (GTAP) database is calibrated for this purpose. Section 2 spells out a mechanism for technology transfer along with the potential IT-BT nexus. Section 3 presents the database, methodology and simulation. Section 4 reports the simulation results. Section 5 concludes.

2. Trade-Embodiment of Technology and Assimilation: Theoretical Premise

2.1 Lacunae in the literature

Trade is the primary conduit for technology flows and fosters productivity escalation, as the more open recipient regions benefit from transfer of knowledge capital embedded in traded products. Thus, sectors with high import contents of relatively technologically sophisticated goods may harness the benefits of technologically superior inputs used in production (Navaretti and Tarr, 2000; Keller, 1997; Coe, et al. 1997; Coe and Helpman, 1995; Das (2002, 2003); Eaton and Kortum, 1996). In the context of biotechnology, Meijl and Tongeren (1998), Nielsen et al. (2000), Nielsen and Anderson (2001), Huang et al. (2002) and Anderson (2004) have considered TFP improvement in the BT sectors and the consequential welfare impacts. In particular, to the best of our knowledge Meijl and Tongeren (2002) considered trade-induced knowledge spillovers in Soybean and Bt corn sectors via chemical inputs and also considered the role of adoption factors based on schooling years, factor proportions and social acceptance. In an empirical paper, Johnson and Evenson (2000) analyse the applicability of industrial R&D to agriculture in the context of different groups of developing economies (LDCs). Based on Yale Technology Concordance (YTC), they show that although different industry of manufacture has diverse agricultural applicability the use of inventions developed in machinery (e.g., tractors or harvesters), chemicals (e.g., fertilizer) and some other sectors are crucial for agricultural production process. In the context of new biotechnology based on gene splicing and genetic programing, this type of inter-industry flows is important for productivity gains.

According to OECD (2001) statistical definition of biotechnology, in general it is "the application of Science & Technology to living organisms as well as parts, products and models … for the production of knowledge, goods and services." This includes both advanced research such as for example, genomics, pharmaco-genomics, DNA sequencing, genetic engineering as well as process biotechnologies. Given the definitional coverage, for the scientific advancement it is imperative to have information rich in content such as functioning and evolution of gene, its sequencing and identifying the homologues. Computer and software is an essential ingredient in this process in the sense that it helps advancing each new sequence and computes its 'distance' from the already existing entries of genetic variety. Advancement in the biotechnology field depends crucially on the development of a widely '<u>cross-linked database and information network</u>'. Like the generic technologies such as steam engine or electric power has contributed to the 'growth, maturity and senescence' of industrial era (Linstone, 2004) and led to emergence of industrial societies, also, IT as a GPT has been pervasive to penetrate wide spectrum of economic activities. To make biotechnological inventions and its diffusion effective, it is argued that it has to be accompanied by concomitant development in other areas such as 'automation of testing processes, instrumentation, and management of systems for processing, interpretation, transmission and retrieval of large numbers of analytic data (OECD, 2001).' This aspect of cross-disciplinary research and infusion is important for evolution of major technology such as biotechnology. Also, development of 'new' technological capabilities depends on the existing level of technological base, human resources and infrastructure and in that regard, information technology provides the foundation on which biotechnology sector could thrive for further cutting-edge research. In fact, Evenson (December 2003) has pointed out in Indian context that '[it] has exploited its capacity to produce software and has benefited greatly from this capacity'; also, it is envisaged that economic reforms in the 1990s placed India in 'science-push' growth path which will facilitate realization of agro-biotech potential by channelizing resources into biotech sectors.

To the best of our knowledge, this issue of technological complementarity between IT and BT, its transmission and resultant economic impacts have not been formally explored. Research in genomics and proteomics depends very much on computer simulated techniques and hence, on the development of IT. Former studies did not investigate formally this aspect of joint IT-BT productivity nexus and its induced effects. However, the nature of technological dependence is a complex one as IT products do not directly enter into the production of BT product varieties, but affects indirectly via substantial enhancement of superior genetic engineering techniques, ecogenomics and ecoproteomics intensive in skill. This paper is a first attempt to model this aspect.

According to OECD (2001), 'to achieve a major change of a technological paradigm, five conditions should be fulfilled: (1) a new range of technically improved products and processes; (2) cost reductions; (3) social and political acceptability; (4) environmental acceptability; (5) pervasive effects throughout the economic system. Regarding first two issues, there is enough scope of accrual of substantial benefits via agro-biotech inventions. Trans-border and inter-sectoral diffusion of such cutting-edge research is contingent on input intensity and trade intensity. According to Acharya and Ziesemer (1996), Meijl and Tongeren (2002) and Eaton and Tongeren (2002), there are substantial horizontal and vertical linkages in the biotechnology industry—for example, New Biotechnology Firms (NBTFs) acting as intermediaries between MNCs and academia in pharmaceutical and chemical industries. It is pertinent to assume that knowledge about producing modern varieties (MVs) and GM-varieties is embedded in the chemicals as intermediate inputs. Crop biotechnology will pass through several successive potential new areas to meet burgeoning demands for food, feed and fibre production, namely: agronomic traits, food processing, pharmaceuticals, specialty chemicals based on renewable biological resources (ISAAA, 2003). Agronomic traits are predominantly qualitative traits (such as herbicide tolerance, pest and disease resistance, insect resistance) and also, to some extent quantitative traits leading to yield gains with cost-effective technology (such as genes for enhancement of food processing). Pharmaceutical and chemical companies are exploring the potential of production of drugs in major GM food and field crops like soybeans, oilseeds, rapeseeds, maize, rice, potato, and alfalfa to produce therapeutic drugs, food products and industrial products

(Nature Biotechnology, 2004).[4]

Regarding other three conditions, there are several technological, socio-institutional and economic factors that influence successful adoption of MVs (Morris and Pingali, 2003). It has been emphasized that for the adoption of 'open pollinated varieties (OPVs)' the information network and exposure to new technologies (via extension programs) matter for productivity improvement (Ransom et al., 2003). Hintze et al. (2003) argue that 'information deficits' conjointly with infrastructural bottlenecks and non-availability of varietal production characteristics in seeds pose constraints on rate of adoption of MVs in Honduras. Gerpacio (2003) considers the role of public and private sector R&D in the maize sector in Asia in generation of new technologies and its successful dissemination. Using a multi-market model, Karanja et al. (2003) find welfare-augmenting effect of potential improvement in maize technologies in Kenya. In a study of latest vintage, Abay and Admassie (2004) has emphasized in a closed economy context for Ethiopia that education is crucial for acquisition and adoption of chemical fertiliser (see also Schultz, 1981; Evenson, 1974; Basu et al., 1999; Parker and Zilberman, 1995; Feder et al., 1985; Rogers, 1962). Johnson and Evenson (2000) find that LDCs broadly similar in terms of output choice, climate or soil type, educational attainment and market size tend to register higher TFP from pool of foreign agricultural R&D and domestic spillovers due to relatively stronger institutional framework.

2.2 Trade-mediated Technology Spillover and Adoption: Embodiment Hypothesis

Current state-of-the-art technologies of recent vintages are researched and invented in the developed countries (DCs). These are *embodied* in the commodities produced using the new ‘ideas’ and spill over to the destinations through bilateral trade linkages. LDCs have depended on foreign technologies originating mainly in the DCs. Their growth and development depend not only on the extent of technology flows that is available to them, but also on their capabilities for effectively absorbing the diffused technology.[5] This type of trade-mediated technology transfer via intermediates is

[4] In this paper, we do not discuss the potential unintended mixing or accidental mixing of drug and non-drug crops ands consequential health hazards. These issues are pertinent. One can analyze the impacts with differentiation of product categories between GM and non-GM varieties as well as drug vis-à-vis non-drug crop types.

[5] Thus, international trade in commodities facilitates propagation of superior ‘technologies’ embodied in those traded goods and services (Dietzenbacher, 2001; Eaton and Kortum, 1996; Keller, 2001; World

common in agro-biotech applications (Hayami and Ruttan, 1985; Timmer, 1988; Meijl and Tongeren, 1998; Parry, 1999; Sedjo, 1999). Embodiment of such technological knowledge occurs in chemicals (e.g., in fertilisers, biopesticides, herbicides improving land productivity) and machinery (like tractors improving labor productivity). Thus, productivity escalation in biological-chemical sectors (either by autonomous, self-propellant growth generating inventions or induced by productivity growth in IT related industry) results in induced factor-bias. Such a technological innovation induces productivity enhancements in user sectors especially food and feed sectors intensive in its usage; namely food processing, materials and vegetable oil sectors via intermediate-input augmenting technical change.

Different factors affect the capacity of a given economy to capture the benefits of innovation. For example, USDA (1999) has investigated the determining adoption factors for Herbicide Tolerant (HT) soybeans and inferred that "larger operations and more educated operators are more likely to use the technology." Analogously, this argument could be extended for new technologies ushering in gene revolution to further induce the conventional breeding technique based on 'green' revolution. Investment in human capital, for instance, can help developing technological capability. Effective assimilation depends, *inter alia*, on the skill intensity of the labor force for unlocking the potential of technology. We refer to this factor as absorption capacity (**AC**). It depends on education and schooling years (Barro and Lee, 1993) and extension programs (Baig et al., 1995; Fontes, 1995; Feder et al., 1985; Straquadine, 1995; Abramovitz, 1997; Cohen and Levinthal, 1989, 1990; Pack and Westphal, 1984, Nelson, 1990). It is proxied by skill-intensity.

Domestic invention and foreign-sourced technological spillovers depend, *inter alia*, on a country's institutional setting like political stability and good governance. Needless to say, it is through the familiarity with another country's institutional factors like legal side protecting intellectual property rights (IPRs), habits and even languages that one geographically closer country becomes culturally congruent leading to social

Development Report, World Bank, 1999 for empirical evidences). The nexus between relative income level and the growth rate of the trading partners has been discussed at length (e.g., Schiff and Wang, 2004). Role of FDI in technology transfer is also emphasized in the literature. However, the primary emphasis being on the trade flows in the medium-run, we focus solely on trade as a vehicle of advanced technology.

cohesion. Evenson (2003) has stressed the role of 'conflicting politics', political sentiment in India and 'political hysteria and hostility to GMOs' in Europe as factors inhibiting the momentum of spread of such state-of-the-art and hence, obstructing the success of International Agricultural Research Centers (IARCs) and National Agricultural Research Centers (NARS) in 'providing leadership in the Gene Revolution.' In the same vein, Schiff and Wang (2002, 2004) discussed, in the context of Latin American and Caribbean countries, the role of governance and institutional quality along with education in appropriating the diffused spillovers for achieving virtuous growth cycles. We incorporate the institutional factors via a parameter reflecting the index of governance (**GP**). Typically, it is argued that technology transmitted from the source will deliver the potential benefits to the recipients if the level of governance quality of origin vis-à-vis client is (almost) similar, if not identical.

Also, domestication of foreign technology depends on indigenous inventive capabilities and own R&D-effort for building technology infrastructure (Evenson, 2003; Johnson and Evenson, 2000). We proxy this by R&D expenditure as a percent of GDP of each region and compare between source and the host nations to derive a bilateral technological congruence (**TC**) parameter. However, unlike Johnson and Evenson (2000) we do not consider the 'technology infrastructure classes'; rather, we encapsulate some of the factors in **AC** and **GP**.

Not only hindrance in acquisition of AC and TC, but also distance (geographical or socio-cultural) limits the extent of knowledge diffusion, its social acceptance and widening of the existing technology frontier.[6] The more the trading regions are institutionally, structurally homogeneous or proximate the more is the mutual compatibility of them becoming bilateral trade partners. Cultural or structural homogeneity and geographical proximity are linked (Linneman, 1966; Groot et al., 2004; Frankel, 1997). Lowering adjustment costs and better GP can enhance integration and facilitate trade flows and makes it socially 'acceptable' via structural homogeneity. Thus, we specify a binary governance parameter as comparative measure of institutional quality indicator between two potential trade partners. For cultural affinity that determines the

[6] According to Keller (2001), the estimated *geographic half-life* of spillovers is only 1200 kilometers i.e., the distance as which half of the diffused technology spillovers have tend to disappear.

degree of social cohesion and acceptance of 'new' technology in a region, it is assumed to depend on overall quality of human resource development. We incorporate such effect via exogenously specified 'social acceptance (**SA**) parameter'--a composite measure.

Conjointly, source and destination-specific **TC** and **GP** determine the binary institutional-structural congruence index (SC) which together with the host-nation-specific absorption capacity (AC) and social acceptance (SA) parameters determines the amalgam technology appropriation parameter (**TAP**). This encapsulates the role of SC, TC and AC to capture the potential benefits of trade-induced technology transfer. The magnitude of such composite index confers some objective measure of proximity (unity identifying almost proximate regions while zero indicating maximum incongruity).

2.3 Embodied Spillover Equations: A Mechanism for Technology Dissemination

Following an exogenous technological improvement in unique sector of one region, all other sectors in the source region, and all sectors in other regions experience *endogenous* TFP improvement via technology embodied in intermediate inputs. We adopt three different specifications for the technology transmission equation: the first one applies for the *trade-induced spillover* between destination regions and the source of technological change; in the second one, we consider *domestic spillover* to the sectors in the source itself following *exogenous* technological change. Also, we consider induced factor-biased technical change in the relevant sectors. The amount of trade-induced knowledge spillover from a source sector in the donor region to a particular sector in the client regions depends on input-specific trade intensity of production. Hence the embodiment index is defined in terms of trade intensities for different specific material inputs; i.e., source and user sector-specific trade-embodiment index. We define this index [E_{ijrs}] as the flow of imported intermediate produced in sector 'i' in source region 'r' that is exported to firms in sector 'j' in recipient region 's' [F_{irjs}] per unit of composite intermediate input of 'i' used by sector 'j' in destination 's' [M_{ijs}]. The latter—M_{ijs}—is a simple aggregate of nominal values and is the total (i.e., domestically sourced as well as composite imported inputs) usage of intermediate input 'i' by sector 'j' in region's'. Thus, it is expressed as

$$E_{irjs} = F_{irjs}/M_{ijs} \quad (1)$$

where F_{irjs} is the imports of 'i' from source 'r' used by sector 'j' in recipient 's'. M_{ijs} is the value of purchases of traded intermediate i by firms in industry j of region r. For governance parameter (**GP_{rs}**), it is measured by the following function:

$$GP_{rs} = min\ [1, GP_s/GP_r] \quad (2a)$$

According to (2a), if destination's' has higher GP_s than that of source 'r' i.e., GP_r, then it is conducive governance structure for's' to effectively utilize the transferred technology. Otherwise, if the client region lags in institutional quality behind the advanced source [i.e., $GP_s<GP_r$], then it poses hindrance in's' for absorbing the technology even if AC is high there. Here, $0 \leq GP_{rs} \leq 1$.

Analogously, for *technological congruence* factor, it is constructed as binary variable (**TC_{rs}**) measuring proximity or closeness between the source and the client regions 'r' and's'. Thus,

$$TC_{rs} = min\ [1, TC_s/TC_r] \quad (2b)$$

Here, also $TC_{rs} \in [0, 1]$ with zero implying further away from the invention frontier of the source nation and unity implying closer to the innovators.

Absorption capacity (AC_r) index and Social acceptance (SA_r) indexes are region 'r' specific (i.e., generically, 'r' can be destination and the origin) and thus carries one subscript as identifier of the concerned region. In the paper, we reserve 's' for the recipient whereas 'r' stands for the source region. It is to be noted that the definition for the spillover coefficient bears an additional subscript for source sector 'i' so that

$$\gamma_{ijrs}\left(E_{ijrs}, \theta_s\right) = E_{ijrs}^{1-\theta_s} \quad (3)$$

where γ_{ijrs} is the spillover coefficient between 'i' in source 'r' and 'j' in destination's' and θ_s is "capture parameter" in's'. θ_s is the product of the recipient-specific AC-index AC_s (where $0 \leq AC_s \leq 1$) and the *binary institutional-structural congruence* index SC_{rs} (where $0 \leq SC_{rs} \leq 1$); it measures the efficiency with which the knowledge embodied in bilateral trade flows from source 'r' is *captured* by the recipients 's' so that:

$$\theta_s = AC_s.SA_s.SC_{rs} \quad (4)$$

Now, SC_{rs} depends on binary governance parameter (GP_{rs}) and binary technology adjacency parameter (TC_{rs}). Thus, we can write

$$SC_{rs} = GP_{rs}.\ TC_{rs} \qquad (4a)$$

Therefore, with 'r' being *unique source* it follows that for destination‘s’ at macro level:

$$\theta_s = AC_s.\ SA_s\ GP_{rs}.\ TC_{rs} \qquad (4b)$$

The actual productivity level from the potential streams of ‘latest technology’ depends on $\theta_s \in [0,1]$ with $\theta_s = 1$ implying full appropriation of foreign technology. For destination region‘s’, θ_s and E_{rs} jointly determine the value of the ‘*Spillover Coefficient’* $\gamma_s(E_{rs}, \theta_s)$. $\gamma_s(.)$ has the properties that:

$$\gamma_s(0) = 0,\ \gamma_s(1) = 1,\ \gamma_s' = (1-\theta_s)\ E_{rs}^{-\theta_s} > 0,\ \gamma_s'' = -\theta_s(1-\theta_s)/E_{rs}^{1+\theta s} < 0.$$

where primes indicate the first (′) and the second (″) derivatives with respect to E_{rs}.

More specifically,

$$\gamma_s(E_{rs}, \theta_s) = E_{rs}^{1-\theta_s}\ ,\ 0 \le \theta_s \le 1 \qquad (5)$$

It is to be noted that trade intensity is treated as a *binary* variable indexed both for the recipient sector ‘j’ in a given region‘s’ and for the source sector ‘i’ and region ‘r’. The regional composition of imports for individual using sectors in s is not known. A pro-rata *assumption* based on import proportionality is made such that an imported input is proportionally distributed across all user sectors.[7] Thus, if F_{irjs} indicates usage in region ‘s’ by industry j of imported intermediate i from source 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’

$$F_{irjs}/F_{ij\bullet s} = F_{ir\bullet s}/F_{i\bullet\bullet s} \qquad (6)$$

where $F_{i\bullet\bullet s}$ is the aggregate imports of commodity ‘i’ in region ‘s’ from all source regions.

Following (6), the coefficients $F_{ij\bullet s}$ is the market value of purchases of imported intermediates i by sector j in s, $F_{ir\bullet s}$ is the value of imports of tradeable good i from r to client s, $F_{i\bullet\bullet s}$ is the value of aggregate imports of tradeable commodity i in r and the *right-hand ratio* is *assumed* to hold for all industries ‘j’ in‘s’ using imported ‘i’ from origin of innovation ‘r’.

[7] However, in the literature on embodied international technology diffusion, this assumption is commonly used. See OECD (2000), *Science and Technology Indicators Scoreboard*.

In the source region, the benefit of a technological change in a sector is reaped *directly* by the other sectors via the usage of *locally* produced intermediates embodying advanced technology and *indirectly* via imported intermediates. Hence, the exogenous TFP improvement in 'r' endogenises TFP improvement in the receiving sectors via *domestic* spillover effect so that the relevant sectoral embodiment index [E_{ijr}] is given by

$$E_{ijr} = D_{ijr}/M_{jr} \qquad (i \neq j) \qquad (7)$$

where D_{ijr} is the quantity of domestic tradeable commodity 'i' used by firms in sector 'j' of source 'r' and M_{jr} is the domestic production of 'j' in 'r'. However, for the source country the relevant capture parameter is defined in terms of the human capital-induced absorption capacity (AC_r). For governance factor and technological adjacency parameter when compared on a binary scale relative to the own region 'r', the 'binary values' are unity implying $SC_{\mathbf{rr}} = 1$. That is, a country is 100% congruent to its own structural parameters. Thus, we assume that the higher is AC and SA for a given constellation of TC and GP in 'r', the higher will be the domestic sectoral spillover such that the spillover coefficient for source region is:

$$\gamma_{ijr}(E_{ijr}, \theta_r) = E_{ijr}^{1-\alpha_r} \qquad (8)$$

where $\alpha_r \in [0, 1]$ is the human capital induced and social acceptance based capture-parameter for source 'r'. θ_r has one-to-one correspondence with α_r.

In agricultural biotechnology, broadly speaking there are two prototypical generic invention: *firstly*, development of agronomic traits and lowering cost of production, and increasing production efficiency (i.e., directly favoring the producer, indirectly benefiting consumers with lower prices) and *second*, development of attributes of interest to consumers for health and nutritional values like development of golden rice variety (i.e., directly benefiting consumers' interest). Biotech products like maize (in this paper, maize is used interchangeably with coarse grains or corn) and soybean (oilseeds) are intermediate inputs to some food processing sectors and those producing dairy products or vegetable oil, fats and associated products. Also, improved productivity via transgenic varieties in the concerned BT sectors induces productivity improvements of primary factors. Two prototypes are: improved productivity of chemical inputs (like Herbicide tolerant (*Ht*) gene varieties in case of soybeans or insect resistant *Bacillus thuringiensis*

(*Bt*) corn) save primarily on land by inducing land productivity, whereas in case of mechanical invention it improves productivity of labor making it labor-saving type. However, in both cases new agro-biotech saves on primary factor depending on the share of each input in production. We model chemical-input augmenting technical change in the soybean, maize, wheat and rice sectors and consider factor-biased technological change in each of them. In each biotech sector, the *degree of factor-bias* for each primary factor input is *assumed* to be equivalent to the share of each factor in the composite value-added. That is, it is *assumed* that share of each category of primary inputs in total endowments of all the categories going into the production of composite value-added reflect the extent of bias for that factor in the user sector.[8] The technology transfer mechanism is given by:

$$\text{af(i, j, s)} = E_{ijrs}^{1-\theta_s}\,.\text{af (i, j, r)} \qquad (9)$$

where af (i, j, r) is the ith intermediate input-augmenting technical change in sector 'j' in 'r' (r≠s), j stands for the element of the sets of biotechnology intensive crop sectors and 'i' indexes the source sector of intermediate-input augmenting technical progress for example, chemical inputs in the context of biological-chemical inventions.

Information flows across institutional and economic boundaries is instrumental for harnessing the growth impetus. We assume that an invention in IT industry cluster induces an innovation in chemicals used as intermediate input in the crop sectors and hence, in turn, induces crop productivity via development of better transgenic varieties. Thus, we implement (9) along with IT-enhancement via equation system (3) to (8). For primary factor bias, we implement the following key equation:

$$\text{afe(k, j, s)} = \Omega\ \text{(k, j, s).af (i, j, r)} \qquad (10)$$

where Ω (k, j, s) is the share of the kth primary factor in the value-added of the user BT sector j in region 's' (i.e., proxy for degree of factor-bias). afe(k, j, s) is the primary factor 'k' augmenting technical change in sector 'j' in 's' induced by input 'i' (*unique* source).

TFP transmission equation for the recipients can be written as

[8] Ideally speaking, it is better to estimate the bias econometrically for each sector in each region. But, given the data limitations, in our framework of CGE analysis it is reasonable to proxy the ‘extent’ of bias by factor shares. This does not undermine our primary purpose of investigating IT-BT nexus.

$$\text{ava(j, s)} = E_{ijrs}^{1-\theta_s}\,.\text{ava (i, r)} \qquad (11)$$

where ava (i,r) and ava (j,s) are respectively the percentage changes in TFP levels in source and destinations [i≠j are the innovating sector and the receiving sectors respectively, and r≠s]. For the source 'r', the transmission equation is:

$$\text{ava(j, r)} = \mathrm{E}_{\mathrm{ijr}}^{1-\alpha_r}\,.\text{ava (i, r)} \qquad (12)$$

3. Methodology and Database

3.1 Database: Sectoral and Regional Aggregation

A version of the comparative static Global Trade Analysis Project's (GTAP) model is customized to suit our purpose. Version 5.4 of the GTAP database (i.e., GTAP Sectoral Classification, revision 1 (GSC1)) representing the state of the world economy in 1997 distinguishes 78 regions and 57 sectors and provides us with the splits of labor payments between the skill and unskilled categories (Dimaranan, 2003). A reduced dimension 15-regions ×15-sectors aggregation of the Version 5.4 of the GTAP database is used to calibrate the model. Table 1 presents the regional and sectoral aggregations.

[Insert Table 1 here]

3.2 GTAP Implementation: Methodology and Parameters

The framework is a modified comparative static computable general equilibrium global trade model (Hertel, 1997). It belongs to the class of CGE models based on the Australian ORANI model (Dixon et al. 1982). 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. Based on the microeconomic foundations of consumer and firm behaviors within the individual regional economies and trade linkages between the regions, this framework enables us to account for behavioral responses of each representative economic agent in response to relative price changes following policy changes. It uses customized windows program General Equilibrium Modeling Package

(GEMPACK) software to solve simultaneously the set of equations describing the behavior of the economic agents (Harrison and Pearson, 1996).[9]

The model has a detailed specification of demand and production structures, welfare and household demands, sectoral demands and international and inter-regional trade. Typically, it has a nested production and utility structure with flexible functional forms and assumes neo-classical behavior on the part of the representative agents viz., private and government households and the firms. Also, perfect competition is assumed in the markets for factor inputs and outputs. Each regional super-household (a representative decision-maker), at the top-most level, maximizes Cobb-Douglas utility subject to overall regional income split between private and public households and regional savings. The private and government households derive demands for goods by utility maximization subject to budget constraints. The utility-maximization behavior gives demand equations for private consumption and government household consumption. The second stage allocates government expenditure across commodities sourced both domestically, from abroad and other domestic regions as well. The third stage allocates this demand across domestic, imported and intra-regional sources. The final stage allocates these imported goods across regions.

Producers use intermediate inputs along with the primary factors of production. The derived demand for primary factor inputs are based on the static profit-maximizing behavior of firms. Armington (1969) assumption specifies that the produced commodities be differentiated by origin of production. Regional investment in making new capital goods is given by the output of a capital goods sector. In our short-run analysis, although the new investment goods are produced they do not add to the productive capital stock so that capital supply is fixed in the simulated period. Prices for commodities are determined via market clearing through interregional and international trade. Each sector produces only one commodity with no joint production. At the top level, a composite output is produced with a Leontief fixed proportion technology using intermediate inputs and a primary input composite. Each intermediate input is produced in a Constant Elasticity of Substitution (CES) production nest using 'domestic' and a 'composite' of foreign goods

[9] This is developed by Ken R. Pearson and colleagues at the Centre of Policy Studies/IMPACT, Monash University, Australia based on GEMPACK software suite.

distinguished by region of origin. Primary factor composite consists of land, labor, and capital, which are combined through CES technology. However, demanders treat imports from different sources as imperfect substitutes and there is scope for substitution between domestic and imported materials of the same commodity.

In our augmented theoretical model, four sets of parameters are: skill-induced **AC** index, governance indicator **GP**, social acceptance parameter **SA**, and technological proximity measure **TC** in addition to the standard model parameters.

As regards AC, we calculate the skill-unskilled labor payment shares for skill-intensity measure. Calculated AC-values for some of the developed regions are such that $AC_{USA}>AC_{ANZ}>AC_{WEU}>AC_{JAP}>AC_{HPAES}>AC_{CAN}$ with α_r proxying AC_{USA} is the highest of all the regions However, some composite regions show higher values.

For **GP**, we use the World Bank's (2003) comprehensive data on six dimensional governance indicator with 'inherent commonality'- see Kauffman et al. (2003, 2004). These values, bounded between -2.5 and + 2.5, are at much disaggregated regional level.[10] On the basis of disaggregated observations for each category, a simple average, composite governance indicator for each mapped region is constructed. For composite regions, we calculate such aggregate values by mapping the component GTAP regions with regions in Kauffman et al. (2003) dataset. Having constructed such individual region-wise indexes, we transform via Equation (2) to find *binary indexes* of each with USA as the benchmark. The values are bounded between '0' (extremely low degree of governance) and *unity* (almost perfect governance). We consider absolute magnitude of such indexes. The composite indicator of the estimates of score on each separate ones is a reasonable proxy for overall attribute of governance. Based on these findings, we infer that USA and Canada are more structurally homogeneous as opposed to Latin American and other LDCs. As expected, Japan, ANZ and EU have higher range of values.

Regarding technology adjacency parameter (**TC**), in the literature the most widely used comprehensive proxy measuring such variable is <u>R&D expenditure as percentage of GDP</u>. It is assumed that the higher is such value, the *higher* is the degree of technological proximity and the *higher* is the scope of integration facilitating knowledge capture. We

[10] These indicators for perceived institutional quality are: Voice and accountability, Political stability, Government effectiveness, Regulatory quality, Rule of law, and Control of corruption. The values of such parameters are not reported here for parsimony.

get higher values for Canada whereas for the rest we get relatively lower or same magnitude within a group. The values of such measure are taken from Human Development Report (2003). Typically, USA, EU, Japan and South Korea has higher binary values of almost unity i.e., they are (almost) technologically similar to each other.

For **SA**, we consider human development index (Human Development Report, 2003)—a measure of standard of living and quality of life. Thus, the higher is the quality of life and living standard of a nation the higher is the degree of acceptance of a new technology as it provides the basis for a well-functioning institutional structure.

3.3 Policy Experiment: Simulation Design and Productivity Shocks

We consider *two generic types* of exogenous shocks: **[i]** technology shocks related to TFP augmentation in IT and BT sector in the US and **[ii]** factor-biased technology shocks enhanced by IT productivity growth. Technological change in the IT sector and in the *Ht* Soybean and *Bt* maize are TFP shocks. Such technological innovation induces productivity enhancements via intermediate in chemical inputs, and manufactures (for IT as source) and in food processing, other agricultural sectors (for BT sectors as sources).

To the best of our knowledge, amongst the recent studies only Keller (1999) calculated a TFP index by industry for 8 OECD countries. We match Keller's (1999) ISIC [Rev.2] sectors with the GSC1 sectors. It is evident that the industries included in the hi-tech and heavy manufacturing clusters experienced rapid technological change with higher average annual TFP growth of 3.4% during 1970-91. Since we do not have data for the base period 1997 being simulated, we extrapolate growth rates over 6 years encompassing the simulated period. Thus, 4% (approximately 3.9%) extrapolated growth rate is used as the Hicks-Neutral technological shock in IT sector in the US[11].

According to Nelson et al. (1999), it is suggested that glyphosphate-resistant soybeans may generate 5% cost-reduction whereas for GM-maize variety the yield gains varies between 1.8 to 8.1%. Nielsen and Anderson (2001), Anderson et al. (2004), Meijl and Tongeren (2002) assume 5% productivity escalation in GM sectors. Thus, we consider 5% Hicks-neutral productivity shocks in *Bt* maize (corn) and *Ht* soybean/oilseed

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[11] According to Keller (1999, 2001) the rate of growth of R&D stock in USA is 7.4% of which 90% is originating in manufacturing comprising hi-tech and heavy manufacturing. That is, the growth of R&D in

sector. Also, we consider *induced* primary factor biased technical change in the crops sectors. It is assumed that IT invention (exogenous) in the US affects productivity of agro-biotech products via propagation of biochemical synthetic pathways and enhances biological-chemical innovations leading to better bio-genetic crop varieties.

Standard GTAP general equilibrium closure for GTAP version 6.2 is used (McDougall, 2003). However, since we do not model technology creation adoption of static model to study potential impact of spillover to trace the one-time gain is insightful (Evenson, December 2003).

4. Analysis of Selective Simulation Results:

4.1. Regional Macroeconomic Repercussions

Four sets of simulations are performed: (1) 4% TFP changes in IT sector in USA(**identifier**: *gtapit*); (2) 5% TFP changes in only Bt maize (grains) sector in USA(**identifier**: *gtpagbt1*); (3) 5% TFP changes in only Ht soybean (oilseeds) sector in USA (**identifier**: *gtpagbt2*); (4) 5% intermediate 'chemical inputs' augmenting technical change in the presence of 4% IT shock (**identifier**: *biasitbt*).[12] Table 2 summarizes simulated impacts on some selected macroeconomic variables.

[Insert Table 2 here]

After the TFP improvement in IT sector in the US and the associated endogenous TFP changes, the economy-wide TFP index registers an improvement in all regions. However, the magnitude of the index differs markedly across the regions (see Table 2). Apart from simulations 2 and 3, USA, being the source of innovation, experiences higher overall technological progress whereas EU and other developing regions experience a TFP improvement of lower magnitude than USA, exception being Canada; more importantly, amongst the other regions, Canada receives higher doses of technology transmission than most others in almost all the scenarios. South Asia and most of the Latin American countries are experiencing modest region-wide TFP performance. In case

manufactures especially in heavy manufacturing and hi-tech. is 0.90×7.4%= 6.4% (approximately). Simple average of the TFP indexes in these 2 sectors is 3.2%

[12] Details list of the variables and equations are not reported for parsimony. However, those who are interested can discuss with the author about the specifics. Sets of simulations for 15×15 global trade model generate too voluminous results to be reported here. Also, the general equilibrium effects can be traced in every detail by considering generic variable each subscripted by 15 sectors, 15 regions and 15 user regions

of scenarios 2 and 3, for USA there is no substantial foreign spillover from two biotech sectors to other sectors especially manufacturing clusters via intermediate usage. Most of the spillover is domestically sourced in those sectors. Thus, the overall index exhibits bit lower magnitude and hence, USA's performance is not as good as in scenarios 1 and 4. For the multi-factor productivity growth the escalation of region-wide technical change translates into growth in regional real GDP. Table 2 shows that, region by region, the overall technical change translates exactly into an equivalent percentage increase in real GDP at factor cost. Given the fact that shock is factor-neutral in nature, with fixity of regional supplies of all the components of value-added, the percentage deviation in real GDP at factor cost in each region is equal to the respective region-wide TFP changes. In the solution period, the index of aggregate real value-added exhibits an increment equal in magnitude to region-wide improvement in TFP growth. Similar considerations explain the changes in variables for other regions.

With fixed supplies of factors of production, the TFP improvement inflates the returns (nominal and real) to the factors. Real income increases in all the major beneficiary regions. More predominant effect occurs in scenarios 1 and 4 with USA, Canada, Mexico, WEU and Chile being the major beneficiaries experiencing the highest doses of trade-induced spillovers. For Canada and Mexico, since they belong to NAFTA, induced spillover is more dominant and for Chile, compared to Mexico the effect is much smaller because it loses from not being part of the FTA with USA.[13]

However, in scenarios 2 and 3 for Japan, South Korea, HPAEs the trade-induced spillover is high due to higher intensity of trade in biotech intermediates, higher AC and SS indexes. For IT and BT intensive sectors, the induced effects are dominant (see section 4.2 below). After the technology shocks, there are changes in price relativities across regions which induce changes in regional TOT, and hence, there is repercussion in the pattern of inter-regional competition. These prices are regional supply prices. This indicates that due to technological benefits there is substantial cost reductions leading to

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through multi-sectoral, multi-regional linkages. However, depending on the major thrust of the paper we discuss most important few. For limitations of space, we do not report and explain all the detailed results.

[13] In fact, in regional trade integration literature, this type of dilution of gains outside a regional trading bloc is discussed. In the context of our paper with technological spillover and its persistence (hysteresis via dynamics), this type of effect can be shown. Given the limited focus, we do not consider those trade policy effects here, but simulations can be mounted with further extension.

decline in export price indexes in all the beneficiary regions—the extent of fall depending on the magnitude of technology transmission and its actual capture by the sectors. From Table 2, we observe that regional export price indexes fall in almost all the regions with much higher reduction in the major beneficiaries of such technology spillover with its higher capture by regions such as Canada, Argentina, Japan, China and WEU. They benefit from reduction in costs via technological inventions especially in scenario 4 with joint technology shocks in both IT and BT sectors.

In all the four simulations, the technological benefits have been welfare-augmenting. Much higher welfare improvement occurs in case of concomitant productivity improvement of IT and BT (scenario 4) than in the case of TFP growth in only BT sectors. It is true in most of the regions exception being South Asia capturing less magnitude of trade-induced benefits due to lower capture. Decomposition of welfare effects exhibits that except in the scenarios 2 and 3, in all cases the allocative efficiency effects are contributing positively in case of Canada, EU, Chile, Argentina, Japan and China. However, the contribution of all technical change is the most dominant one for welfare enhancement. In scenarios 2 and 3, welfare gains is much higher for EU, Japan, South Korea and HPAEs. This is because of higher share of traded intermediate inputs from IT and resultant trade-induced technology transmission in biotech-intensive products especially in maize, wheat, soybean, processed foods, vegetable oils and fats, meat and dairy products from the regions benefiting from higher doses of transmitted technology capture. As will be evident from Table 3, this depends on the magnitudes of the embodiment index and the spillover coefficient.[14]

[Insert Table 3 about here]

The aggregate spillover index gives average *overall* magnitude of technology appropriated by all user sectors in the US as well as host regions from the IT and BT sectors via intermediates. From Table 3, it is evident that the aggregate embodiment index in USA $[E_{ir}]$ is higher than most of the destinations especially the LDCs $[E_{irs}(s \neq r)]$. The capture-parameter (θ_r) in USA is higher than θ_s in all the destinations,

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[14]Aggregate 'Embodiment and Spillover Index' for any region *r* is defined as the share-weighted average of such sectoral indexes - weights being the share of output of sector *j* in aggregate output of all sectors in a region *r*.

it is clear that USA reaps the maximum spillover (γ_{ir}) compared to most of the LDCs except Mexico and Canada. This is due to the fact that for those two NAFTA regions trade-embodiment is higher along with much higher capture parameter values for Canada as compared to Mexico. For EU, Japan, ANZ, and South Korea, the aggregate spillover coefficient (γ_{irs}) is of much higher magnitude than in most of the LDCs in South America and South Asia. This is because the higher value of the capture parameter $[\theta_r]$ magnifies the value of the embodiment index and hence enables them to record a much higher TFP improvement. In conformity with our theory, the regions with higher binary structural congruence vis-à-vis the US and higher skill intensity-induced AC (namely, Canada, ANZ, EU, Japan, South Korea) register higher trade-induced spillover and productivity reflected in higher real GDP. Relatively laggard and less congruous regions viz., Argentina, Brazil, South Asia, Mexico register moderate growth effects. Note that the ordering of the spillover coefficient in Table 3 matches the ordering of the real GDP results in Table 2.

The above discussion illustrates the fact that traded intermediates in conjunction with AC and SS are crucial for facilitating technology transfer. The innovating region and the regions with higher SC and TAP-parameter like the source reap the maximum productivity growth by sourcing a relatively high proportion of the technological improvement bearing input from the source region. The changes in price relativities coupled with the Armington (1969) specification of commodity substitution lead to inter-regional competition via international trade. For the global economy as a whole, we see that there has been an increase in the quantity index of world trade by 0.8 percent. Following the shock, the aggregate volume of exports increases in the principal beneficiaries of TFP growth namely, USA, Canada, Japan, China, South Korea, Argentina and EU. The preceding discussion shows that the TFP shock erodes competitiveness of laggard regions like South Asia and some South American countries whereas USA, Canada, Japan and EU, reaping almost the maximum potential benefits, become more competitive than others. A much larger rise in the volume of exports from USA, Canada, Japan, Argentina, China and EU and relatively smaller order of magnitude of fall in the volume of exports from other countries gaining from indirect spillovers translate into a rise in the volume of global and regional trade in case of joint productivity shocks in IT and BT sectors (see row 4, Table 4). As the TFP improvements act as an export supply shifter for each generic commodity, for each commodity the volume of global merchandise exports, as well as imports, increases.

[Insert Table 4 about here]

A relatively much larger fall in export prices in other regions as compared to the falls in these prices in USA translate into a much larger decline in the regional price index of merchandise exports in them than in USA (row 2, Table 4). Even South Asia benefits because of mainly IT-induced spillover in these regions—with especially India becoming competent hub of such IT-related development and its burgeoning cross-border trade. From Table 4, it can be inferred that the magnitude and directions of the changes in commodity-specific export price indexes are driven by the changes in regional aggregate export price indexes. These aggregate export price indexes are share-weighted averages across regions of the exports price index of each commodity from exporting region--the weights being the shares of regional exports in global exports. Considering USA as the destination of exports from other hosts, we observe that the percentage increases in the volume of imports from them are uniformly greater than those in Argentina, Brazil and South Asia. Since the market prices of the tradeables imported registered a fall, the relative price changes in favor of most of these markets translate into a higher percentage increase in demand for commodities sourced from USA and other DCs as opposed to imports from these LDCs. Similar consideration explains the much larger percentage increases in bi-lateral imports of the tradeables into Canada and WEU's market from USA than from other LDCs. By contrast, in case of composite region ROW there are substantial intra-regional trade flows so that the changes in price relativities between ROW itself and the other supplying regions determine the percentage changes in bi-lateral import sales in ROW between the base-case scenario and the solution under the TFP shock. In the post-shock scenario, we see that intra-regional imports in the tradeables in ROW from its constituent regions decline whilst USA and others gain market share in ROW. As expected, we see that this has been governed by the magnitude of the spillover coefficients dominating the sectoral TFP growth.

4.2 Differential Sectoral Impacts

There has been uneven distribution of productivity enhancements across sectors. This can be ascribed to the differentials in base-period values of the bi-lateral sectoral embodiment indexes $[E_{irjs}]$. Considering the case of the client regions of embodied technological spillover, it is evident that these indexes depend on the source and user sector-specific trade-embodiment index. In effect, following the TFP shock the supply prices for all the produced commodities fall in USA and other developed economies compared to those experiencing lesser benefits from transmitted technological spillover. The computed spillover coefficients for IT, heavy manufacturing and services are higher in USA and other DCs than those in the LDCs.[15]

[Insert Tables 5 and 6 about here]

A glance at Table 5 reveals that the impact of the technological improvement is not as uniform across sectors and other regions although the direction of change matches our expectation. So while this impact has been more or less neutral across sectors in USA and rest of the world, biotech industries and the sectors which use them as intermediates for producing final food products experience falls in costs in the regions experiencing higher induced spillover and productivity enhancement. For USA, Canada, Japan, China, Argentina, South Korea and EU, regional price indexes fall in all industries whereas it does not fall that much in South Asia, rest of Latin America and composite ROW because of relatively low technology capture and less transmitted gains. For the relatively technologically laggard region, regional exports decline in IT and food products. Although the trade-embodiment indexes do not vary much between each concerned region especially for agricultural crop and other BT sectors, the magnitude of the sectoral spillover coefficients for all the sectors in Canada, Japan, South Korea and EU are of a higher order of magnitude than those in ROW. Since the magnitude of the sectoral and economy-wide capture parameter is much higher in the developed regions especially Canada, EU, Japan than the regions that are relatively incongruous with lower magnitude of capture, this magnifies the values of the sectoral spillover coefficients in the former sets of countries. This accounts for the sectoral effects as reflected in Tables 5 and 6.

Biotech industries like food products and vegetable oils and fats using the BT-

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[15] For parsimony, we do not report all the embodiment indexes and spillover coefficient for all the scenarios. We report the major results especially for IT-BT nexus related simulations.

crops as inputs reap substantial potential benefits from the TFP shock and its endogenous technology spillover. This leads to productive efficiency as reflected in the percentage declines in the supply prices of these two sectors. Note that in USA, the origin of the technological improvement, and for Canada, Japan and EU the values of the spillovers are higher leading to substantial TFP gains. The largest accrual of productivity gains in USA and these regions is due to its sourcing of a relatively high proportion of IT and biotech products from its own market as well as from trade flows. Given relatively lower endowments of technology capture-parameters in Argentina, Brazil, Mexico, Chile, South Asia and China (because of low SC values) as compared to USA, they do not perform as well.

So far as the *endogenous* TFP improvements are concerned, there is intra-sectoral variation within a region (Table 6). Between sectors, there are variations because of differences in input shares of IT and BT products in the final products of the concerned sectors. Thus, heavy manufactures, services or chemicals using IT and equipments intensively gain more in terms of production and endogenous spillover when IT is the source. For food, feed and other agricultural crops, and agro-biotech sectors the productivity escalation in maize, soybeans and chemicals translate into much higher induced spillover and hence, resultant productivity improvement. As conjectured, the TFP improvements across sectors are in conformity with the magnitude of the spillover coefficients and it accords well with our *a priori* expectations.

5. Concluding Remarks

Under a mechanism of trade-embodied technology diffusion, using a CGE model this paper explores the role of absorptive capacity and socio-institutional factors for the capture of potential technology flows. We have done it in the context of productivity enhancement in information technology and biotechnology. It has been shown that the governance, technological similarity, social acceptance and their amalgam structural congruence are important for successful assimilation of spillover. Moreover, invention in the IT sector contributes positively to BT sectors' technological progress. Technical change in USA has differential productivity improvements in its trading partners depending on constellation of capture parameter. Higher skill intensity facilitates adoption of transmitted productivity gains and higher magnitude of capture for the regions structurally congruent to each other; we found higher percentage increases in the real income, real GDP and overall indexes of TFP growth in the major beneficiaries. On the contrary, relatively less proficient regions, with lower productive efficiency parameter, experiences relatively less pronounced TFP growth.

The research could be further extended to incorporate the simulation design in which the relative endowments of skilled and unskilled labour change in the regions. Such a scenario might be explored to work out the effects of a long-term investment in human capital accumulation, social infrastructure. Another possible area would be to consider the case with factor augmenting technical change occuring at very different rates for the labor types. Also, focusing on appropriateness of technology and indigenous R&D capabilities will be valuable for enunciating policy insights so as to foster absorptive capacity, governance and socio-institutional factors. It would be worthwhile to explore the scope of integrating the role of invention and patent protection in the LDCs into a global CGE framework (see Johnson and Evenson (2000)). Also, given the current debate and public opinion about acceptance of GM versus non-GM crops, and drug vis-à-vis non-drug types it would be worthwhile to disaggregate the agro-biotech sectors into distinct classes of differentiated products. That will give more insights about the role of social acceptance, consumers' perception about GM and non-GM varieties. Also, following Evenson (December 2003), it would be worthwhile to model the dynamic benefits of complementarities between 'gene revolution' and 'green revolution' via the development of current state-of-the-art technologies yielding modern transgenic varieties. However, given the limited scope of the study, this paper is an attempt in that direction.