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Issues and challenges on technology spillovers in emerging economies

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Abstract

This paper deals with the theoretical and conceptual issues on the role of technology spillovers and the channels through which they diffuse particularly in the context of developing and transition economies. The paper also delves into the measurement challenges related to technology spillovers. International trade, foreign direct investment (FDI) and human capital figure as the major mechanisms through which technology spillovers take place. In so doing, some challenges and limitations are also brought out with respect to measurement and methodological approaches employed in the context of previous studies in emerging economies.

Keywords: *technology spillovers, diffusion, productivity spillovers, R&D spillovers.*

1.0 Introduction

Recent contributions to the theories of international trade and economic growth have identified a number of channels through which trade affects the productivity growth. Grossman and Helpman (1991) suggest four such mechanisms. First, international trade provides channels of communication that stimulate cross-border learning. For example, this may happen by exporting to knowledgeable foreign buyers who provide blueprints and technical assistance or suggestions to improve the manufacturing process. Second, international contacts enable increased imitations which facilitate the development of new technologies and technology adaptation. Third, international trade enables a country to employ specialized and advanced intermediate goods invented overseas, thereby enhancing the productivity of its own resources. And lastly, international trade indirectly affects the overall productivity level of its economy by raising a country's productivity in new technology development and innovation. Clearly, the first two mechanisms relate to knowledge or technology spillovers whereas the latter two relate to trade related spillovers. The paper discusses the current literature relating to theoretical and empirical contributions on the role of technology spillovers and the mechanisms through which they diffuse. The empirical studies on spillovers covered in this paper include studies from developing, and emerging economies.

It is observed that International trade, foreign direct investment (FDI) and human capital figure as the major mechanisms through which technology spillovers take place. The paper is organized into six sections; the first being the introductory one. The second section covers studies on the conceptual issues related to the role of technology spillovers. While the third section delves into the measurement challenges related to technology spillovers, the fourth section discusses some challenges and limitation in the different methodological approaches. The fifth section focuses on various spillover mechanisms. Finally, the last section provides a summary of the issues and challenges raised by the paper which may serve as pointers for future research.

2.0 Conceptual issues

2.1 Technology spillovers

The term *spillover* pertains to the transfer of knowledge across economic players. It has been argued that such spillovers may ultimately lead to productivity gains (Coe and Helpman, 1995). For instance, spillovers allow firms to acquire knowledge from other economic players without having to pay for that knowledge in a formal market transaction (Acs et al., 1994). The endogenous growth theory emphasizes that the engine of a country's economic growth stems from the endogenous development of knowledge through spillover effects (Romer, 1986). More specifically, a country's economic prosperity is influenced by the accumulation and spillover of knowledge through positive externalities. These theories of endogenous technical change that emerged in the early 90's fundamentally viewed technology as knowledge.

In this framework (Aghion and Howitt 1992; Romer 1990; and Segerstrom, Anant, and Dinopoulos 1990)[2] two major characteristics of technology have been emphasized:

First, technology is non-rival in the sense that the marginal costs for additional users to employ technology are negligible. David (1992) and Quah (2001 a, b) have used the terms '*perfectly expansible*' and '*infinitely expansible*' respectively to positively define this characteristic. This distinguishes knowledge from rival factor inputs like human and physical capital that can be employed by one firm at a time. In other words the marginal costs to use the same rival factor for the second firm are infinite.

Second, the returns to investments towards new technologies are partly private and partly public. This implies that while there may be strong private incentive and motivation for innovation, technological investments may benefit external firms and individuals other than the original inventor by adding to their knowledge base or public return. Such learning involves a positive externality called *technology or knowledge spillovers.* For example, the design of a new product might accelerate the invention of a competing product via imitation or reverse engineering.

Other researchers have further developed this theoretical approach by examining the consequences of both domestic and international knowledge spillovers

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[2] See also (Evenson and Westphal, 1995) and (Keller, 2004) for overviews.

for a country's growth rate. For instance, studies on the role of spillovers have focused on the importance of inward FDI in generating knowledge flows from foreign MNE's to a host country's domestic firms (Feinberg & Majumdar, 2001).

A general consensus emerging in research literature is that MNEs possess superior knowledge and technological resources when entering foreign markets, thus allowing them to successfully compete with local firms in foreign markets.

2.2 Disembodied and embodied technology spillovers

It is evident from the discussions in the previous sections that the theories of technical change have substantially contributed to a better understanding about technology spillovers. This theory also emphasizes two important mechanisms or channels through which foreign trade leads to technology spillovers[3]:

First, direct learning about foreign technological knowledge increases the country's domestic stock of knowledge. This assumption captures the idea that by trading with an industrial country that has a larger stock of knowledge a developing country stands to gain in terms of direct knowledge it can acquire. The foreign knowledge thus acquired can be actively used to invent new products thereby raising a developing country's productivity in new technology development and innovation. It may be called *disembodied technology spillovers.*

Rhee et al. (1984) for instance, describe the importance of such direct learning channels in South Korea during its industrialization process. Direct learning may also happen by exporting to knowledgeable foreign buyers who provide blueprints and technical assistance or suggestions to improve the manufacturing process (Grossman and Helpman, 1991).

Second, technology diffuses internationally through foreign intermediate goods. The idea is that foreign intermediate goods involve the implicit usage of design knowledge that was created with the R&D investment of the foreign investor. The gain from having access to such knowledge that would otherwise be costly to acquire may be called *embodied*[4] *technology spillovers*. Foreign direct investment through capital goods imports and purchases from MNC subsidiaries could also lead to such spillovers. Although the importing country has indirect access to the results of foreign R&D, only the manufactured outcome is available. It might be also possible to acquire embodied technological knowledge through reverse engineering.

2.3 Non-codified knowledge spillover

The creation of new technology is an important driver of firm success. However, not all firms can create technology within their boundaries and even firms that can do so sometimes make use of externally generated technical knowledge (Chesebrough and Teece, 1995). Such sourcing especially in the context of *tacit or non-codified knowledge* helps firms to effectively utilize technological knowledge. Furthermore, it may not be possible to codify all knowledge embodied in a patent or a blueprint. Most studies[5] on technology transfer conclude that only the broad outlines of technological knowledge are codified—the remainder is *'tacit'*.

[3] See (Rivera-Batiz and Romer, 1991), (Grossman and Helpman, 1991).

[4] Refers to foreign technological knowledge of the blueprint embodied in the intermediate good.

[5] (Polayni, 1958), (David, 1992), (Evenson and Westphal, 1995), (Teece, 1977), (von Hippel, 1994).

In this view technological knowledge is to some extent tacit as it may not possible for a person to define a particular problem solving activity that he or she is actively engaged in (Keller, 2004). Polanyi (1958) contends that tacit knowledge spillover can specifically take place only *'from master to apprentice'*.

A more generic view is that non-codified knowledge is usually transferred through demonstrations, personal instructions or through the provision of expert services (David, 1992). This view has been reinforced by (Teece, 1977) who finds that the non-codified part of the costs for transferring technology between plants are substantial. In his study sample of 26 projects from relatively advanced countries he estimated that the costs of the within firm transfers was on average almost 20% of the total project costs.[6] Teece's findings have been reinforced by (von Hippel, 1994) study that shows non-codified knowledge continues to be important for understanding patterns in the creation and diffusion of knowledge.

3.0 Measurement Challenges

As technology is an intangible and difficult to measure directly, three widely used proxies to measure technology spillovers are (1) R&D expenditures (2) Patents (3) Total Factor Productivity

3.1 R&D

A growing volume of literature has also focused on the examination of the determinants of innovative activity measured by R&D expenditure (see Cohen and Levin, 1989, survey). Since 1965, the Organization of Economic Cooperation and Development (OECD) have published internationally comparable data on R&D expenditures. The OECD data primarily captures resources spent towards original innovation of relatively rich countries who report substantial R&D expenditures (OECD, 2002). It must be noted that the OECD data does not capture resources spent on imitation. The OECD data also does not report R&D expenditures of developing and poor countries. R&D expenditures are typically poorly measured proxies and year-to-year fluctuations in these variables are particularly noisy. One of the main challenges is that studies utilizing R&D expenditures fail to consider the stochastic nature of innovation. Besides yearly fluctuations R&D expenditures may also widely vary across industries due to heterogeneity thereby limiting comparisons.

3.2 Patents

A patent for an invention is granted by government to the inventor, giving the inventor the right for a limited period to stop others from making, using or selling the invention without the permission of the inventor. An innovation is judged by a patent examiner must be sufficiently important to be worthy of a patent. In comparison to R&D expenditures patent data has been collected over a longer time frame. The developing countries too have substantial patent data (WIPO, 2003).The WIPO databases comprise of International patents granted to developing countries for a long period of time.

However, there are some major challenges with using patent data. First, a large set of innovations are not patented since the patent decision is the choice of the firm. And second, patents cannot help us make inferences about learning via

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[6] For transferring machinery equipment technology the share was 36% Teece (1977, 248).

imitation or reverse engineering, or other tacit forms of knowledge transfers. Recent research on technology diffusion has addressed this issue in part by using patent citation data (Jaffe and Trajtenberg, 1999). Listed in the patent application; citations refer to prior patents that bear similarities to the technology for which protection is sought. They help demarcate the property right conferred by a patent, indicating what is excluded from its claims. Since no other measure of the influence of inventions on one another exists, patent citations hold great attraction for the study of knowledge diffusion.

3.3 Total factor productivity (TFP)

Total factor productivity (TFP) is well known since the 1950's- if one subtracts from output the contribution of inputs such as labor and capital, the remainder is due to factor "technology." The term A in the Cobb-Douglas production function $Y=AK^aL^b$ is due to the factor technology. TFP attempts to measure increases in production that are *not* due to an increased use of economic inputs. In other words, TFP is ultimately a residual, which makes its measurement potentially very sensitive to the exclusion of certain inputs.

In comparison to R&D and patents, TFP is a derived measured of technology as it is computed from data on inputs and outputs. Inputs and outputs are typically poorly measured and year-to-year fluctuations in these variables are particularly noisy. For instance, Hajime Katayama et al. (2003) study show that use real sales revenues, depreciated capital spending, and real input expenditures will often confound higher productivity with higher mark-ups, thereby causing measurement errors and biases. Moreover, growth rates in physical output are not really observed; what is observed is the growth in nominal revenue deflated by a broad price index (Tybout, 2001). Firms undergoing rapid expansion tend to drive down their output prices relatively faster. In a differentiated product market undergoing rapid input growth the true output growth is understated. Therefore, mark-up estimates should accordingly be biased downward (Pakes and Griliches, 1984).

Some studies have used physical quantities to measure Total Factor Productivity (Ahluwalia 1985; Burange 1999; Upender 1996). These studies utilize the wholesale price index of manufacturing products as a deflator. Balakrishnan and Pushpangadan (1994) point out that such a measure is valid only if the price of materials relative to the price of output is more or less constant for the period of analysis. However, with changes in these relative prices estimated productivity varies inversely. Hence, they advocate the double deflation method, where the values of output and input are deflated by an output and input price index respectively. Rao (1996) argues that measuring TFP with single and double deflation method results in biased estimates. Due to these difficulties in computing TFP, researchers have employed TFP measures in studies of technical change together with data on R&D (Griliches, 1995). By establishing a relationship between TFP changes and R&D spending the likelihood of measuring changes in technology inappropriately is substantially reduced.

4.0 Methodological Challenges

4.1 Association and structure studies

A number of different approaches have been employed to study empirically the importance of international technology spillovers. A large set of studies consists of the so-called international R&D spillover regressions.[7] Keller (2004) distinguishes between two types of studies-*association and structure* using the so-called R&D spillover regression approach. *Association studies* focus on the productivity effects of foreign R&D on domestic productivity. They are analogous to the literature that has examined the effects of other firms R&D on a given firm's productivity in a closed economy (Griliches 1979, 1995; Scherer 1984). A production function approach is used to relate TFP to measures of domestic (R) and foreign R&D (S) activities: In $TFP_{ct} = \alpha_c + \alpha_t + \beta_r \text{In } R_{ct} + \beta_s \text{In } S_{ct} + \varepsilon_{ct}$

Where c denotes country and t subscripts time; α_c and α_t are generalized and time-varying intercept, and ε_{ct} is the error term. The term S captures the impact of foreign R&D, is given by a weighted sum of other country's R&D: $S_{ct} = \Sigma\omega_{ch}S_{ht}$ where ω_{cht} is a bilateral weight that captures the relative importance of R&D in country h for productivity in country c. Also, Aitken and Harrison (1999) study examines the importance of foreign direct investment (FDI) as a source of international technology spillovers on the productivity of domestic firms. It must be noted that association studies identify spillovers from FDI, by estimating an augmented production function, where the dependent variable is a measure of firm's performance. The performance is measured in a variety of ways, namely the level or growth of value added, sales, or productivity measures such as output per employee or total factor productivity.

Many of the past studies on developing economies include studies in countries like Mexico (Blomström, 1986), Uruguay (Kokko et al., 1996) and Indonesia (Sjöholm, 1999) that point to positive and significant productivity spillovers. In contrast, the results for recent panel data research in developing countries show negative effects in two major studies by (Aitken and Harrison, 1999) on Venezuela 1976-89 and (Kathuria, 2000) on India 1975-89. Other studies such as (Feinberg and Majumdar, 2001) on India 1980-1994 find insignificant effects. For transition economies, the evidence is quite conflicting. Liu (2002) in China, find positive effects, while other studies find negative effects in Romania (Konings, 2001) and the Czech Republic (Djankov and Hoekman, 2001). Hence, the overall evidence is rather contradictory. One reason for such contradictory findings could be related to the setting of the study, notably the time of the data and host country's level of development. Moreover, it may also be a result of varying methodologies employed.

The second set of studies termed as *structure studies* add a specific channel, or mechanism of diffusion to the regression specification. These studies incorporate more of the structure of the underlying model than association studies. An influential example is the study by (Coe and Helpman, 1995) which is discussed in detailed in the following section.

According to the authors if a country imports primarily from high-R&D partner countries, it is likely to receive relatively much technology embodied in intermediate goods, which should be reflected in a higher productivity level and vice versa. Since association studies propose a common reduced-form equation their framework cannot

[7] Most of these are aggregate level studies; see (Keller, 2004) for a recent survey.

be very specific. Thus structure studies are more advantageous as they provide more information which aide in interpretation.

4.2 Cross-section and panel data

Studies on spillovers vary in their level of analysis, particularly with respect to the types of dataset employed. Some of the older studies use industry level data, while the recent firm level studies allow for a more refined measurement of received spillovers. Moreover, firm level data offer careful controls for influences including firm-specific effects on productivity, and thus avoid aggregation biases. Before embarking on a further discussion, two methodological challenges need to be discussed. First, most of the studies reviewed employ two main types of datasets, cross-sectional data and panel data.

Many of the earlier studies employ cross-sectional data, while the more recent studies employ panel data. However, cross-section specifications fail to identify the direction of causality between two variables, like FDI and productivity improvements. MNEs tend to gravitate towards the more productive industries as well as technology intensive industries. Hence, productivity differences across sectors may influence the inflow of FDI to a sector. A positive association between local firm's productivity and FDI may be a result of MNE's entering industries with higher productivity, rather than local firms increasing productivity as a result of the foreign investor presence. This selectivity bias of foreign firms into more productive industries creates a causality problem between the dependent variable (firm productivity) and the independent spillover variable (foreign presence in the industry). Thus a positive coefficient in a cross-section dataset is weak evidence of spillovers as the reverse causality is highly plausible. Failing to account for this effect may result in spurious positive coefficients between spillovers and foreign presence. Therefore, panel data techniques are more appropriate to investigate productivity spillovers.

5.0 Mechanisms of technology spillovers

Many authors have studied mechanisms, or channels through which technology spillovers primarily occur. Trade-imports, FDI, exports and human capital figure as the major mechanisms.

5.1 Imports

Coe and Helpman (1995) were the first to test the prediction of the trade and growth models of (Grossman and Helpman, 1991), and (Rivera-Batiz and Romer, 1991). The (Coe-Helpman, 1995) approach has been widely used in studies on technology spillovers. For instance, consider an aggregate production function for country *i* at time *t*, $Y_{it} = F_{it}(L_{it}, K_{it}, S_{it})$, where *Y, L, K* and *S* denote GDP, labour, physical capital, and knowledge capital, respectively. Let's assume a Cobb-Douglas production function and apply logarithms, $\log TFP_{it} = \alpha_S \log S_{it}$, where $\log TFP_{it} = \log Y_{it} - \alpha_L \log L_{it} - \alpha_K \log K_{it}$. In Coe and Helpman's (1995) study of industrial countries, SD is domestic R&D stock, and SM is foreign R&D embodied in imported goods, $\log S_{it} = \alpha_D \log SD_{it} + \alpha_M \log SM_{it}$.

Coe and Helpman (1995) have further elaborated on the measurement of the trade-related foreign R&D spillover variable *SM*. They point out the variable *SM* is an import-share weighted sum of R&D stocks of trade partners only captures the trade composition effect of foreign R&D, it does not capture the trade intensity effect of foreign R&D. The result being two countries with very different import intensities but identical trade composition would have the same value of the variable SM. Due to these measurement drawbacks, (Coe and Helpman, 1995) proposed to use M*log *SM* as the preferred measure of trade-related foreign R&D spillovers, where *M* is the ratio of imports to GDP. This variable M incorporates the effects of both trade intensity and trade composition.

Summarizing the above considerations, (Coe and Helpman, 1995) specify the following regression equation: $\log TFP_{it} = \alpha_{it} + \alpha_D \log SD_{it} + \alpha_M M_{it} \log SM_{it} + \varepsilon_{ct}$ (2), where α_{it} is a constant term that varies with country and time, and ε_{ct} is an error term. The Coe and Helpman's approach is reinforced by (Gwanghoon Lee, 2005) recent study examining the effect of international R&D spillovers via intermediate goods imports on a country's productivity. Utilizing newly constructed panel data from seventeen OECD countries during 1971–2000, their estimation models are built on Coe and Helpman's model. The estimation results confirm the robust positive effect of international R&D spillovers through the channel of intermediate goods imports. This contradicts recent skepticism about the results of Coe and Helpman's study that has been raised with the development of panel data econometrics.

5.2 Exports

In-house R&D expenditure is one of the most widely used technology variable in various studies on the firm's export competitiveness. Firm-specific technology absorption and development capabilities are crucial in determining international competitiveness (Lall 1992; Mowery and Oxley 1997). A plethora of firm-level studies conducted in developing countries have utilized in-house R&D expenditure to test the effects of R&D on the firm's export competitiveness. The empirical evidence to this date has yielded mixed results. However, it must be noted that most of the studies report a positive relationship between R&D intensity and exports. For example, (Alvarez, 2001) and (Ozcelik, 2004) study for Chilean and Turkish manufacturing firms reported positive relationship between R&D intensity and exports. Aggarwal (2001) disaggregated study also found a positive relationship between R&D intensity and exports in the Indian medium-high technology manufacturing industries.

There are a number of studies showing exporting firms learn about foreign technology through exporting experience. These firms benefit through their interaction with foreign customers, as the latter impose higher product quality standards in comparison to domestic customers. At the same time foreign customers also provide information on how to meet these high standards. Case study on the export success of a number of East Asian countries in the 1960s documents instances in which technologically sophisticated buyers have transmitted blueprints and proprietary knowledge to the exporting firms (Yung-Whee Rhee et al. 1984). The literature has also emphasized the importance of exporting or internationalization as a knowledge accumulation process in the context of firm's productivity gains (Girma et al., 2004).

5.3 Foreign direct investment

Foreign direct investment (FDI) has been considered as an important channel or conduit for technology diffusion. Traditionally, the literature on the role of inward FDI has pointed to four possible channels through which knowledge may spill over to a host country's economic actors. First, market access spillovers can occur through commercial linkages between foreign MNEs and local suppliers. Such spillovers may give local firms access to new technological capabilities as well as foreign customers preferences regarding issues such as product design and quality. Second, a demonstration effect may take place when domestic firms imitate foreign MNEs organizational practices, either through formal inter-firm collaboration or through more informal channels.

Third, a training effect may occur when local employees gain important skills while working for a foreign MNE, and subsequently transfer to other organizations. Recent studies bear testimony to multinational enterprises (MNEs) generating technological learning externalities for domestic firms through labor training and turnover or through the provision of high-quality intermediate inputs.[8] Finally, foreign entrants may increase local competition through the infusion of new technologies into the local market which may subsequently act as a catalyst for domestic firms to become more competitive.

5.4 Human Capital

A broad consensus in literature suggests that countries need a certain level of indigenous human capital to be able to benefit from knowledge transfer by multinational enterprises (Lall, 1992). The two determinants of successful technology diffusion that have been emphasized- are science and engineering human capital and in-house R&D expenditure (Cohen and Levinthal, 1989). Both have been associated with the concept or the notion of ‘absorptive capacity’. Absorptive capacity is the idea that a firm or country needs to have a certain type of skill in order to be able to successfully adopt foreign technological knowledge. Empirical research on absorptive capacity conducted at the national and industry level highlight the importance of indigenous human capital. For instance, (Eaton and Kortum, 1996) find that inward technology diffusion as measured by international patenting is increasing the level of a country’s human capital.

Xu (2000) study identifies a human-capital threshold suggesting that relatively rich countries benefit from hosting U.S. multinational subsidiaries because the poorer countries are far below the threshold level of human capital in the host country. Caselli and Coleman (2001) use data on imports of office, computing, and accounting machinery as a measure of inward technology diffusion. They find that computer imports are positively correlated with measures of human capital. In Caselli et al., the measures of human capital have only a quantity dimension, the average number of years of schooling or school enrolment in the population. Conversely, Hanushek and Kimko (2000) have shown that the quality dimension of human capital is as important. Their results using standardized science and engineering test scores for around thirty countries seem to bear testimony to this.

6.0 Summary of the Issues and challenges raised

It is evident from the above discussion that empirical quantification on the effects of international technology spillovers is a fairly recent one. To date different strands of research provide conflicting results. Empirical studies on technology spillovers provide to some extent conflicting results because of conceptual and measurement differences. There are at least four main issues with the current literature. First, as with the import discipline literature there is strong tendency to

[8] See (Kamal Saggi, 2002) for detailed discussion of possible spillover channels associated with FDI.

implicitly infer productivity or efficiency gains associated with trade liberalization effect of foreign competition. However, no efforts have been made to quantify the cost of those gains. The costs of these gains are often embodied in overhead, license fees, training and other items that do not get measured in the input vector (Tybout, 2001). Furthermore, the benefits these expenditures generate are not fully reaped in the same periods in which they are incurred.

Second, with regards to measures of efficiency or productivity most studies utilize industry-wide price deflators to convert plant-specific revenues to plant-specific measures of physical output. Since products within each industry are heterogeneous, this procedure attributes relative price fluctuation to physical output fluctuation, thereby leading to biased estimates. The best measure of technology spillovers is probably a patent citation. However, there is considerable criticism on the interpretation of the meaning of patent citations. Patent citations are often added by patent examiners. Thus, the inclusion of a given citation in a patent application does not necessarily indicate that the inventor knew about the existence of the technology embodied in the cited patent. Furthermore, citations only capture knowledge flows that result in a novel, patentable technology. They cannot help us make inferences about learning via imitation or reverse engineering, or other tacit forms of knowledge transfers.

Despite this criticism, there exists little evidence on the validity of using patent citations as a measure of knowledge flows. Most firm-level studies utilize R&D expenditures averaged over a particular time period. This procedure may cause the R&D expenditures to vary substantially, thereby leading to measurement errors. R&D expenditures are reliable measures of technology spillovers if yearly noise is taken into consideration. Third, almost all of these studies focus on single channels like imports, exports as conduits for technology spillovers. However, international activities like exporting and importing intermediates and capital goods are often complementary, so firms pursue them in bundles. Such studies that focus on a single channel as conduits for international technology spillovers may generate misleading conclusions.

Fourth, current empirical work on international technology spillovers relies on aggregate data, which results in composition and aggregation biases. Furthermore, aggregate level studies fail to account for heterogeneity or inter-industry differences. Future empirical work must include micro-level (firm or plant) data sets. A major contribution of micro-level data sets is a better estimation of micro behavior. Micro-level data can help to take a major step forward as the data records the outcome of economic decisions at the firm level. Lastly, quantitative and qualitative methods should be combined. The empirical literature mostly uses quantitative data on high levels of aggregation, while other studies focus on specific case studies. However, few studies combine qualitative and quantitative methods in insightful ways that allow informed interpretation of the quantitative results.

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