

# Total Factor Productivity\*

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August 2006

## Abstract

Total Factor Productivity (TFP) is the portion of output not explained by the amount of inputs used in production. The following definition describes the measurement and importance of TFP for growth, fluctuations and development as well as likely future directions of research.

Total Factor Productivity (TFP) is the portion of output not explained by the amount of inputs used in production. As such, its level is determined by how efficiently and intensely the inputs are utilized in production.

TFP growth is usually measured by the Solow residual. Let  $g_Y$  denote the growth rate of aggregate output,  $g_K$  the growth rate of aggregate capital,  $g_L$  the growth rate of aggregate labor and  $\alpha$  the capital share. The Solow residual is then defined as  $g_Y - \alpha * g_K - (1 - \alpha) * g_L$ . The Solow residual accurately measures TFP growth if (i) the production function is neoclassical, (ii) there is perfect competition in factor markets, and (iii) the growth rates of the inputs are measured accurately.

TFP plays a critical role on economic fluctuations, economic growth and cross-country per capita income differences. At business cycle frequencies, TFP is strongly correlated with output and hours worked. Based on this observation, Kydland and Prescott (1982) initiated the real business cycle (RBC) literature. In the standard business cycle model, shocks to TFP are propagated by pro-cyclical labor supply and investment, thereby generating fluctuations in output and labor productivity at business cycle frequencies with an amplitude that resembles the U.S. data. Subsequent work has introduced pro-cyclical fluctuations in measured TFP by incorporating unmeasured labor hoarding and/or capacity utilization in the standard framework (e.g. Burnside et al. (1995) and King and Rebelo, 1999).

As shown in the landmark article by Robert Solow (1956), long-run growth in income per capita in an economy with an aggregate neoclassical production function must be driven by growth in TFP. For over 30 years, the conceptual difficulty when trying to endogenize

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TFP growth was how to pay for the fixed costs of innovation in a perfectly competitive economy with constant returns to scale in capital and labor. In this context, all output is exhausted by paying capital and labor their marginal products, and therefore, no resources are left to pay for the innovation costs. Romer (1990) and Aghion and Howitt (1992) solved this problem by granting the innovator monopolistic rights over his innovation, which are sustainable through the patent system. In this way, innovators can recoup the initial fixed costs of innovation through the profit margin they make from commercializing their patent.

By linking the TFP growth rate to innovation, endogenous growth models shed light on the determinants of TFP growth. R&D subsidies and an abundance of skilled labor reduce the marginal cost of conducting R&D and increase the rate of innovation development and therefore, the TFP growth rate. Increases in the size of markets increase the innovators' revenues, leading to more innovation and higher TFP growth.

Solow (1956) also demonstrated that cross-country differences in technology may generate important cross-country differences in income per capita. Klenow and Rodriguez-Clare (1997) and Hall and Jones (1999) have confirmed that a majority of the gap in income per capita between rich and poor countries is associated to large cross-country differences in TFP. Cross-country differences in TFP can be due to differences in the physical technology used by countries or in the efficiency with which technologies are used. To explore the relative importance of these factors, it is necessary to have data on direct measures of technology. Comin, Hobijn and Rovito (2006) put together direct measures of technology adoption for approximately 75 different technologies and show that the cross-country differences in technology are approximately four times larger than cross-country differences in income per capita. Further, technology is positively correlated to income per capita. Thus, cross-country variation in TFP is, to a large extent, determined by the cross-country variation in physical technology.

### Likely future directions

*Economic fluctuations:* Recognizing that a large portion of TFP growth is caused by endogenous innovation decisions has significant implications for the business cycle. This is likely to be an important research topic in the near future. Comin and Gertler (2006) show that low-persistence, non-technological shocks generate pro-cyclical fluctuations in the market value of innovations. Agents' arbitrage these innovation opportunities and generate a pro-cyclical rate of innovation development and hence, of TFP growth. The model-induced fluctuations in TFP are as large and persistent as in the data. More importantly, by linking a component of TFP to innovation activity, TFP becomes a mechanism that propagates low-persistence shocks, thus increasing its persistence, rather than a source of disturbances, as in standard RBC models. This same logic can be extended to other processes that determine the endogenous level of technology such as endogenous technology adoption processes which are more relevant in developing economies. This may be an important ingredient to understanding high and medium term fluctuations in developing economies.

*Long-run growth:* A significant fraction of innovations are not patented. For some, this is because they are not embodied in any new good or are not a recipe for a new chemical process and, therefore, are not patentable. Others are not patented because innovators simply decide not to apply for a patent. Three important areas of research are to understand (i)

how important patents are for innovation activity, (ii) the determinants of non-patentable innovations and (iii) how they interact with the patentable-R&D type of innovations that fit the properties of the Romer (1990) and Aghion and Howitt (1992) models.

Two recent papers have argued that patents are not necessary for the innovators to recoup the innovation costs. Innovators in Hellwig and Irmen (2001) can obtain rents to cover innovation costs despite being perfectly competitive because they face an increasing marginal cost of producing the intermediate goods that embody their innovations. Boldrin and Levine (2000) model innovation in perfectly competitive settings. In their model, to copy an innovation, it is necessary to purchase one unit of the good that embodies it. Hence, the innovator is the monopolist of the first unit produced, and the revenues he extracts from selling it may cover for the innovation costs, making up for a lack of patent protection.

Comin and Mulani (2006) model the development of disembodied innovations such as managerial and organizational techniques, personnel, accounting and work practices, and financial innovations. These are very different from embodied innovations in that the rents extracted by the innovators are not associated to selling the innovation per se. This has some interesting implications. First, the revenues accrued by the innovator-producer originate from the increased efficiency in producing his good or service with the innovation. If the innovator-producer has some monopolistic power in the market for his good or service, the increased efficiency from using the innovation in production yields an increase in profits that may cover the innovating costs. Second, since the innovator-producer's gain from innovating comes from the increased efficiency of production, the marginal private value of developing disembodied innovations is increasing in the value of the firm. This has important cross-sectional and time-series implications. In the cross-section, firms with higher values (resulting from larger sizes or ability to charge higher markups) have more incentives to develop disembodied innovations. In the time series, shocks that reduce the value of the firm reduce its incentives to develop disembodied innovations. One such shock may be an increase in the probability that a competitor steals the market. If the occurrence of this shock requires the development of a new patentable product, the model implies the possibility of an aggregate trade-off between investments in developing disembodied and embodied innovations.

*Development:* Understanding the determinants of technology adoption is key to explaining cross-country variation in TFP. On the theory side, we have an increasing number of theories linking the adoption of technologies to the role of institutions (Acemoglu et al., 2006), financial markets (Alfaro et al. (2006) and Aghion et al., 2006), endowments (Caselli and Coleman, 2006) and policies (Holmes and Schmitz, 2001). The challenge ahead is to bring these theories to the data and assess their empirical relevance. The new country-level data on measures of micro technologies must be an important input towards this goal.

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