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Technological-knowledge bias and the industrial structure under costly investment and complementarities

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ABSTRACT

We develop an extended directed technological change model with vertical and horizontal R&D to analyze the economic growth rate, the technological-knowledge bias and the industrial structure, assuming: (*i*) complementarities between intermediate goods, and (*ii*) internal costly investment. We find that complementarities directly affect long-run technological-knowledge bias and relative production, both elements influence the economic growth rate and neither affects the skill premium and the relative number of firms. We also verify that the relationship between the relative supply of skills and both economic growth and the industrial structure suggested by our model is qualitatively consistent with recent empirical data for a number of developed countries.

1. Introduction

In this work, we develop an extended directed technological change model with simultaneous vertical and horizontal R&D, complementarities between intermediate goods and internal costly investment, in order to study the long-run behavior of the economic growth rate, the technological-knowledge bias and the industrial structure.

Our closed economy model builds on the original framework of Acemoglu and Zilibotti (2001) extended by the introduction of physical capital and: (*i*) vertical differentiation following Aghion and Howitt (1992), (*ii*) Hayashi's (1982) internal investment costs in both physical capital and R&D and (*iii*) complementarities between intermediate goods used in the production of final goods, as in Evans et al. (1998). Therefore, assumptions (*ii*) and (*iii*) constitute a generalization of the standard Skill Biased Technological Change (*SBTC*) literature. In particular, the model assumes that final goods are produced through a combination of labor and quality-adjusted complementary intermediate goods and that two distinct production technologies, skilled and unskilled, are available. Then, to produce each final good, firms can employ either skilled labor and skilled-specific intermediate goods or unskilled labor and unskilled-specific intermediate goods.

We model economic growth as occurring both along an extensive (horizontal R&D) and an intensive (vertical R&D) margin, i.e. both through expanding variety and increasing quality of existing varieties of intermediate goods. We then relate horizontal R&D to measures of industrial structure and show that vertical R&D is the ultimate engine of growth. The adopted Schumpeterian approach on temporary monopoly position generating higher profits for the currently innovating firm enables us to endogenize economic processes designated as the causes of modern economic development and recurring structural change (e.g., Howitt, 1999). Also, given that a larger number of product lines (horizontal innovation) puts pressure on economic resources due to its physical nature, in contrast to the immaterial nature of vertical innovation, we believe that using the two dimensions of technology (as in, e.g., Howitt, 1999; Peretto and Connolly, 2007; Segerstrom, 2000) allows us to attain a more comprehensive reflection of the endogenous economic growth and industrial concentration mechanisms.

Our decision to introduce the assumption of costly investment is motivated by the argument that directed technological change growth models should consider investments as a decision variable of the firm, implying that firms undergo expenses associated to investments both in capital accumulation and R&D, as part of total capital investments (e.g., Anagnostopoulou, 2008; Benavie et al., 1996; Cohen, 1993; Thompson, 2008; Van der Ploeg, 1996). The addition of this specific element enables us to analyze skill-biased technological development in a more realistic environment of internal capital investment costs, which include R&D expenses.

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In order to reflect another relevant feature of modern industrialized economies in our baseline model, we introduce the element of complementarity between intermediate goods in final goods production. This assumption is primarily motivated by the argument that complementarities should be an essential feature in explaining economic growth, business cycles and underdevelopment (Ciccone and Matsuyama, 1996; Evans et al., 1998; Matsuyama, 1995). We incorporate the important idea that an increase in the number of complementary goods leads to an increase in the production of a capital good, and that an increase in the production of a specific intermediate good raises the demand for its complementary intermediate goods. Introducing this specific element into the model contributes to enriching our analysis on the skill-biased technological development and economic growth.

Within the proposed framework, we analyze the balanced-growth-path (BGP) effects of internal costly investment and complementarities on economic growth, technological-knowledge bias and skill premium. We also examine the same effects on industrial structure, measured by the relative number of intermediate-good firms and by relative production, i.e., the number of firms and production in skilled vis-à-vis unskilled labor-complementary intermediate-good sectors. We find that both elements costly investment and complementarities affect the economic growth rate but that the complementarity degree alone influences technological-knowledge bias through the price channel and relative production through the technological-knowledge bias channel, while neither one of the two elements affects the skill premium and the relative number of intermediate-good firms in equilibrium.

We also examine the relationship between the relative supply of skills (skilled versus unskilled labor) and the key variables of the model. This analysis is motivated by the increased importance of skilled labor in most developed (and developing) economies, and also because of the key role that this issue has played in the SBTC literature. We find a positive relationship between the relative supply of skills and the technological-knowledge bias, the economic growth rate and the industrial-structure variables, thus qualitatively accommodating recent empirical evidence for a number of European countries.[1]

As regards the skill premium, this turns out to be independent of the relative supply of skills, even under complementarities and internal investment costs. We show that this is due in particular to our production function characteristics (namely, a constant elasticity of substitution between factors equal to 2) exactly offsetting the initial supply and the market-size and price-channel effects, which leaves the equilibrium skill premium being determined solely by the absolute productivities ratio. Intuitively, if technological development induced by changes in the relative supply of skills, i.e. *SBTC*, leads to an increase in the productivity of labor favored by technological development (in particular skilled labor), this result suggests that the persisting increase in the wage inequality between skilled and unskilled workers observed in several developed countries throughout the past 30 years may have been due to such increases in the productive advantage of skilled workers.

The remainder of this work is organized as follows. The next section presents the available evidence on the industrial structure, the relative supply of skills and economic growth for a number of European countries. Section 3 sets up the model specifying the role of internal costly investment and complementarity degree, and presents the main results focusing on consumers, final-goods and intermediate-goods sectors and R&D. In Section 4, the BGP equilibrium is defined and discussed. Section 5 provides a comparative analysis of the steady-state effects of costly investment, complementarity degree, and relative labor endowment. Conclusions are presented in Section 6.

2. Empirical evidence: industrial structure, relative supply of skills and growth

In this section, we present the cross-country data with respect to the industrial structure, measured by the number of firms and by production in high- *vis-à-vis* low-tech manufacturing sectors, by considering the OECD high-tech low-tech classification.[2] We will call these ratios the relative number of firms and relative production, respectively. We also collected data on the ratio of skilled to unskilled workers, i.e., the relative supply of skills, measured as the ratio of college to non-college graduates among persons employed in manufacturing. "College graduates" refers to those who have completed tertiary education (corresponding to the International Standard Classification of Education [ISCED] levels 5 and 6), while "non-college graduates" refers to those who have completed higher-secondary education or less (ISCED levels from 0 to 4).

The data concerns the 1995–2007 average and covers 25, 16 and 29 European countries regarding, respectively, the number of firms, production, and the supply of skills (educational attainment). The source is the Eurostat on-line database on Science, Technology and Innovation – tables "Economic statistics on high-tech industries and knowledge-intensive services at the national level" and "Annual data on employment in technology and knowledge-intensive sectors at the national level, by level of education" (available at http://epp.eurostat.ec.europa.eu). At the aggregate level, we gathered data on the *per capita* real GDP growth rates for the same period, also from the same Eurostat on-line database.

Empirical data, as illustrated by Figs. 1 and 2, suggest a significant variability of the industrial structure across countries by considering the number of firms and total production in high- *vis-à-vis* low-tech sectors. Nevertheless, interesting regularities stand out: (*i*) the number of firms and total production are smaller in high- than in low-tech sectors (i.e., the *relative* number of firms and relative production are below unity) in all countries; (*ii*) the correlation between the relative number of firms and relative production is positive; (*iii*) the economic growth rate is mildly positively correlated with the relative supply of skills.

We use regression analysis to document the correlation between the relative supply of skills and both the industrial structure and the economic growth rate more formally. Table 1 reports the details on the OLS regressions performed on the data depicted by Fig. 2.[3]

3. Model specifications

3.1. Consumption side

The economy consists of a fixed number of identical and infinitely-lived households and has a zero population growth. Indexed with $a \in [0, 1]$ depending on their ability level, households consume final goods, own firms (equity) and inelastically supply low-skilled, L_a

[1] In our model, "sector" represents a group of firms producing the same type of labor-complementary intermediate goods. Since the data shows that the high-tech sectors are more intensive in skilled labor than the low-tech sectors – e.g., for the average of the European Union (27 countries), 30.9% of the employment in the high-tech manufacturing sectors is skilled ("college graduates"), against 12.1% of the employment in the low-tech manufacturing sectors – we consider the skilled and unskilled labor-complementary intermediate-good sectors in the model as the theoretical counterpart of the high- and low-tech sectors in the data. See Section 2 for further details on the data.

[2] High-tech industries are, e.g., aerospace, computers and office machinery, electronics and communications, and pharmaceuticals, while the low-tech sector comprises, e.g., petroleum refining, ferrous metals, paper and printing, textiles and clothing, wood and furniture, and food and beverages. See http://stats.oecd.org.

[3] Notice that, even though the goodness of fit of the regressions in Table 1 might most likely increase if we added explanatory variables, the bivariate approach followed therein accommodates, in particular, the fact that the log–log linear relationships between the industrial-structure variables and the relative supply of skills have an exact analytical counterpart in terms of the BGP equilibrium of the model developed in Sections 3 and 4. Moreover, it is important to emphasize that our focus throughout the paper will be on the correlation (its sign) and not on the causality effects between the variables of interest.