Journal of Macroeconomics 40 (2014) 172–189

Contents lists available at ScienceDirect

Journal of Macroeconomics

journal homepage: www.elsevier.com/locate/jmacro

Technology structure and skill structure: Costly investment and complementarity effects quantification ☆

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ARTICLE INFO

Article history:
Received 23 June 2013
Accepted 18 March 2014
Available online 12 April 2014

JEL classification:
O31
O41

Keywords:
High-tech
Low-tech
Skills
Complementarity
Tobin-q
Technological-knowledge bias

ABSTRACT

Based on an extended model of endogenous directed technical change and on cross-country data, we identify and quantify the long-run link between: (i) the technology structure (high- vs. low-tech sectors) and the skill structure (high- vs. low-skilled workers), by considering an explicit role for the (potential) complementarity between technological goods; (ii) the Tobin-q and the technology characteristics of the firms through their impact on economic growth. Our estimation and calibration exercise suggests the existence of a moderate degree of complementarity and of an elastic relationship between the Tobin-q and key technology parameters.

1. Introduction

This paper aims to identify and quantify the long-run link between the technology structure and the skill structure, by considering an explicit role for the (potential) complementarity arising between technological goods. By considering internal investment costs, the paper also tackles the long-run relationship between the Tobin-q and the technology characteristics of the firms, such as the degree of complementarity between technological goods, through the impact of the latter on the long-run economic growth rate. To this end, we take advantage of the analytical structure of an extended model of endogenous model and estimate it based on the available cross-country data for the technology structure and the skill structure.

The importance of analysing the relationship between the technology structure and the skill structure under costly investment and complementarity effects is suggested by a number of empirical facts. From the extant literature, we retain that: (i) there is an impact of the technology structure, measured by either the number of firms or by production in high- vis-á-vis low-tech manufacturing sectors, on industrial performance (Pilat et al., 2006) and on the skill premium (Cozzi and

☆ We thank an anonymous referee and the editor for their valuable comments and suggestions. The usual disclaimer applies. CEF.UP – Center for Economics and Finance at University of Porto – is financially supported by FCT (*Fundação para a Ciência e a Tecnologia*), Portugal, as part of the Strategic Project PEst-C/EGE/UI4105/2011.

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http://dx.doi.org/10.1016/j.jmacro.2014.03.007
0164-0704/

Impullitti, 2010); (ii) complementarities between technological goods are a relevant feature in explaining industrial growth (e.g., Matsuyama, 1995; Ciccone and Matsuyama, 1996); (iii) there is a positive relationship between the Tobin-q and the R&D and technology characteristics of the firms (e.g., Chan et al., 1990; Connolly and Hirschey, 2005). Moreover, by gathering data for a number of European countries between 1995 and 2007,[1] we find that there is a positive relationship between the technology structure (regarding both the number of firms and production in high-vis-á-vis low-tech manufacturing sectors) and both the skill premium and the skill structure (the latter being measured as the ratio of high- to low-skilled manufacturing workers). In particular, we infer from this evidence that the skill structure featuring a higher proportion of high-skilled workers is associated with technological change directed towards the high-tech sectors, given the observed positive elasticity of the technology structure regarding the skill structure.

In the light of these facts, this paper develops an extended directed technological change model of endogenous growth that integrates a number of key ingredients. First, the model incorporates endogenous directed technical change, such that final-goods production uses either low- or high-skilled labour with labour-specific intermediate goods, while R&D can be directed to either the low- or the high-skilled labour complementary technology; hence, the intermediate goods are the technological goods in the model, and "sector" denotes a group of firms producing the same type of labour-complementary intermediate goods. Since the data shows that the high-tech sectors are more intensive in high-skilled labour than the low-tech sectors,[2] we consider the high- and low-skilled labour-complementary intermediate-good sectors in the model as the theoretical counterpart of the high- and low-tech sectors (e.g., Cozzi and Impullitti, 2010). This directed technical change setup allows us to have an endogenous high- vs. low-tech technological bias.

Second, in order to allow for endogenously determined production and number of firms, we consider simultaneously horizontal and vertical R&D, where the former pertains to the creation of new products/firms and the latter to the increase of product quality of existing products and, thereby, of production per firm. Under our R&D specification, the choice between vertical and horizontal innovation is related to the allocation of R&D expenditures, which are fully endogenous. Therefore, we endogenise the rate of growth along both the vertical and the horizontal direction, and hence the number of firms in each sector.[3] Given the distinct nature of vertical and horizontal innovation (immaterial vs. physical) and the consequent asymmetry in terms of R&D complexity costs, this framework then makes economic growth and firm dynamics closely related: vertical R&D is the ultimate growth engine, while horizontal R&D builds an explicit link between aggregate and technology-structure variables (the number of firms and production in high- and in low-tech sectors).[4]

Finally, the model features two additional assumptions: (i) we allow for an interaction between the quantity of one intermediate good and the marginal productivity of the other intermediate goods, such that substitutability or complementarity may arise between the intermediate goods used in the production of final goods; (ii) we include internal investment costs á la Hayashi (1982) (e.g., Benavie et al., 1996; Thompson, 2008). Therefore, the model establishes a relationship between the technology structure and the skill structure regulated by the degree of substitutability/complementarity between technological goods (i.e., intermediate goods), together with a relationship between the Tobin-q and the technology characteristics of the firms.

By solving the model for the balanced-growth path (BGP), we uncover the analytical mechanism that explains the cross-country behaviour of the technological structure. Two types of effects exist: the market-size effect, through which a higher proportion of high-skilled workers induces technological change directed towards the high-tech sectors, and the skill-premium effect, reflecting the *absolute* productivity advantage of high-skilled workers. However, the interaction between the quantity of one technological good and the marginal productivity of the other technological goods plays a crucial role here. In particular, goods must be either substitutes or complements with the degree of complementarity *below* a certain threshold such that the elasticity of the technology structure with respect to the skill structure is positive, as observed in the cross-country data. That is, the increased incentives for allocating resources to R&D activities that come from complementarity must not be too large to offset the technological-knowledge bias channel. It is noteworthy that no upper limit seems to arise in related models featuring complementarites (e.g., Evans et al., 1998; Jones and Williams, 2000; Thompson, 2008).

Next, we take our model to the data and quantitatively associate the empirical facts on the technology structure and the skill structure to the degree of substitutability/complementarity between technological goods. In particular, we are interested in checking whether the case of complementarity, which features as a key assumption in a significant strand of the theoretical literature that studies poverty traps, growth and business cycles (e.g., Matsuyama, 1995; Ciccone and Matsuyama, 1996; Evans et al., 1998), has empirical support. Although the BGP level is indeterminate, as is usual in the endogenous growth models, we take advantage of the two-sector structure of our model to obtain fully determined BGP log-log linear relationships between the technology-structure variables, the skill premium and the relative supply of skills. Then, based on this analytical BGP relationships and on the cross-country data for the technology structure and the skill structure, we compute indirect estimates of the value of the parameter that regulates the degree of substitutability/

[1] The Appendix A provides further details on the data.

[2] According to the data for the average of the European Union (27 countries), 30.9% of the employment in the high-tech manufacturing sectors is high-skilled ("college graduates"), against 12.1% of the employment in the low-tech manufacturing sectors (see the Appendix A for more details on the data).

[3] An alternative approach in the literature assumes that the allocation of resources between vertical and horizontal R&D implies a division of labour between the two types of R&D. Since the total labour level is determined exogenously, the rate of growth along the horizontal direction is exogenous, i.e., the BGP flow of new products occurs at the same rate as (or is proportional to) population growth.

[4] In the working paper by Gil et al. (2012), a similar setup is used to study a related but different research question.