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Accounting for research and productivity growth across industries ☆

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ABSTRACT

What factors underlie industry differences in research intensity and productivity growth? We develop a multi-sector endogenous growth model allowing for industry-specific parameters in the production functions for output and knowledge, and in consumer preferences. We find that long run industry differences in both productivity growth and R&D intensity mainly reflect differences in "technological opportunities", interpreted as the parameters of knowledge production. These include the capital intensity of R&D, knowledge spillovers, and diminishing returns to R&D. To investigate the quantitative importance of these factors, we calibrate the model using US industry data. We find that diminishing returns to research activity is the dominant factor.

1. Introduction

Total factor productivity (TFP) growth rates differ widely across industries, and these differences appear linked to persistent cross-industry differences in R&D intensity – see Fig. 1. This link is sometimes interpreted as causation. However, a priori it is not clear why the *level* of industry R&D should affect industry productivity *growth*, a point that has been made by Jones (1995) for the aggregate economy. Rather, both R&D and productivity growth depend on the response of firms to deeper industry parameters.

We develop a general equilibrium model in which both research activity and productivity growth vary endogenously across industries, to identify the factors that account for differences in each. We show that the factors that influence TFP growth also have an impact on R&D intensity. However, the converse is not true: there exist industry characteristics that affect the level of industry R&D, but not necessarily industry productivity growth rates.

The empirical literature has identified three sets of factors as potential determinants of industry variation in research intensity and productivity growth: technological opportunity (factors that affect the efficiency of research), appropriability (the extent to which R&D benefits the innovator) and demand (which influences the returns to research). These factors are implemented in the model using standard preference and technology parameters drawn from growth theory. The industry-

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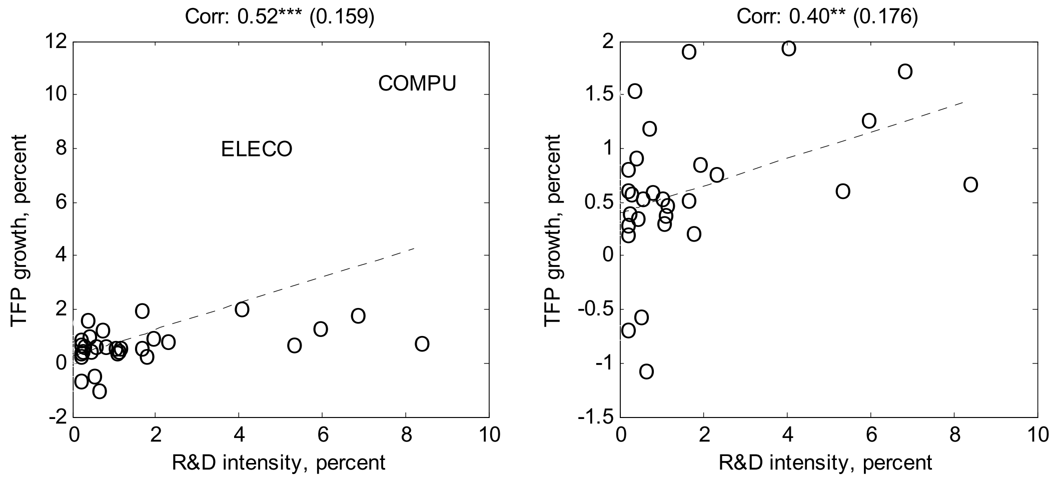

Fig. 1. Productivity growth and R&D intensity. Productivity growth rates for US industries over the post-war era are reported by Jorgenson et al. (2007). R&D intensity is the median ratio of R&D expenditures to sales among firms in Compustat over the period 1950–2000. Data are for manufacturing. The dotted line represents fitted values for each graph. The right panel excludes two potential outliers, computer equipment and electronic components. See also Terleckyj (1980) for an early survey. Two and three asterisks indicate statistical significance at the 5 and 10 percent levels, respectively.

specific factors we study are: diminishing returns to research, knowledge spillovers over time, knowledge spillovers across firms, capital intensity in the production of goods, capital intensity in the production of ideas, the elasticity of substitution across different varieties of goods within each industry, and the industry's market size.

As our interest is in industry comparisons, we focus on equilibria where the distribution of productivity within sectors is stable and rank-preserving. We find that differences in industry TFP growth rates depend only on factors of technological opportunity. These include the extent to which research is subject to diminishing returns, the capital share of research spending, and total knowledge spillovers. By contrast, differences in R&D intensity also depend on the extent to which knowledge spillovers accrue from the firm's *own* stock of knowledge, which we interpret as a measure of appropriability.[2] Product demand is fundamental in providing incentives to perform research: nevertheless, we find that *industry differences* in equilibrium TFP growth rates and R&D intensity do not depend on demand parameters that are constant over time.[3]

To narrow down which factors of technological opportunity best account for cross-industry comparisons in a production-function based framework, we calibrate the model using US industry data. We find that the capital intensity of research cannot account for observed industry differences in productivity growth rates. Furthermore, we find that variation in appropriability has little impact on industry variation in R&D intensity. Thus, the model indicates that variation in diminishing returns to research and in the magnitude of spillovers must jointly account for patterns of productivity growth and research activity. Finally, for each industry we select these two parameters so that the equilibrium productivity growth rate and R&D intensity level in the model match the values in the data exactly. We find that the degree of diminishing returns to R&D is the main factor behind industry variation in productivity growth rates and in R&D intensity.

In related work, Klenow (1996) studies the determinants of cross-industry differences in TFP growth and R&D intensity in a 2-sector version of the Romer (1990) model. Krusell (1998) develops a 2-sector framework to endogenize the decline in the price of capital relative to consumption goods documented by Greenwood, Hercowitz and Krusell (1997), and Vourvachaki (2007) develops a two-sector endogenous growth model to endogenize technical progress in IT: however, in these papers, there is only research in one sector, and the focus is not on the factors that determine industry TFP growth rates. In the partial equilibrium model of Nelson (1988), the extent to which knowledge spills from a firm to its competitors affects R&D intensity but not TFP growth rates, and our general equilibrium environment also yields this result. Klevorick et al. (1995) and Nelson and Wolff (1997) provide evidence supporting this claim.

Section 2 provides an overview of the related literature. We do this to line up the factors we wish to embody later in our model. Section 3 describes the structure of the model and outlines the main results, and Section 4 studies its long run behavior. Section 5 uses a calibration of the model to determine the relative importance of different potential determinants of research and productivity differences. Section 6 discusses possible extensions.

[2] We discuss how our notion of appropriability compares to other notions of appropriability later in the paper.

[3] For example we show that, while the price elasticity of demand affects the potential returns to innovation in partial equilibrium, it may not affect returns in general equilibrium when all firms are conducting research and trying to keep pace with each other. We also show that, if R&D intensity is measured using the R&D-to-sales ratio, as is common, then the price elasticity of demand may enter R&D intensity not because it affects resource allocation but by *construction*, since the denominator (sales) contains a markup reflecting this elasticity.