Centre of Excellence
for Science and Innovation Studies

CESIS Electronic Working Paper Series

Paper No. 442

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June, 2016

The Royal Institute of technology
Centre of Excellence for Science and Innovation Studies (CESIS)
http://www.cesis.se

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Abstract: In year 1998, the seminal study *Research Innovation and Productivity: An Econometric Analysis at the Firm Level*, commonly labeled CDM (the acronym of the three authors' names, Crépon, Duguet and Mairesse), was published in this journal. The empirical framework, presented there, following on ideas in the research of Zvi Griliches at the NBER and is one of the most influential contributions in recent literature on economics of innovation. The original CDM paper and papers inspired by its framework have received hundreds of citations in the empirical innovation literature. Whether directly linked or not to the CDM framework, the flow of studies improving on and enlarging the scope and methods of the empirical literature on R&D, innovation and productivity is continuing. Some of them, for example, focus on financing innovation, or innovation and employment, or innovation and trade, or competition, or intellectual property; some adopt a managerial perspective, or an innovation system approach in a Schumpeterian tradition, etc. This introduction to the special issue of EINT surveys a collection of 12 papers on the CDM model by 25 authors from eight countries. The papers take stock of the evolution of research based on the original CDM model launched 20 years ago, linking it to the previous literature, and proposing developments and generalizations of it in various dimensions.

Keywords: CDM; R&D; innovation; productivity; micro-econometrics

JEL codes: C30; D24; O30; O31; O33

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Background

In 1998, the seminal paper Research Innovation and Productivity: An Econometric Analysis at the Firm Level by Crépon, Duguet and Mairesse, commonly referred to as the CDM paper (following the initials of the three authors' names), was published in a special issue of this journal. An earlier version of the paper was first presented at a conference held at the National Academy of Sciences, Washington, D.C. in 1995.

In the introduction to the 1998 EINT special issue, Bronwyn Hall and Francis Karmarz note that Crépon, Duguet and Mairesse find rough proportionality between firm size, R&D and innovation output, in contrast to Motohashi (1998) and Bound, Cummins, Hall, Jaffe and Griliches (1984). Using French firm level data, the study also documented positive correlation between innovation input and innovation output measured as both patents and share of sales due to innovative product, and a positive association between innovation output and productivity even when they controlled for capital and skill.

The CDM model, which can be traced back to Griliches' path diagram of the knowledge production function (1990), had no immediate impact in the research literature. The delay is mostly due to lack of good innovation data at the micro level. This situation has changed radically in recent years.

Today the CDM model has become the workhorse in the empirical literature on innovation and productivity and been applied to micro data of over 40 countries. The method propounded has been applied even outside the strict literature on innovation and productivity. The original CDM paper and papers inspired by its framework have received hundreds of citations.

The CDM framework introduces a structural model that explains productivity by innovation output and the latter by research investment, and it suggests a method of correcting for the selectivity and the endogeneity inherent in the model. Because it was based on data from a precursor to the Community Innovation Survey (CIS) conducted in France, this framework has been found most appropriate to analyze and study innovation survey data based on the Oslo Manual (OECD, 2005), which is the guideline for the CIS. The CIS has now been implemented biannually by the member states of the European Union, and there are similar innovation surveys conducted by other countries within and outside the OECD.

Over the years a number of variations of the original CDM model have been proposed depending on whether they use continuous or discrete data for innovation input and output, various measures of those variables, and various estimation methods (ALS, 3SLS, sequential 2SLS, maximum likelihood). The original cross-sectional model has been extended to panel data, dynamic models, and applications on multiple types of innovation activities and economic outcome measures.

This special issue takes stock of the evolution of research based on the CDM model, linking it to the previous literature, and proposing developments and generalizations of it in various dimensions. The background of the special issue is a call for papers and three associated workshops in London 2013, Paris 2014 and Maastricht 2015 aimed to critically discuss questions such as: How relevant is the CDM framework? To what extent did it result from the availability of new micro-economic data almost two decades ago, provided in particular by the Community Innovation Surveys in European countries? To what extent does it reflect the micro econometric state of the art in the 1990s? How can the CDM framework be enhanced and improved to answer questions today? How can we improve our understanding of the economics of innovation by creative exploitation of the growing accessibility to regional, national and international databases?

Bibliometric studies

Two bibliometric studies form the introduction to the special issue which collects 12 papers by 25 researchers from seven European countries and the U.S. The paper by *Broström and Karlsson* describes the evolution of the literature on R&D, innovation and productivity between 1990 and 2012 and the impact it had on the wider scientific literature with a particular attention to the CDM paper. It uses the Web of Science, Scopus and Google scholar databases to perform a bibliometric and citation function analysis. Regarding the impact of the CDM paper, the authors conclude that its contribution was to a large extent methodological, as most of the citations to it are about how research had to be done and less about the estimates obtained.

The paper by *Notten, Mairesse and Verspagen* use the Web of Science and Scopus databases and various clustering methods (acyclical graphs, community detection algorithms, and main path methods) to create a forward and backward citation network around the CDM paper focusing on the horizontal spread across knowledge communities and the vertical spread of knowledge re-combinations. Three main clusters of invisible colleges and genealogical paths within each cluster are identified, showing the extension of the CDM outreach and the evolution of knowledge within this literature.

Empirical applications

The following five papers use the CDM framework to the analysis of other aspects of innovation on data from four different countries. *Hall and Sena* examine the role of formal and informal appropriability choices in addition to, and in interaction with, innovation in the form of new products or new processes on total factor productivity. They merge three waves of the UK Community Innovation survey (CIS 3, 4 and 5) with the Annual Respondents Database and the Business Strategy Database, which provide information on firms' inputs and outputs. They find that firms that innovate and rate formal methods for the protection of Intellectual Property relatively highly are more productive than firms that choose informal appropriation methods, except possibly for large firms. They also find that the effect of innovation on productivity is strongest for firms in the services, trade, and utility sectors, and actually negative in the manufacturing sector.

Van Leeuwen and Mohnen focus on environmental innovations: end-of-pipe and process-integrated investments on the input side, and pollution-reducing and resource-saving innovations on the output side. Using micro data from 3 waves of CIS data for the Netherlands, combined with the survey of environmental costs of firms and production statistics, they obtain evidence corroborating the weak version of the Porter hypothesis, namely that environmental regulations (existing or anticipated) affect eco-investments and indirectly eco-innovations. The strong version of the Porter hypothesis, that environmental regulations also increase productivity, is only corroborated for resource-saving eco-innovations, which are a form of process-integrated innovation.

Czarnitzki and Delanote examine whether there is input and output additionality from R&D grants and whether, if there is output additionality, it is greater for subsidized R&D than for privately-financed R&D. On CIS data for Flanders from 2004 to 2010 together with accounting data from the Belfirst dataset and subsidy data from the Flemish agency in charge of innovation subsidies, they find that subsidized firms do more R&D, and that both subsidized and private R&D have similar marginal effects on innovation output.

Jaumandreu and Mairesse concentrate on the effects of innovation on productivity. They consider a structural model with two equations, a marginal cost equation and a demand equation, and test various ways in which product and process innovation could enter the two equations: individually, separately or jointly. The model is applied to panel data of the Spanish ESEE survey from 1990-2006. The marginal cost and demand functions of the firms are estimated with different specifications for the effects of process and product innovations. Process innovations are found sometimes to reduce cost and other times to increase them, for reasons that the present model cannot explain. Demand is increased by product innovation and process innovation, either alone or together, although the result is not very significant.

The original CDM model was a static model estimated on cross-sectional data. In the meantime many more waves of the innovation survey took place, and therefore we see more and more panel data being used and dynamic models being estimated. All the empirical papers in this issue use panel data and some of them explicitly model the dynamics. *Bond and Guceri* estimate a reduced form of the CDM model allowing for time-invariant individual-specific, as well as transitory and persistent unobserved effects. They estimate their model by system GMM on UK establishment data and find that TFP is 14% higher in establishments that have substantial R&D activities. Examining within-group spillovers from R&D-doing establishments to those with no R&D, they find that positive externalities are only present when the two establishments are in the same industry.

New modelling approaches

Crépon, Duguet and Mairesse (1998) estimated their model by asymptotic least squares (also known as minimum distance estimator). Most of the ensuing studies have used a sequential 2SLS estimation procedure as Hall and Sena, van Leeuwen and Mohnen, and Bartelsman, van Leeuwen and Polder do in this issue. Czarnitzki and Delanote propose a control function approach as an alternative way to handle the endogeneity and selectivity issues. *Baum, Lööf, Nabavi and Stephan* estimate the traditional CDM model but use a more general estimation method, known as Generalized Structural Equation Model including a latent variable created by factor analytical methods to capture unobserved factors. A full information maximum likelihood (FIML) estimator of a seemingly unrelated equation (SUR) system is applied to estimate coefficients for each of the including sectors simultaneously within the recursive system allowing for cross-correlation of some of the disturbances. Their analysis of three waves of Swedish CIS data from 2008 to 2012 shows that some key coefficients of the CDM model vary across sectors, in particular the R&D effect in the innovation output equation and the innovation output effect on labor productivity.

While some dynamics was introduced through the evolution of the individual effects in the papers by Bond and Guceri and Jaumandreu and Mairesse, a dynamic feedback effect from productivity to R&D in Baum et al., and through some ad hoc lagged effects in most of the other papers, it is explicitly modeled in the paper by *Peters, Roberts and Vuong*. This paper goes one step further than the CDM model by building a dynamic optimization model with stochastic elements. R&D is decided on the basis of expected costs, innovation success, productivity and profits. The authors focus on the effect of the firm's financial strength on R&D. They use the Mannheim Innovation panel from 1993 to 2008 for firms from five high-tech manufacturing industries merged with Creditreform data on the financial strength of firms. They find that financial strength increases both the expected innovation success and long-term payoff, thereby giving a greater incentive for financially strong firms to engage in R&D. Like Baum et al. and Hall and Sena they also find heterogeneity across sectors.

A serious source of endogeneity in the CDM model comes from measurement errors especially in the innovation output measures from the innovation surveys. While most CDM-studies uses IV techniques to mitigate measurement error in the regressors, *Mairesse and Robin* conduct a systematic exploration of the magnitude of the errors-in-variable problem and consequent estimation biases on three waves of innovation survey in France covering the years 2000, 2004 and 2008. Measurement errors seem to be less important for R&D than for innovation output and, indeed, errors in variables seems to be a more important problem than simultaneity.

The *Bartelsman, van Leeuwen and Polder* paper proposes a novel way to allow the macroeconomic effects of innovation to differ from the microeconomic effects, not just because of the presence of spillovers, as in the paper by Bond and Guceri, but also by a composition effect, when large firms for instance are more innovative and through their size weigh more in the aggregate. They show that the positive effect of innovation on productivity in the aggregate could in part be due to such a composition effect. They use the Micro Moments Database (MMD), i.e. indicators of distributions and correlations of variables across countries that are drawn from micro data. Another advantage of using these data is the avoidance of the confidentiality problem in getting access to innovation survey data.

Political economy

Antonelli closes the special issue by linking the CDM model to the political economy justification of government intervention to stimulate R&D. The R&D equation of the CDM model is derived from a first-order condition of optimality equating the marginal cost to the marginal benefit of R&D. Due to well-known market failures, the inappropriability of R&D benefits among others, the discussion around innovation policy has largely focused on ways to reduce the marginal costs of doing R&D via R&D subsidies and tax incentives. Antonelli redirects our attention to the alternative way to stimulate R&D and innovation, targeting the demand side rather than the supply side of R&D. Innovation can occur by boosting the demand for knowledge. The higher price of R&D in the downstream market for knowledge could in turn lead to more innovation.

The special issue CDM 20 Years After is thus a compendium of further examples of application of the CDM framework, attempts to improve the estimation and to link micro and macro studies of innovation, future directions to generalize the model by including dynamics and uncertainty, and lessons as well as reflections on how to stimulate innovation.

Funding

We thank the Swedish government agency VINNOVA for financial support.

References

Bound, J., Cummins, C., Hall, B.H., Jaffe, A., and Z. Griliches. 1984. "Who Does R&D and Who Patents?" in Zvi Griliches, ed., R&D, Patents and Productivity, Chicago: Chicago University Press.

Crépon, B., E. Duguet and J. Mairesse. 1998. "Research, Innovation and Productivity: An Econometric Analysis at the Firm Level." *Economics of Innovation and New Technology* 7(2): 115-158.

Griliches, Z. 1990. "Patent statistics as economic indicators: A survey." *Journal of Economic Literature* 28 (4): 1661-1707.

Motohashi, K. (1998). "Innovation Strategy and Business Performance of Japanese Manufacturing Firms." *Economics of Innovation and New Technology* 7(2): 27-52.

Hall, B. H., and F. Kramarz. 1998. "Introduction: The Effects of Technology and Innovation on Firm Performance, Employment, and Wages." *Economics of Innovation and New Technology* 7(2): 99-107.

OECD-Eurostat. 2005. The Measurement of Scientific and Technological Activities. Oslo Manual. Proposed Guidelines for Collecting and Interpreting Innovation Data. 3rd ed. Paris: OECD Publishing.