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CDM FRAMEWORK FOR R&D–INNOVATION–PRODUCTIVITY RELATIONSHIP: THEORETICAL AND EMPIRICAL PERSPECTIVES

CDM МОДЕЛЬ ДЛЯ ВЗАЄМОЗВ'ЯЗКУ ДОСЛІДЖЕННЯ І РОЗРОБКИ–ІННОВАЦІЇ–ПРОДУКТИВНІСТЬ: ТЕОРЕТИЧНА ТА ЕМПІРИЧНА ПЕРСПЕКТИВИ

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This research uses the CDM framework to examine the relationship between R&D investment, innovation activity, and firm-level productivity. The study provides clear insights into the mechanisms that link innovation and economic performance by addressing methodological challenges such as selectivity bias and simultaneity. The findings show that innovative firms experience higher productivity growth, with the impact varying across regions and industries. The research also defines five stylized facts: the positive influence of firm size and age on innovation, the role of competition in driving innovation, the importance of workforce qualifications and professional development, the complementary role of IT investments, and the significant effect of innovation on productivity growth. These insights form a foundation for policymaking that foster innovation and boost productivity growth.
Keywords: CDM model, R&D, innovation, productivity, stylized facts.

Вплив інноваційної активності на динаміку продуктивності праці на рівні підприємств є важливою темою економічних досліджень, оскільки інновації сьогодні розглядаються як ключовий фактор економічного зростання. Мета цього дослідження полягає у вивченні взаємозв'язку між інвестиціями в дослідження і розробки (ДіР), інтенсивністю інноваційної активності та заростанням продуктивності праці на рівні підприємств із використанням CDM моделі. Актуальність теми обумовлена необхідністю кращого розуміння механізмів, які визначають вплив інновацій на економічні результати, а також потребою в розробці ефективних політик для стимулювання інноваційної активності. Методологія дослідження базується на застосуванні CDM моделі, яка дозволяє врахувати ключові методологічні виклики, зокрема проблему селективності та одночасності. CDM модель включає три етапи оцінювання структурної економетричної моделі: ухвалення рішення про інвестиції в ДіР, процес виробництва знань та оцінку економічної ефективності. Застосування цієї моделі допомагає оцінити вплив інвестицій у ДіР на інтенсивність інноваційної діяльності та, в підсумку, на продуктивність праці. Результати дослідження підтверджують, що інноваційно активні підприємства мають вищі шанси на зростання продуктивності праці, причому вплив інноваційної активності варіюється залежно від регіону та галузі. За результатами дослідження було сформовано п'ять стилізованих фактів (емпіричних закономірностей), які висвітлюють ключові чинники, що впливають на інноваційну активність: позитивний вплив розміру та віку підприємства, значимість конкурентного середовища, важливість кваліфікації працівників і професійного розвитку, роль інвестицій у інформаційні технології та значний вплив інновацій на зростання продуктивності праці. Практична цінність дослідження полягає в наданні обґрунтованих емпіричних даних, які можуть бути використані для формування інноваційної політики, зокрема у створенні умов для доступу до фінансових ресурсів, підтримки професійного розвитку та стимулювання впровадження новітніх технологій.
Ключові слова: CDM модель, ДіР, інновації, продуктивність, стилізовані факти.

Problem statement. Economic research has long focused on the relationship between innovation activity and economic performance. Yet, significant gaps still need to be in understanding the mechanisms driving this relationship at the firm level. While innovation is widely recognized as a critical determinant of productivity growth, the interplay between R&D investments, the intensity of innovation activities, and their economic outcomes varies across industries, regions, and firm characteristics. Existing studies often need to grapple with methodological challenges such as simultaneity, endogeneity, and selectivity bias, which can distort results and hinder the formulation of reliable policy recommendations.

Firm-level analyses frequently overlook heterogeneity in innovation strategies, knowledge capital, and market structures, leading to incomplete insights into the factors shaping the innovation-productivity nexus. The lack of consistent data frameworks and econometric approaches further complicates cross-country comparisons and the identification of universal patterns. These challenges are particularly evident in sectors where innovation takes diverse forms, such as service industries, which rely heavily on human capital, organizational innovation, and advanced IT systems.

Addressing these gaps requires a robust analytical framework that captures the complexities of firm-level innovation. The CDM model provides a comprehensive structure for examining how R&D investment decisions, the production of knowledge, and the resulting productivity gains interconnect. By leveraging this model, the research seeks to address methodological challenges, explore the factors driving innovation activity, and offer evidence-based insights to guide policy interventions that foster innovation and enhance productivity.

Analysis of recent research and publications. Economic literature has thoroughly explored the role of innovation in driving economic growth. The relationship between innovation and productivity has been analysed by researchers, including P. Aghion, B. Crépon, E. Duguet, H. Lööf, J. Mairesse, P. Mohnen, and B. Hall. Studies focusing on the innovation activities of Ukrainian firms and methods to stimulate these have been conducted by researchers such as V. Gryga, V. Heyets, I. Yegorov, L. Kavunenko, O. Krasovska, O. Lapko, I. Lukyanenko, and Y. Ryzhkova.

The purpose of this study is to investigate the relationship between R&D investment, innovation activity, and firm-level productivity using the CDM framework, addressing methodological challenges and providing evidence-based insights to inform strategies that foster innovation and enhance economic performance.

Presentation of the main research material. In 1998, French economists Crépon, Duguet, and Mairesse developed a structural econometric model based on Zvi Griliches' knowledge production function to examine the relationships between R&D investment, innovation activity, and firm-level productivity [1, p. 1]. Known as the CDM model, it has become a workhorse of empirical research on innovation and productivity, applied to firm-level data from over 40 countries [2, p. 232]. By addressing the endogeneity problem, the CDM model enables a comprehensive analysis of how R&D decisions, innovation implementation, and productivity growth interconnect.

Before discussing how to build CDM models, two key challenges must be addressed: simultaneity and selectivity bias. Selectivity bias arises when researchers observe the dependent variable only under specific, non-random conditions. In CDM models, this bias occurs because data on R&D spending and implemented innovations are available only for firms that choose to invest in R&D. This creates endogeneity, as the factors influencing the decision to innovate also affect the scale and intensity of innovation activity, leading to biased and inconsistent ordinary least squares (OLS) estimates. To resolve this, researchers often apply the Heckman two-step procedure, which corrects for selectivity bias and improves the reliability of model estimates.

Simultaneity arises when regressors and the dependent variable are mutually interdependent, complicating estimation. In CDM models, simultaneity occurs because the same factors often drive decisions on R&D investment, the intensity of innovation activities, and productivity. For example, a positive coefficient for R&D investment in the knowledge production function might suggest that higher innovation intensity leads to more implemented innovations. However, this could reflect other factors, such as improved management systems. Similarly, performance variables may become endogenous in the production function due to unobservable factors, such as external shocks or firm-specific attributes, like management quality, which correlate with output and innovation. To address simultaneity, researchers commonly use the instrumental variables method. CDM models use predicted values of dependent variables from earlier stages as instruments since these values are uncorrelated with error terms, allowing OLS to produce unbiased parameter estimates. The CDM framework, organized into three stages, addresses both simultaneity and selectivity issues, ensuring robust and reliable econometric results.

The CDM framework unfolds in three stages:

– *Investment Decision*: In the first stage, firms decide whether to invest in R&D and the scale of such investments. This decision depends on profitability expectations, precisely the net present value of cash flows from R&D, which must be positive. Firms will only proceed if the anticipated returns are within zero.

– *Knowledge Production*: The second stage focuses on the knowledge production function, linking R&D investments to measurable outcomes. Depending on the research objectives and available data, performance indicators may include the sales volume of innovative products, the number of registered patents, or the count of implemented innovations.

– *Economic Efficiency*: The third stage estimates an extended Cobb-Douglas production function to assess the relationship between innovation outcomes and economic efficiency. Labor productivity is typically the primary metric, offering insights into how innovation contributes to performance improvements.

Most econometric studies using the CDM approach rely on microdata from the Community Innovation Survey (CIS) [5]. While these studies share a common methodological framework, they differ significantly in the variables analyzed and the econometric techniques applied. Some studies assess economic efficiency through profitability metrics, while others focus on factor productivity, allowing for comparisons across different adaptations of the CDM framework. Research rooted in the Schumpeterian tradition often examines how the firm size and market structure influence innovation activity. Based on Schumpeter's hypothesis, this approach suggests that larger firms in concentrated markets are more likely to innovate.

Schumpeter's first hypothesis suggests that a firm's innovation activity increases with its size [6, p. 153]. However, empirical studies provide a more nuanced perspective, showing that innovation often grows faster than the firm does. Several factors contribute to this relationship. Larger firms typically enjoy better access to financial resources and are more likely to attract venture capital. The knowledge production function may also exhibit increasing returns to scale, amplifying innovation outcomes. Since innovation costs are largely fixed, their relative proportion in unit production costs decreases as production scales up, creating additional incentives for innovation.

Empirical research identifies firm size as a critical factor in innovation activity. However, evidence on the intensity of innovation remains mixed. Early studies, which supported the idea that R&D spending increases faster than firm size, often used surveys with fewer than 1,000 firms and failed to account for unobserved heterogeneity at the sectoral and firm levels, potentially leading to biased results. More recent studies using more extensive datasets and incorporating sector-specific characteristics have produced conflicting findings, highlighting the need to address structural heterogeneity when analyzing the link between firm size and innovation intensity.

Recent studies show a proportional relationship between R&D spending and firm size. For example, researchers found a negative correlation between firm size and innovation

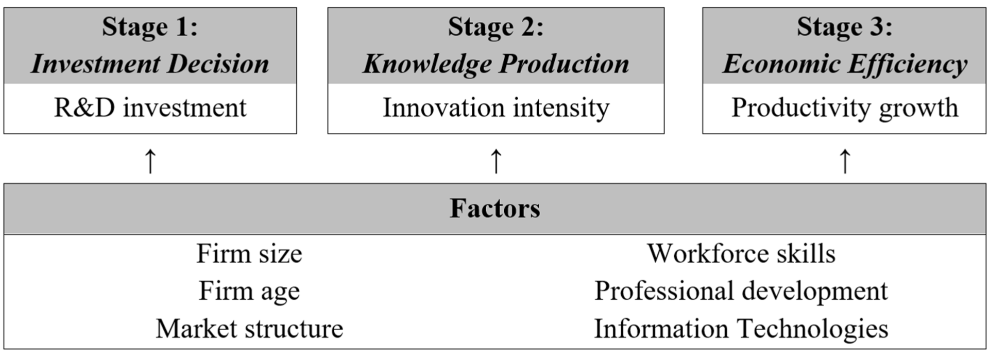

Figure 1. The CDM framework

Source: created by the author based on [3, p. 292; 4, p. 510] activity, with total innovation spending steadily rising as firms grow, but its intensity remaining unchanged. These findings were formalized as a stylized fact and further validated by evidence showing that the intensity of innovation spending is independent of firm size. Research using the CDM approach also demonstrates that firm size significantly affects innovation activity, though the effect is smaller for service firms than industrial firms. For product innovation, the marginal effect ranged from 16% for SMEs to 77% for large firms, while for process innovation, it ranged from 17% to 69% [7, p. 145]. Schumpeterian economic growth models typically show a positive correlation between firm size and age [8, p. 537]. These findings support the *first stylized fact*: firm size and age growth positively influence the likelihood of a firm investing in R&D and the intensity of innovation activity.

The second Schumpeterian hypothesis suggests that market power encourages firms to innovate by anticipating future monopoly rents. This mechanism is formalized in first-generation endogenous growth models, which indicate that increased competition reduces the potential rents for monopolists, discouraging innovation and slowing economic growth. However, empirical studies challenge these theoretical conclusions. A positive correlation has been found between market concentration and innovation intensity among British firms, which can be explained by an extended Schumpeterian model where competition fosters innovation [9, p. 560]. This model distinguishes between two innovation strategies: leaders and followers, both engaging in a step-by-step innovation mechanism, where the follower first adopts the leader's technology and then seeks cost leadership.

Thus, competition produces two opposing effects: the Schumpeterian effect, which encourages innovation to capture monopoly rents, and the competition-avoidance effect, where firms innovate to avoid direct competition, as in a Bertrand competition model. These effects create an inverse U-shaped relationship between competition levels and innovation activity [10]. In models depicting this U-shape, firms innovate to increase the difference between post-innovation rents and pre-innovation rents rather than the absolute size of those rents. A key distinction in these updated Schumpeterian models is that innovation is not confined to new firms; incumbent firms also engage in innovation, thus potentially allowing increased competition to stimulate innovation.

Empirical evidence from developed countries generally supports this inverse U-shaped relationship between market competition and innovation intensity. Data from a U.S. survey of firms between 1976 and 2001 confirms this hypothesis [11, p. 1666]. A similar relationship is observed in Swedish joint ventures, where increased competition shifts innovation activity towards acquiring new knowledge from internal sources. For SMEs, this trend encourages the formation of strategic alliances and increases innovation spending. Research on Swiss firms shows that when initial competition levels are low, an increase in competitors raises the likelihood of innovation, with the Schumpeterian effect prevailing at higher competition levels and the competition-avoidance effect at lower levels [12, p. 679]. These findings support the *second stylized fact*: a competitive market environment positively influences the likelihood of a firm investing in innovation and the intensity of such activities.

Recent studies using the CDM approach examine factors influencing innovation activity, including human capital and advanced IT. The proportion of employees with higher education and indicators such as investment in professional development and employee participation in training often measure human capital. However, no conclusive evidence establishes a statistically significant impact of human capital on innovation activity. For example, a study of Finnish companies found that employees' technical skills positively affected innovation implementation, while a study of German firms found no such correlation. Similarly, empirical research shows no clear link between the number of training sessions and innovation outcomes. In Australian firms, training positively affected innovation in SMEs but not in larger firms [13, p. 968]. These findings support the *third stylized fact*: workforce qualifications and professional development positively influence the likelihood of a firm investing in innovation and the intensity of such activities.

Studies suggest that investments in IT complement human capital in driving innovation. For example, Japanese SMEs using advanced IT are 11% more likely to implement innovations than those relying on traditional technologies. Additional investments in innovation increase this likelihood by 17 percentage points, bringing it to 28% [14, p. 174]. In a study of 7,302 firms across 25 European countries, electronic business technologies raise the likelihood of sales growth by 15%, while IT-related innovations boost it to 40% [15, p. 1324]. IT use, which enables more flexible organizational structures, has also significantly affected innovation. A 10% increase in IT investment raises the probability of product innovation by 7.2% and process innovation by 8.4% [16, p. 345]. In the UK, firms using advanced IT are 6% more likely to introduce new products and 9% more likely to introduce new processes [17, p. 693]. In Estonia, Lithuania, Latvia, and Poland, advanced IT increases the likelihood of product innovations by 2% and process innovations by 3% [18, p. 469]. These results support the *fourth stylized fact*: the use of advanced IT positively influences the likelihood of a firm investing in innovation and the intensity of those activities.

The final stage of the CDM approach models the relationship between innovation activity and its economic effectiveness. By examining the innovation-productivity link at the micro level, the model captures sources of heterogeneity that aggregate analysis may miss. Firms adapt to their environments by adopting mixed innovation strategies, and micro-level analysis allows for modeling the channels through which knowledge assets influence productivity.

In the third stage, the CDM model analyzes the link between innovation and productivity using an extended Cobb-Douglas production function incorporating knowledge capital. Researchers often measure knowledge capital as the stock of past R&D investments, though newer data sources, such as innovation activity surveys, have introduced alternative proxies. These refinements broaden the scope for evaluating how innovation drives productivity.

Knowledge capital influences profit and productivity through two key channels: directly, by improving productivity, and indirectly, by shifting the demand curve for a product. The first channel involves process and organizational innovations; the second concerns product and marketing innovations. To assess the impact of these innovations on productivity growth, empirical models often include a dummy variable derived from innovation surveys, with profit per employee as the dependent variable. Independent variables typically include the number of employees and a proxy for innovation activity.

A review of studies on the link between innovation and productivity using the CDM approach highlights the limitations of cross-sectional data, which hinder the ability to capture dynamic effects. While innovation surveys typically combine three years of data on firms' innovation activities and economic performance, the inability to create panel data restricts most analyses to a static framework.

The RMMP model, one of the first dynamic CDM models, accounts for individual effects and idiosyncratic errors, confirming a robust causal link between innovation activity and labor productivity [19, p. 301]. Using data from firms in the Netherlands and France, the model shows that the probability of productivity growth for Western European firms rises by 9% to 13% with each innovation implemented. This probability is significantly higher in knowledge-intensive services, ranging from 23% to 29%, compared with around 9% in less knowledge-intensive services. For the typical Western European service firm, a 10% increase in implemented innovations is linked to a 9% rise in the likelihood of productivity growth [20, p. 184].

The link between innovation and productivity has drawn significant attention across sectors. In Sweden, a 1% rise in innovation activity is associated with a 9% average increase in the likelihood of productivity growth, although the exclusion of unprofitable firms may skew the results [21, p. 336]. Studies of Italian firms show a feedback loop: past productivity shapes innovation intensity, which drives future productivity. The innovation here boosts the probability of productivity growth by 11% on average [22, p. 451–454], underscoring its dual role as both a cause and consequence of economic performance.

Regional studies show substantial variation in the strength of the innovation-productivity link, shaped by market conditions and local innovation ecosystems. For instance, in the Netherlands, service firms experience a 13% increase in productivity growth probability [23, p. 384], while in the United States, innovation in business services boosts productivity by about 20% [24, p. 57]. Firms in technology-intensive industries generally achieve higher returns from innovation than those in less knowledge-driven sectors. Overall, the evidence underscores the critical role of innovation as a driver of productivity growth, particularly in knowledge-intensive sectors.

Technology intensity also plays a role. In France, IT-focused R&D proves especially fruitful. A 1% increase in R&D spending boosts the probabilities of product innovation by 34%, process innovation by 22% and productivity growth by 39% [7, p. 150]. In China, cost-saving service innovations raise productivity growth likelihood by 10% [25, p. 1599]. These results underline innovation's strong but varied effects on productivity, shaped by regional and sectoral contexts. Thus, the final *fifth stylized fact* is that the implementation of innovations by a firm positively and statistically significantly influences the likelihood of productivity growth.

Conclusions. This research highlights the crucial role of innovation in driving firm-level productivity growth, supported by evidence from applying the CDM framework across various contexts. The CDM model provides valuable insights into the mechanisms linking R&D investment, innovation intensity, and economic performance by addressing challenges such as selectivity bias and simultaneity. The findings confirm that firms engaging in innovation consistently experience higher probabilities of productivity growth, with the magnitude of this impact varying across regions, industries, and technological intensities.

In this research, we defined five stylized facts summarizing key insights into the relationship between innovation and productivity. First, firm size and age positively influence innovation. Larger and older firms allocate more resources to innovation, benefiting from economies of scale, better access to financial resources, and experience, while R&D intensity remains steady. Second, a competitive market environment fosters innovation, creating an inverse U-shaped relationship where moderate competition drives innovation, but extreme competition or market concentration limits it. Third, workforce qualifications and professional development enhance innovation, with skilled employees and investments in training increasing innovation activity, although the impacts vary by sector and firm size. Fourth, advanced IT investments complement innovation by enabling flexible structures and improving processes, especially in knowledge-intensive sectors. Fifth, innovation significantly drives productivity growth, with a 1% increase in innovation activity raising the likelihood of productivity growth by 23% on average.

These stylized facts underscore the importance of innovation in economic development and provide a foundation for targeted policymaking. Addressing structural barriers, improving access to financial resources, and promoting R&D collaboration are critical steps for fostering innovation and unlocking productivity growth across industries and regions. This study contributes valuable empirical insights that can inform policy design and implementation and deepen understanding of the innovation-productivity nexus.

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