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Statistics of High-Technology Manufacturing: Methodological Foundations

The article explores the historical evolution and methodological transformation of approaches to classifying high-tech industries and assessing their contribution to economic development. Drawing on scientific works that have analyzed this topic since the 1950s, the author examines the transition from qualitative assessments of technological progressiveness to quantitative measurements based on the indicator of research and development (R&D) intensity (the ratio of R&D expenditures to value added or sales). Methodological approaches developed by scholars and international organizations are discussed, and normative threshold values for identifying high-tech industries are presented.

Particular attention is given to the limitations of the sectoral approach, which predominantly relies on input indicators – such as R&D expenditures and the share of scientific and technical personnel – and insufficiently accounts for qualitative and institutional factors that influence innovation dynamics. The article also highlights conceptual contradictions arising from the assumption of technological homogeneity within industries, as well as methodological distortions caused by defining high-tech industries solely based on aggregated statistical indicators without considering intra-industry heterogeneity or the innovation activity of individual enterprises. It is emphasized that high R&D expenditures do not always reflect the actual enhancement of technological potential, as part of these expenditures may be directed towards non-technological measures, such as loss prevention, while low-tech industries may produce goods based on advanced technologies.

To overcome these limitations, a comprehensive, multi-dimensional resource-output approach to evaluating high-tech production is proposed. This approach combines quantitative and qualitative indicators, incorporating the diagnosis of an enterprise's technological potential, the analysis of measures to strengthen it, and the assessment of the effectiveness of these measures and the overall performance of the enterprise through the category of "overall quality".

The author outlines practical measures for Ukraine, including recommendations for developing methodologies for the identification and certification of high-tech enterprises, creating state registers of such enterprises, and implementing a multi-dimensional form of state statistical reporting that combines both quantitative and qualitative indicators to monitor their activities. These measures, especially under conditions of limited resources and time, could serve as the foundation for implementing a targeted approach to innovation stimulation, the formation of national technological champions, and the enhancement of Ukraine's international competitiveness, which is particularly relevant in the context of post-war economic recovery.

Keywords: *high technologies, manufacturing, statistics, methodology, innovations, research and development, technological development, classification, indicators.*

Formulation of the Problem. In both scientific and policy literature, it is widely recognized that in the context of globalization, the ability to develop and implement advanced technologies plays a decisive role in accelerating economic growth and enhancing the competitiveness of business entities. High-tech manufacturing industries, which base their strategies on technological innovations, are active participants in international markets, and their dynamic development contributes to improving the efficiency of other sectors of the economy. From a statistical perspective, the challenge lies in consistently defining and measuring the parameters of high-technology manufacturing across national datasets, which is essential for monitoring progress, assessing effectiveness, and informing evidence-based policy decisions.

The active promotion of high-tech industries has been supported by international organizations such as the Organization for Economic Cooperation and Development (OECD) and by the broader scientific community. Within discussions on competitiveness and the preservation of national positions in global markets, econometric models have been developed to explore the correlation between expenditures on research and development (R&D) and export performance [1]. Such models have informed strategic policy recommendations, leading to the widespread use of the term "high technology" in political, academic, educational, and public discourse.

In Ukraine, the emphasis on high-tech sectors is also evident. For example, the study "Post-War Reconstruction of Ukraine: Vision of the Economic Department of the National Academy of Sciences of Ukraine" notes that "...high-tech sectors of manufacturing industry with high added value (energy and transport machine engineering, production of equipment for agriculture and food industry) will gain momentum" [2, p. 14]. Similarly, strategic documents on regional development for 2021–2027 highlight "knowledge-intensive production (high-tech mechanical engineering)" as a priority under the concept of smart specialization [3, p. 163]. Furthermore, the Strategy for Digital Development and Innovation of Ukraine until 2030 emphasizes the creation of a robust innovation infrastructure to support high-tech sectors, including semiconductor technologies, the space industry, unmanned transport, and green technologies, as a key mechanism for enhancing national competitiveness [4].

However, the terminology used in official documents remains inconsistent. The draft Law of Ukraine "On the Fundamentals of Industrial Policy" [5] refers simultaneously to knowledge-intensive production, science-intensive production, and high-tech sectors, while provisions for industrial park participants mention "high-tech production". This multiplicity of terms, intended to describe similar concepts, complicates the development of a coherent national policy and creates challenges for statistical assessment. The lack of terminological consistency hinders clear prioritization, leads to program duplication, and results in inefficient resource allocation, ultimately reducing the effectiveness of management decisions and the ability to track economic outcomes accurately.

Accordingly, there is a clear need for a national methodological framework that enables the identification, classification, and statistical evaluation of high-technology manufacturing. Such a framework would allow policymakers and researchers to harmonize definitions, monitor sectoral development, assess efficiency, and facilitate international comparisons.

Thus, the purpose of this study is to develop methodological foundations for the identification of high-technology manufacturing in Ukraine, providing a structured approach to measure technological potential, innovation activity, and overall performance of enterprises in this sector.

Analysis of Research and Publications. The issue of the prioritization of high-tech production for the state has been widely discussed in numerous works by Ukrainian scholars [6-10]. The main conclusion uniting these studies is the necessity to strengthen the high-tech foundation of the economy through active promotion of innovation factors for economic growth. Researchers emphasize that the post-war recovery of Ukraine must be based on deep structural transformations, which foresee a transition from an agro-resource-based economy to an industrial-innovative one through the creation of modern high-tech industries. One of the main problems remains the precise definition of the term "high technologies". An important challenge is the identification and categorization of high-tech sectors. Some industries directly produce high-tech goods, actively using research and development (R&D), while others produce intermediate and capital goods that also have a high level of technological complexity but benefit from R&D only indirectly. Various indicators are used to assess the technological level of an industry: some reflect the scale of investments (such as R&D expenses, the number of scientists and engineers), while others measure the effectiveness of innovations (for example, the number of patents). However, the boundaries that define what constitutes a high-tech industry remain conditional and often unclear.

Despite numerous claims regarding innovations in various industries, the internal processes of technological changes in companies have been studied much less than other aspects of business. Thus, there is an urgent need for the development of new methodological approaches to assess the technological level of economic activity and its consequences, taking into account the best global practices. This is the subject of ongoing research, including the work of emerging scholars [11].

The purpose of this article is to examine the evolution of methodological approaches to defining high-tech industries and analyze the criteria on which the aggregation of industries based on their technological level is based.

Research Results and Discussion. The issues discussed above have been explored by the author since 2006 [12]. The catalyst for this scientific research was the Presidential Decree of Ukraine, "On the Decision of the National Security and Defense Council of Ukraine from April 6, 2006, 'On the State of the Scientific and Technological Sphere and Measures for Ensuring the Innovative Development of Ukraine'" issued on July 11, 2006 No. 606/2006 [13]. This study led the author to conclude, as early as 2007, that due to the lack of appropriate scientific-methodological and informational-statistical tools, it is impossible to fully and objectively assess the current national potential for producing high-tech products, and, in turn, develop the necessary policies and programs for its stimulation. This significantly complicates the country's entry into the global high-tech goods market [14].

To address these issues, a series of measures were proposed: defining a system of criteria for identifying high-tech industries, products, and professions, and codifying them using appropriate classifiers; developing and approving a methodological framework for identifying and assessing domestic high-tech producers; preparing a comprehensive questionnaire to survey industrial enterprises in Ukraine on their current and potential capabilities to produce competitive high-tech products, and conducting a nationwide survey of enterprises across all ownership types.

The implementation of these measures was expected to provide the first comprehensive, objective assessment of the capabilities of Ukrainian high-tech producers, support the development of a comparative analysis with global high-tech industries, and inform policy and strategic programs aimed at stimulating domestic high-tech industries. The proposed strategies and the results obtained are outlined in the works [15; 16].

Two decades later, as Ukraine seeks to restore its economy in the wake of war, with an emphasis on establishing industries that could drive innovation, the methodological foundations for identifying high-tech industries have become particularly relevant. Addressing these challenges will help create the basis for modern methods to identify promising sectors of economic activity that can contribute to achieving technological sovereignty and ensuring economic stability. In turn, this will foster targeted interactions between the financial system and high-tech companies in the process of implementing Ukraine's innovation-driven development tasks.

When analyzing existing methodological approaches to assessing the technological level of production, it is appropriate to refer to the classic work of Maclaurin (1954) [17; 18], who proposed the concept of technological progressiveness of companies. His approach became one of the first systematic attempts to evaluate the technological development of industries using empirical indicators.

Maclaurin analyzed thirteen American industrial sectors between 1925 and 1950, including chemicals, automotive, aviation, electrical engineering, food, and machine-building industries. These sectors represented a wide spectrum of technological advancement and product types, providing a robust basis for comparison. Maclaurin's methodology relied on three primary criteria.

1. Research Conception – the presence of R&D departments responsible for technological processes and new product development. This criterion was considered vital for assessing technological progressiveness.

2. Patent Activity – the number of patents issued, which reflected innovation dynamics within the company and industry.

3. Scientific Potential – the number of scientists with academic degrees (particularly Ph.D.s), indicating the company's ability to generate new knowledge and technologies.

Maclaurin emphasized that technological progressiveness is not merely the result of scientific achievements but is formed through a combination of research concepts, institutional conditions, and managerial decisions. Factors such as the market environment, government funding for strategic sectors, military contracts, and effective management of innovation were crucial in determining technological progress.

A significant contribution of Maclaurin's research was his insight that innovation should be assessed not only through quantitative measures like patents but also through qualitative factors such as a strategic vision that aligns science, engineering, and entrepreneurship into a coherent development system. This synergy creates the foundation for radical technological transformations.

Maclaurin categorized industries based on their technological progressiveness using the criteria mentioned above (Table 1, constructed by data from [17]. Rating Based on Introduction of Important New Products or Processes). The following table summarizes the results.

The analysis of technological progress across different industries can be summarized into the following categories.

1. Highest Rate of Progress. Industries such as chemical manufacturing, photographic manufacturing, and airplane manufacturing demonstrated the highest levels of technological advancement. These sectors exhibited robust R&D activities, high patent production, and a significant scientific workforce.

2. High Progres: Sectors like radio and television manufacturing and electric light manufacturing showed high technological progress, though in some cases (e.g., electric light manufacturing), R&D activities accelerated post-1940, which was a turning point for innovation in these sectors.

3. Medium Progress. Industries such as automobile manufacturing and steel had moderate technological progress. These sectors invested less in R&D and patents but still demonstrated a degree of innovation.

4. Lower Progress. Industries such as food processing and cotton textile manufacturing showed minimal technological progress. They had limited R&D involvement, lower patent output, and fewer scientists contributing to innovation. Interestingly, coal mining, despite having fewer innovations, still employed a considerable number of Ph.D.s, reflecting the sector's reliance on applied scientific expertise.

From a methodological standpoint, Maclaurin's study offers valuable insights into the factors

Table 1

Technological progressiveness, 1925–1950

Category	Research Conception, 1929	Patents Issued	Number of Scientists with Doctor's Degrees
Highest Rate of Progress: Chemical manufacturing (heavy)	Yes	High	High
Photographic manufacturing	Yes	High	High
Airplane manufacturing*	Yes	Medium**	High
Oil refining	Yes	High	High
High Progress: Radio and television set manufacturing	Yes	High	High
Electric light manufacturing	Yes	Medium	High
Medium Progres Automobile manufacturing	No	Medium-low	Medium-low
Paper manufacturing (except newsprint)	No	Medium-low	Medium-low
Steel	No	Medium-low	Medium-low
Lower Progress: Food processing	No	Medium-low	Medium-low
Cotton textile manufacturing	No	Low	Low
Coal mining	No	Low	Low***
House assembling in tracts	No	Very low	0

Notes: *Progress has come primarily through government funds.
**Primarily since 1940.
***The U.S. Bureau of Mines has a considerable number of Ph.D.s.

that contribute to technological progress. The categorization based on R&D activity, patent issuance, and scientific potential provides a framework for comparing technological advancement across industries. The research emphasizes the importance of institutional support (e.g., government funding), as well as internal management practices, in driving innovation.

Maclaurin's work highlights that technological progress is not only driven by quantitative indicators (like patents) but also by qualitative factors such as strategic alignment between science, engineering, and market needs. The development of high-tech industries requires a synergy of these factors, along with a conducive innovation ecosystem–comprised of education, scientific culture, and entrepreneurial leadership [18].

Maclaurin's methodology remains highly relevant, integrating both quantitative (e.g., patents, scientific workforce) and qualitative (e.g., strategic vision, market dynamics) criteria for assessing technological progress.

In the 1950s, C. F. Carter and B. R. Williams expanded on the concept of technological progressiveness. One of their primary objectives was to identify the characteristics that made firms technically progressive or innovative. Their central hypothesis was that technically progressive firms should apply scientific and technological advancements and possess the capability to produce or adapt new products and processes. However, Carter and Williams recognized a significant issue in their approach: their concept of technical progressiveness lacked precision due to the absence of clearly defined criteria. This led them to propose the following reasoning [19, p. 178]: "We believe there is no difficulty in establishing the 'degree of technical progressiveness' that a firm has achieved. We studied a group of highly progressive firms and compiled a long list of their characteristics, which, in our opinion, are common to all or most of them. A study of less progressive firms, based on the established criteria, showed that the results of these firms fall within a wider range".

In their subsequent work, "Characteristics of Technical Progressiveness in Firms", published in 1959, Carter and Williams presented a more refined methodology, categorizing 150 firms into three distinct groups [20].

1. Progressive. These firms were at the forefront of applied science and technology, rapidly assimilating new ideas and incorporating advancements from related fields.

2. Non-progressive. Firms in this category were not interested in science and technology and focused solely on maintaining traditional methods without exploring new alternatives.

3. Moderately progressive. This larger group included firms that were neither technological leaders

nor fully committed to scientific advancements, representing a middle ground between progressive and non-progressive firms.

Carter and Williams' methodology was based on 29 characteristics of technical progressiveness, which allowed for a multifaceted evaluation of a firm's approach to new knowledge, research and development, production and sales policies, investment decision-making processes, internal coordination, management practices, personnel selection, and the characteristics of key personnel. As the authors themselves noted, these factors collectively fell under the term "general quality". They concluded that, in some cases, a firm's attention to various aspects of general quality preceded technical changes over time, while these elements were a necessary condition for implementing technical advancements.

Despite the methodological contributions of Carter and Williams, their concept of technological progressiveness did not gain widespread traction and was not developed further. It did not become a central part of the high-tech industries concept, which continued to rely primarily on a single criterion: the level of research and development expenditures.

Nevertheless, the methodological value of the Carter and Williams approach lies in its pioneering effort to create a comprehensive, multi-criteria system for evaluating a firm's technological potential. This system accounted for not only scientific and innovative indicators but also organizational, managerial, and behavioral factors, offering a more holistic framework for assessing technological progress.

However, the theoretical and methodological achievements of Maclaurin, Carter, and Williams did not lead to the development of a fully-fledged concept of high-tech industries. Beginning in the 1960s, the focus on technological progress in industry shifted toward quantitative indicators. This transition was driven by the increasing use of R&D intensity–the ratio of research and development expenditures to sales or value-added–as the primary statistical measure. R&D intensity gradually became the cornerstone for classifying high-tech industries, both in academic research and international comparisons.

This shift toward a data-driven approach was influenced by the growing availability of reliable statistical data on R&D expenditures across sectors. It also reflected the growing recognition that high-tech industries are defined by the largest investments in innovation and knowledge-based capital. While these quantitative measures facilitated cross-country comparisons and more objective assessments, they also narrowed the definition of "high-tech", focusing predominantly on R&D activities. This focus on R&D intensity has been criticized for potentially neglecting other important qualitative aspects of technological progress, such as the institutional support structures and organizational factors that contribute to innovation [16].

In his 1958 study, Erik Hoffmeyer [21] examined trends in the specialization of the U.S. economy between 1890 and 1954 and discovered that the United States had increasingly concentrated on the production of research-intensive goods. To quantify this shift, Hoffmeyer introduced a new indicator, which he termed "research intensity." This indicator was based on the share of R&D expenditures relative to total sales. This was the first time such a metric was formally used to describe technological intensity.

Hoffmeyer further classified commodities into 11 groups according to their research intensity. For instance, Group 7 included sectors such as machinery and vehicles–radar, electrical apparatus, aircraft equipment, and similar technologies. This classification allowed Hoffmeyer to explore the relationship between the technological complexity of these products and the competitive advantages they conferred upon the United States in the global marketplace. His findings indicated that, since the late 19th century, the comparative advantage of the United States had increasingly rested on its ability to produce new, research-intensive goods, while imports from other countries largely consisted of traditional, less technologically advanced products.

Hoffmeyer's study underscored the role of research intensity in maintaining the United States' technological edge, noting that a significant portion of enterprise revenues being directed into R&D activities was crucial for sustaining this advantage. This focus on research-intensive industries, he argued, contributed to reducing the U.S. balance-of-payments deficit and strengthening its global trade position.

Expanding on this notion of research-intensive industries, Dr. Bretschneider [22, p. 429], in his presentation on technological progress in the British chemical sector, introduced a third category of industries alongside the traditional capital-intensive and labor-intensive sectors: the research-intensive industries. He argued that such sectors, particularly in the chemical industry, were increasingly characterized by technological advancements in equipment, especially automation. This, according to Bretschneider, was closely linked to machinery used in nuclear power generation, where significant innovations were not always in the machinery itself but in the materials used or in the scaling up of existing technologies. In many cases, the novelty lay in adopting new materials or developing larger, more efficient units rather than radically new technological breakthroughs.

In 1966, Gruber, Mehta, and Vernon [23] examined the role of R&D in international trade and investment in the United States. Their study focused on analyzing the research efforts of various industries, using the ratio of R&D expenditures to sales as a key indicator. They also introduced another measure: the percentage of R&D personnel (scientists and engineers involved in R&D) relative to total employment. Based on these two indicators, they ranked 19 industries according to their R&D efforts and categorized them into two main groups: science-intensive industries and other industries. Science-intensive industries were characterized by high research efforts and a strong orientation toward new product development. The authors highlighted that, in these industries, the emphasis on research is directly linked to the creation of innovative products. By analyzing the data from the U.S., European, and non-European countries, Gruber, Mehta, and Vernon compared four science-intensive industries across these regions, using their classification as a benchmark for international assessments.

The industries with the highest research efforts were identified based on their R&D-to-sales ratio and the percentage of total employment dedicated to R&D activities. The five industries with the highest research efforts, such as transportation equipment, electrical machinery, scientific instruments, chemical products (including pharmaceuticals), non-electrical machinery, demonstrate significantly higher R&D expenditure ratios and a larger proportion of their workforce involved in R&D activities.

This classification by Gruber, Mehta, and Vernon offered a valuable framework for understanding the global competitiveness of industries based on their technological and research capabilities. Their work highlighted the importance of R&D investment in maintaining technological leadership, both domestically and in international trade.

By the late 1960s, the term "technology-intensive industries" emerged in scientific works and official documents. After debates about the technological development differences between Europe and the United States, the U.S. government established an inter-ministerial committee to study the relationship between technological development and international competitiveness. The committee recommended that the U.S. Department of Commerce conduct analytical studies on the economic and technological issues related to discrepancies in technological levels and the scale of international flows of technology, goods, and investments, and to monitor any slowdown or decline in the growth of American technology-intensive industries.

To address this issue, the Director of the Technology Research Program and lead analyst at the U.S. Department of Commerce, M. Boretsky (a scholar of Ukrainian origin), proposed using three criteria to identify technology-intensive products (even though the focus was on identifying industries, not products): research and development, scientific and technical personnel, and level of skill of the workforce [24].

According to Boretsky's methodological approach, the assessment of the technological level of industries involved the categorization of products . In addition to agricultural products, minerals, and raw materials, the author distinguished: Nontechnology intensive manufactured products and Technology intensive manufactured products.

The most significant items within the "non-technologically intensive" category include textiles and clothing, steel, non-ferrous metals, paper products, furniture, glassware, and similar goods. Trade in these products is primarily determined by relative market prices. While the level of technological knowledge embedded in these products may influence trade to some extent, this effect is more potential than actual. This is because, with few exceptions, the technological advancements in these sectors have evolved gradually through industrial craft development, rather than through advanced engineering solutions or coordinated R&D efforts.

On the other hand, the technologically intensive product group includes armaments, chemicals, non-electrical machinery, electrical machinery and apparatus (including electronics), all types of transport equipment (such as aircraft and automobiles), and scientific and professional instruments. The main criterion for classifying these products as technologically intensive is the intensity of new technology application in their production – that is, the extent to which R&D is integrated into manufacturing processes. In addition, key factors for classification include the engagement levels of scientific and engineering personnel in non-R&D roles (such as design, production supervision, and customer support), as well as the relative skill levels and craftsmanship of workers involved in the production process.

The researcher primarily focused on the fourth category – products that are technologically intensive in their production processes. For the United States, the relative intensity of technological influence in the production of specific goods is presented in the following table. Industries are divided into three main groups: Ordnance (Armaments); Chemical and Engineering Products (including electronics and transport equipment); and All Other Manufacturing (Table 2, constructed by data from [24]).

The analysis of the data presented in Table 2 reveals the following key trends and observations.

Expenditures on R&D (Item A). A notable decline in R&D intensity is observed in the ordnance sector, with R&D expenditures as a percentage of value-added dropping from 75.9% in 1960/1961 to 37.7% in 1970. The chemical and engineering industries experienced a moderate decrease from 14.8% to 12.2%, indicating a stabilization at a mature technological level. In contrast, all other manufacturing industries saw almost no change, with their R&D intensity

Table 2

Relative Intensity of Technology Application in U.S. Industry

Category	1960/1961	1970
A. Expenditures on R&D, Percent of Value Added		
Ordnance	75.9	37.7
Chemicals and Engineering Products	14.8	12.2
All Other Manufacturing	1.2	1.1
Average, All Industry	6.6	5.8
B. R&D Employment as Percent of Production Workers		
Ordnance	28.1	24.1
Chemicals and Engineering Products	7.9	7.4
All Other Manufacturing	0.9	1.0
Average, All Industry	3.0	3.0
C. Scientist and Technician Employment in Functions Other than R&D, Percent of Production Workers		
Ordnance	23.9	28.2
Chemicals and Engineering Products	9.1	11.2
All Other Manufacturing	2.3	2.3
Average, All Industry	4.4	5.9
D. Employment of Craftsmen as Percent of "Operatives and Laborers"		
Ordnance	NA	46.6
Chemicals and Engineering Products	55.7	49.2
All Other Manufacturing	32.2	34.9
Average, All Industry	39.0	39.3

remaining steady at 1.2% in 1960/1961 and 1.1% in 1970. On average, total industry R&D expenditures declined slightly from 6.6% to 5.8%, reflecting a modest contraction in overall research intensity across U.S. manufacturing.

R&D Employment (Item B). Employment in R&D relative to production workers showed a slight decrease in the technology-intensive sectors: in ordnance, the proportion fell from 28.1% to 24.1%, while in chemical and engineering products, it dropped from 7.9% to 7.4%. Conversely, in other industries, the share of R&D employment increased marginally from 0.9% to 1.0%. The overall average remained stable at 3%, indicating that high-tech sectors continue to account for the bulk of research employment.

Scientific and Technical Employment in Non-R&D Functions (Item C). Both technology-oriented sectors exhibited growth in scientific and technical employment outside of R&D. Ordnance saw an increase from 23.9% to 28.2%, while chemical and engineering products grew from 9.1% to 11.2%. For all other manufacturing industries, this metric remained unchanged at 2.3%. The industry average for scientific and technical employment in non-R&D functions increased from 4.4% to 5.9%, indicating a growing demand for technical support roles in these sectors.

Craftsmen Employment (Item D). In 1970, craftsmen represented 46.6% of operatives and laborers in the ordnance industry (data unavailable for 1960/61). In chemical and engineering products, the proportion of craftsmen declined from 55.7% to 49.2%, likely due to automation and shifting labor structures. In other manufacturing industries, the share of craftsmen increased slightly from 32.2% to 34.9%, while the overall industry average remained stable at 39.0% in 1960/61 and 39.3% in 1970.

In conclusion, technology-intensive manufacturing industries invest roughly 11 to 12 times more of their value-added output in R&D compared to all other manufacturing sectors combined. These industries are also characterized by a higher concentration of research personnel, scientific and technical staff, and skilled craftsmen, underlining their critical role as both innovators and disseminators of technological advancements within the national economy.

At the international level, the technological advantage of industrially advanced nations is primarily concentrated in technology-intensive industries. Trade in products from these industries depends not only on the level of technological knowledge embedded in the products but also on the scope of this knowledge and the relative prices of the products in the global market.

Nestor E. Terleckyj [25] proposed a methodology aimed at systematically assessing the impact of R&D on industrial productivity (Fig. 1, Table 3, constructed by data from [25]). Figure 1 shows the dynamics of average total factor productivity indexes for industry groups with high, medium, and low private R&D intensity in 1958 (combined direct R&D expenditure and R&D attributed to purchased inputs as a share of value added) over the period 1948–1966, based on data for 33 industries (1948 = 100) [25, p. 40–41].

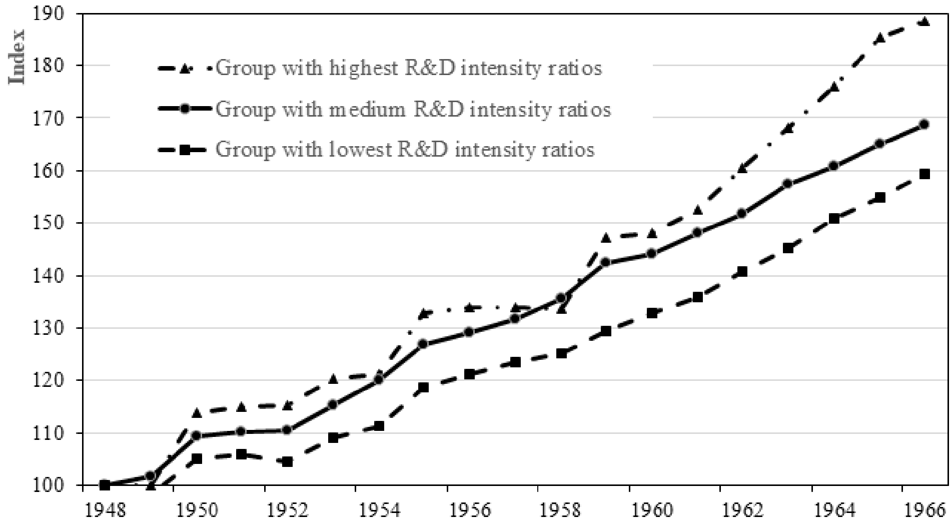

Fig. 1. Average total factor productivity of industry groups by 1958 private R&D intensity, 1948–1966 (33 industries, 1948 = 100)

Table 3

Grouping of industries by the ratio of combined R&D to value added (1958 ratios)

Top Third	%	Middle Third	%	Bottom Third	%
Transportation equipment and ordnance	10.7	Stone, clay and glass products, etc.	1.4	Metal mining	0.4
Chemicals	8.6	Fabricated metals	1.4	Apparel	0.4
Electrical machinery	7.4	Farming	1.1	Leather	0.4
Instruments	6.3	Food, etc.	1.1	Water trans.	0.4
Petroleum refining	5.2	Communication util.	0.9	Coal mining	0.3
Machinery, exc. electrical	4.8	Furniture	0.6	Oil and gas	0.3
Rubber	3.4	Beverages	0.6	Tobacco	0.3
Textiles	2.5	Contract construction	0.6	Railroads	0.2
Airlines	1.6	Lumber	0.5	Printing & publishing	0.2
Primary metals	1.5	Electric and gas utilities	0.4	Wholesale trade	0.1
Paper	1.4	Nonmetallic mining	0.4	Retail trade	0.1

The methodology comprises two key stages.

1. Identification of R&D and Extended Definition of Intensity. Terleckyj considers both direct R&D expenditures conducted within the industry itself and indirect expenditures “embedded” in the purchase of intermediate and capital goods from other industries that perform R&D. This approach allows the calculation of a combined R&D intensity, which more accurately reflects the actual level of research activity within an industry. The methodology also distinguishes between private and government-funded R&D, as well as R&D performed within the industry versus R&D “embedded” in purchases from other industries.

2. Ranking and Grouping of Industries. Industries are divided into three groups based on the ratio of combined R&D expenditures to value added (1958 data). Top Third – industries with the highest R&D intensity, ranging from 1.4% to 10.7% of value added; Middle Third – industries with moderate R&D intensity, ranging from 0.4% to 1.4%; Bottom Third – industries with the lowest R&D intensity, ranging from 0.1% to 0.4%. At this stage, the process involves

ranking and classification only; the grouping itself does not imply any effect on productivity.

Findings on the Impact of R&D on Productivity. After ranking, Terleckyj compared the average growth rates of total factor productivity (TFP) across the three groups: Top Third to average TFP growth of 3.6%; Middle Third to average TFP growth of 3.0%; Bottom Third to average TFP growth of 2.6%.

Industries with higher combined R&D intensity generally exhibited faster productivity growth, although during economic downturns the productivity of the top group could temporarily fall below that of the middle group due to the high recession sensitivity of capital-intensive industries.

A separate analysis of private versus government R&D enables the assessment of differentiated external effects on industrial productivity.

In summary, Terleckyj's methodology integrates an extended definition of R&D, systematic ranking of industries, and quantitative testing of R&D effects on productivity, making it a comprehensive and scientifically robust tool for evaluating the relationship between research expenditures and industrial performance.

Building on the work of American scholars, the OECD launched an initiative aimed at reducing the technological disparity between European countries and the United States. In 1970, the Organization prepared a report [26]. A dedicated section of this report focused on science-based industries, highlighting that, over the past thirty years, new technologies had transformed industrial sectors in ways comparable to the impact of metals in the 19th century and petrochemicals between the two world wars.

To identify the most technology-intensive industries, OECD researchers measured several key indicators, including: R&D expenditures as a percentage of sales; R&D expenditures as a percentage of value added; R&D expenditures per employee (or per total employment) (Table 4, constructed by data from [26]). Based on these measures, industries were ranked and divided into two main groups. In all OECD countries, aerospace, electronics, pharmaceuticals, electrical machinery, chemicals, and instruments exhibited a high level of research intensity, while textiles, paper, food, and beverages displayed significantly lower values.

Table 4

Science-Intensity Levels Defined by the OECD (1970)

Group I. Science-Based Industries	**Group II. Mixed Industries**	**Group III. Average Industries**	**Group IV. Non-Science-Based Industries**
Aircraft	Machinery	Nonferrous metals	Textiles
Electronics	Fabricated metal products	Ferrous metals	Paper products
Pharmaceuticals	Petroleum refining	Other transport equipment	Food and beverages
Chemicals	–	–	Other manufacturing industries

As a result, a new classification was introduced, along with the analytical term "science-based industries". The purpose of this new framework, as with earlier ones, was to identify the role of science and technology in determining the export performance and international competitiveness of OECD member countries. Special emphasis was placed on industries whose activities and outputs were fundamentally driven by scientific advancements.

Building on the OECD's 1970 classification of science-based industries, the 1980s saw further refinements in how technological intensity and innovation were measured across industries. While the 1970 report focused on identifying sectors driven by scientific research, the 1983 U.S. Department of Commerce report introduced a more distinct differentiation between technology-intensive and high-technology industries. This shift in terminology and criteria allowed for more precise identification and statistical measurement of industries based on their R&D investments, workforce composition, and their roles in driving technological progress and economic competitiveness. This conceptual evolution laid the foundation for subsequent frameworks and methodologies, both in the U.S. and internationally, to track and analyze the growing importance of high-tech industries in the global economy. This paragraph helps to connect the previous OECD work directly with the U.S. 1983 report [27] and establishes the historical context for the transition from general terms like "technology-intensive" to the more refined "high-technology" classification (Table 5, constructed by data from [27]). It makes it clear that the OECD's earlier work provided a foundation for later advancements and that the new U.S. methodology introduced more measurable criteria. This also sets the stage for a broader discussion of how these evolving definitions shaped the monitoring and understanding of technological industries in global economies.

Table 5

Classification of US Manufacturing Industries in Accordance with Their Technological Intensity

Industry Groupings	Criteria of Intensity					
	Expenditures on R&D as Percent of Gross Product Originated			Employment of Scientists, Engineers, and Technicians as Percent of Total Employment (1961)		
	1961	1970	1980	1961	1970	1980
A. All Manufacturing Industries	7.4	6.9	7.2	5.4	5.9	6.1
B. Technology Intensive Industries						
Chemicals and Related Products (SIC 28)	10.1	9.7	10	13.9	14.7	13.1
Nonelectrical Machinery (SIC 35)	6.9	6.3	8.2	8.5	8.7	10.6
Electrical and Electronic Equipment (SIC 36)	20.8	19.2	15.8	14.3	14.3	13.3
Transportation Equipment, Missiles, and Ordnance (SIC 37)	26.4	22.6	22.9	10.7	12.1	11
Instruments and Related Products (SIC 38)	8.3	10.9	13.3	13.6	13.2	13.3
Technology Intensive Average	**16.9**	**14.8**	**14.2**	**11.7**	**12.2**	**11.9**
B1. High Technology Industries						
Drugs and Medicinals (SIC 283)	11.2	16.9	22.1	17.8	16.8	18.1
Office Computing and Accounting Equipment (SIC 357)	28.5	36.2	33.2	NA	19.5	15.6
Radio, Television, Communications Equipment and Electronic Components (SIC 365, 366, and 367)	24.2	23.7	16.4	18.7	18.1	18.5
Electrical Apparatus and Equipment (SIC 36 Minus SIC 365, 366, and 367)	17.6	14.5	14.7	9.7	10.2	6.3
Aerospace and Missiles (SIC 372 and 376)	50.7	39.6	45.9	11.1	19.3	15.6
Instruments and Related Products (SIC 38)	8.3	10.9	13.3	13.6	13.2	13.3
High Technology Average	**27.6**	**24.6**	**23.2**	**13.3**	**16**	**15.5**
B2. Technology Intensive Other Than the High Technology industries						
Chemicals Except Drugs and Medicinals (SIC 28 Minus SIC 283)	10	8.3	7.6	13.3	14.3	12
Nonelectrical Machinery Except Office Computer and Accounting Equipment (SIC 35 Minus SIC 357)	4.5	2.3	2.9	NA	6.9	6.9
Motor Vehicles and Equipment (SIC 371)	9.9	10.4	15.9	4.5	6.3	3.6
Transportation Equipment Other Than Motor Vehicles; Aircraft and Missiles (SIC 37 Minus SIC 371, 372, and 376)	3.1	2.1	1.2	27.8	4.1	17
B2 Average	**16.9**	**14.8**	**14.2**	**11.7**	**12.2**	**11.9**
C. Non-Technology Intensive Industries, Average	1	1.2	1.4	1.3	1.5	1.6

B. Godin [28], referring to early OECD publications on this topic, notes that the first analytical works by OECD experts on high technology were largely based on the American classification scheme. In fact, they extrapolated the structure of U.S. industry (the aforementioned list of ten high-technology industries) to all member countries of the organization, which was later criticized.

Following this, in order to develop indicators for high-technology trade, the OECD organized a symposium in 1983, where works on international trade theory and its key concepts were reviewed. Symposium participants concluded that there was a need to define high-technology indicators, as foreign direct investment and technology trade had become as effective as exports in gaining control over markets.

In cooperation with the Fraunhofer Institute for Systems and Innovation Research (Germany), the OECD developed its own classification based on data from 1970–1980, assessing the direct R&D content in the output of each of 22 manufacturing industries across 11 OECD member countries [29]. In 1984, the first official classification was published, consisting of three levels of technology intensity: High – R&D intensity above 3%; Medium – R&D intensity between 1% and 3%; Low – R&D intensity below 1%.

According to this methodology, six industries were classified as high-technology under the International Standard Industrial Classification (ISIC Rev. 2) codes, all of which demonstrated high R&D intensity: Aircraft and spacecraft manufacturing; Pharmaceuticals; Office, accounting, and computing machinery; Radio, television, and communication equipment; Scientific instruments; Electrical machinery.

Studies of industry aggregation by levels of technology intensity conducted over the past 40 years by the OECD and Eurostat have consistently shown the presence of three industries in the top tier of technological intensity: aircraft and spacecraft manufacturing, pharmaceuticals, and computer manufacturing (Table 6, constructed by data from [16]).

Table 6

Official Lists of High-Technology Manufacturing Industries as Defined by the OECD

1984	1994	2001	2009
Aircraft and spacecraft	Aircraft and spacecraft	Aircraft and spacecraft	Aircraft and spacecraft
Pharmaceuticals	Pharmaceuticals	Pharmaceuticals	Manufacture of basic pharmaceutical products
Office, accounting, and computing machinery	Office, accounting, and computing machinery	Office, accounting, and computing machinery	Manufacture of computers, electronic and optical products
Radio, television, and communication equipment	Radio, television, and communication equipment	Radio, television, and communication equipment	–
Scientific instruments	–	Medical equipment and optical instruments	–
Electrical machinery	–		–

This continuity across successive classifications underscores the long-term dominance of aerospace, pharmaceuticals, and computer-related industries within the high-technology segment of global manufacturing. These sectors continue to be core drivers of innovation, maintaining consistently high R&D intensity and a strong concentration of scientific and engineering personnel. As such, they serve as benchmarks for assessing technological advancement within the OECD framework.

In the 2016 OECD study [30], the organization presented an updated taxonomy of industries based on R&D intensity, defined as the ratio of R&D expenditure to value added. This new classification – developed under ISIC Rev. 4 – expanded upon previous methodologies by incorporating both manufacturing and non-manufacturing sectors, dividing them into five categories: High R&D intensity; Medium-high R&D intensity; Medium R&D intensity; Medium-low R&D intensity; Low R&D intensity

Despite the methodological updates and broader scope, the findings reaffirmed a key long-term trend: aerospace, pharmaceuticals, and computer-related industries continue to occupy the top tier of the high-technology hierarchy, consistently exhibiting the highest levels of R&D intensity (Table 7, constructed by data from [30]).

Table 7

The high R&D intensity industries, OECD (2016)

ISIC Rev. 4 Code	Industry	R&D as % of GVA
3031	Air and spacecraft and related machinery	**31.69%**
21	Pharmaceuticals	**27.98%**
26	Computer, electronic and optical products	**24.05%**

Thus, as in earlier OECD classifications (1984, 1994, 2001, 2009), the aerospace, pharmaceutical, and computer/electronic industries continue to be defined as high-technology industries (high R&D intensity industries), serving as the benchmark group for global comparisons of technological advancement.

Conclusion. Analyzing the evolution of methodological approaches to aggregating production by technology intensity, developed by researchers from various countries and forming the basis of official international classifications of high-technology industries, leads to the following conclusions.

For over 80 years, the primary indicator in high-technology classifications has been direct R&D intensity, supplemented by additional metrics such as indirect R&D intensity (R&D expenditures for intermediate and capital goods purchased domestically or imported), the intensity of scientific and engineering personnel, and higher education intensity.

The traditional methodological approach for identifying top-tier industries relies on quantitative assessment according to a normative procedure: calculating the industry average and selecting sectors whose indicators significantly exceed it, meeting established thresholds. In OECD official methodologies, these thresholds were as follows: 1984 – above 3%; 1994 and 2001 – above 5%; and 2009 – above 8%.

Industries aggregated under this approach have been referred to by various names over time, which essentially represent the same category of production: technological progressiveness, research-intensive, science-based, highest research effort, research-oriented, technology-intensive, high-technology, high R&D intensity.

Despite its widespread use, the sectoral approach has several limitations. According to Nobel laureate P. Krugman [31, p.106], measuring knowledge intensity and aggregating top-tier industries into a technology-intensive or high-technology segment is primarily based on inputs rather than outputs. Moreover, using R&D-to-sales ratios and the ratio of scientists and engineers to total employment as indicators of technology intensity raises certain concerns. First, these measurements focus on formal activities, which can be misleading for industries where learning by doing is essential or for innovative firms that are too small to separate R&D from other activities. Second, calculations focus on a fixed set of industries within a specific time period, which can distort the picture as innovative sectors mature and become less dynamic, or as low-innovation sectors give rise to new sub-industries with high rates of technological change – such as the emergence of fiber-optic manufacturing from the glass industry.

Our research also identified additional shortcomings of this approach and its core indicators. When determining high-technology production, calculations are based on data for the general type of economic activity, rather than individual enterprises, assuming that all share similar characteristics. As a result, all companies classified under a high-technology industry by their primary activity are monitored, but not all divisions or resources within a company may be focused on high-tech activities.

Furthermore, all products manufactured by high-technology industries are classified as high-tech, even if they are not, simply due to the industry's status. Conversely, high-tech products from low-tech industries are considered low-tech. This limitation is evident in companies that engage in multiple activities and produce different categories of goods, such as pharmaceuticals and chemicals.

The study relied on data from leading industrial countries, whose industry R&D structures reflect national scientific and technological priorities. However, the resulting classification is applied to the OECD as a whole, as well as to other countries harmonizing their statistics with international standards, regardless of their own innovation expenditures in these sectors.

Significant R&D spending may be directed toward various goals (economic, social, or environmental) or to prevent potential losses, which may not result in better or more advanced final products. While high R&D intensity reflects relative efforts to generate new technological knowledge, it does not necessarily indicate the use of advanced production technologies or the production of high-tech goods.

Similarly, a high concentration of highly educated personnel in an industry may indicate not only a high-tech producer but also a high-tech user. However, the ability to utilize new technologies does not automatically translate into the ability to produce high-tech products, which applies to both low- and high-technology industries. Conversely, a low concentration of highly educated personnel should not be interpreted as an indicator of low technology intensity. In conclusion, the current methodological approach does not allow for a comprehensive assessment of the multi-faceted concept of "technology-intensive" industries, as it focuses only on selected parameters.

To obtain objective information on the state of the national high-tech sector in Ukraine, it is advisable not to limit the analysis to the three industries classified as high-tech within the OECD/Eurostat system. Instead, it is proposed to apply a multi-aspect resource-result approach that integrates both quantitative and qualitative evaluation criteria. This approach encompasses three interrelated stages.

1. Diagnosis of Technological Potential of Economic Entities. This analysis covers the main carriers of technology: personnel, intellectual property, machinery and equipment, and products. It allows for the assessment of the condition, operability, and advancement of technologies.

2. Analysis of Measures to Strengthen Technological Potential. This involves evaluating expenditures and innovative measures aimed at increasing the efficiency of economic entities.

3. Assessment of Performance of Economic Entities. Both economic and non-economic results of activity are considered. Based on these indicators, it is proposed to define the category of overall quality of the economic entity, reflecting the balance between technological potential and performance.

Thus, the new concept complements the traditional evaluation of high-tech status. While high-tech remains one of the indicators, it is supplemented by a more comprehensive assessment of "overall quality", which takes into account the efficiency of potential utilization and the results achieved.

Proposed Measures.

1. Development of Methodological Recommendations for the Identification of Advanced Technology Products. This will enable the creation of a State Register of High-Tech Products in Ukraine's industrial sector, with three target aspects:

- fiscal: tax incentives for the production of goods, export preferences, and benefits for foreign investors;
- statistical: assessing the effectiveness of innovative activities, the level of technology intensity in industry, and the performance of public and private capital expenditures;
- methodological: creating a foundation for the identification and qualification of high-tech manufacturers.

2. Development of Methodological Recommendations for the Identification and Qualification of High-Tech Enterprises. This will allow state authorities to certify economic entities and assign them the status of high-tech enterprise. Based on certified enterprises, a State Register of High-Tech Industrial Enterprises of Ukraine will be formed. The functions of this register include:

– providing targeted support such as fiscal incentives, state grants, subsidies, preferential lending, and government orders to stimulate the production of high-tech products;

– monitoring and forecasting changes in the high-tech sector to support timely managerial decision-making.

3. Development of a Multi-Aspect Form of State Statistical Reporting – Report on Resources, Expenditures, and Results of a High-Tech Enterprise. This questionnaire will gather information on the available potential, strategic measures, innovative activities, and operational tactics of enterprises. It will allow:

- establishing the relationship between enterprise parameters, applied advanced technologies, and the production of high-tech products;
- investigating the influence of internal factors on operational performance and structural changes in the enterprise.

The proposed measures ensure the consistent implementation of this new concept through tools for targeted support and monitoring of high-tech enterprises [32]. Furthermore, it is essential to create a mechanism for developing national technological champions and related structures that ensure their uninterrupted activity and support their further development. This approach focuses on innovation modules, rather than individual industries, facilitating the acceleration of high-tech sector growth and enhancing Ukraine's international competitiveness. The author's proposals may serve as directions for further research.

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Статистика високотехнологічного виробництва: методологічні основи

У статті досліджується історична еволюція та методологічна трансформація підходів до класифікації високотехнологічних галузей і оцінювання їхнього внеску в економічний розвиток. Спираючись на наукові праці, що аналізують цю тематику з 1950-х років, авторка розглядає перехід від якісних оцінок технологічної прогресивності до кількісних вимірів, що базуються на показнику інтенсивності досліджень і розробок (співвідношення витрат на дослідження і розробки (ДіР) до доданої вартості або обсягу продажів). Розглянуто методологічні підходи, розроблені науковцями та міжнародними організаціями, а також наведено нормативні порогові значення для визначення високотехнологічних галузей.

Особлива увага приділяється обмеженням секторального підходу, який орієнтується переважно на вхідні показники (витрати на ДіР та частку науково-технічного персоналу) і недостатньо враховує якісні та інституційні чинники, що впливають на динаміку інновацій. У статті висвітлюються концептуальні суперечності, що виникають через припущення про однорідність технологічних характеристик підприємств усередині галузей, а також методологічні викривлення, спричинені визначенням високотехнологічних галузей виключно на основі агрегованих статистичних показників без урахування внутрішньогалузевої різнорідності чи інноваційної активності окремих підприємств. Підкреслюється, що високі витрати на ДіР не завжди відображають реальне нарощування технологічного потенціалу, оскільки частина таких витрат може бути спрямована на нетехнологічні заходи, зокрема на попередження збитків, тоді як у формально низькотехнологічних галузях можуть вироблятися товари на базі передових технологій.

Для подолання зазначених обмежень запропоновано комплексний, багатоаспектний ресурсно-результативний підхід до оцінювання високотехнологічного виробництва. Він поєднує кількісні та якісні індикатори, передбачаючи діагностику технологічного потенціалу підприємства, аналіз заходів щодо його зміцнення та оцінювання результативності цих заходів і ефективності діяльності підприємства через категорію “загальна якість”.

Авторка окреслює практичні заходи для України, що охоплюють рекомендації щодо розроблення методики ідентифікації та сертифікації високотехнологічних підприємств, створення державних реєстрів таких підприємств, а також упровадження багатоаспектної форми державної статистичної звітності, яка поєднує кількісні та якісні показники для моніторингу їхньої діяльності. Такі заходи, особливо в умовах обмежених ресурсів і часу, можуть стати підґрунтям для реалізації адресного підходу до стимулювання інновацій, формування національних технологічних чемпіонів і підвищення міжнародної конкурентоспроможності України, що є особливо актуальним у контексті повоєнного економічного відновлення.

Ключові слова: *високі технології, виробництво, статистика, методологія, інновації, дослідження і розробки, технологічний розвиток, класифікація, індикатори.*

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