Fraunhofer ISI Discussion Papers *Innovation Systems and Policy Analysis* No. 83

Innovation without growth? Exploring the (in)dependency of innovation on economic growth

Nils B. Heyen, Andrea Zenker, Heike Aichinger, Tanja Bratan,
Tanja Kaufmann, Esther Schnabl

Place: Karlsruhe
Date: April 2024

Responsible for content

Nils B. Heyen, nils.heyen@isi.fraunhofer.de; Andrea Zenker, andrea.zenker@isi.fraunhofer.de; Heike Aichinger, heike.aichinger@isi.fraunhofer.de; Tanja Bratan, tanja.bratan@isi.fraunhofer.de; Tanja Kaufmann, tanja.kaufmann@isi.fraunhofer.de; Esther Schnabl, esther.schnabl@isi.fraunhofer.de; Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe

Recommended citation

Heyen, Nils B.; Zenker, A.; Aichinger, H.; Bratan, T.; Kaufmann, T.; Schnabl, E. (2023): Innovation without growth? Exploring the (in)dependency of innovation on economic growth (Discussion Papers Innovation Systems and Policy Analysis No. 83). Karlsruhe: Fraunhofer ISI.

Published

April 2024

ISSN

1612-1430

DOI

10.24406/publica-2916

Contents

Figure and tables

Abstract

For more than a decade, advocates of both green growth and degrowth have argued about the role of economic growth for the transformation towards a societal system that ensures social well-being on a global scale without transgressing planetary boundaries. Given that such a transformation needs innovations of various kinds, this article explores the question of how dependent innovation is on economic growth and what effects a potential long-term economic stagnation or decline may have on innovation processes and systems. We approach the subject from different angles using mixed methods. First, we present a quantitative analysis of the linkages between economic growth and innovation activities on a sectoral level, based on data of the Community Innovation Survey (CIS) for Germany. Here, we find two sectors (petroleum and advertising industries) showing negative growth rates but still a higher than average share of innovative enterprises. Subsequently, we present an in-depth qualitative case study of the international pharmaceutical sector, which allows us to include a qualitative evaluation dimension. Here, we investigate different innovation approaches and find that both the amount of capital needed to finance research and development activities and the added health benefit of novel drugs vary greatly. We finally conclude that economic growth is not a necessary condition for all kinds of innovation and reflect on some implications for innovation policy. If in a post-growth era financial resources are limited, a shift to less capital-intensive types of innovation and a concentration on innovations which address prioritised societal or ecological needs seem feasible.

1 Introduction

Given the grand societal challenges of our time, both academic and public spheres have in recent years witnessed a general debate on the role of economic growth for the transformation towards a societal system that ensures social well-being within planetary boundaries. According to the so-called green growth position, economic output must be decoupled from environmental consumption, but at the same time it must still increase in order to maintain (or further improve) the level of welfare and prosperity in the industrialised countries. Most governments and international organisations (European Commission 2019, 2022b; OECD 2011; World Bank 2012) have adopted this position, in which green innovations and technologies are considered to play key roles (Smulders et al. 2014). In contrast, advocates of the so-called degrowth position argue that economic output must necessarily decrease to stay within planetary boundaries, but at the same time societal prosperity is nevertheless possible. For more than a decade, this position has been driven by a movement of academic scholars and civil society actors (Kallis et al. 2012, 2018; Schmelzer et al. 2022). Despite their heterogeneity, they are united by a critique of the growth paradigm and the demand for a far-reaching transformation of economic practices and life styles in society (including social innovation).

In a remarkable study on behalf of the German Environment Agency that brought together researchers from both mainstream and ecological economics, Petschow et al. (2020, 2022) comprehensively investigated the scientific evidence at hand for the green growth and the degrowth positions and came to the conclusion that "both positions are based on core assumptions that cannot be adequately substantiated scientifically" (Petschow et al. 2020, p. 6). The authors therefore develop a third analytical position: the precautionary post-growth approach. According to this position, it is not essential whether or to what extent economic output must actually decline in order to achieve the generally accepted ecological (reducing environmental consumption) and societal (maintaining/increasing social well-being) objectives. Rather, the key issue is to become generally less dependent on economic growth in the pursuit of these goals (Petschow et al. 2020, 2022). Therefore, the authors see the need to take precautions in order to ensure that the objectives can be reached independently of economic growth (i.e., also in case of long-term stagnation or decline).

Referring this argument to innovation practices and assuming that innovations are needed to ensure social well-being on a global scale without transgressing planetary boundaries, the question arises how dependent innovation actually is on economic growth. According to the common (neoclassical) view on economics, there is a general virtuous circle at work here: innovation leads to an increase of productivity of a company resulting in profits and economic growth, whereas profits and growth provide the necessary financial resources to invest in innovation activities (Binswanger 2013; Galindo et al. 2014; OECD 2015). However, to what extent is innovation dependent on economic growth – do we necessarily need growth to innovate? And what effects may a potential long-term economic stagnation or decline have on innovation processes and systems? Would it lead, for instance, to a reduction in innovation activity and fewer innovations in a quantitative sense, or would it rather trigger a qualitative shift to other types of innovation with possibly lower financial requirements, as is the case for many social innovations?

This article aims to shed light on these questions addressing the (in)dependency of innovation on economic growth. Given the enormous complexity of this surprisingly under-researched issue, we focus on some tentative and exploratory steps, approaching the subject from different angles and using different methodological approaches. On the one hand, we explore some empirical examples of economic sectors showing considerable innovation activities under the condition of no or declining growth. On the other hand, we investigate different innovation approaches within one sector and analyse their financial sources and societal benefits.

The remainder of the article is structured as follows. We first reflect on the relevant literature regarding the relationship between innovation and economic growth (section 2). We then present a quantitative analysis based on data of the Community Innovation Survey (CIS) for Germany (section 3). Here, we find two sectors (petroleum and advertising industries) showing both negative growth rates and above average shares of innovative enterprises. To further explore and explain these findings, we add a document-based qualitative analysis of both sectors. In the subsequent section (section 4), we present an in-depth qualitative case study of the pharmaceutical sector from a global perspective. Choosing this sector allows us to include a qualitative evaluation dimension regarding societal benefits (health outcomes) based on acknowledged assessment methods. Here, we analyse several innovation approaches (conventional, public health, and alternative/non-profit) and find that the amount of the budget needed and the added health benefit of a novel drug vary greatly. We finally conclude that economic growth is not a necessary condition for innovation of all kinds, and we reflect on some implications for science, technology and innovation (STI) policy (section 5). If in a post-growth era financial resources are limited, a shift to less capital-intensive types of innovation and a concentration on innovations which address prioritised societal needs seem feasible.

2 Background: innovation and economic growth

According to the common techno-economic narrative, innovation and economic growth form a virtuous circle in which innovation leads to growth and growth leads to innovation (Sartorius et al. 2022). In this view, innovations are novel or improved products that have been introduced to markets or novel/improved processes that have been brought into use by a company (OECD/Eurostat 2018). Both increase the productivity or efficiency of the innovating firm, since more output is generated with the same input (or the same output with less input) of the production factors capital, labour, or natural resources (OECD 2015). As a result, the innovator gets an advantage over his competitors, is likely to grow and make profits (Binswanger 2013). Following Schumpeter (1934), this sets in motion a process of "creative destruction" resulting in a dynamic macro-economic development or economic evolution (see also Fagerberg 2003). Neo-classical growth theory includes technological progress as a determinant of growth, alongside labour and capital. Here, technology is seen as being determined outside of the economic system (exogenously). While variations in the production factors labour and capital are expected to lead to a short-term equilibrium, technological advances are assumed to lead to productivity increases, which in turn increase output. This generates economic growth (see particularly Solow 1957).

In contrast, endogenous (or new) growth theories attempt to explain economic growth endogenously, i.e. growth is understood as resulting from internal determinants (see, for instance, Aghion et al. 1992; Grossman et al. 1994; Lucas 1988; Romer 1990; also Fagerberg 2003). These determinants are related to human capital, knowledge, investment in physical capital as well as technology, research and development (R&D) or innovation. According to this view, technological progress is generated within the economic system by economic actors and increases productivity to the advantage of the innovator. However, part of the new technology can spill over into the economic system and taken over by imitators. This generates dynamic development and growth. More recent studies emphasise the importance of growth for wealth and well-being and consider innovation as key factor with strong positive impact on economic growth (Gyedu et al. 2021; OECD 2015).

At the same time, and more important for this article's focus, profits and economic growth are seen as necessary to provide the financial resources for investments in new innovation activities. Galindo and Méndez (2014), for instance, found that better economic conditions create new entrepreneurial opportunities and promote innovation activities. They argue that as long as the demand for the produced goods expands, a self-reinforcing feedback loop of growth, entrepreneurship, and innovation can be observed. This is in line with the demand-pull hypothesis by Schmookler (1966), which states that innovation is highly dependent on demand and economic growth. It has strongly shaped the common view of economic growth as an important driver of innovation (in addition to technology-push effects).

Although there has been much empirical support for the demand-pull hypothesis at both the aggregate/sector level (Brouwer et al. 1999; Geroski et al. 1995; Kleinknecht et al. 1990) and the firm level (Cainelli et al. 2006; Dai et al. 2021; Piva et al. 2007), the evidence is not unambiguous (Jasny et al. 2023). It has been argued that the demand-pull effect can vary greatly depending on, for instance, the National System of Innovation (NIS), i.e. the country-specific institutional context (Filippetti et al. 2011), sector-specific features such as low-tech or high-tech orientation (García-Quevedo et al. 2016), and the type of innovation including product/technological and process/management innovation (Crespi et al. 2008; Ma et al. 2018).

In another study on the demand-pull hypothesis (Jasny et al. 2023) conducted in the same research context as our own study presented in this article, the authors match data from the European Manufacturing Survey 2018 for Germany and macroeconomic sector-growth statistics and run a regression analysis distinguishing between growth on the level of an individual firm and growth on the corresponding sector level. They find that while firm-level growth is strongly associated with the innovation activities of firms, sector-level growth is not. Thus, positive sector growth has little or no positive influence on firms' innovation activities, while negative sector growth, on the contrary, can even have a positive impact on innovation activities of firms.

Furthermore, it has been investigated to what extent a general economic crisis (understood as a limited period resulting in no or negative growth) affects firms' innovation activities. Regarding the global financial crisis of 2008/2009, the results are again somewhat mixed. On the one hand, there is strong evidence that at the aggregate level the financial crisis clearly reduced firms' innovation investments (Archibugi et al. 2013; Filippetti et al. 2011; Paunov 2012). On the other hand, the same studies show that the issue is more complex than that. For instance, Filippetti and Archibugi (2011) also found that, despite the crisis, the majority of European firms did not change their innovation investments. This supports the general persistence of innovative activities over time, explored by Cefis and Orsenigo (2001). In another study, Archibugi et al. (2013) found that in spite of the general reduction of innovation investments at the aggregate level, a few firms even increased their investments in innovation activities during the economic crisis (especially firms that had already been highly innovative before the crisis as well as fast growing new firms). Regarding these crisis-related findings, however, it must be taken into account that most innovating actors assumingly make their decisions in the expectation of future growth, taking the crisis as a temporary occurrence and not as a permanent condition of no or declining growth.

With regard to our second research question about potential effects of such a long-term economic stagnation or decline on the kind and quality of innovation activities, it is important to broaden the purely economic perspective looking both at the role of (technical) innovation in the degrowth discourse and at other types of innovations, especially social innovations.

In contrast to the green growth position considering (green) innovations and technologies as crucial to achieve environmental goals (OECD 2011; Smulders et al. 2014), in the degrowth community the role of technical innovations is less clear, since both technological scepticism and enthusiasm can be found here (Kerschner et al. 2018; Sartorius et al. 2022, pp. 6-7). From the perspective of the sceptics, new technologies represent the old 'innovation for growth' paradigm or the green growth approach which needs to be criticised and overcome (Strand et al. 2018). In contrast, the enthusiasts believe that technologies could contribute to the targeted degrowth society as long as these technologies are designed in a specific (e.g., 'democratised' or otherwise beneficial) way. However, both sides agree that technologies should be evaluated according to specific normative criteria (Kerschner et al. 2018), such as Illich's (1973) concept of conviviality (Vetter 2018).

Other degrowth scholars focus on the innovating actors. Pansera and Fressoli (2020), for instance, distinguish growth-oriented from post-growth-oriented organisations and present several examples of what they call "post-growth modes of innovating" in which science and technology development are "re-oriented towards solving social needs without imposing economic growth as a necessary outcome" (Pansera et al. 2020, p. 17). Thus, also from a degrowth perspective, technical innovations are desirable, but only under specific normative conditions in terms of societal prosperity (whatever that may mean in a specific case).

The orientation of firms towards other goals than the maximisation of profit relates to the concept of 'social entrepreneurship' which is, compared to degrowth, much more common and accepted in mainstream debates (OECD 2013). Social enterprises strive to address societal needs or the common good, and they develop and offer solutions to societal challenges. These solutions are often considered as (one type of) social innovations, although there are many different definitions and meanings of this term (Ayob et al. 2016; Howaldt et al. 2019; Sartorius et al. 2022).

Nevertheless, considering social innovations (or other innovation types that might follow a different logic than technical, market-based or profit-oriented innovations) and the corresponding innovative actors (Warnke et al. 2016) is necessary in order to be sensitive to potential changes in the way of innovating under conditions of no or declining growth. It can be assumed, for instance, that social innovations may often need less financial capital compared to highly R&D intensive technical innovations. However, in most cases, the issue of how such divergent financial needs possibly relate to intended and non-intended environmental and societal impacts (other than economic growth) of selected innovations or innovation types is an open question posing severe challenges for all potential evaluation efforts (Sartorius et al. 2022).

All in all, innovation and its relationship to economic growth seem to be far more complex than the common techno-economic narrative of growth-dependent innovation suggests. In the following section, we present our quantitative analysis of the linkages between economic growth and innovation activities on a sectoral level for Germany. We deliberately do not take a period of general economic crisis, but the period 2016-18 as our starting point, and explore to what extent longer periods of stagnation or negative growth influence innovation patterns. Subsequently, we present our in-depth qualitative study of the international pharmaceutical sector, in which we also explore an alternative, non-profit oriented innovation approach.

3 Linkages between growth and innovation on a sectoral level

Germany's economy shows – with few exceptions – positive trends over the last 50 years regarding the development of the Gross Domestic Product (GDP) compared to the preceding year (DeStatis 2023b). In addition, Germany’s industry was part of the leading group of the European Innovation Scoreboard until 2017 and today is still considered a “strong innovator”.[1] However, a more in-depth view of individual sectors reveals a more heterogeneous picture, as our following analyses on innovation and growth characteristics for different sectors in Germany show.

Using the Community Innovation Survey (CIS) published by Eurostat, we selected innovation variables (such as the share of innovative enterprises, see details below) and investigated them on a sectoral level (NACE classes).[2] Sectoral gross value added (GVA) figures were added to this data, allowing us to consider GVA as a proxy for economic growth. We started our analysis using data from CIS11 (2018) and added GVA data from the German Federal Statistical Office. As we assumed a certain time lag between growth and innovation, we chose the time span of 2015-18 for analysing growth development of GVA. Subsequently, we included CIS12 (2020) data in our investigation. Where possible and useful, the following analyses refer to both empirical bases.

Our calculations refer to NACE divisions (two-digit level), as far as data is available for innovation and growth characteristics. Some divisions could not be included due to non-availability of data, and some cases required a summarised view on individual two-digit sectors. The availability of data for economic key figures and innovation data allowed us to eventually include a total of 29 sectors, which represent about 45% of Germany's GVA in 2018.[3]

Our analysis follows a 3-step-approach that starts with a comparative view on NACE sectors focusing on the share of innovative enterprises and the sectoral GVA growth. We then provide a more in-depth view on innovation activities in selected sectors and include additional innovation-related variables such as information on innovation types (product/process innovation) or expenses on R&D activities. The third step aims to enrich this statistical information by additional qualitative insight on the two most noticeable sectors.

3.1 Growth and innovation in Germany’s industries

Comparing sectoral GVA development between 2015 and 2018 displays results between +28.0 for NACE J62-J63 (computer programming, consultancy, and information service activities) and -33.3 for NACE H50 (water transport).[4] However, in order to not over-emphasise strong yearly changes, we used the compound annual growth rates (CAGR) and calculated yearly averages. This resulted in more moderate values: +8.6% for J62-J63, and -12.6% for H50.

In the attempt to simultaneously consider economic growth and innovation, we confronted GVA growth (CAGR in %) with the share of innovative companies from the CIS. Figure 1 shows that the majority of sectors have positive average GVA growth rates during 2015-18, which reflects the positive development of Germany's economy. Simultaneously, a number of sectors have 80% or more

---

1 See https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en.

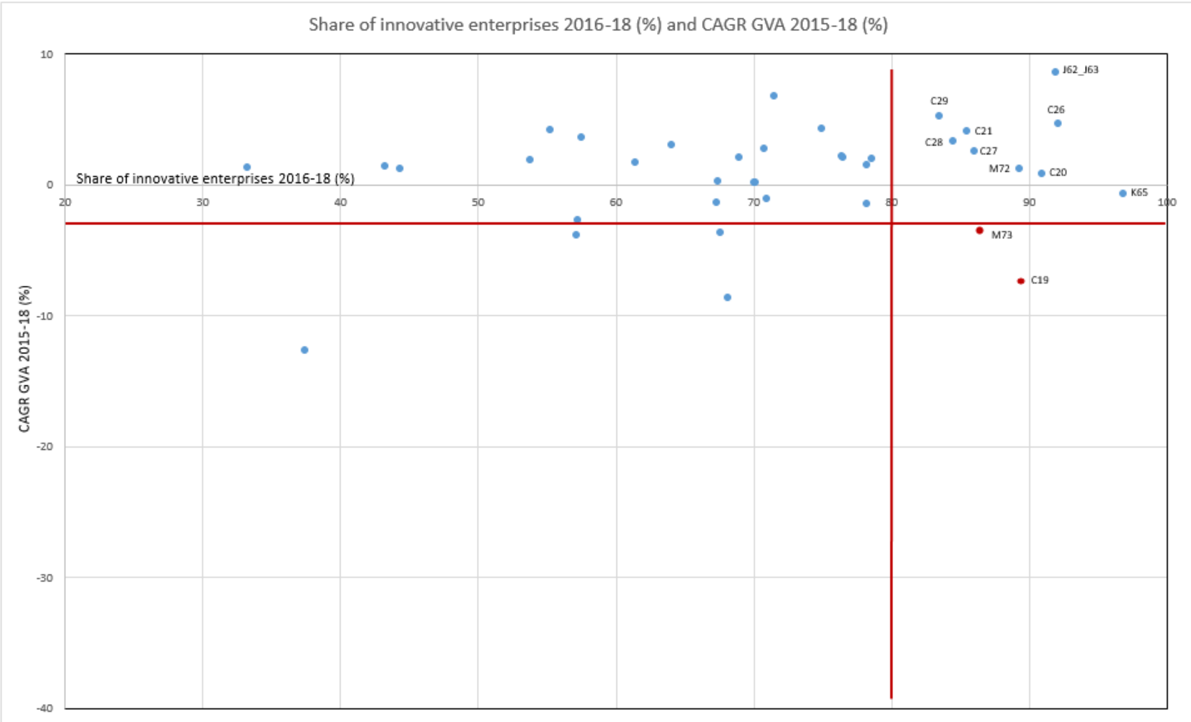
2 NACE (Nomenclature of Economic Activities) is the European statistical classification of economic activities.

3 For comparison: agriculture, forestry and fishing produced 0.76%, production industries 30.30% (from which manufacturing: 22.23%), and service sectors generated 68.94% of Germany's GVA in 2018 (DeStatis 2021).

4 Price adjusted, chained, 2015=100.

innovative enterprises[5] (see right of the vertical red line in Figure 1), including the manufacture of computer and electronic products (C26), computer programming and consultancy (J62-63), the manufacture of chemical products (C20), of electrical equipment (C27), pharmaceutical products (C21), machinery (C28), motor vehicles (C29), as well as scientific R&D (M72). These sectors show both positive economic growth rates and very high shares of innovative enterprises.

Figure 1: Innovative sectors (share of innovative enterprises) 2016-18 and sectoral growth (of GVA) 2015-18



Source: Eurostat, Community Innovation Survey (CIS11), DeStatis 2021, own calculation and presentation.

However, there are three industries with similar high shares of innovative enterprises, but negative average growth rates. These sectors are K65 (insurance, reinsurance and pension funding, except compulsory social security), C19 (manufacture of coke and refined petroleum products) and M73 (advertising and market research). Whereas K65 only shows a slightly and rather negligible negative growth rate of -0.69%, the negative average growth rates of C19 and M73 are below -3% and therefore remarkable (see on the right below the horizontal red line in Figure 1). Despite these negative growth rates, both sectors still show very high shares of innovative enterprises. Hence, they deserve further scrutiny and will be analysed in more detail in section 3.2.

We repeated the analysis for the subsequent period 2018-20 (CIS12 and CAGR GVA 2017-20) and found that the results for sectors C19 and M73 are robust over time: in both industries, again more than 80% of the enterprises reported innovation activities between 2018 and 2020, and both industries show negative average growth rates between 2017 and 2020. Moreover, several other sectors switched to the group featuring very high shares (80% or more) of innovative enterprises and distinct (below -3%) negative growth rates: manufacture of basic metals (C24), machinery (C28), motor

[5] Eurostat defines innovative enterprises as follows: "The enterprise is considered as innovative (INN) if during the reference period it introduced successfully a product or process innovation, had ongoing innovation activities, abandoned innovation activities, completed but yet introduced the innovation or was engaged in in-house R&D or R&D contracted out. Non-innovative (NINN) enterprises had no innovation activity mentioned above whatsoever during the reference period." (https://ec.europa.eu/eurostat/cache/metadata/en/inn_cis11_esms.htm)

vehicles (C29), transport equipment (C30), and activities related to financial and insurance services (K66). We assume that these phenomena are largely related to the COVID-19 pandemic and subsequent production shutdowns, supply shortages and further effects on manufacture and delivery.

Some sectors proved stable in having above-average shares of innovative enterprises and positive average growth rates of their GVA (J62-J63, computer programming and consultancy; C21, manufacture of pharmaceutical products; C26, manufacture of computer and electronic products; and M72, scientific R&D). Others still belong to the group with high shares of innovative enterprises, but now have slightly negative growth rates compared to the 2015-18 figures (C20, manufacture of chemical products; and C27, manufacture of electrical equipment).[6] C17 (manufacture of paper and paper products) newly entered the group of sectors with more than 80% of innovative enterprises in CIS12 (81.0% compared to 78.6% in the previous survey).

The analysis of the 2018-20 period also shows two industries (N79 and H51) with high growth slumps and shares of innovative enterprises between 60% and 80%. Both industries are related to travel activities, H51 being air transport, and N79 representing travel agency, tour operator and other reservation service and related activities. These sectors strongly suffered during the pandemic. While H51 shows an increasing share of innovative enterprises from 67.4% to 77.8%, N79 features a lower share of innovative enterprises from 70.1% to 62.1%. Apparently, the exceptional situation led to differing innovation behaviours in these two industries.

Taking into consideration that the COVID-19 pandemic represents an exceptional situation with very specific consequences, the subsequent analysis focuses on CIS11 data (exploring innovation activities between 2016 and 2018) and 2015-18 average annual growth rates, but additionally refers to more recent developments using CIS12 data. This allows us to consider temporal developments and to reflect on potential impacts of the COVID-19 pandemic.

In order to gain further insight into innovation activities in sectors with different GVA growth rate patterns, Tables 1 and 2 provide information on innovation characteristics of the industries with high shares of innovative enterprises and varying growth characteristics (all sectors on the right side of the vertical red line in Figure 1). First of all, it becomes evident from Table 1 that the group of no strong or non-growth sectors in the 2015-18 period belong more or less to the similar growth type in the 2017-20 period, K65 being an exception. However, there are some changes in the positive growth group (from the 2015-18 period), since C27, C28 and C29 show negative GVA growth figures for the 2017-20 period.

With respect to the share of innovative enterprises, Table 1 shows for C21 (manufacture of basic pharmaceutical products) a remarkable increase from 85.5% to 96.2% between 2016-18 (CIS11) and 2018-20 (CIS12). This is undoubtedly an effect resulting from the COVID-19 pandemic (vaccine production). However, the share of product innovative enterprises decreased in all positive growth sectors between the two periods, while the share of business process innovative enterprises shows some variation. For instance, C21 reported an increasing share of business process innovative enterprises and a decreased share of non-innovators. Another interesting case is M72 (scientific R&D), showing an increased share of innovative enterprises between the two periods with increases in both product and process innovating firms. Consequently, the share of non-innovating firms decreased to almost 0% between 2016-18 and 2018-20. Concerning the sectors with negative growth rates in the 2015-18 period, M73 (advertising and market research) shows a slight decrease of the innovative enterprises share, with increasing shares of product innovators and decreasing shares of

[6] Both industries even reported higher shares of innovative enterprises in CIS12 compared to CIS11.

process innovators. In contrast, C19 (manufacture of coke and refined petroleum products) increased its share of innovating firms, and increasing shares can also be observed for both product and business process innovating firms.

Table 1: Innovation and growth characteristics on sector level (industries with >80% of innovative enterprises in 2016-18)[7]

NACE in growth categories (for industries with at least 80% of innovative enterprises, 2016-18)*	CAGR GVA 2015-18 (%), *[italics: 2017-20]*	Innovative enterprises 2016-18 (%), *[italics: 2018-20]*	Product innovative enterprises 2016-18 (%), *[italics: 2018-20]*	Business process innovative enterprises 2016-18 (%), *[italics: 2018-20]*	Non innovative enterprises 2016-18 (%), *[italics: 2018-20]*
Positive growth 2015-18 (CAGR GVA, higher than 1.5%)					
J62_J63 Computer programming, consultancy, and information service activities	8.6 *7.0*	91.9 *91.8*	72.6 *69.6*	68.1 *76.7*	8.1 *8.2*
C29 Manufacture of motor vehicles, trailers and semi-trailers	5.2 *-6.1*	83.5 *86.0*	51.0 *45.4*	67.4 *66.3*	16.5 *14.0*
C26 Manufacture of computer, electronic and optical products	4.6 *2.5*	92.1 *91.4*	73.6 *58.2*	76.1 *66.1*	7.9 *8.6*
C21 Manufacture of basic pharmaceutical products and pharmaceutical preparations	4.1 *4.3*	85.5 *96.2*	61.5 *54.8*	68.6 *74.1*	14.5 *3.8*
C28 Manufacture of machinery and equipment n.e.c.	3.4 *-4.6*	84.5 *84.4*	66.0 *53.9*	69.8 *61.3*	15.5 *15.6*
C27 Manufacture of electrical equipment	2.5 *-2.3*	86.0 *87.3*	59.7 *56.8*	67.8 *75.1*	14.0 *12.7*
No strong growth 2015-18 (CAGR GVA, -1.5% to 1.5%)					
M72 Scientific research and development	1.2 *0.5*	89.3 *99.6*	51.9 *63.8*	58.1 *69.8*	10.7 *0.4*
C20 Manufacture of chemicals and chemical products	0.8 *-1.2*	90.9 *96.5*	69.4 *48.7*	75.6 *70.4*	9.1 *3.5*
K65 Insurance, reinsurance and pension funding, except compulsory social security	-0.7 *-2.9*	96.8 *79.7*	64.6 *60.7*	72.7 *67.6*	3.2 *20.3*
Negative growth 2015-18 (CAGR GVA, less than -1.5%)					
M73 Advertising and market research	-3.5 *-4.7*	86.4 *85.3*	53.9 *59.1*	78.0 *67.0*	13.6 *14.7*
C19 Manufacture of coke and refined petroleum products	-7.4 *-12.5*	89.4 *96.5*	41.5 *54.2*	71.1 *79.0*	10.6 *3.5*

* Descending order according to CAGR GVA.

Source: Eurostat, Community Innovation Survey (CIS11 & CIS12), DeStatis 2021, own calculation and presentation.

Attempting to obtain more in-depth information about research, development and innovation characteristics for the selected sectors, Table 2 shows that most industries with at least 80% innovative enterprises in the 2016-18 period have considerable shares of R&D performing firms. Only

[7] Industries with more than 80% innovative enterprises (product and/or business process innovations) between 2018 and 2020, but less than 80% between 2016 and 2018: C17 – Manufacture of paper and paper products (2018-20: 81.0%; 2016-18: 76.6%); C24 – Manufacture of basic metals (2018-20: 86.2%; 2016-18: 78.2%); C30 – Manufacture of other transport equipment (2018-20: 90.1%; 2016-18: 76.5%); K66 – Activities auxiliary to financial services and insurance activities (2018-20: 81.0%; 2016-18: 68.1%).

advertising and market research (M73) as well as insurances (K65) report less than half of the sample enterprises with R&D activities. Notably, the share of R&D performing firms in sector M73 strongly decreased between 2016-18 and 2018-20. This is also the industry with the lowest innovation and R&D expenses per innovative enterprise. However, the share of turnover with new or significantly improved products increased between the first and second time periods.

Table 2: Innovation expenditures and turnover on sector level (industries with >80% of innovative enterprises in 2016-18)

NACE in growth categories (for industries with at least 80% of innovative enterprises, 2016-18)*	Share of enterprises with in-house or contracted-out R&D (%) *[italics: 2018-20]*	Innovation expenses (1,000 Euro / innovative enterprise) *[italics: 2018-20]*	Expenditure on R&D activities (1,000 Euro / innovative enterprise) *[italics: 2018-20]*	Share of expenditure on R&D activities from innovation expenditure (%) *[italics: 2018-20]*	Share of turnover with new or significantly improved products *[italics: 2018-20]*
Positive growth 2015-18 (CAGR GVA, higher than 1.5%)					
J62_J63 Computer programming, consultancy, and information service activities	61.0 *56.1*	1,097.4 *1,054.8*	665.4 *773.6*	60.6 *73.3*	23.3 *18.7*
C29 Manufacture of motor vehicles, trailers and semi-trailers	53.8 *50.5*	42,388.0 *36,743.7*	27,175.3 *23,519.3*	64.1 *64.0*	48.7 *48.2*
C26 Manufacture of computer, electronic and optical products	77.9 *76.6*	4,834.6 *4,112.8*	3,590.7 *3,230.2*	74.3 *78.5*	36.8 *24.8*
C21 Manufacture of basic pharmaceutical products and pharmaceutical preparations	72.4 *77.6*	35,527.9 *29,310.7*	24,469.0 *20,460.4*	68.9 *69.8*	19.2 *20.1*
C28 Manufacture of machinery and equipment n.e.c.	65.6 *62.7*	2,430.8 *2,432.8*	1,609.9 *1,706.4*	66.2 *70.1*	20.2 *18.6*
C27 Manufacture of electrical equipment	56.6 *59.2*	3,814.6 *3,328.1*	2,730.1 *2,500.6*	71.6 *75.1*	29.6 *22.2*
No strong growth 2015-18 (CAGR GVA, -1.5% to 1.5%)					
M72 Scientific research and development	88.0 *93.1*	4,583.3 *4,388.0*	3,643.5 *3,927.2*	79.5 *89.5*	30.9 *30.5*
C20 Manufacture of chemicals and chemical products	81.0 *79.6*	4,549.7 *4,539.6*	2,965.9 *3,106.1*	65.2 *68.4*	15.2 *12.7*
K65 Insurance, reinsurance and pension funding, except compulsory social security**	42.7 *43.1*	2,039.8 *2,674.0*	808.0 *1,416.1*	39.6 *53.0*	8.3 *12.0*
Negative growth 2015-18 (CAGR GVA, less than -1.5%)					
M73 Advertising and market research	31.8 *17.9*	243.8 *101.5*	70.6 *44.8*	28.9 *44.1*	9.4 *17.7*
C19 Manufacture of coke and refined petroleum products	67.6 *55.1*	6,510.6 *6,838.9*	*2,583.8* *1,943.5*	39.7 *28.4*	14.0 *10.8*

* Descending order according to CAGR GVA 2015-18, cf. Table 1.
** K65 share of innovative enterprises 2018-20: 79.7%.

Source: Eurostat, Community Innovation Survey (CIS11 & CIS12), DeStatis 2021, own calculation and presentation.

Table 2 also confirms industry-specific patterns: some industries are reporting high and very high expenses for R&D and/or innovation (e.g., C29 and C21), while others have comparatively modest expenses for R&D and innovation (mainly services such as M73, K65, and J62_J63).[8] Moreover, we find a large variation with respect to the share of the industry's turnover gained through new or significantly improved products. At the top of the spectrum is the automotive sector (C29), with nearly half of its turnover resulting from such products. However, industries showing positive growth rates tend to have higher turnover shares achieved with new products, especially compared to negative growth industries. In the no (strong) growth group, M72 (scientific R&D) proves to be an exception with about one third of its turnover realised through new products. Regarding the negative growth group, both advertising (M73) and petroleum producing industries (C19) have below average shares of their turnover through new products, but the development varies: while increasing for M73, this share decreases for C19.

In summary, among the industries with very high shares of innovative enterprises we find both sectoral examples with positive economic growth rates (in terms of sectoral GVA) and others with negative growth rates. Additionally, the specific innovation characteristics among these industries strongly vary. In the following, we take a deeper look at the two sectors we identified as showing more than 80% of innovative enterprises and negative growth rates: manufacture of coke and refined petroleum products (C19), and advertising and market research (M73).

3.2 Two shrinking sectors with a high share of innovative enterprises

3.2.1 Manufacture of coke and refined petroleum products (C19)

At two-digit level, this sector is grouped in manufacture of coke oven products (19.1) and manufacture of refined petroleum products (19.2).[9] In Germany, the industry comprised about 101 enterprises (DeStatis 2023a)[10] and 20,000 employees in 2020. However, division 19.1 plays a very small role, with only 0.3% of employees, whereas most activities fall into division 19.2. Because of its significance within this industry, in the following we focus on the petroleum industry (19.2).

The data presented in section 3.1 show a strong decline in GVA for both periods considered (-7.4% for 2015-18; -12.5% for 2017-20). The petroleum industry was severely hit by the COVID-19 pandemic. While GVA amounted to €5.4 billion in 2019 (0.2% of German GDP), it was only €2.0 billion in 2020 (DeStatis 2022). However, when looking at a longer period of time, it can be observed that GVA of C19 often show strong changes from one year to another, which can partly be explained by demand fluctuations and the comparatively high volatility of oil products' prices.

Complementary to GVA, growth can also be considered in terms of employment and firm number development. Data on employment is available since 1991. At that time, C19 accounted for about 39,000 employees in Germany. During the 1990s, the number was reduced to 19,000 by 1997. Since then, it oscillated around this figure and reached 20,000 in 2020 (0.04% of total employment), so that no clear assessment on employment growth or decline can be derived for the last 25 years (DeStatis 2022). Another indication of negative growth in this industry is revealed by the shrinking number of enterprises over the years. For this indicator, data is only available for a shorter period of time: in 2010, there were about 134 enterprises, coming down to about 101 in 2020. Furthermore, oil consumption also shows a negative trend. Since its peak in 1979, total German oil consumption decreased from 163.2 million tons to 106.6 million tons in 2019 (BP 2023). Nevertheless, looking at

8 Partly, this finding may be explained by different average firm sizes per industry and/or different ways of innovating.

9 For more details on activities and products see Eurostat 2008.

10 According to sales tax statistics (advance notifications); companies with sales above EUR 17,500 per year.

the different types of products shows that the amount of fuel oil and petrol produced decreased, while the amount of products like kerosene and diesel fuel increased (BAFA 2022).

With its products, the petroleum industry is important mainly for energy supply for the transport sector, heating, and the chemical industry. The transport sector plays an important role for the petroleum industry, with around 60% of all oil products used for transporting people and goods. The chemical industry utilises petroleum products as raw material (especially naphtha) and for its energy-intensive production processes. This is why some production sites of the chemical industry are directly connected with refineries via pipelines. Apart from refineries, the industry is comprised of producers of special oils or lubricants and of manufacturers of asphalt and bitumen. However, mineral oil processing in Germany is highly dependent on imports, with only two percent of crude oil supply stemming from national resources (BMWK 2023).

As shown in section 3.1, C19 displays high shares of innovative firms, and Table 3 provides further insights on innovation activities within this industry. It shows that innovation activities relate more to business process innovation than to product innovation; this relation has been increasing over time. While this finding applies to the manufacturing sector in general, C19 features a very high share of 79% of companies engaged in business process innovation in 2020. This share is above the averages of the manufacturing sector and the industries defined by Eurostat as "innovation core activities" (see explanation below Table 3). A similar observation can be made for product innovation as well as for innovation activities in general. Comparing both time periods, it becomes evident that the share of innovative enterprises in C19 increased more strongly than in the other industries considered. What is more, drivers are often related to climate change: government policies are highly relevant, with 43.4% of enterprises in C19 assessing this factor as being of high importance. Notably, customer demand also seems to drive innovation activities for climate protection (31.9%), as well as (presumably) increasing costs or input prices (33.0%).

Table 3: Innovation activities of enterprises in the sector of manufacture of coke and refined petroleum products (C19) 2016-18 and 2018-20 in comparison

Share (in %) of …	Manufacture of coke and refined petroleum products (C19) *[italics: 2018-20]*	Manufacturing (NACE code C) *[italics: 2018-20]*	Industries referred to as "innovation core activities"* *[italics: 2018-20]*
Enterprises engaged in innovation activities	89.4 *96.5*	72.4 *74.5*	67.8 *68.8*
Enterprises engaged in product innovation	41.5 *54.2*	44.9 *37.2*	40.1 *35.6*
Enterprises engaged in business process innovation	71.1 *79.0*	59.0 *59.1*	55.4 *56.2*
Innovative enterprises assessing the importance of factors related to climate change as high: government policies or measures**	*43.4*	*13.9*	*15.2*
Innovative enterprises assessing the importance of factors related to climate change as high: increasing costs or input prices**	*33.0*	*23.2*	*21.3*
Innovative enterprises assessing the importance of factors related to climate change as high: increasing customer demand**	*31.9*	*10.4*	*11.0*

* Eurostat's classification of "innovation core activities" (Com.Reg. 995/2012) includes NACE codes B (mining and quarrying), C (manufacturing), D (electricity, gas, steam and air conditioning supply), E (water supply, sewerage, waste management and remediation activities), G46 (wholesale trade, except of motor vehicles and motorcycles), H (transportation and storage), J (information and communication), K (financial and insurance activities), M71 (architectural and engineering activities; technical testing and analysis), M72 (scientific research and development), and M73 (advertising and market research).

** Questions related to climate change were newly introduced in CIS12, thus no figures for CIS11 available.

Source: Eurostat, Community Innovation Surveys (CIS11 and CIS12).

Despite the high innovativeness of C19, negative economic growth (in terms of GVA) can be expected for the future. Most relevant in this respect are decisions at the national political level that strongly impact the sales volume of petroleum products for transport and heating. In order to attain its goals for climate protection, the German government aims to reduce CO_2 emissions of the transport sector by 48% in 2030 compared to 1990. Additionally, Germany aims to become greenhouse gas-neutral by 2045, which entails a reduction in greenhouse gas emissions to zero for the transport sector. These goals imply the growth of non-petroleum-based drive technologies at the expense of petroleum products. In consequence, refineries are faced with a severe structural change, whose extent and consequences cannot be foreseen yet (IG BCE 2021). Petroleum utilised in production processes needs to be reduced radically, and demand for petroleum products will also have to shrink drastically. However, refineries may alter their business model and replace oil by electricity from renewable energies, the production of green hydrogen, or the production of biogenic and synthetic fuels. A plethora of innovations and investments are needed to attain these goals. However, at the same time, added value will be shifted from mineral oil-based C19 to other industries.

3.2.2 Advertising and market research (M73)

This sector is defined as "the creation of advertising campaigns and placement of such advertising in periodicals, newspapers, radio and television, or other media as well as the design of display structures and sites" (Eurostat 2008). It is subdivided into advertising (73.1), including advertising agencies (73.11) and media representation (73.12), as well as market research and public opinion polling (73.2). Not included are activities like publishing of advertising material or the production of commercial messages for TV, film or radio. The data on sales tax reveals that there were about 27,000 firms in Germany in 2020 (DeStatis 2023a).[11] The vast majority (89%) are classified as advertising agencies (73.1), while the rest is almost split equally between the other two categories (73.12 and 73.2).

As described in section 3.1, the development of GVA hints at a negative growth trend. In comparison to C19, the development of GVA in M73 is less volatile over time. GVA had been rather stable in the 1990s, but has shown a declining trend since 2000. A slight recovery could be observed between 2006 and 2008, but the level of the 1990s was not reached again.

Employment shows a rather different trend: as opposed to GVA, employment grew steadily from 1991 until the economic and financial crisis in 2007 (107,000 compared to 285,000 employees). However, after a sharp decline in the aftermath of the economic crisis, it has been relatively stable with about 245,000 employees (242,000 in 2019 corresponding to 0.5% of total employment). Data on sales tax which is available for 2010 to 2020 reveals an almost steady decline of the number of firms by 30% down to about 27,000 firms. However, this decline mainly affects advertising agencies (M73.11) as well as market research and public opinion polling (M73.2). At the same time, the number of firms in media representation (M73.12) grew (DeStatis 2023a).

According to CIS data, M73 shows a high rate of innovating firms: almost nine in ten companies are engaged in innovation activities (85.3 % in CIS12). As can be seen in Table 4, M73 firms are more active in product innovation and business process innovation than companies in the industries defined by Eurostat as “innovation core activities” (see explanation below Table 3), with business process innovation being more pervasive (67.0%), though with decreasing trend over time. It is also worth noting that almost 60% of innovative enterprises aim to strategically focus on improving existing goods and services.

[11] Sales tax statistics (advance notifications); companies with sales above EUR 17,500 per year.

Table 4: Innovation activities of enterprises in the sector of advertising and market research (M73) 2016-18 and 2018-20 in comparison

Share (in %) of …	Advertising and market research (M73) *[italics: 2018-20]*	Industries referred to as "innovation core activities"* *[italics: 2018-20]*
Enterprises engaged in innovation activities	86.4 *85.3*	67.8 *68.8*
Enterprises engaged in product innovation	53.9 *59.1*	40.1 *35.6*
Enterprises engaged in product innovation: goods	22.2 *25.7*	31.9 *27.0*
Enterprises engaged in product innovation: services	52.7 *56.7*	25.2 *23.4*
Enterprises engaged in business process innovation	78.0 *67.0*	55.4 *56.2*
Innovative enterprises assessing the importance of business strategy as high: focus on improving existing goods or services	60.2 *56.8*	52.8 *48.6*

* See explanation below Table 3.

Source: Eurostat, Community Innovation Surveys (CIS11 and CIS12).

These data give hints for explaining the pattern of economic decline and yet strong innovation. The shrinking number of firms in advertising agencies (73.11) as well as market research and public opinion polling (73.2) indicate that established business models are being challenged. At the same time, rising numbers of firms in media representation (73.12) indicate new opportunities. The drivers behind these changes are to be found in the potentials of new technologies and media. They are complexly interwoven and have been leading to a structural change of the industry. The internet and in particular social media attract increasing shares of advertising budgets. Spending on television advertising is still higher, but digital media advertising has become more important than other forms of media (Percy et al. 2021). Advertising in these media, however, does not necessarily rely on the intermediating role of an agency between advertisers and media. In addition, the way companies address customers has become more personalised. Thus, technological capabilities have gained importance. While spending for advertising greatly depends on the economic development of other industries, nowadays, economic growth does not necessarily imply rising demand for advertising agencies' services. Advertising budgets may be shifted to companies which in the first place are classified as tech industries, e.g. computer programming, consultancy and related activities (J62) or information service activities (J63).

In sum, the two sectors analysed (C19 and M73) are characterised by negative economic growth rates and yet strong innovation activities in recent years. It has been shown that these trends correspond to long-term changes of economic activities. In the case of the petroleum industry (C19), political decision-making aiming at the de-carbonisation of the transport sector will reinforce this trend. In case of advertising and market research (M37), the observed decline can mainly be explained by new technological opportunities that change the ways in which companies address potential customers. This underlines the finding that innovation is – despite of decline at the sectoral level – important for firms' realignment and transformation. It is, however, important to note for both cases that other industries' GVA may grow at the same time.

3.3 Limitations of the analysis

The CIS delivers very detailed (self-reported) information on innovation activities for many, but not for all industries. It largely focuses on manufacturing and selected service sectors. However, manufacturing accounts for just about 20% of Germany's GVA in 2020. Public services or education, for instance, are not included in the CIS, but take an important share of the economic activity and also show innovation activities. Especially when discussing grand societal challenges like climate change, biodiversity loss, resource scarcity, it can be expected that all parts of a socio-economic system need to adapt their strategies and behaviours. Therefore, innovations in until now less considered parts of the economy (agriculture, public services, further service sectors, education, etc.) as well as non-technical innovations are expected to also play an important role. It should also be mentioned that the two industries analysed in detail (C19 and M73) do not represent a significant part of the German economy.[12] Nevertheless, C19 is responsible for providing key basic materials which are used in processing industries, and M73 delivers important services for other sectors.

Another limitation is that we used GVA development over time, but other indicators of economic growth might have the power to broaden the picture and deliver further insights into industrial activities under pressure of capital and resources. While our in-depth analysis of the two sectors attempted to broaden the view along these lines, it also pointed to the problem of volatility of GVA in some industries and illustrated that different trends may be observed depending on the growth indicator under consideration.

Finally, as the inclusion of two periods showed (2016-18 and 2018-20), external influences like a pandemic can change previous patterns, suggesting that industries need to constantly adapt their strategies not only in terms of markets and employment but also with respect to innovation activities.

[12] In 2019, C19 produced 0.18% of German GVA, while M73 was responsible for 0.43% of the total GVA. For comparison, the manufacture of basic pharmaceutical products and pharmaceutical preparations (C21) led to 0.85 % of Germany's GVA.

4 Growth dependency in the pharmaceutical sector

In this section, we explore the growth dependency of different innovation approaches within the international pharmaceutical sector focusing on varying actors, financial sources, and added health benefits. We chose the pharmaceutical sector because it allows us to include a qualitative evaluation dimension: acknowledged methods such as Health Technology Assessment (HTA) provide a sophisticated evidence base to distinguish between, for instance, pharmaceutical innovations with or without a clear health benefit.

In general, the pharmaceutical sector is considered to be crisis-proof and less dependent on economic cycles than other sectors (Leopold et al. 2014; Buysse et al. 2010; O'Brien 2020). Between 2001 and 2020, for instance, global pharmaceutical revenues increased by 324% and thereby surpassed the growth of the global GDP of 252% within the same period (statista 2021; The World Bank 2021). The pharmaceutical sector is also considered a knowledge-based industry in which innovation and growth are traditionally science-driven (cf. also Table 2, C21, for the high share of R&D expenditures of German firms in this sector).

Unlike hardly any other field, a strict and complex regulatory framework applies to pharmaceutical R&D: novel drug candidates have to undergo several phases of pre-clinical and clinical research before they are eligible for market approval. Success rates for newly discovered compounds to reach product maturity are estimated at below 1% because only a small fraction enters clinical trials and among these, 90% eventually fail at different stages throughout the clinical trial process (Harrison 2016; Hay et al. 2014; Hughes et al. 2011; Sun et al. 2022; Takebe et al. 2018). This makes the process of drug discovery and development long and highly cost-intensive. Estimates of the average price of the development of a novel drug compound vary widely and range from about $100 million to almost $3 billion (Gaudilliere 2021; DiMasi et al. 2016; Maxmen 2016; Light et al. 2012; Prasad et al. 2017). Therefore, innovation in the pharmaceutical sector typically requires long-term and large volume financing.

However, to what extent does such a dependency on financial capital apply to all innovation approaches within the pharmaceutical sector? And what is the relationship between the capital invested and the health benefits achieved? In the following, we analyse three heterogeneous pharmaceutical innovation approaches: the conventional approach, the public health (pharmaceutical) approach, and an alternative, non-profit oriented approach. For each, we shed light on the key actors, their roles and motivation(s), on the financial and non-financial sources for R&D, and on the health benefits. Table 5 provides an overview.

Table 5: Different innovation approaches within the pharmaceutical sector

	Key actors	**Actors' roles**	**Actors' motivation**	**Financial sources for R&D**	**Non-financial sources for R&D**	**Health benefits**
Conventional approach	Multi-national companies ("big pharma")	Development of novel drugs including candidate selection, clinical trials, drug approval, market entry, production, global distribution, pharmacovigilance	Primarily entrepreneurial motivation: making profits, increasing stock market value	Primarily private capital raised by companies (stock trading, investments) and revenues from drug sales Some public funding	Various incentives including extended protection of intellectual properties and free pricing policies for newly approved drugs Additional incentives, like accelerated and facilitated approval processes, apply to orphan drugs and break-through therapies	Large number of people provided with drugs Individual health benefit varies greatly for each drug
	Publically funded research actors (universities, research and technology organisations (RTOs)), and start-ups	Basic research and early stage drug development; thereby addressing policy aims such as public health needs, excellence of science, and business promotion	Primarily scientific interest, contribution to societal goals			
	Others: complex transnational innovation networks including various stakeholders such as contract research organisations (CROs), contract manufacturing organisations (CMOs), health care providers, administrative bodies, health insurances	Providing an ecosystem for safe and economic drug development	Heterogeneous, depending on actor			

	Key actors	Actors' roles	Actors' motivation	Financial sources for R&D	Non-financial sources for R&D	Health benefits
Public health approach	Public funding bodies including pan-national organisations (e.g. European Commission, WHO), national governments and ministries, as well as national funding organisations	Priority setting (e.g. via action plans, strategies) and funding for future public health outcomes; partly also promoting appropriate drug use (esp. in antibiotics)	Addressing urgent public health needs, focusing on gaps in the conventional pharmaceutical approach, ensuring that innovations reach the market, equal access to medicines and global justice	Funding by public actors and charitable foundations, also some company funding	Market access and reimbursement regulation, tax concessions, health recommendations (e.g. for vaccinations)	High health benefit, ranges from a large number of people (e.g. vaccines) to small subgroups (e.g. rare diseases) In case of antibiotics, public health outcomes are also dependent on as little use as possible
	Research actors including companies, universities, and RTOs	Basic research and early stage drug development				
	Charitable foundations and NGOs	Late stage drug development (e.g. Global Antibiotic Research and Development Partnership (GARDP))				
Alternative (non-profit) approach	Citizens, patients and their families/friends, patient-led initiatives (partly cooperating with research actors)	Representing affected groups, articulating the motivation and need for alternative innovations	Public health, self-help and inclusion of vulnerable groups	Private donations, philanthropic and public funding Overall, very low capital intensity, low-scale production	High intrinsic motivation (e.g. due to personal affectedness), voluntary engagement	High health benefit for specific affected groups Limited reach due to low-scale-quantities Risks regarding quality and safety standards
	Civil society organizations (e.g. NGOs, open-source-platforms, self-help-collectives, charitable foundations), partly cooperating with research actors	Bundling interests, knowledge and resources to foster alternative research initiatives and innovative activities; sometimes own production of drugs (DIY)	Creating new therapies for groups with neglected diseases; non-profit or social entrepreneurship			
	Public hospitals and pharmacies	Finding alternatives to conventional drugs and starting non-profit-initiatives for alternative production	Enabling access to affordable therapies and drugs; non-profit			

Source: own illustration.

4.1 Conventional approach

Given the aforementioned need for long-term and large volume financing as well as the need for technically skilled staff, the pharmaceutical sector is dominated by large transnational companies, capable of taking the necessary financial burden and risks (hence the term "big pharma"). Beside obtaining revenues from drug sales, stock sales and taking out loans are also relevant sources for raising capital (Moreno et al. 2019). Therefore, it is typically claimed by the pharmaceutical industry that competitiveness and the ability to attract investors are prerequisites for companies to raise the capital required for R&D, and that economic growth and profitability will positively contribute to innovation activities (Moreno et al. 2019). However, a direct link cannot be assumed, given that an increasing dependency of the pharmaceutical industry on stock markets over the past decades was accompanied by a decline in reinvested capital (Gaudilliere 2021). With a lack of transparency in reporting the cost of innovations and the share of reinvestments into R&D, the extent to which innovation activities play a relevant role in attracting investors also remains unclear (Cohen et al. 2021). It has been observed that budgets for marketing new drugs by far exceed the investments for R&D, suggesting that (pharmaceutical) innovativeness is not the only driver for profitability (Light et al. 2012).

What is more, pharmaceutical companies usually benefit from direct and indirect public funding. Governments typically try to incentivize pharmaceutical innovation directly by public funding, but also by providing a beneficial framework: in many countries, price policies apply which exempt novel drugs from restrictions during their introductory phase. Pharmaceutical innovations also benefit from a supplementary patent protection of five years to compensate for the long development time.[13] Moreover, innovation activities do not only take place within the pharmaceutical industry. Rather, the development of novel therapeutic compounds and diagnostics originates from a complex and specialised innovation system where mainly publically funded non-profit institutions like universities and research and technology organizations (RTOs) provide the knowledge base. Additionally, the system comprises start-ups, contract research organizations (CROs), and a complex public infrastructure. Therefore, a significant share of the investment into a new drug originates from public sources (Galkina Cleary et al. 2018; Stevens et al. 2011; Toole 2012).

In this light, the question arises as to what extent pharmaceutical innovations actually lead to desired public or societal benefits. It has been critically discussed that a narrow focus on new products may overestimate the societal value of novel compounds, and that further measures like therapeutic value, or economic markers like cost-effectiveness, should be taken into account (Kesselheim et al. 2013; Stiller et al. 2021). However, from a purely economic point of view, it may be more reasonable for a pharmaceutical company to direct its innovation activities towards extending intellectual property (IP) protection rather than developing ground-breaking innovations (Annett 2021; Hess et al. 2005). Therefore, novelty and innovation per se do not equal health benefits: in a HTA-based study by Wieseler et al. (2019), for instance, no added benefit could be shown for the majority (58%) of 216 newly approved drugs that had entered the German market between 2011 and 2017. Most studies, referring to international data since the 1970s, even find that the proportion of new drugs with a clear therapeutic gain is below 16% (Kaitin et al. 1991; Barral 1996; Morgan et al. 2005; Motola et al. 2006; van Luijn et al. 2010). Other and more recent studies come to similar conclusions (Rodwin et al. 2021; Stiller et al. 2021; Vokinger et al. 2021).

Finally, measuring the innovativeness of the pharmaceutical sector or individual companies typically makes use of data on market entries of new drugs, approvals by national regulatory authorities (e.g.

[13] See the EU legislation, for instance: https://single-market-economy.ec.europa.eu/industry/strategy/intellectual-property/patent-protection-eu/supplementary-protection-certificates-pharmaceutical-and-plant-protection-products_en.

the U.S. Food and Drug Administration (FDA) or the European Medicines Agency (EMA)), the number of drug candidates in clinical trials, or patents. However, such a focus on novel compounds does not take into account any innovative actions that do not lead to a novel drug. In particular, *process innovations* are often less visible and not communicated even though they may greatly contribute to lowering production costs and providing affordable medicines, as can be observed for generic drugs (Nguyen et al. 2022; cf. also Table 1 for the high share of business process innovative enterprises in the pharmaceutical sector C21 in Germany).

Process innovations also play an important role in reducing resource consumption and CO_2 emissions during manufacturing as well as hindering pharmaceutical ingredients from entering the environment. This is key, because the pharmaceutical industry has increasingly been under scrutiny for its environmental impact. In addition to developing cleaner manufacturing processes, the pharmaceutical industry has responded to this by developing more eco-friendly pharmaceuticals ("benign-by-design"). This is referred to as "green pharmacy" (Toma et al. 2018) and includes drugs that are better absorbed by the human body or that biodegrade more rapidly in the environment.

4.2 Public health (pharmaceutical) approach

With both costs and potential profits being high in the pharmaceutical industry, companies tend to focus on drug developments that are most likely to generate profits (Newman 2018). These include drugs for cancer and chronic illnesses that are common in the developed world, where both volumes and prices tend to be high. At the same time, many companies have withdrawn from seemingly less profitable fields like the development of novel antibiotics or vaccines despite the urgent public need for innovation here (Light et al. 2012; Plackett 2020; Simpkin et al. 2017).

This drive for profits has created a narrow focus in pharmaceutical R&D efforts, which is commonly described as the "90-10 rule", where 90% of the pharmaceutical industry's global investments treat only 10% of the world's population (Stiglitz et al. 2010). Unfortunately, this logic does not satisfy public health needs adequately, as there is too little breadth in R&D. Key disease areas and emerging health threats are not being addressed (e.g., Newman 2018) as prices and/or sales volumes of potential products are too low. Governments strive to reduce this gap through public funding and incentives in market access, reimbursements and tax incentives (Congressional Budget Office 2021). Health recommendations, such as for vaccinations, can also have a significant effect on supply and demand (Congressional Budget Office 2021). Therefore, R&D and commercialisation regarding pharmaceutical products for public health do not follow the conventional market-driven pattern. This can be observed in particular in the areas of antimicrobial resistance and antibiotics (4.2.1), vaccines (4.2.2), and rare diseases and orphan drugs (4.2.3).

4.2.1 Antimicrobial resistance and antibiotics

Antibiotics are a cornerstone of modern medicine and essential for public health because they can curb transmission of infectious diseases. However, against the backdrop of increasing antimicrobial resistance, their continued use is jeopardised because the discovery and development of new antibiotics is not cost-effective (Cook et al. 2022) and much less favourable than for other drugs (Plackett 2020). As a result, many large pharmaceutical companies have abandoned antibiotic development while SMEs lack the capital and other resources to fill the void (Simpkin et al. 2017). The increasing health threat caused by emerging antimicrobial resistances to existing antibiotics and a lack of new antibiotics has led to the creation of major national and international initiatives and action plans to invigorate the pipeline. These include the global action plan on antimicrobial resistance by the World Health Organization (WHO) and the Global Antibiotic Research and Development Partnership (GARDP)[14], which has been created by the WHO and the Drugs for Neglected Diseases initiative *(*DNDi). In Europe, the Directorate-General for Research and Innovation of the European Commission (DG-RTD) is one of the major funders of R&D for antibiotics, providing mainly direct project funding (Simpkin et al. 2017). However, public funding initiatives have been criticised for i) focusing primarily on the early stages of research and lacking later stage push efforts to actually bring new products to the market, ii) missing pull incentives that encourage private investment in clinical trials and commercialisation, and iii) a lack of international coordination across the various initiatives, which risks duplicating efforts and leaving funding gaps (Simpkin et al. 2017).

Conventional economic reward models based on reimbursements do not work for antibiotics because the public health goal is to minimise use and to have so called "reserve antibiotics" as a back-up, which are used only in case of failure of standard antibiotics. Therefore, novel subscription models are being explored that guarantee income to pharmaceutical companies in return for unlimited access to the antibiotics for a limited period of time (Barlow et al. 2022). This can include an up-front payment during the early development phase (Plackett 2020). Also, market entry reward (MER) programmes have been suggested as a solution to this economic hurdle (Renwick et al. 2018).

4.2.2 Vaccines

Like antibiotics, vaccines are essential for human health (Schuchat 2011) and have been a game changer in the fight against many infectious diseases. However, over the past few decades, the number of pharmaceutical companies involved in vaccine development has decreased significantly because the cost of the R&D process is high and the market much smaller than for other drug products (Offit 2005). The latter is partially due to vaccines being preventative treatments that are administered infrequently, rather than regular treatments for illnesses that are purchased repeatedly (Xue et al. 2020). At the same time, societal benefits of most vaccines far outweigh potential profits to be made by pharmaceutical companies, leading to misbalance and underinvestment (Athey et al. 2022) compared to disease treatments.

When the COVID-19 pandemic hit in 2020, public funding was instrumental in developing vaccines: the US government initiated the Public Private Partnership (PPP) "Operation Warp Speed" with a public investment of $18 billion (Baker et al. 2020), providing funding to all the major companies involved in R&D for a COVID-19 vaccine. In Germany, the company BioNTech did not only use publicly funded infrastructures for its previous basic research, but it additionally received €375 million from the German government for the development of a vaccine (Reuters 2020). To reap the benefits of their investments, the US government, the European Commission as well as governments of many other countries purchased several billion doses in advance to ensure their populations would be vaccinated early on (e.g., European Commission 2022a). Moreover, during the COVID-19 crisis, there was a shift towards government and philanthropic funding also for later stages of pharmaceutical innovation, far beyond scientific and clinical research (Robinson 2021).

Due to their limited purchasing power, developing countries do not only face inequitable access to existing vaccines, but there is also little incentive for pharmaceutical companies to develop vaccines for neglected and poverty related diseases, despite the high disease burden, as prices need to be low, making developments unprofitable. Again, public funding has tried to address this, for example with the Drugs for Neglected Diseases initiative (DNDi), which was set up by key research and health organisations as a PPP to develop such vaccines.

[14] See https://gardp.org/.

The DNDi has been quite successful also beyond vaccines (Maxmen 2016) and has developed twelve new treatments so far according to its website.[15] In contrast to what large pharmaceutical companies frequently announce as developing costs for a new drug ($1.3 billion; Light et al. 2012), the DNDi states it can develop a new drug for between $110 and $170 million (Maxmen 2016). Other examples of PPPs include the International AIDS Vaccine Initiative, the Medicines for Malaria Venture and the Global Alliance for TB Drug Development. PPPs have the benefit that they pool different resources and can decouple R&D costs from the price of products.

4.2.3 Rare diseases and orphan drugs

Rare diseases are another area where commercial interest in drug development is low because it is usually not profitable. The small number of potential patients also makes clinical trials and marketing more challenging (Aartsma-Rus et al. 2021). In the US, the Orphan Products Grants Program[16] aims to address this gap, and in Europe the EU research framework programme (currently Horizon Europe) as well as ERA-NET provide public funding for orphan drugs. In addition to funding, the European Medicines Agency (EMA) provides other incentives for orphan drugs development such as reduced fees for protocol assistance, a centralised authorisation procedure and ten years market exclusivity (EMA 2022). In the US, the Orphan Drugs Act offers similar incentives with a seven year market exclusivity, tax credit for clinical trials, and exemption from user fees (FDA 2022).

In sum, the public health (pharmaceutical) approach constitutes an essential addition and corrective mechanism to the conventional approach by funding drug developments that would otherwise not take place. These are typically in the fields of antibiotics, vaccines, and drugs for rare diseases. Such pharmaceutical innovations address public health needs and seem to be dependent on public funds much more than on the economic growth of pharmaceutical companies. Moreover, the public health approach is primarily dependent upon priority-setting by national governments, which has a secondary dependency on economic well-being, but not necessarily on economic growth. In Germany, for instance, priority-setting has led to a sharp increase of health-related public R&D spending compared to GDP after the onset of the COVID-19 pandemic in 2020, and an above GDP increase can already be observed for over a decade prior to that.[17] In addition to funding, support for the public health approach comes from market access and reimbursement regulation, tax concessions as well as health recommendations, such as for vaccinations.

4.3 Alternative (non-profit) approach

Outside the regular pharmaceutical R&D setting represented by the conventional and the public health approach, there are various 'grassroots' and open-source innovation activities within peer-to-peer communities trying to create better access to medical (or alternative) solutions or to provide vital pharmaceuticals to people in need. Often based on alternative principles of open-source or 'do-it-yourself' (DIY), these innovative activities come from bottom-up niches and adopt a non-profit logic. In contrast to classical pharmaceutical innovation, grassroots and open-source innovations seem to be less dependent on financial capital, because new configurations of technologies and practices are developed on the basis of other resources and motivations.

One of the origins is the DIY-science movement, in which biopharma research and DIY-laboratories are a prominent stream (Wu et al. 2020). Today, other alternative innovation forms such as patient-

[15] See https://dndi.org/.

[16] See https://www.fda.gov/industry/medical-products-rare-diseases-and-conditions/orphan-products-grants-program.

[17] Own calculation, based on data from OECD (see https://stats.oecd.org/; Government budget allocations for R&D (GBARD), Socio-economic objective (SEO) set to "Health") and Statista (see https://de.statista.com/; GDP).

led initiatives, self-help-collectives, foundations, open-source pharma platforms and not-for-profit associations aim at finding solutions to largely ignored public health problems, neglected diseases, and marginalised (vulnerable) groups. Examples are the Open Source Pharma Foundation (OSPF 2022) or the "Solve ME/CFS Initiative" (Solve M.E. 2022), which both rely on open-source collective intelligence projects, crowdsourcing with big data, and crowdfunding campaigns for basic research and drug development.

Typical activities of the alternative approach are low-scale experiments, open-source manuals, co-creation, but also process innovation in the sense of copying existing compounds and finding a cheaper and more efficient way to produce on a small scale and less dependently on expensive machinery. Guiding principles used by the DIY and grassroots activists in the field were originally pioneered by the open-source software movement (Munos 2006). The motivation behind all these alternative practices is closely connected to the fight against neglected diseases and the exclusion from access to affordable treatments for certain groups of the population. At the same time, the actors are inspired by the idea of open knowledge, self-help and more autonomy vis-à-vis the established health system and large pharmaceutical companies.

Although the DIY-development of drugs often happens on a small scale and informal basis, examples show that even essential pharmaceuticals such as contraception, hormone (self)-treatments, epinephrine and HIV-drugs can be developed in local or digital self-help-collectives through an open-source approach. The group "Four Thieves Vinegar collective", for instance, developed an open-source portable chemistry lab for DIY production of Daraprim, a drug against HIV (Oberhaus 2018). Facing shortages and high prices of generic drugs, established actors of the healthcare system such as hospitals or pharmacies have also started to make their own DIY medicines and help patients that cannot afford expensive drugs vital for them to survive (Peters 2018). Here, interesting examples include Civica[18] in the US, a non-profit generic drug company created by four hospital groups (Syrop 2018), and the small scale production of a specific drug at the Amsterdam UMC Academic Centre (Stokel-Walker 2019). In addition, individual researchers, doctors and pharmacists engage in initiatives or convince their institutions to make non-profit-pharmaceuticals and cooperate in open-source projects (Munos 2006; Stokel-Walker 2019).

Overall, the alternative approach can be characterised by a low capital intensity and a limited reach. Financial support often comes from non-corporate donations, crowdfunding-campaigns via digital platforms, philanthropic foundations and, to a limited extent, from public funds. The flow of the capital can partly be described as circular, because it goes from the people affected (and their relatives, friends, advocates) to more specialised actors, trying to use the capital for potential innovative solutions, and then ideally back to the ones who need it. Sometimes, the capital is not moving at all, because affected persons invest it in their own DIY-activities and use the value created for themselves. In general, the financial resources are used in a non-profit logic, often with the support of volunteer work and a high degree of intrinsic motivation.

The public health benefits of these practices are worth mentioning. First of all, they are seen as contributing to the democratisation of the pharma sector by creating awareness and by developing affordable and accessible therapies and medicines (Wu et al. 2020). Second, they perform without big financial investments, working on a small scale and through a strong intrinsic motivation of affected persons and their advocates. Third, they involve patients and therefore can foster exchange about the experiences of patients and their needs. Lastly, these practices put a lot of volunteer effort on questions of public interests, especially with regard to neglected diseases. For instance, the sudden public interest in Long COVID due to the COVID-19 pandemic has shed light on the activities and knowledge gathered by the ME/CFS-Community about post-viral-diseases (Solve M.E. 2022).

[18] See https://civicarx.org/.

Certainly, there are a number of concerns as well. Often, there is no clear scientific evidence of the clinical benefit of the pharmaceuticals produced by these grassroots initiatives. Also, liability and legitimacy issues arise in the cases of DIY activities with no legal approval, official authorisation or clinical trials for the products (Furness 2018). Besides, the practice of pharmacies making drugs themselves on a small scale might not be very sustainable in the long-term. DIY-laboratories are hindered to scale-up as they are lacking financial capital for more advanced lab equipment (Wu et al. 2020). What is more, it could be argued that the DIY approach could further reduce incentives for conventional pharmaceutical companies to develop and produce drugs for rare conditions, and that it may put patients at risk because regulators do not check the compounding processes of these pharmacies on a regular basis. Another challenge is that practical guidelines for pharmacies on how to compound formulations for patients with rare diseases in compliance with the official standards and regulations are very limited, despite the increasing number of attempts (Polak et al. 2021).

4.4 Conclusion on pharmaceutical innovations

In view of the three innovation approaches described above (cf. Table 5), one can conclude that pharmaceutical innovations are first of all dependent on R&D and hence on capital needed to finance these activities. However, this does not necessarily make innovations dependent on growth (in the strict sense of 'no innovation without growth'), neither in micro-economic nor in macro-economic terms, for several reasons.

First, the amount of the financial budget needed to create pharmaceutical innovations obviously varies. Low budget innovations do exist, as grassroots and open-source innovation activities or the Drugs for Neglected Diseases initiative (DNDi) have shown. If less financial capital is available due to no or negative growth rates, the development of pharmaceutical innovation still seems feasible.

Second, the added therapeutic gain of a new drug or, in more general terms, the added public health benefit of pharmaceutical innovations varies, as can be learned from HTA data and other meta-studies. Therefore, neither more available financial capital nor more newly approved drugs will automatically lead to increased health benefits, especially not from a public health perspective.

Third, apart from financial sources following a growth logic (stock and drug sales), there are several other R&D funding options for pharmaceutical companies including public funding, philanthropic funding, private donations or even crowdfunding (of course, these funds may also be affected by times of no or negative economic growth). Thus, firm growth does not seem to be a necessary condition for pharmaceutical R&D and innovation activities in general.

Finally, historic and more recent examples (such as the COVID-19 pandemic) show that also in times of macro-economic downturns and crisis, the pharmaceutical sector has grown, public funds for pharmaceutical innovations have been increased, and pharmaceutical innovations have been created. This points to the enormous influence that public funding actors' strategic priority-setting may have.

All in all, it can be concluded that economic growth is not, in the strict sense of propositional logic, a 'necessary condition' for pharmaceutical innovation, on neither a micro-economic nor macro-economic level. What is more, the classical market mechanisms often fail to incentivise pharmaceutical innovations with the highest health benefit. Thus, the relationship between pharmaceutical innovation, R&D, financial capital and economic growth is highly complex, especially when taking into account the various sources of the financial capital and the added health benefits.

4.5 Limitations of the analysis

Although we took a global perspective to make allowance for the fact that many pharmaceutical innovation processes take place on a global level, the available data and studies often refer to individual countries only. What is more, our analysis represents a perspective from the Global North rather than the Global South (e.g., Rajan 2017), where many aspects of the alternative (non-profit) pharmaceutical innovation approach might be more common.

Another limitation is the general lack of data and meta-studies regarding the conventional and the public health approach as well as the lack of empirical studies regarding the alternative (non-profit) approach. Although, to the best of our knowledge, we have taken into account the most important studies and the available data, the picture remains fragmented, and generalisations and conclusions are difficult to make. In addition, due to our focus on the growth dependency of several innovation approaches, we inevitably have neglected further influencing factors such as knowledge management, firms' strategic processes, or the role of innovation pioneers.

Furthermore, the comparison of the three innovation approaches within the pharmaceutical sector holds some challenges. Since public funding and infrastructure are very important also in the conventional approach, and companies also play a significant role in the public health approach, there is certainly an overlap between both approaches. In addition, it is difficult to compare such different entities as, for instance, a novel drug developed and marketed on a global scale by a multinational company, on the one hand, and a DIY process innovation developed by a regional 'grassroots' initiative to reproduce a specific compound for self-use, on the other hand. Both innovations differ substantially in terms of innovation type, amount and type of the invested financial capital, distribution scale, health benefits, key actors involved, and so forth. Their comparability is therefore limited, as is our attempt to systematise such differences in Table 5.

Finally, it has to be noted that for a new drug to reach patients, many parallel activities and innovations beyond the development of the compound are usually required, for instance, the availability of companion diagnostics, adjustments in clinical guidelines, or new treatment and monitoring regimes. Given this dependency on the wider ecosystem, assessing pharmaceutical innovation in isolation is generally limited.

5 Conclusion

In addition to the case study-specific limitations discussed in previous sections (3.3 and 4.5), there are two more that should be mentioned before concluding this article. First, it can be assumed that in contemporary industrialised countries most innovating actors take decisions in the expectation of future growth, regardless of whether a phase of growth or non-growth is currently going on. This, of course, is also mirrored in all quantitative data we used for our analyses. How the innovating actors would have decided and acted if they had expected a long-term or enduring phase of non-growth is unknown. Historically, there have been no long-term non-growth phases in industrialised countries so far that we could empirically analyse and learn from.

Second, available quantitative innovation data are usually based on conventional metrics, which produces some blind spots. One is that the qualitative dimension addressing the societal or environmental benefit or harm of an innovation is generally ignored; the other is that the focus is on product and process innovations, neglecting other innovation types such as institutional or social innovations. In the case study on the pharmaceutical sector, we attempted to additionally shed some light on both aspects (considering the added health benefit of novel drugs and some innovation activities following an alternative non-profit approach). However, due to a lack of data and empirical studies, this was limited.

Despite all limitations, we believe that our analyses and results provide sufficient evidence to conclude that economic growth is not always a necessary condition for innovation. The counter-examples presented in this article show that innovation also occurs in non-growth-situations and that there is no linear or simple relationship between innovation and economic growth meaning that more (less) growth would automatically lead to more (less) innovation or even greater (lesser) societal benefit.

However, it still seems reasonable to assume that economic growth, be it on the level of firms through direct gains or on the level of the state through tax revenues, facilitates the availability of financial capital required for many types of innovation. Therefore, less or no growth may reduce the available capital for innovation and innovation processes. This could possibly lead to a reduction in innovation activity and to fewer innovations in a quantitative sense. However, as our analyses show, less or no growth could also lead to

a) an increase in innovation activity, for instance, due to changing and possibly economically threatening framework conditions, as we have seen for the petroleum and advertising industries (section 3.2); or

b) a shift to less capital-intensive types of innovation or innovation approaches, as we have observed for 'grassroots', DIY, or open-source innovation activities in the alternative, non-profit innovation approach within the pharmaceutical sector (section 4.3); or

c) a concentration on selected innovation candidates which from a qualitative perspective have a high potential to address urgent societal needs, as we have seen for antibiotics, vaccines, or orphan drugs in the publicly funded public health approach (section 4.2).

Taking this perspective, and again the example of the pharmaceutical sector, a macro-economic long-term development of non-growth or negative growth might even constitute an opportunity for politics and society to reflect and possibly rearrange the relationship between the (then limited) available financial capital, the alignment of innovation processes, and the targeted societal benefits of pharmaceutical innovations. Since, from a societal perspective, pharmaceutical innovations with a clear (added) health or sustainability benefit are preferable, it seems wise to make it more attractive for companies to create such innovations by means of, for instance, financial incentives by public funds (addressing all stages of the development process including clinical trials, market approval, and commercialization), regulation (market approval, reimbursement schemes, drug prices based on cost-benefit evaluations, etc.), or open-source mechanisms. Similar arguments may be feasible for other economic sectors.

These considerations are very much in line with the mission-oriented innovation policy approach (Mazzucato 2018; Lindner et al. 2021; Wittmann et al. 2021; 2022) and with the rather recent frame for science, technology and innovation (STI) policy, which Schot and Steinmueller (2018) call the "transformative change" STI policy frame. If STI policy after the "normative turn" (Daimer et al. 2012) is supposed to increasingly address the grand societal challenges of our time and if, at the same time, financial (and other) resources are more and more limited, then a stronger prioritisation and focus on those societal needs and goals that are considered most important is needed. From this perspective, the key question for STI policy is not so much to what extent it contributes to economic growth, as it has been the case in the two dominant STI policy framings since the Second World War, "innovation for growth" and "national systems of innovation" (cf. Schot and Steinmueller 2018). Rather, the key question is how STI policy can support the achievement of selected societal and transformative goals even without economic growth, thus with stagnating or increasingly limited financial resources.

Even if STI policy does not take up this task with such clarity, it seems to become increasingly important to consider non-growth, degrowth, or post-growth scenarios more frequently in innovation policy strategies, programmes, and communication, in addition to usual scenarios of societal development featuring only different rates of positive economic growth. This applies not only for STI policy, but also for many research areas, such as climate research (Keyßer et al. 2021), economics (Victor 2012), and also innovation research, to name a few. Ultimately, such possible post-growth scenarios also concern the resilience of innovation systems (Roth et al. 2021).

To understand how to possibly increase the resilience of contemporary innovation processes through a greater independency from economic growth, it seems necessary to further explore and learn from the manifold forms of unconventional and less capital-intensive innovation practices that already exist today, no matter whether they call themselves non-profit, non-growth, low-budget, low-tech, or sustainability-oriented (Robra et al. 2023). In addition, more knowledge is needed about potential system-specific dependencies on economic growth, be it national or technological innovation systems, energy systems, healthcare systems, or social insurance systems (cf. Petschow et al. 2020, 2022). Analogous to the current debate on technology sovereignty (Edler et al. 2023) fueled by recent geo-political and geo-economic developments and international interdependencies being increasingly perceived as risky, it may prove crucial to take measures to avoid or reduce such system-specific growth dependencies. Innovation could also help in this regard.

Finally, additional questions for future research relate to non-financial incentives and drivers for innovation, such as cultural or motivational factors. What kind of conditions and incentives may lead actors to innovate under conditions of post-growth and limited financial resources? And how do post-growth oriented (i.e. growth-independent) innovation processes and systems look like? With our article we hope to stimulate further research and reflections on innovation as being more independent of economic growth than often assumed.

References

Aartsma-Rus, A.; Dooms, M.; Le Cam, Y. (2021): Orphan Medicine Incentives: How to Address the Unmet Needs of Rare Disease Patients by Optimizing the European Orphan Medicinal Product Landscape Guiding Principles and Policy Proposals by the European Expert Group for Orphan Drug Incentives (OD Expert Group). In: Frontiers in pharmacology, 12, p. 744532. https://doi.org/10.3389/fphar.2021.744532.

Aghion, P.; Howitt, P. (1992): A Model of Growth Through Creative Destruction. In: Econometrica, 60 (2), p. 323. https://doi.org/10.2307/2951599.

Annett, S. (2021): Pharmaceutical drug development: high drug prices and the hidden role of public funding. In: Biologia Futura, 72 (2), pp. 129–138. https://doi.org/10.1007/s42977-020-00025-5.

Archibugi, D.; Filippetti, A.; Frenz, M. (2013): Economic crisis and innovation: Is destruction prevailing over accumulation? In: Research Policy, 42 (2), pp. 303–314. https://doi.org/10.1016/j.respol.2012.07.002.

Athey, S.; Conti, R. M.; Fiedler, M.; Frank, R. G.; Gruber, J. (2022): The economic case for federal investment in COVID-19 vaccines and therapeutics remains strong. Available at https://www.brookings.edu/essay/the-economic-case-for-federal-investment-in-covid-19-vaccines-and-therapeutics-remains-strong/.

Ayob, N.; Teasdale, S.; Fagan, K. (2016): How Social Innovation 'Came to Be': Tracing the Evolution of a Contested Concept. In: Journal of Social Policy, 45 (4), pp. 635–653. https://doi.org/10.1017/S004727941600009X.

BAFA (2022): Mineralöldaten für die Bundesrepublik Deutschland: Entwicklung der Inlandsablieferungen für Mineralölprodukte - Zeitreihe. Eschborn. Available at https://www.bafa.de/DE/Energie/Rohstoffe/Mineraloelstatistik/mineraloel_node.html.

Baker, S.; Koons, C. (2020): Inside Operation Warp Speed's $18 Billion Sprint for a Vaccine. Available at https://www.bloomberg.com/news/features/2020-10-29/inside-operation-warp-speed-s-18-billion-sprint-for-a-vaccine.

Barlow, E.; Morton, A.; Megiddo, I.; Colson, A. (2022): Optimal subscription models to pay for antibiotics. In: Social science & medicine (1982), 298, p. 114818. https://doi.org/10.1016/j.socscimed.2022.114818.

Barral, P. E. (1996): 20 Years of Pharmaceutical Research Results Throughout the World (1975-94). Rhone-Poulenc Rorer Foundation.

Binswanger, H. C. (2013): The Growth Spiral. Money, Energy, and Imagination in the Dynamics of the Market Process. Berlin: Springer.

BMWK (2023): Mineralölversorgung. Available at https://www.bmwk.de/Redaktion/DE/Artikel/Branchenfokus/branchenfokus-energieversorgung-05.html.

BP (2023): Statistical Review of World Energy. Available at http://www.bp.com/statisticalreview.

Brouwer, E.; Kleinknecht, A. (1999): Keynes-plus? Effective demand and changes in firm-level R&D: an empirical note. In: Cambridge Journal of Economics, 23 (3), pp. 385–399. https://doi.org/10.1093/cje/23.3.385.

Cainelli, G.; Evangelista, R.; Savona, M. (2006): Innovation and economic performance in services: a firm-level analysis. In: Cambridge Journal of Economics, 30 (3), pp. 435–458. https://doi.org/10.1093/cje/bei067.

Cefis, E.; Orsenigo, L. (2001): The persistence of innovative activities. In: Research Policy, 30 (7), pp. 1139–1158. https://doi.org/10.1016/S0048-7333(00)00139-6.

Cohen, A.; Ultee, R.; van Veldhoven, G. (2021): Making pharmaceutical companies report what matters about innovation. In: British Journal of Clinical Pharmacology. https://doi.org/10.1111/bcp.14993.

Congressional Budget Office (2021): Research and Development in the Pharmaceutical Industry,

Cook, M. A.; Wright, G. D. (2022): The past, present, and future of antibiotics. In: Science translational medicine, 14 (657), eabo7793. https://doi.org/10.1126/scitranslmed.abo7793.

Crespi, F.; Pianta, M. (2008): Demand and innovation in productivity growth. In: International Review of Applied Economics, 22 (6), pp. 655–672. https://doi.org/10.1080/02692170802407429.

Dai, X.; Li, Y.; Chen, K. (2021): Direct demand-pull and indirect certification effects of public procurement for innovation. In: Technovation, 101, p. 102198. https://doi.org/10.1016/j.technovation.2020.102198.

Daimer, S.; Hufnagl, M.; Warnke, P. (2012): Challenge-oriented policy-making and innovation systems theory: reconsidering systemic instruments. In: Fraunhofer ISI (Ed.): Innovation system revisited. Experiences from 40 years of Fraunhofer ISI research. Stuttgart: Fraunhofer Verlag. ISBN: 3839604435, pp. 217–234.

DeStatis (2021): Volkswirtschaftliche Gesamtrechnung. Inlandsproduktberechnung, detaillierte Jahresergebnisse.

DeStatis (2022): Volkswirtschaftliche Gesamtrechnung. Inlandsproduktberechnung, detaillierte Jahresergebnisse.

DeStatis (2023a): Umsatzsteuerstatistik - Voranmeldungen. Available at https://www-genesis.destatis.de/.

DeStatis (2023b): Volkswirtschaftliche Gesamtrechnungen. Wichtige Zusammenhänge im Überblick 2022. Available at https://www.destatis.de/DE/Themen/Wirtschaft/Volkswirtschaftliche-Gesamtrechnungen-Inlandsprodukt/Publikationen/Downloads-Inlandsprodukt/zusammenhaenge-pdf-0310100.pdf?__blob=publicationFile, accessed 01.08.2023.

DiMasi, J. A.; Grabowski, H. G.; Hansen, R. W. (2016): Innovation in the pharmaceutical industry: New estimates of R&D costs. In: Journal of Health Economics, 47, pp. 20–33. https://doi.org/10.1016/j.jhealeco.2016.01.012.

Edler, J.; Blind, K.; Kroll, H.; Schubert, T. (2023): Technology sovereignty as an emerging frame for innovation policy. Defining rationales, ends and means. In: Research Policy, 52 (6), p. 104765. https://doi.org/10.1016/j.respol.2023.104765.

EMA (2022): Orphan incentives. Available at https://www.ema.europa.eu/en/human-regulatory/research-development/orphan-designation/orphan-incentives.

European Commission (2019): The European Green Deal. Brussels.

European Commission (2022a): Safe COVID-19 vaccines for Europeans. Available at https://ec.europa.eu/info/live-work-travel-eu/coronavirus-response/safe-covid-19-vaccines-europeans_en.

European Commission (2022b): Towards a green, digital and resilient economy. Our European Growth Model. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Comittee and the Committee of the Regions. COM(2022) 83 final. Available at https://economy-finance.ec.europa.eu/system/files/2022-03/com_2022_83_1_en_act_part1_v5_0.pdf, accessed 01.08.2023.

Eurostat (2008): NACE Rev. 2. Statistical classification of economic activities in the European Community. Luxembourg. Available at https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF.

Fagerberg, J. (2003): Schumpeter and the revival of evolutionary economics: an appraisal of the literature. In: Journal of Evolutionary Economics, 13 (2), pp. 125–159. https://doi.org/10.1007/s00191-003-0144-1.

FDA (2022): Designating an Orphan Product: Drugs and Biological Products. Available at https://www.fda.gov/industry/medical-products-rare-diseases-and-conditions/designating-orphan-product-drugs-and-biological-products.

Filippetti, A.; Archibugi, D. (2011): Innovation in times of crisis: National Systems of Innovation, structure, and demand. In: Research Policy, 40 (2), pp. 179–192. https://doi.org/10.1016/j.respol.2010.09.001.

Furness, D. (2018): 'Rogue medicine in a bathtub': 4 experts on the vice and virtue of pharma hacking. Available at https://www.digitaltrends.com/cool-tech/diy-medicine-expert-interview/.

Galindo, M.-Á.; Méndez, M. T. (2014): Entrepreneurship, economic growth, and innovation: Are feedback effects at work? In: Journal of Business Research, 67 (5), pp. 825–829.

Galkina Cleary, E.; Beierlein, J. M.; Khanuja, N. S.; McNamee, L. M.; Ledley, F. D. (2018): Contribution of NIH funding to new drug approvals 2010-2016. In: Proceedings of the National Academy of Sciences, 115 (10), pp. 2329–2334. https://doi.org/10.1073/pnas.1715368115.

García-Quevedo, J.; Pellegrino, G.; Savona, M. (2016): Reviving demand-pull perspectives: The effect of demand uncertainty and stagnancy on R&D strategy. In: Cambridge Journal of Economics, bew042. https://doi.org/10.1093/cje/bew042.

Gaudilliere, J.-P. (2021): Pharmaceutical innovation and its crisis: drug markets, screening, and the dialectics of value. In: BioSocieties, 16 (3), pp. 411–432. https://doi.org/10.1057/s41292-021-00235-7.

Geroski, P. A.; Walters, C. F. (1995): Innovative Activity over the Business Cycle. In: The Economic Journal, 105 (431), p. 916. https://doi.org/10.2307/2235158.

Grossman, G. M.; Helpman, E. (1994): Endogenous Innovation in the Theory of Growth. In: Journal of Economic Perspectives, 8 (1), pp. 23–44.

Gyedu, S.; Heng, T.; Ntarmah, A. H.; He, Y.; Frimppong, E. (2021): The impact of innovation on economic growth among G7 and BRICS countries: A GMM style panel vector autoregressive approach. In: Technological Forecasting and Social Change, 173, p. 121169. https://doi.org/10.1016/j.techfore.2021.121169.

Harrison, R. K. (2016): Phase II and phase III failures: 2013-2015. In: Nature Reviews Drug Discovery, 15 (12), pp. 817–818. https://doi.org/10.1038/nrd.2016.184.

Hay, M.; Thomas, D. W.; Craighead, J. L.; Economides, C.; Rosenthal, J. (2014): Clinical development success rates for investigational drugs. In: Nature Biotechnology, 32 (1), pp. 40–51. https://doi.org/10.1038/nbt.2786.

Hess, J.; Litalien, S. (2005): Battle for the Market: Branded Drug Companies' Secret Weapons Generic Drug Makers Must Know. In: Journal of Generic Medicines: The Business Journal for the Generic Medicines Sector, 3 (1), pp. 20–29. https://doi.org/10.1057/palgrave.jgm.4940095.

Howaldt, J.; Hochgerner, J. (2019): Desperately Seeking: A Shared Understanding of Social Innovation. In: Howaldt, J.; Kaletka, C.; Schröder, A.; Zirngiebl, M. (Eds.): A world of new practices. München: Oekom. ISBN: 9783962381578, pp. 18–21.

Hughes, J. P.; Rees, S.; Kalindjian, S. B.; Philpott, K. L. (2011): Principles of early drug discovery. In: British journal of pharmacology, 162 (6), pp. 1239–1249. https://doi.org/10.1111/j.1476-5381.2010.01127.x.

IG BCE (2021): Branchenausblick 2030+: Mineralölverarbeitung und Raffinerien. Berlin. Available at https://www.arbeit-umwelt.de/wp-content/uploads/StAuU_BA-Raffinerie.pdf.

Illich, I. (1973): Tools for Conviviality. New York: Harper & Row.

Jasny, J.; Schubert, T. (2023): Post-growth and the demand-pull hypothesis of innovation: Biting the hand that feeds you? In: Fraunhofer ISI Discussion Papers "Innovation Systems and Policy Analysis", (No. 76).

Kaitin, K. I.; Phelan, N. R.; Raiford, D.; Morris, B. (1991): Therapeutic ratings and end-of-phase II conferences: initiatives to accelerate the availability of important new drugs. In: Journal of clinical pharmacology, 31 (1), pp. 17–24. https://doi.org/10.1002/j.1552-4604.1991.tb01882.x.

Kallis, G.; Kerschner, C.; Martinez-Alier, J. (2012): The economics of degrowth. In: Ecological Economics, 84, pp. 172–180. https://doi.org/10.1016/j.ecolecon.2012.08.017.

Kallis, G.; Kostakis, V.; Lange, S.; Muraca, B.; Paulson, S.; Schmelzer, M. (2018): Research on Degrowth. In: Annual Review of Environment and Resources, 43, pp. 291–316. https://doi.org/10.1146/annurev-environ-102017-025941.

Kerschner, C.; Wächter, P.; Nierling, L.; Ehlers, M.-H. (2018): Degrowth and Technology: Towards feasible, viable, appropriate and convivial imaginaries. In: Journal of Cleaner Production, 197, pp. 1619–1636. https://doi.org/10.1016/j.jclepro.2018.07.147.

Kesselheim, A. S.; Wang, B.; Avorn, J. (2013): Defining "innovativeness" in drug development: a systematic review. In: Clinical pharmacology and therapeutics, 94 (3), pp. 336–348. https://doi.org/10.1038/clpt.2013.115.

Keyßer, L. T.; Lenzen, M. (2021): 1.5 °C degrowth scenarios suggest the need for new mitigation pathways. In: Nature communications, 12 (1), p. 2676. https://doi.org/10.1038/s41467-021-22884-9.

Kleinknecht, A.; Verspagen, B. (1990): Demand and innovation: Schmookler re-examined. In: Research Policy, 19 (4), pp. 387–394. https://doi.org/10.1016/0048-7333(90)90022-X.

Light, D. W.; Lexchin, J. R. (2012): Pharmaceutical research and development: what do we get for all that money? In: BMJ, 345, e4348. https://doi.org/10.1136/bmj.e4348.

Lindner, R.; Edler, J.; Hufnagl, M.; Kimpeler, S.; Kroll, H.; Roth, F.; Wittmann, F.; Yorulmaz, M. (2021): Mission-orientied innovation policy. From ambition to successful implementation. Karlsruhe: Fraunhofer ISI. Available at https://www.isi.fraunhofer.de/content/dam/isi/dokumente/policy-briefs/policy_brief_mission-oriented-innovation-policy.pdf.

Lucas, R. E. (1988): On the mechanics of economic development. In: Journal of Monetary Economics, 22 (1), pp. 3–42. https://doi.org/10.1016/0304-3932(88)90168-7.

Ma, Y.; Hou, G.; Yin, Q.; Xin, B.; Pan, Y. (2018): The sources of green management innovation: Does internal efficiency demand pull or external knowledge supply push? In: Journal of Cleaner Production, 202, pp. 582–590. https://doi.org/10.1016/j.jclepro.2018.08.173.

Maxmen, A. (2016): Busting the billion-dollar myth: how to slash the cost of drug development. In: Nature, 536 (7617), pp. 388–390. https://doi.org/10.1038/536388a.

Mazzucato, M. (2018): Mission-oriented innovation policies: challenges and opportunities. In: Industrial and Corporate Change, 27 (5), pp. 803–815. https://doi.org/10.1093/icc/dty034.

Moreno, S. G.; Epstein, D. (2019): The price of innovation - the role of drug pricing in financing pharmaceutical innovation. A conceptual framework. In: Journal of Market Access & Health Policy, 7 (1), Article No. 1583536. https://doi.org/10.1080/20016689.2019.1583536.

Morgan, S. G.; Bassett, K. L.; Wright, J. M.; Evans, R. G.; Barer, M. L.; Caetano, P. A.; Black, C. D. (2005): "Breakthrough" drugs and growth in expenditure on prescription drugs in Canada. In: BMJ, 331 (7520), pp. 815–816. https://doi.org/10.1136/bmj.38582.703866.AE.

Motola, D.; Ponti, F. de; Poluzzi, E.; Martini, N.; Rossi, P.; Silvani, M. C.; Vaccheri, A.; Montanaro, N. (2006): An update on the first decade of the European centralized procedure: how many innovative drugs? In: British Journal of Clinical Pharmacology, 62 (5), pp. 610–616. https://doi.org/10.1111/j.1365-2125.2006.02700.x.

Munos, B. (2006): Can open-source R&D reinvigorate drug research? In: Nature reviews. Drug discovery, 5 (9), pp. 723–729. https://doi.org/10.1038/nrd2131.

Newman, M. (2018): Drug companies are incentivised to profit not to improve health, says report. In: BMJ, 363, k4351. https://doi.org/10.1136/bmj.k4351.

Nguyen, N. X.; Sheingold, S. H.; Tarazi, W.; Bosworth, A. (2022): Effect of Competition on Generic Drug Prices. In: Applied health economics and health policy, 20 (2), pp. 243–253. https://doi.org/10.1007/s40258-021-00705-w.

Oberhaus, D. (7/26/2018): Meet the Anarchists Making Their Own Medicine. In: VICE, accessed 20.01.2022.

OECD (2011): Towards Green Growth. Paris: OECD Publishing. https://doi.org/10.1787/9789264111318-en.

OECD (2013): Policy Brief on Social Entrepreneurship. Entrepreneurial Activities in Europe. Luxembourg.

OECD (2015): The Innovation Imperative. Contributing to Productivity, Growth and Well-being. Paris: OECD Publishing. https://doi.org/10.1787/9789264239814-en.

OECD/Eurostat (2018): Oslo Manual 2018: Guidelines for Collecting, Reportung and Using Data on Innovation. 4th Edition, The Measurement of Scientific, Technological and Innovation Activities. Luxembourg: OECD Publishing. https://doi.org/10.1787/9789264304604-en.

Offit, P. A. (2005): Why are pharmaceutical companies gradually abandoning vaccines? In: Health Affairs, 24 (3), pp. 622–630. https://doi.org/10.1377/hlthaff.24.3.622.

OSPF (2022): About Open Source Pharma Foundation. Available at https://www.ospfound.org/about.html.

Pansera, M.; Fressoli, M. (2020): Innovation without growth: Frameworks for understanding technological change in a post-growth era. In: Organization, 28 (3), 380-404. https://doi.org/10.1177/1350508420973631.

Paunov, C. (2012): The global crisis and firms' investments in innovation. In: Research Policy, 41 (1), pp. 24–35. https://doi.org/10.1016/j.respol.2011.07.007.

Percy, L.; Elliott, R. (2021): Strategic advertising management. Oxford, United Kingdom: Oxford University Press. ISBN: 9780198835615.

Peters, R. (2018): A New Business Model for Pharma? Frustrated by drug shortages and high costs, hospitals adopt a DIY approach. In: Pharmaceutical Technology, 42 (2), p. 10.

Petschow, U.; aus dem Moore, N.; Hofmann, D.; Pissarskoi, E.; Lange, S. (2022): Cornerstones and positions of a precautionary post-growth economy: The end of the growth-based model of prosperity. In: Lange, B.; Hülz, M.; Schmid, B.; Schulz, C. (Eds.): Post-Growth Geographies. Spatial Relations of Diverse and Alternative Economies. Bielefeld: transcript, pp. 323–346. https://doi.org/10.1515/9783839457337-024.

Petschow, U.; aus dem Moore, N.; Pissarskoi, E.; Korfhage, T.; Lange, S.; Schoofs, A.; Hofmann, D.; with contributions from Hermann Ott (2020): Social Well-Being Within Planetary Boundaries: the Precautionary Post- Growth Approach. Dessau-Roßlau. Available at https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2020_12_14_texte_234-2002_precautionary_post-growth.pdf.

Piva, M.; Vivarelli, M. (2007): Is demand-pulled innovation equally important in different groups of firms? In: Cambridge Journal of Economics, 31 (5), pp. 691–710. https://doi.org/10.1093/cje/bem010.

Plackett, B. (2020): Why big pharma has abandoned antibiotics. In: Nature, 586 (7830), S50-S52. https://doi.org/10.1038/d41586-020-02884-3.

Polak, Y.; Jacobs, B. A. W.; Kemper, E. M. (2021): Pharmacy Compounded Medicines for Patients With Rare Diseases: Lessons Learned From Chenodeoxycholic Acid and Cholic Acid. In: Front. Pharmacol., (12).

Prasad, V.; Mailankody, S. (2017): Research and Development Spending to Bring a Single Cancer Drug to Market and Revenues After Approval. In: JAMA internal medicine, 177 (11), pp. 1569–1575. https://doi.org/10.1001/jamainternmed.2017.3601.

Rajan, K. S. (2017): Pharmocracy. Value, politics & knowledge in global biomedicine. Durham: Duke University Press. ISBN: 9780822373285.

Renwick, M.; Mossialos, E. (2018): What are the economic barriers of antibiotic R&D and how can we overcome them? In: Expert opinion on drug discovery, 13 (10), pp. 889–892. https://doi.org/10.1080/17460441.2018.1515908.

Reuters (2020): BioNTech wins $445 million German grant for COVID-19 vaccine. Available at https://www.reuters.com/article/health-coronavirus-germany-vaccine-idUSKBN2661KP.

Robinson, J. C. (2021): Funding of Pharmaceutical Innovation During and After the COVID-19 Pandemic. In: JAMA, 325 (9), pp. 825–826. https://doi.org/10.1001/jama.2020.25384.

Robra, B.; Pazaitis, A.; Giotitsas, C.; Pansera, M. (2023): From creative destruction to convivial innovation - A post-growth perspective. In: Technovation, 125, p. 102760. https://doi.org/10.1016/j.technovation.2023.102760.

Rodwin, M. A.; Mancini, J.; Duran, S.; Jalbert, A.-C.; Viens, P.; Maraninchi, D.; Gonçalves, A.; Marino, P. (2021): The use of 'added benefit' to determine the price of new anti-cancer drugs in France, 2004-2017. In: European journal of cancer (Oxford, England : 1990), 145, pp. 11–18. https://doi.org/10.1016/j.ejca.2020.11.031.

Romer, P. M. (1990): Endogenous Technological Change. In: Journal of Political Economy, 98 (5, part 2), S71-S102.

Roth, F.; Warnke, P.; Niessen, P.; Edler, J. (2021): Insights into systemic resilience from innovation research. Karlsruhe: Fraunhofer ISI. https://doi.org/10.24406/PUBLICA-FHG-416797.

Sartorius, C.; Dütschke, E.; Hansmeier, H.; Heyen, N. B.; Preuß, S.; Warnke, P.; Zenker, A. (2022): The Role of Innovation in a Postgrowth Society. In: Leal Filho, W.; Azul, A. M.; Doni, F.; Salvia, A. L. (Eds.): Handbook of Sustainability Science in the Future. Cham: Springer International Publishing, pp. 1–17. https://doi.org/10.1007/978-3-030-68074-9_16-1.

Schmelzer, M.; Vetter, A.; Vansintjan, A. (2022): The future is degrowth. A guide to a world beyond capitalism. London: Verso. ISBN: 9781839765841.

Schmookler, J. (1966): Invention and economic growth. Cambridge, Mass.: Harvard Univ. Press. ISBN: 0674464001.

Schot, J.; Steinmueller, W. E. (2018): Three frames for innovation policy: R&D, systems of innovation and transformative change. In: Research Policy, 47 (9), pp. 1554–1567. https://doi.org/10.1016/j.respol.2018.08.011.

Schuchat, A. (2011): Human Vaccines and Their Importance to Public Health. In: Procedia in Vaccinology, 5, pp. 120–126. https://doi.org/10.1016/j.provac.2011.10.008.

Schumpeter, J. A. (1934): The Theory of Economic Development. An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle. Cambridge, Mass.: Harvard University Press. ISBN: 0674879902.

Simpkin, V. L.; Renwick, M. J.; Kelly, R.; Mossialos, E. (2017): Incentivising innovation in antibiotic drug discovery and development: progress, challenges and next steps. In: The Journal of Antibiotics, 70 (12), pp. 1087–1096. https://doi.org/10.1038/ja.2017.124.

Smulders, S.; Toman, M.; Withagen, C. (2014): Growth theory and 'green growth'. In: Oxford Review of Economic Policy, 30 (3), pp. 423–446. https://doi.org/10.1093/oxrep/gru027.

Solow, R. M. (1957): Technical Change and the Aggregate Production Function. In: The Review of Economics and Statistics, 39 (3), pp. 312–320.

Solve M.E. (2022): About Us. Available at https://solvecfs.org/about-us/.

statista (Ed.) (2021): Pharmaceutical market worldwide. Available at https://www.statista.com/topics/1764/global-pharmaceutical-industry/.

Stevens, A. J.; Jensen, J. J.; Wyller, K.; Kilgore, P. C.; Chatterjee, S.; Rohrbaugh, M. L. (2011): The role of public-sector research in the discovery of drugs and vaccines. In: The New England journal of medicine, 364 (6), pp. 535–541. https://doi.org/10.1056/NEJMsa1008268.

Stiglitz, J. E.; Jayadev, A. (2010): Medicine for Tomorrow: Some Alternative Proposals to Promote Socially Beneficial Research and Development in Pharmaceuticals. https://doi.org/10.7916/D87W6NXD.

Stiller, I.; van Witteloostuijn, A.; Cambré, B. (2021): Do current radical innovation measures actually measure radical drug innovation? In: Scientometrics, 126 (2), pp. 1049–1078. https://doi.org/10.1007/s11192-020-03778-x.

Stokel-Walker, C. (2019): DIY drugs: should hospitals make their own medicine? In: The Guardian. Available at https://www.theguardian.com/science/2019/oct/15/diy-drugs-should-hospitals-make-their-own-medicine.

Strand, R.; Saltelli, A.; Giampietro, M.; Rommetveit, K.; Funtowicz, S. (2018): New narratives for innovation. In: Journal of Cleaner Production, 197, pp. 1849–1853. https://doi.org/10.1016/j.jclepro.2016.10.194.

Sun, D.; Gao, W.; Hu, H.; Zhou, S. (2022): Why 90% of clinical drug development fails and how to improve it? In: Acta pharmaceutica Sinica. B, 12 (7), pp. 3049–3062. https://doi.org/10.1016/j.apsb.2022.02.002.

Syrop, J. (2018): Group of US Hospitals to Form Nonprofit Generic Drug Company. Available at https://www.centerforbiosimilars.com/view/group-of-us-hospitals-to-form-nonprofit-generic-drug-company, accessed 20.01.2022.

Takebe, T.; Imai, R.; Ono, S. (2018): The Current Status of Drug Discovery and Development as Originated in United States Academia: The Influence of Industrial and Academic Collaboration on Drug Discovery and Development. In: Clinical and translational science, 11 (6), pp. 597–606. https://doi.org/10.1111/cts.12577.

The World Bank (2021): GDP. Available at https://data.worldbank.org/indicator/NY.GDP.MKTP.CD.

Toma, A.; Crişan, O. (2018): Green pharmacy - a narrative review. In: Clujul medical (1957), 91 (4), pp. 391–398. https://doi.org/10.15386/cjmed-1129.

Toole, A. A. (2012): The impact of public basic research on industrial innovation: Evidence from the pharmaceutical industry. In: Research Policy, 41 (1), pp. 1–12. https://doi.org/10.1016/j.respol.2011.06.004.

van Luijn, J. C. F.; Gribnau, F. W. J.; Leufkens, H. G. M. (2010): Superior efficacy of new medicines? In: European Journal of Clinical Pharmacology, 66 (5), pp. 445–448. https://doi.org/10.1007/s00228-010-0808-3.

Vetter, A. (2018): The Matrix of Convivial Technology – Assessing technologies for degrowth. In: Journal of Cleaner Production, 197, pp. 1778–1786. https://doi.org/10.1016/j.jclepro.2017.02.195.

Victor, P. A. (2012): Growth, degrowth and climate change: A scenario analysis. In: Ecological Economics, 84, pp. 206–212.

Vokinger, K. N.; Hwang, T. J.; Daniore, P.; Lee, C. C.; Tibau, A.; Grischott, T.; Rosemann, T. J.; Kesselheim, A. S. (2021): Analysis of Launch and Postapproval Cancer Drug Pricing, Clinical Benefit, and Policy Implications in the US and Europe. In: JAMA oncology, 7 (9), e212026. https://doi.org/10.1001/jamaoncol.2021.2026.

Warnke, P.; Koschatzky, K.; Dönitz, E.; Zenker, A.; Stahlecker, T.; Som, O.; Cuhls, K.; Güth, S. (2016): Opening up the innovation system framework towards new actors and institutions. In: Fraunhofer ISI Discussion Papers "Innovation Systems and Policy Analysis", no. 49.

Wieseler, B.; McGauran, N.; Kaiser, T. (2019): New drugs: where did we go wrong and what can we do better? In: BMJ, 366, l4340. https://doi.org/10.1136/bmj.l4340.

Wittmann, F.; Hufnagl, M.; Lindner, R.; Roth, F.; Edler, J. (2021): Governing varieties of mission-oriented innovation policies: A new typology. In: Science and Public Policy, 48 (5), pp. 727–738. https://doi.org/10.1093/scipol/scab044.

Wittmann, F.; Lindner, R.; Hufnagl, M.; Roth, F. (2022): Mission-oriented innovation policy for transformative change. A toolbox for implementation and impact assessment. Karlsruhe: Fraunhofer ISI. https://doi.org/10.24406/PUBLICA-587.

World Bank (2012): Inclusive Green Growth: The Pathway to Sustainable Development. Washington, DC. Available at https://openknowledge.worldbank.org/handle/10986/6058.

Wu, Q.; He, Q. (2020): DIY Laboratories and business innovation ecosystems: The case of pharmaceutical industry. In: Technological Forecasting and Social Change, 161, p. 120336. https://doi.org/10.1016/j.techfore.2020.120336.

Xue, Q. C.; Ouellette, L. L. (2020): Innovation policy and the market for vaccines. In: Journal of law and the biosciences, 7 (1), lsaa026. https://doi.org/10.1093/jlb/lsaa026.