The Contribution of Basic Research Projects Funded by the Austrian Science Fund to Economic and Societal Impacts

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The Austrian Science Fund (FWF) is the main funder of basic research projects in Austria, selecting projects purely based on their scientific quality, rather than any impacts outside academia. Nevertheless, usually such impacts arise from basic research over time, even if unintended. This study combines various methodological approaches to illustrate the wide range of economic and societal impacts FWF-funded research projects contribute to. A survey among principal investigators combined with FWF's own database, bibliometric analysis of publications and patents, case studies as well as economic modelling and estimations lead to a detailed picture of the type and quantity of impacts outside academia.

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Kurzfassung – Der Beitrag des FWF zu Wirtschaft und Gesellschaft

Der Fonds zur Förderung der wissenschaftlichen Forschung (FWF) finanziert Grundlagenforschung allein auf Basis der wissenschaftlichen Qualität, potenzielle Anwendungen außerhalb der Wissenschaft zählen nicht zur Entscheidungsgrundlage. Trotzdem tragen FWF-finanzierte Forscher:innen sowohl beabsichtigt als auch unbeabsichtigt signifikant zu wirtschaftlichen und gesellschaftlichen Effekten bei. Diese reichen von direkten Anwendungen durch die Forscher:innen selbst bis hin zur Nutzung der Forschungsergebnisse durch Dritte. Sie entstehen überraschend teils schon kurzfristig und nicht erst nach vielen Jahren.

Ökonomische Effekte folgen aus der Nachfrage, die z.B. mit Gehältern für PhDs und Postdocs, Umsätzen von Start-ups oder neuer Produkte in etablierten Unternehmen einhergehen: Konservativ geschätzt finanzieren sich die FWF-Mittel von 236 Mio. Euro im Jahr 2022 schon innerhalb eines Jahres über Steuer- und Sozialversicherungseinnahmen selbst. 1€ FWF-Förderung ist mit 1,1 € an Staatseinnahmen und 2 € BIP verbunden. Diese Effekte sind nicht kausal, aber unterschätzt und nur eine Seite der Medaille:

Zu den Nachfrage- kommen längerfristige Produktivitätseffekte hinzu. Vorsichtig zu interpretierende ökonometrische Schätzungen nach unterschiedlichen Ansätzen ergeben eine Produktivitätssteigerung von 2-3% des *BIP pro Arbeitsstunde* oder von 0,2-0,6% des *BIP pro Kopf* als Folge einer 10%-igen Erhöhung der FWF- oder FWF-ähnlichen Förderung innerhalb von mehreren Jahren. Produktivitätseffekte werden jedenfalls durch die zahlreichen dokumentierten Beispiele aus FWF-geförderten Projekten zwischen 2009 und 2022 gestützt:

Dazu zählen 40 Lizenzen, 171 Erfindungen, die häufiger zitiert werden als der Durchschnitt österreichischer Firmenpatente, was auf technologisch bedeutendere Innovationen hinweist; 150 Technologien, 200 Produkte sowie 60 Start-ups. FWF-geförderte Forschung hat zu mehr als der Hälfte (11) der 20 Phönix-Gründungspreisträger der Jahre 2019-2023 beigetragen. 85% der aktiven Start-ups haben ihr Headquarter in Österreich: die wirtschaftliche Umsetzung von Spitzengrundlagenforschung erfordert oft die persönliche Beteiligung der Forscher:innen. Ca. 1.600 früher FWF-finanzierte Forscher:innen arbeiten in Unternehmen.

Zu den gesellschaftlichen Effekten zählen Beiträge zu Gesundheit (25% der befragten Projektleiter:innen, z.B. neue Behandlungsmethoden), Umweltschutz (18%, z.B. Reduktion von Treibhausgasen), Gesetzesänderungen (9%) und Sicherheit (6%, z.B. Schutz vor Cyberangriffen). Fallstudien beleuchten die Nobelpreis-prämierten Genschere und Quantenforschung, den Archäologie-Tourismuspark Elea-Velia und das Biotech-Start-up Proxygen.

FWF-finanzierte Projekte tragen insgesamt in erstaunlich hohem Ausmaß zu wirtschaftlichen und gesellschaftlichen Effekten bei, gegeben dass diese gar nicht Förderziel sind. Sie könnten durch bessere Rahmenbedingungen für Innovation in Österreich noch stärker ausfallen, z.B. durch mehr Risikokapital, um das Wachstum von Start-ups zu tragen. FWF-Ausschüttungen könnten deshalb eine wichtige Rolle für Strukturwandel spielen und eignen sich wegen der Kombination aus kurz- und längerfristigen Effekten auch für ein Konjunkturprogramm.

Executive Summary

- The Austrian Science Fund FWF funds **basic research projects** which do not need to aim at any potential applications or uses outside academia to be funded: Peer review of project proposals is limited to **scientific quality**, potential economic or societal impacts outside academia do not count towards funding decisions.
- Well in line with international findings however, FWF-funded projects **contribute significantly to** plenty of such impacts outside academia, whether intended or unintended by the principal investigators leading the projects: they may result from direct follow-on efforts of the investigators themselves to develop uses outside academia, or from others using FWF-funded research results for applications. **Impacts arise not just in a distant future, but even in the short-term**, from the knowledge and the skills gained by researchers, but also from spending effects linked to the wages of researchers or turnover of start-ups.
- To reach this conclusion, we relied on a **comprehensive methodological approach** and a **variety of data sources** which complement each other. We describe both observable applications and uses outside academia, which can be traced directly to FWF's funding ("stories") and use economic modelling and econometric estimations to provide a quantitative dimension ("numbers"). We run our own survey among principal investigators, analyse patent and bibliometric data, conduct case studies and use a variety of databases such as on start-ups.
- We start with the financial return for the taxpayer. Surprisingly, in the most conservative lower-bound estimates, **FWF achieves self-financing even in the short-term**, **based on** demand-side or **spending effects**. This means that all of the € 236 million that the FWF disbursed in Austria in 2022 arrived back in the public finance coffers within roughly a year. As a lower bound, 1€ of FWF funding relates to 1,11 € of tax revenues and social security contributions and 2€ of GDP. This is due to the high wage content of FWF spending in Austria on PhD and post-doc salaries, to revenues achieved or taxes paid by start-ups or their staff, income associated with new or improved products or production processes in established firms as well as researchers trained in FWF-funded research projects that now work in industry. All of this is based on effects in Austria, we do not use FWF-impacts abroad for the modelling. The effects are not causal, but are modelled conservatively.
- **Supply-side, or productivity effects come on top of these short-term effects**, but are much harder to identify given the available data, FWF's small budget relative to the size of the economy and Austria being a small open economy with large international spillovers. A structural time-series model using **Austrian data only** indicates that **an increase of FWF funding by 10% is associated with an increase of *GDP per hour worked* (productivity) of 2-3%** over a period of roughly five years on top of the spending effects outlined, petering out after about 10 years. **International panel data** indicate that **10% more "FWF-type" funding per capita is associated with an increase of 0.2-0.6% of *GDP per capita***. The estimates of the supply-side effects have to be interpreted cautiously though, they need better data. That such longer-term structural supply-side effects certainly do exist however is well documented by the results of our analysis:

- 8% (24%) of project leaders who responded to our well-balanced survey with a response rate of 35% indicated a (very) high economic (societal) impact; **about 33% (58%) indicated a current or potential economic(societal) impact from their FWF-funded research**.
- Combining our survey results with FWF's database based on final project reports, as well as with further statistical analysis e.g. of patent databases, we count the following economic impacts to which projects that ended between 2009 and 2022 contributed to: 1.600 **researchers** now working in industry; 40 **licences** for others to use research results by FWF-funded projects; 171 **patented inventions** leading to a total of 861 patents when considering patent applications in several patent offices; close to 150 **new or improved** production processes or **technologies** in established firms; about **200 new or improved products** (from the survey only; FWF data points to 288 technical products, mostly in software) and approx. 60 **start-ups** of which 39 are registered as active in the Dealroom database (34 with location in Austria). For two of these categories, patents and start-ups, we can asses not just quantity, but also quality:
- **Patents** declared as based on FWF-funded research **achieve more citations** on average as the average of Austrian company patents, driven by a higher share of patents that achieve more than 6 citations, rather than a single outlier. This in line with the international empirical literature that shows that **patents based on high quality basic research are** – not surprisingly – **technologically broader and usually protect inventions which are potentially more far-reaching**, relevant for a broader set of follow-on inventions than the average company patent.
- Moreover, about 14% of FWF-funded journal publications published between 2003 and 2021 which can be found in the Lens database were cited by at least one patent, compared with 8% of ERC-funded papers in the timespan 2007-2016, although the share of various scientific disciplines should be taken into account. In total, **they receive almost 10.000 patent citations**, i.e indicating potential use of the research results for an invention. FWF-funded research is also cited more often by interdisciplinary patents compared to scholarly work from Austrian institutions on average.
- Regarding start-ups, 11 of the 20 prize winners of the Austrian start-up prize Phoenix 2019-2023 across its four categories draw on knowledge gained in FWF-funded research projects (4 won the spin-off prize, 4 the prototype prize, two the start up prize and another one the female entrepreneur prize**). Start-ups are also geographically much more localised in Austria than other impacts** - about 85% are headquartered in Austria, whereas about 50% of new products or processes are in Austria. This is in line with the literature that observes that **start-ups based on frontier research often need the direct involvement of the researchers to be able to commercialise research results**, so that start-up location is often close to the original academic research location.
- On average, it took about **five years** from the beginning of the research to the application, a bit shorter than in international surveys (6-7 years), possibly linked to FWF's high funding share of life sciences, where basic research is closest to applications.
- Among **societal impacts**, we rely more heavily on the survey. 46% of researchers indicated a current or potential future contribution to **media beyond specialist audiences**

(e.g., general public print media), 25% to **cultural heritage** (e.g. globally free access to digital conservation projects), 25% to **health improvements** (e.g. new drugs and therapeutic methods), 18% to **environmental improvements** (e.g. improved biodiversity, reduced CO2 emissions from cleaner production technology), 9% a **change to a regulation** (e.g. new norms and standards) and 6% improved **security** of the population (e.g. improved protection against cyberattacks).

- The case studies can identify the precise impact pathway of FWF-funding from the research activities to the final applications and uses. They include the pathway from research to the **archaeological tourism park Elea-Velia** and research tools, the **Austrian quantum ecosystem** with several start-ups (2 of which won a Phoenix prize), the Nobel-prize winning **Gene scissors** (with two papers to which FWF contributed funding that are the most patent-cited among all FWF publications) and the **biotech start-up Proxygen**.
- Maybe most relevant are the **number and quality of start-ups which draw on the knowledge gained in FWF-funded research projects**, in line with the international empirical literature that has long been pointing to **start-ups as an important way of commercialising frontier research results**. Austrian innovation performance has been characterised by successful modernising and technological upgrading of established firms and industries, but by a less dynamic start-up-driven structural change towards more knowledge-intensive activities. **If the wider framework conditions for the growth of start-ups can be improved in Austria**, in particular the availability of private growth venture capital, **FWF funding could become a driver of structural change**, of home-grown knowledge-intensive large firms. This would also improve even further the economic return to FWF or other public research funding: to fully reap benefits of any public research investment, **the wider framework conditions for producing and doing business in Austria have to be favourable**.
- There are **limitations** to our study: in many cases, FWF-funded research was not the only contributor to an economic or societal impact. As an example, starting up a firm needs more than a knowledge base or trained PhD-researchers, such as equipment or non-research staff. Private venture capital or other national public funding sources such as FFG or AWS, or international ones such as the ERC, are sometimes involved.
- At the same time our results are clearly **underestimated**, as our data are incomplete. E.g., even though the survey worked well, an even higher response rate than 35% would have led to further accounts of impacts. Of those who did answer, 40-50% did not know about the financial revenues attached to the economic impacts. The analysis of patent citations suffers from incomplete acknowledgement of FWF funding in journal publications - 36% of the FWFs 100 top-cited journal publications are not linked with the FWF in the Lens database. Moreover, **researchers trained are currently not properly tracked, even though they may the biggest and most sustainable gain for the Austrian economy and society**. We only use a rough estimate from the survey. Our results hence certainly underestimate the economic and societal impacts from FWF funding, including our numbers on the financial return to FWF funding, even if accounting for the contribution of other funding sources to the impacts.

1. Introduction: overall study design

This report aims at analysing the economic and societal impacts, intended or unintended, of basic research projects funded by the Austrian Science Fund FWF. While basic research is usually undertaken without any application or use in view, it is well known that it leads – often by chance – to many applications and uses, even many years after the actual research has taken place. As an example, many studies have empirically shown a positive impact of academic science or basic research on output indicators of innovative activity such as patents or on economic outcomes such as total factor productivity growth (Adams, 1990; Ahmadpoor & Jones, 2017; Fleming et al., 2019; Jaffe, 1989; Mansfield, 1980, 1991, 1995). Others survey the various ways in which basic research and its ensuing expanded stock of knowledge become economically useful to explain this puzzle (Lane, 2009; Pavitt, 1991; Salter & Martin, 2001), leading scientists to be convinced of the crucial economic importance of basic research (e.g., Dudley, 2013, p. 33: "History clearly shows how fundamental science drives revolutions in technology").

But tracing the economic impact of basic research (or fundamental knowledge) is not straightforward. There are few econometric studies dedicated to the economic impact of basic research, or even more specifically to grant-funded basic research, by contrast with firm-level R&D or all publicly funded R&D. Many studies are done for the US, a large country at the technological frontier with a large academic sector and a large share of high-tech industries, which reduces some of the methodological issues and increases the real effect of basic research: while the fundamental problem of a long time-lag between the research and its application remains, international spillovers are lower. Economic impact will not just depend on the quality of the research, but also on the framework conditions for commercialising knowledge, such as the availability of venture capital (Lane, 2009), an area where Austria notoriously underachieves (Janger & Slickers, 2023). Research-intensive sectors use basic research more intensively (Adams, 1990; Ahmadpoor & Jones, 2017; Czarnitzki & Thorwarth, 2012), and Austria is historically characterised by low shares of research-intensive sectors (Janger et al., 2011; Janger, Schubert, et al., 2017; Leitner et al., 2015). These difficulties make narrative impact approaches as in the UK Research Excellence Framework important (Khazragui & Hudson, 2015).

As a consequence, this study adopts a broad framework to capture economic and societal impacts (Figure 1). We differentiate between two central ways to show the economic (and societal) impact of FWF-funded research: in the first way, the transmission channel between FWF funding and (potential) application is observable. Both statistical indicators of knowledge use and case-based narrative approaches can be employed ("stories"). In the second way, there is an unobservable relationship ("black box") between FWF-funded research results and economic outcomes, but econometric estimation and modelling lead to "numbers", monetarised economic impact. The first has the advantage of being easily understandable, allowing for the communication of concrete impacts. It does not allow though for the calculation of overall economic benefits in terms of value added or employment, a rate of return or elasticity with respect to FWF funding, which is possible in the second way. The two approaches complement each other, the first one lending credibility to the second approach through concrete examples of the actual use of FWF-funded results and results from the first approach feeding into the second one.

Within the first approach ("stories" – observed use of FWF-funded results/researchers in economic or societal applications), we analyse the quantity & quality of the following impacts:

- Direct use of FWF-funded research results in patents by FWF-funded researchers, including relevance for grand challenges (section 5.1)
- Use of FWF results in patents by non-FWF-funded researchers (overall contribution of FWF results to growth of technological knowledge); (section 5.2)
- Contribution of FWF-funding to a skilled research workforce; (section 6)
- Case studies on high-quality examples from the preceding work packages, including start-ups, drugs, research tools&methods…; (section 7)

Within the second approach ("numbers" – overall economic impact), we analyse in section 8:

- Short-term impact through spending flows (PhD wages, material purchases) and any economic impact of firms, drugs, etc. analysed in the first approach
- Medium-term impact of FWF-funded PhD qualifications on productivity
- Longer-term impact of FWF funding on productivity growth, GDP and employment

We capture the components of a production function/innovation chain, where FWF-funded research is the input, outputs such as research publications and outcomes such as patents are countable/observable, while wider economic impacts on overall productivity must be estimated/modelled.

In this study, when we refer to "impact", it is understood to mean both economic and societal impact (i.e. not just social impact, but impact on society in the broadest sense), **applications or uses outside of academia**. To be more precise, we use the following definition throughout, building on the UK's research excellence framework definition[1]:

Research impacts are direct or indirect, intended or unintended applications or uses of fundamental research outside of academia. This also includes the training of researchers who have left academia.

- Economic impact: an "effect on, change or benefit to the economy"
- Societal impact: an "effect on, change or benefit to society, art&culture, public policy or services, health, the environment or quality of life beyond academia"

Scientific impacts, such as citations to academic journals, are not applications outside academia. Public, policy-oriented presentations of academic papers are not an impact, if they don't lead to an effect on, change or benefit to society. FWF-funded research does not need to be the only source of impact for us to count it as impact. In practice, as can be observed from publications and patents (section 5), academic papers often acknowledge

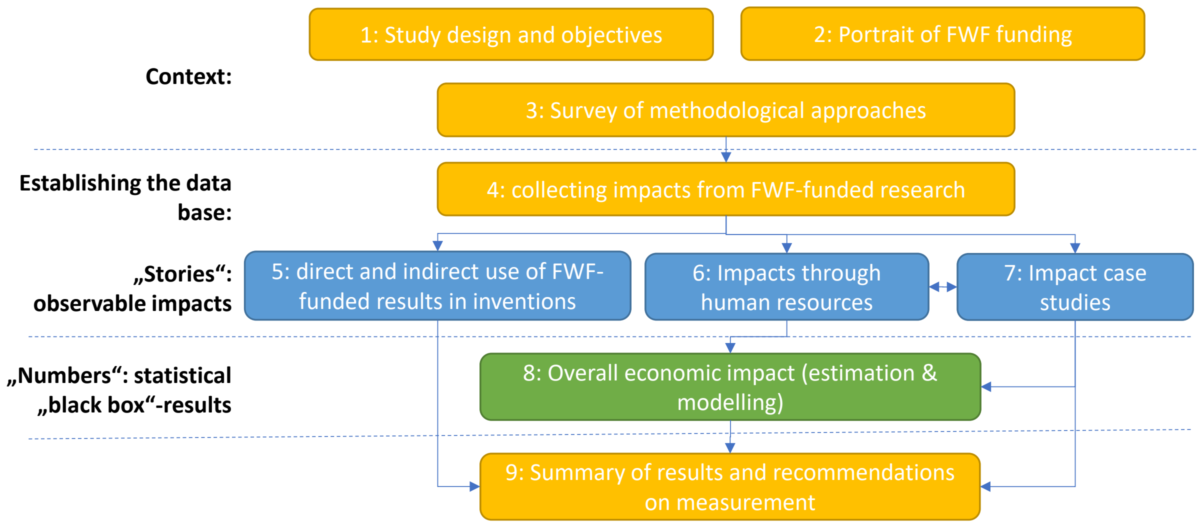
[1] https://www.ukri.org/who-we-are/research-england/research-excellence/ref-impact/

several funders as they can result from a variety of research projects. When we ask about FWF's funding role in how these impacts came about, we hence use the term "contribution".

Our results are likely to **underestimate** the true impact of FWF funding in Austria, because impacts will arise in the future and somewhere else. Also note that we take the scientific quality of FWF-funded research projects as given – we do not evaluate FWF's selection processes.

The study will proceed as depicted in **Figure 1**:

Figure 1: **Study design & structure**

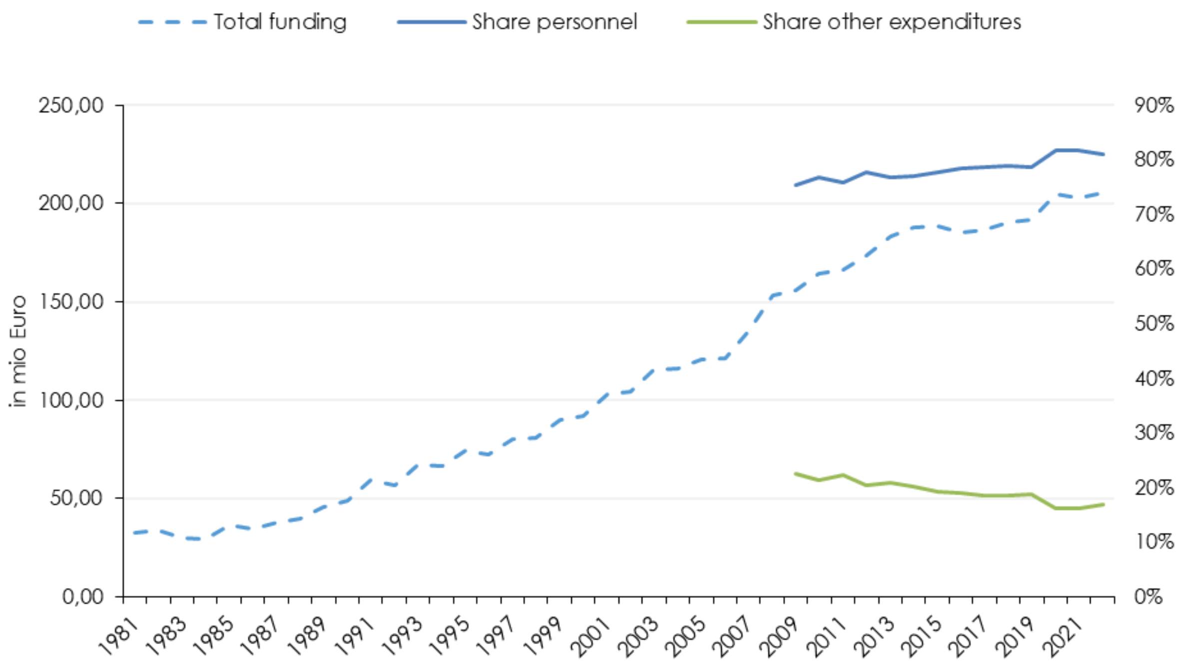


Source: Authors.

2. A short portrait of FWF funding

The Austrian Science Fund (FWF) is Austria's main project-based funding organisation for basic research. In 2022, it disbursed about 205 mio € in total funding for research grants (Figure 2), adjusted for inflation. While funding has increased over time, grant-funding of basic research by the FWF is low by comparison with peer countries such as Germany, Switzerland, the Netherlands, the UK or the US (Janger et al., 2019); in the web-based RTI-monitor of the Austrian Council for Research, Science, Innovation and Technology, FWF funding is only close to 60% of the average level of USD in PPP per capita of a number of peer countries.[2] The main share is for personnel costs, e.g. PhD-students or post-docs working in the projects. Other costs include, e.g., costs for data or lab equipment.

Figure 2**: FWF funding in real €, 1981-2022 (left axis), shares of cost categories (right axis)**



Source: FWF. Calculations by WIFO. Data deflated, 2015=100.

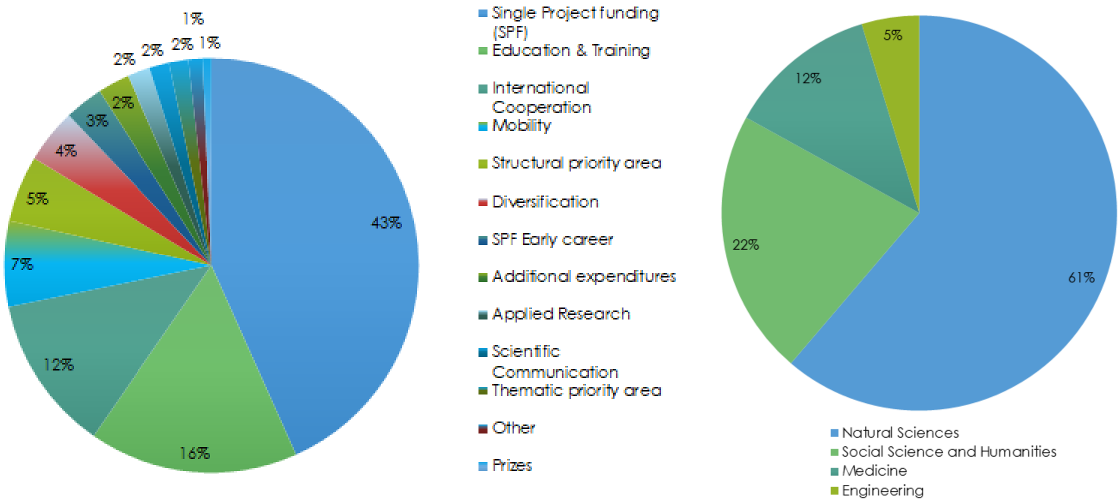
FWF funds a variety of funding schemes, but its overall focus is on funding bottom-up, curiosity-driven (pure) basic research projects (Janger et al., 2019). Single-investigator project funding is most important at about 43% in 2017, followed by various researcher-oriented funding schemes such as doctoral programmes (11%) or mobility schemes (7%). International cooperation is also important (11%). Its share of funding for translating basic research into applications of about 2% in 2017 is lower than in many other research grant-funding agencies such as the Dutch NWO, the British UKRI or the NIH in the US. The FWF mainly funds natural sciences (including

[2] https://fti-monitor.forwit.at/B/B.5

biology), while engineering – which is usually closer to use-inspired basic research than other disciplines – achieves only a low share in total funding, of about 5% in 2017. Section 4 includes more detail on the projects analysed in this study (share of 4% for engineering).

FWF selects projects based on international peer review. Success rates for single project funding are in the range of 25%, higher than at the ERC but lower than at e.g. the Swiss equivalent SNSF. FWF selects projects purely on the basis of their scientific merit, not with a view to any potential economic or societal impact, by contrast with e.g. UK or Dutch funding organisations (Janger et al., 2019). Reviewers only assess the scientific quality, feasibility and qualifications of the applicant team.

Figure 3: **Share of FWF funding schemes in total (left panel) and share of disciplines in single Project funding (right panel), 2017**



Source: Janger et al., 2019. The data are from 2017, so that current numbers will be slightly different.

For the purpose of this study, we don't differentiate between individual funding schemes of the FWF. As an example, in the survey (section 4), while respondents see the projects that they led, we don't differentiate our questions according to the funding scheme. In the analysis of FWF-publications cited by patents (section 5), we also take all FWF-publications and examine their citations without distinction by programme. We look at economic and societal impacts of FWF-funding as a whole.

3. Tracing the impact of grant-funded basic research – a survey of methodological approaches

This section first establishes a conceptual understanding of how FWF-funded research may become relevant for, or may contribute to economic or societal impacts, guiding our work in the following sections. It then briefly surveys the literature with respect to methodological approaches for analysing the economic impact of basic research and to its results.

Figure 4 illustrates the various ways FWF-funded research may contribute to economic or societal impacts. We argue that there are **two main outputs** of FWF-funded research projects, **additions to the stock of knowledge and trained researchers**, based on the literature on benefits of publicly funded basic research (Lane, 2009; Pavitt, 1991; Salter & Martin, 2001): key to benefits is not just the knowledge gained itself, but the learning capabilities developed throughout the funded research activities. There are **three main pathways** for them to contribute to applications or uses outside academia:

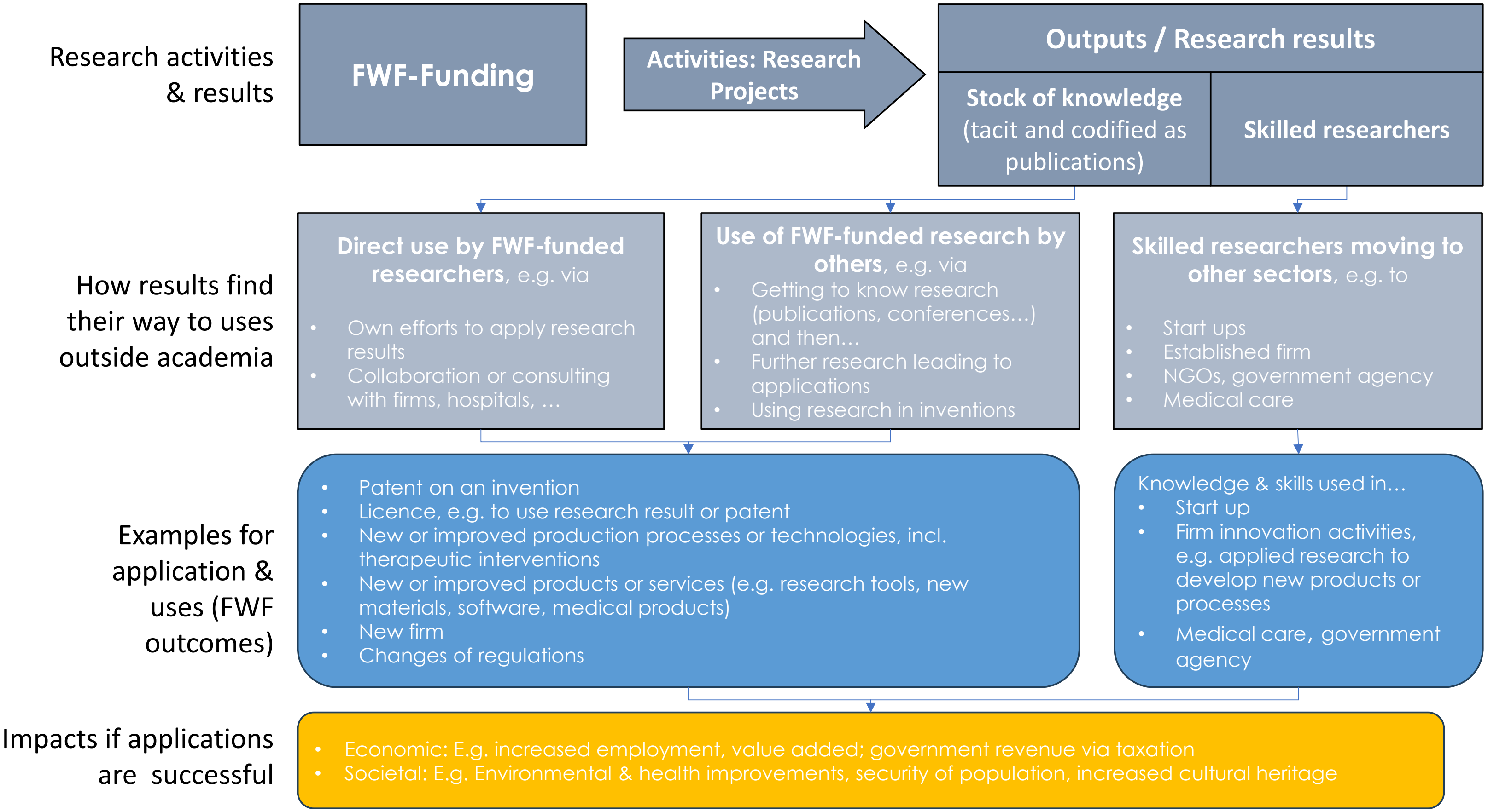
Increases of the knowledge base can be **tacit**, i.e. remain with the **FWF-funded researchers**. In this case, only they could potentially develop this knowledge further into applications or uses such as a start-up firm, unless they enter into research collaborations or consulting relationships with others interested into translating knowledge into applications. If the **knowledge gain is published** in a journal, or presented at conferences etc**., a wider circle of potential users has access** to the knowledge gained. FWF-publications can for e.g. be cited in patents, or in publications which build on them and that are in turn used for applications. Examples for applications and uses outside academia from the knowledge gained in FWF-funded projects include patents, new or improved production processes or technologies as well as new or improved products used or sold by established firms and new firms.

Skilled researchers, as an example researchers who acquired research skills such as handling advanced instruments during their participation in an FWF-funded project, may leave academic research and **move to another sector** where their skills are useful. They could move to firms' innovation departments, governmental agencies or the health care sector, potentially after some further training or qualifications. There, they contribute to innovations, or solving complex problems requiring research skills.

The importance of the three pathways is likely to differ by **industrial characteristics**. In science-based industries drawing heavily on codified knowledge such as pharmaceuticals, links between academic output and firm-level innovation may be quite direct, as evidenced by citations of patents to academic papers. In industries innovating rather by accumulating tacit knowledge, flows of embodied knowledge via trained researchers may be more important (Salter & Martin, 2001). Geographic proximity is also likely to play a role.

If successful, applications and uses outside academia via all three channels may lead to economic and societal impacts. Economic impacts include, e.g., additional employment or economic value added. Both lead to increased taxation revenue for the government, which may end up with a gain on the resources it invested into FWF's funding over time. Societal impacts include health and environmental improvements, from new medicines or new technologies, but may also improve security and expand cultural heritage, as examples.

Figure 4: **Impact pathways from FWF-funding to final economic and societal impacts**



Source: Authors. Note that FWF-funding may just be one among several funding sources for the research results used in applications or impacts outside academia.

This conceptual understanding underpins our data collection (section 4) and our choice of methodologies to link FWF-funded research to impacts (sections 5-8), illustrated in Figure 5.

There are several **data collection options** for each of the three pathways outlined. The easiest is probably translation of knowledge by the FWF-funded researchers themselves. As part of the funding, they have to indicate at the end of the project any applications or uses outside academica, feeding an FWF-database on research outcomes/impacts. Applications arising at a later stage may be captured by surveys or interviews, or by analysis of patent citations to their publications. Translation by others can also be captured in this way, while surveys are likely to face low response rates. The most difficult are trained researchers. If there are no unique identifiers such as social security numbers asked of them during the FWF-funded project, alternatives in the form of webscraping career platforms or surveys are all imperfect substitutes.

The diversity of **methodological approaches** to link grant-funded basic research to economic and societal impact reflects the available data (for an overview, see Greenhalgh et al., 2016). Approaches have their advantages and drawbacks (section 1), with some better at showing in detail precisely how FWF-funded research contributes to a concrete impact outside academia, while others cut out the pathways but put a number on the returns to funding.

- **Narrative approaches**

Case studies of the impact of specific projects allow for a precise attribution of outcomes and impacts to the grant and the research activities it funded, if it is possible to interview the researchers involved, as well as the people that used the research for impacts outside academia (if different). These people are best placed to assess the pathway between the research activity and the relevance of the results for applications and uses. In an intervention logic or theory of change, the progress from inputs to outputs and further on to outcomes and impacts can be traced precisely. This explains the use of narrative approaches in the Research Excellence Framework to assess the impact of the research funded (Khazragui & Hudson, 2015), although it is important to stress that this exercise refers to the assessment of the UK's base funding. Well-known other examples of a retrospective case-oriented approach are Project Hindsight, which was conducted by the US Office of the Director of Defense Research and Engineering in the 1960s (Sherwin & Isenson, 1967), or the subsequent study *Technology in Retrospect and Critical Events in Science* (TRACES) (Franck, 1969).

Because interviews take a lot of time, and research funding agencies fund thousands of projects, narrative approaches are limited in illustrating impacts of a multitude of projects (and providing numbers for calculating overall rates of return to funding). They may also not find instances where research is used by others without the researchers knowing about it, e.g. by others reading their publications or building on their research. To find such instances, patent-to-paper citations can be used.

- **Surveys**

Surveys allow for a larger number of impacts to be studied than case studies, but have to manage acceptable response rates, which are often lower when surveying firms. While in principle they can be trusted to adequately capture the relevance of the contribution of basic research to innovation outputs, they have to take survey responses at face value as it is difficult and time-consuming to approach respondents for more details. More complex informations important for tracing the impact of public grant-funding of basic research, such as asking about concrete names of publications or patent numbers, may not be given in such surveys.

In the literature, rather than academic researchers, mostly firms have been surveyed so far that use academic research for their innovative activity, e.g. in the US and in Germany (Beise & Stahl, 1999; Mansfield, 1991, 1998), or in several EU countries (Pace survey, Arundel et al., 1995). The Community Innovation Survey has questions on cooperations with universities or research institutions, but does not differentiate by funding source. Drucker & Goldstein (2007) assess several approaches for the impact of regional universities, among them surveys.

If the information provided is detailed enough, rates of return can be calculated, as in Mansfield (28% for the US). In both the US and Germany, the papers cited find that 5% of firm sales would not have been possible without academic research input. Surveys also allow for questions on the time lag between academic research and impacts outside academia (6-7 years, according to Mansfield, 1991, 1998). We also point out that both Mansfield and Beise & Stahl do not ask specifically about the use of basic research in firms, but about the use of "academic" (Mansfield) and "publicly-funded research at universities and research institutions" (Beise & Stahl). Even at universities, there is a lot of applied research judging by the R&D surveys. E.g., in Austria, 50% of the research performed at universities is classified by university researchers as applied or experimental development in their response to the biennial R&D survey administered by Statistics Austria.

- **Bibliometric analysis of patent-to-paper citations**

Patent documents include references to other patents and to published papers which are relevant for them. Databases such as PATSTAT or The Lens collect this information, enabling large-scale analysis of citations of patents to FWF-funded papers (in The Lens, funding acknowledgements are already included, while in PATSTAT, matching with bibliometric databases such as Scopus or Web of Science would have to be added). Patent-to-paper citations allow for analysing both applications by the funded researcher themselves as well as by others. In addition, the quality of patents can be assessed using various quality metrics (section 5.1.).

One drawback is that it is not known which role exactly the published paper played for the invention. Because it may have been claimed by the patent examiners, the inventor may not even have known about the paper (section 5.2). A second drawback is that only patents can be traced in this way to publications, potentially missing many other applications and uses outside academia. Patent-to-paper analysis can hence be seen as very complementary to narrative approaches for tracing the impact of grant-funded basic research. A recent example for this approach is Munari et al. (2024); in the 2022 report version, they provide a survey and a detailed explanation of how the methodology works (Munari et al., 2022). See also Marx & Fuegi (2020) for a recent survey. The literature started much earlier, but mostly by identifying the citations in all patents to academic papers in general, not to academic papers funded by a specific source (e.g. Narin et al., 1997).

- **Cost benefit analysis**

Cost-benefit-analysis could be understood as determining whether one of the case studies mentioned above achieves a positive benefit to society, i.e. whether it generates larger benefits over time than costs. Cost-benefit-analysis assesses specific projects, using valuation techniques – often with the help of assumptions – to arrive at clear net present values, or corresponding social rates of return. Historically, it has been conceived as a tool to work against lobbying interests for infrastructure projects (Florio & Sirtori, 2016). It would be difficult to use this tool for evaluating the net present value of the entire FWF funding, as the benefits of each specific research project would have to be investigated and summed up. It could be useful to look at specific parts of FWF Funding, such as the funding for quantum physics (see case study in section 7), this is however out of the scope of this project. Internationally, it has been done e.g. for the benefits of medical research in the UK, as funded by the Medical Research Council (Health Economics Research Group et al., 2008). Medical research lends itself to such exercises, as outcomes such as improvements in the number of quality adjusted life years (QALY) can be readily measured. It is also frequently used to assess the benefits of public basic research infrastructures such as CERN (Florio et al., 2016; Florio & Sirtori, 2016), where one method to estimate the benefit of CERN is simply to assume that the time researchers spend in research is beneficial for society.

- **Econometric approaches**

Econometric estimations usually look at the elasticity of productivity with respect to R&D expenditures, treating the precise nature of translation as a black box ("these models do not explain the link between publicly funded basic research and economic performance in a direct way; they simply look at inputs (such as papers) and outputs (firm sales) without analysing the process linking them." Salter & Martin, 2001, p. 514).

Most papers look at private R&D (Azoulay et al., 2019; Hall et al., 2010); public R&D, and even less publicly grant-funded basic research, is much less investigated. Studies that do such as (Adams, 1990; Azoulay et al., 2019; Jaffe, 1989) look at US-data, a large, relatively closed country where international spillovers are less of an issue than in, e.g., small open European countries. The recent paper by Azoulay et al (2019) looks at the effect of NIH-funded research on innovation, benefitting from the closeness between science and commercialisation in this field (see also Toole, 2011), and from the large number of observations in targeted disease areas – the NIH operate via disease-specific institutes and often fund not pure basic, but applied research. Azoulay et al. 2019 can't calculate a formal rate of return for the NIH, but using a back-of-the-envelope approach, they propose that one dollar of NIH funding is associated with drug sales of 2.34 US-dollars.

Country-level international studies such as Guellec & Van Pottelsberghe de la Potterie (2004) usually look at R&D performed in publicly funded organisations, rather than publicly-funded basic research: some large OECD countries such as Germany do not even collect R&D data by type of expenditures (Basic-applied-experimental). And where such data are collected, there is usually no linkage between type of R&D performed and source of R&D funding, so that it is not known who funds the basic research performed (e.g., in Austria, the government via the block grant, FWF via project funding, or other funding sources, such as the ERC, the WWTF, etc.). In those countries that do collect data on R&D expenditure by type, only total basic research performed in public research institutions (universities and others) is hence available which confounds project grant-funded with block grant-funded basic research.

Guellec and Van Pottelsberghe de la Potterie (2004) estimate that one percent of additional research performed in publicly funded research organisations (laboratories, universities,…) leads to a higher multifactor productivity of 0.17 percent. Hall's et al. (2010) survey of mostly returns to private R&D investments leads to returns of 10-30 percent (i.e., each dollar invested yields a return between 10-30%, much higher than e.g. typical bond or stock market yields).

- **Economic modelling approaches**

There are two broad classes of models used to show economy-wide impacts of specific "shocks" or events of interest, such as e.g., an increase in public spending on basic research. First, there are demand-side models which feed the actual R&D spending into a model of the economy based on input-output lnkages, leading to direct, indirect and induced effects of the R&D spending on the wider economy. The effects are short-term effects based on spending multipliers, i.e. arising from researchers spending the additional income received on e.g. restaurants and consumer goods, or from firms investing more. They are rarely used to estimate the impact of grant-funded basic research, with an exception being e.g., the impact assessment of the US-American ARRA American Recovery and Reinvestment Act (Lane, 2009), where the Bureau of Economic Analysis' input-output model was used. "This approach functionally equates the impact of science to that of building a football stadium or an airport: The impact is derived from the demand side and depends on the amount of spending on bricks, mortar, and workers." (Lane, 2009, p. 128). The big advantage is that the spending information is clearly observable, and the effects on demand in the economy as well – by contrast with the second class of models which simulates the supply side (see e.g. for EU models Ortega et al., 2020; Veugelers, 2021).

The main effect from research materialises here only in the long term via the effect of higher R&D spending on innovation, which in turn affects economy-wide productivity. In the short term, because workers are taken from production to perform research, there is even a negative effect. There are several types of models within this second class, but many face the issue that they either ignore basic research as with models of endogenous technical change (Akcigit et al., 2021) or if they do model the effects of basic research, the effects are based on estimated or calibrated model parameters, which then are used to model the economy-wide impact. There are few econometric estimations though of the effect of basic research on innovation and productivity (see above). Akcigit et al. (2021) use French firm-level data on basic research to estimate their model, but they do not have "real" effects of grant-funded basic research performed in the public sector.[1]

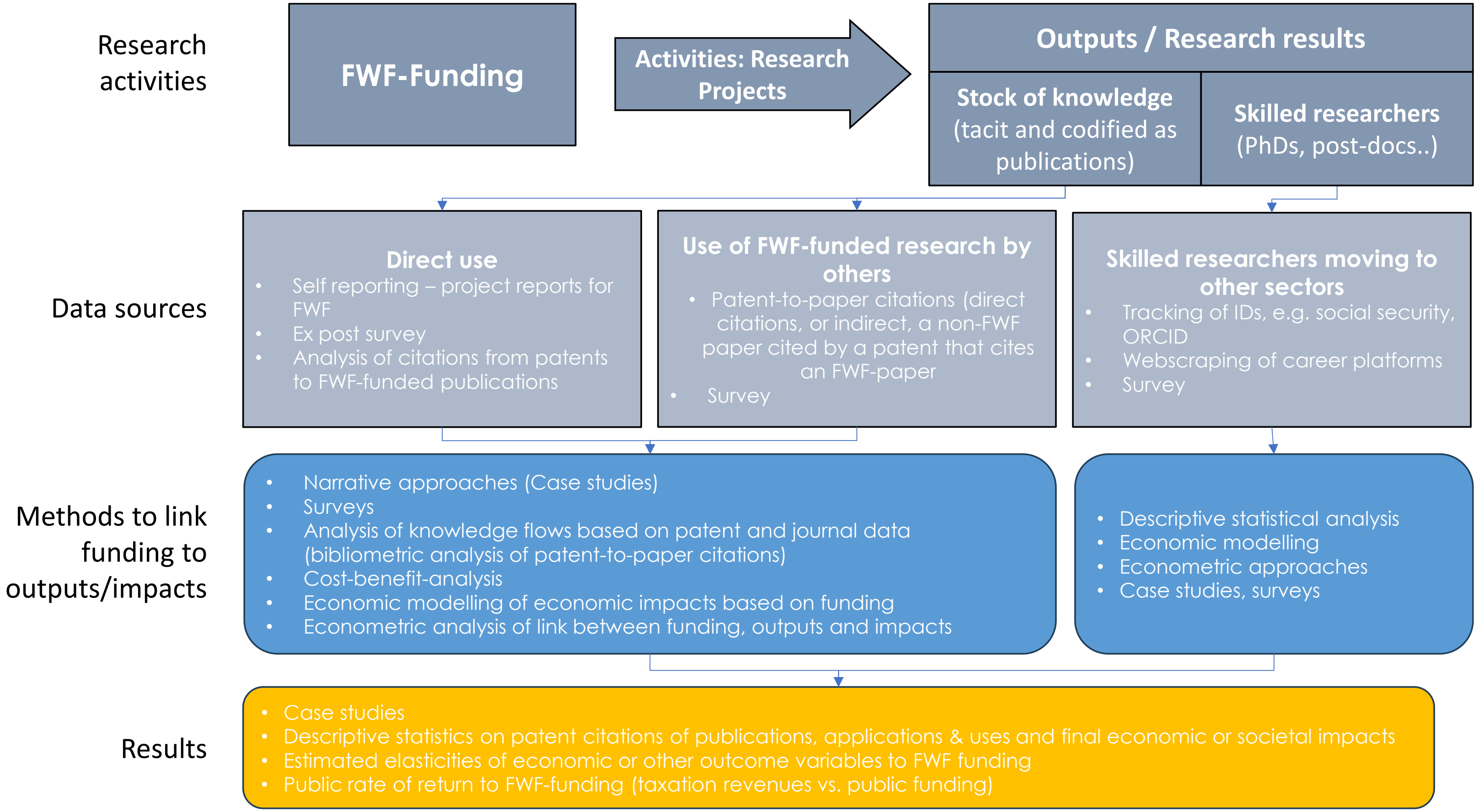
The macro-econometric endogenous EU-model Nemesis simulates the effect of an increase in total R&I public funds to be 0.74 on private R&D expenditures, which increases the stock of knowledge which in turn boosts total factor productivity, but again based on past econometric estimations. After 15 years, the multiplier of increased EU R&D expenditures is at about 10. In the NEMESIS model, there is also a negative effect in the beginning from highly-skilled workers moving from production activities into research and innovation (Veugelers, 2021). In the case of trained researchers from the FWF, this can be questioned, as PhDs or post-docs will not have been previously active in firms' production lines.

Jones & Summers (2022) review both the econometric and the growth modelling literature on the social returns to investments in innovation (mostly from business R&D). They find as a conservative lower-bound estimate that one dollar of investment in innovation leads to a return of 4 US-Dollars, with an upper bound of 20 US-Dollars.

A major difficulty for various approaches are the time lags involved between research results and applications or uses outside academia.

[1] Interestingly, they find that an indifferent research subisidy to firms oversubsidises applied research; if it was possible to give research subsidies by type of research – basic vs applied – the optimal subsidy for basic research would be 49%, while the one for applied research would be 11%, based on a French firm-level dataset.

Figure 5: **Data sources and methodological approaches for tracing the impact of grant-funded basic research**



Source: Authors.

4. Collecting data on impacts outside academia from FWF-funded basic research

This section describes how the relevant data used in the study were collected. One central data source for recording the impacts of FWF funding is a survey conducted among Principal Investigators of FWF funding. Further details on this survey and its results are described in the following subchapters.

The survey data are supplemented by other data sources, above all the funding outcomes collected by the FWF via Researchfish.[4] The data includes information from all project leaders who submitted their final report for projects ending after 31 January 2019. For projects that have ended since 2012, the FWF has transferred the data to Researchfish (where available) and the project leaders were asked to supplement/update the information. Naturally, not all information on the impact of a project is available when a final report is submitted. Start-ups may not be founded until later, patents may not be granted until later, licences may not be agreed until later and societal impacts usually take even longer to become visible. It is therefore not surprising that most of the information in this data source relates to the years 2018-2020. Significantly less information is available before and after this period.

Further data sources are the Start-up database Dealroom.cc which was used to gain more information on the firms or start-ups identified as drawing on knowledge based on research funded by the FWF; the patent database PATSTAT and the bibliometric database The Lens, which are described in section 5 on the use of FWF-funded research for inventions. Further data and statistics were used for the case studies and the estimations, also explained in detail there.

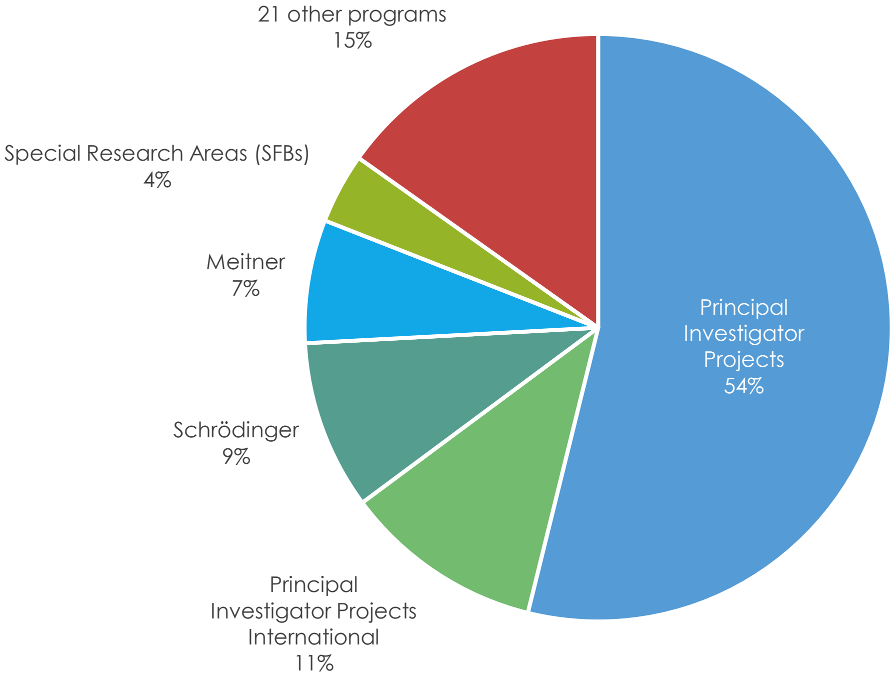
4.1. Base Population of the survey

The base population for this study, especially for the survey of project leaders, includes all FWF funded programmes that were completed between 2009 and 2022 (i.e. the projects may have started before 2009). "Projects" refers to all 26 FWF funding schemes in this period except for the "Science Communication" programme, i.e. including prizes, grants and, for example, doctoral programmes.[5] For pragmatic reasons, in the following all funding programmes are therefore referred to as "projects". In total, the population comprises 7,658 projects, more than half of which are Principal Investigator (PI) projects (see Figure 6).

[4] https://researchfish.com/

[5] More information on the FWF's funding programmes since 2009 can be found in the Research Radar (https://www.fwf.ac.at/en/discover/research-radar), descriptions of current funding programmes can be found at https://www.fwf.ac.at/en/funding.

Figure 6: **Proportion of different funding schemes in the observation period** (completed projects between 2009 and 2022)



Source: FWF funding database.

These 7,658 projects were managed by 4,763 project leaders[6] who were invited to participate in this voluntary survey. One person received 12 grants during this period, two people received ten grants each. 78 different researchers led more than five projects each (7% of all projects). 3,193 researchers received only one grant each (42% of all projects).

The total of 7,658 projects were carried out at 397 different research institutions. Most of these were at the University of Vienna (19% of all), followed by the Vienna University of Technology (9%), the University of Innsbruck (8%), the Medical University of Vienna (8%), the University of Graz (6%) and the Austrian Academy of Sciences (5%). In 42 projects, the research centre is unknown (0.5% of all projects). The top 16 research institutions include 15 public universities and the Austrian Academy of Sciences, followed by the Institute of Science and Technology Austria ISTA, which only opened in 2009 (1% of all projects). Only one project was carried out at each of 221 research centres (3% of all projects), which are mainly international institutions.

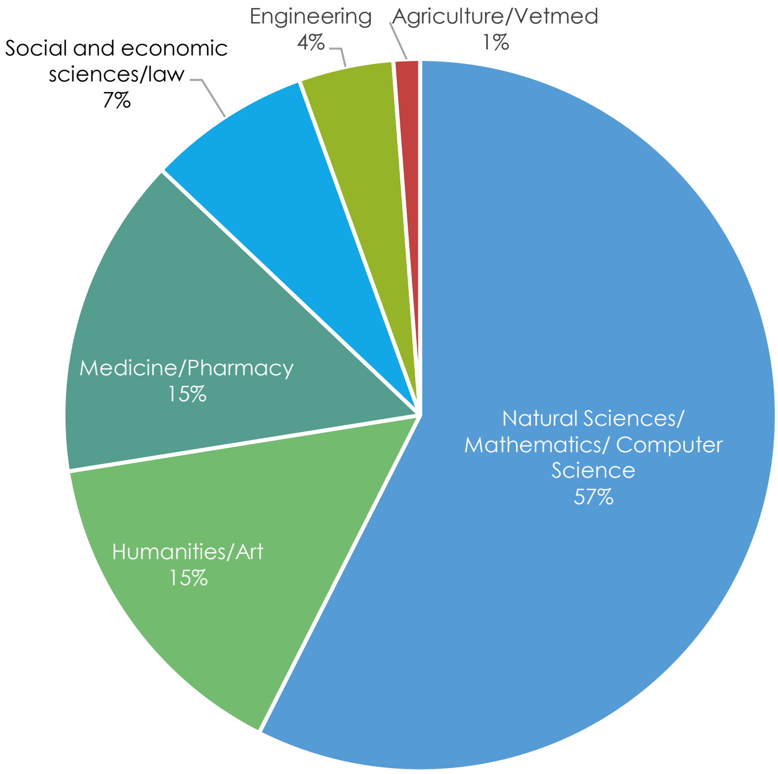
On average, a project was endowed with €288,317 (not price-adjusted), although there are of course very large differences depending on the funding scheme. An average of €4.5 million was spent on doctoral programmes and an average of €1.85 million on doc.funds. An average of €1.46m was awarded for Wittgenstein Awards between 2009 and 2022 (currently €1.9m is awarded) and ∅ €1.15m for Start Prizes. PI projects received an average of €271,365 during this period (not price-adjusted). The lowest funding was awarded to the Schrödinger Programme (∅ €98,418), the Charlotte Bühler Programme (∅ €59,400) and the Top Citizen

[6] The number of 4,763 principal investigators is based on the first and last names in the FWF database. Due to name changes, there are actually fewer individuals.

Science Programme (∅ €48,123). In total, just over €2.2bn was spent on all of the projects analysed here.

57% of all projects are in the natural sciences/mathematics/computer science, 15% each in the humanities/arts and m edicine/pharmacy, 7% in social and economic sciences/law, 4% in engineering and 1% in agricultural sciences/veterinary medicine (see Figure 7).

Figure 7: **Average shares of the disciplines in all funding during the observation period**



Source: FWF funding database.

This also roughly corresponds to the disciplinary distribution of PI projects. In international PI projects, the proportion of natural sciences/maths/computer science is slightly higher, while that of the humanities/arts is slightly lower. Of the doctoral programmes, 62% are in the natural sciences/mathematics/computer science, 19% in medicine/pharmacy and 12% in social sciences and economics/law. In the Meitner Programme, 66% are in the natural sciences/mathematics/computer science and 22% in the humanities/arts; in the Richter Programme, 43% are in the natural sciences/mathematics/computer science, 29% in the humanities/arts and 18% in social sciences, economics and law. Of the special research areas (SFB), 56% are in the natural sciences/mathematics/computer science and 28% in medicine/pharmacy. In the reporting period, 81% of the Wittgenstein Prizes were awarded to researchers from the natural sciences/mathematics/computer science, 8% from the humanities/arts, 6% from the social sciences and economics/law and 5% from medicine.

Table 1: **Average shares of the disciplines in the larger funding programmes during the observation period**

	Natural Sciences/ Mathematics/ Computer Science	Engineering	Medicine/ Pharmacy	Agriculture/ Vetmed	Social and economic sciences/law	Humanities/Art	Total
PI Projects	57%	4%	13%	1%	7%	18%	100%
PI Projects International	64%	7%	13%	2%	9%	5%	100%
Doctoral Programmes (DKs)	62%	1%	19%	0%	12%	6%	100%
Meitner Programme	66%	3%	3%	0%	5%	22%	100%
Richter Programme (incl. Peek)	43%	2%	5%	3%	18%	29%	100%
Special Research Areas (SFBs)	56%	4%	28%	2%	4%	7%	100%
Wittgenstein Prizes	81%	0%	5%	0%	6%	8%	100%
Æ all Programms	57%	4%	15%	1%	7%	15%	100%

Source: FWF funding database.

The observation period of the survey covers all projects that were completed between 2009 and 2022, i.e. they may have started before 2009 and projects that are still running after 2022 are not included. The first eight projects in the base population began on 1 March 1999 (all Special Research Areas, SFBs), i.e. 10 years before our core observation period. Overall, 24% of all projects in our population started before 2009, 7-8% in each of the following years and fewer from 2018 onwards (as they were not completed by the end of 2022). 53% of the projects started before 2012, 47% after that. However, since we are interested in the potential impact of the projects in this study, it is more relevant when the projects ended and how long there was time afterwards for any impact to develop. In all years between 2009 and 2022, 6 to 8% of the projects ended, 55% between 2009 and 2016, 45% thereafter until 2022.

Figure 8 shows the distribution of the funding schemes over time during the observation period, which is defined as projects that were completed between 2009 and 2022. The figure says nothing about the duration of the funding programmes but is intended to illustrate how the funding programmes are distributed during the observation period (most funding programmes did not end in 2022 but continue to this day).

Figure 8: **Period in which projects ran during the observation period, depending on the funding programme**

Source: FWF funding database. Green fields: Duration of the projects; Red fields: End of the last project in the observation period.

4.2. Methodology of the survey

The survey was sent via e-mail to all project leaders of projects that were completed between 2009 and 2022. The questionnaire contained questions on the potential economic and societal impacts of the projects. Concrete conceivable economic impacts (e.g. patents, start-ups) were asked in greater detail, while societal impacts were mainly asked open-ended, as the conceivable spectrum is too broad for closed questions.

For this survey, we **define research impacts as direct or indirect, intended, or unintended applications or uses of fundamental research outside of academia (see section 1)**. This also includes the training of researchers who have left academia. The survey asks about the contributions of FWF-funded research completed between 2009 and 2022 to the following two types of impact.

Economic impact: an effect on, change or benefit to the economy.

Societal impact: an effect on, change or benefit to society, art & culture, public policy or services, health, the environment, or quality of life beyond academia.

The letter of invitation to participate in the survey made it very clear that the FWF funds basic research and does not expect any impact outside of academia. Nevertheless, there may be intended or unintended impacts outside of academia of the funded projects in which this survey is interested.

The questionnaire was intensively tested and commented on by 17 senior researchers proposed by the FWF for this pretest. They covered a wide range of disciplines and funding programmes.

The final questionnaire was then sent to 4,729 project leaders (excluding the pretest participants). The invitation email was followed by two reminder emails. The field phase lasted from 21 February 2024 to 18 March 2024. 723 (15%) of the e-mails were returned as undeliverable or the recipients were unavailable for a long time (due to maternity leave, illness, a long field trip or similar). This resulted in a net sample of 4,006 contacts. Of these, 1,404 completed the questionnaire in full, and the 17 questionnaires from the pretest could also be included in the analysis for the most part (∑1.421 usable questionnaires). This results in a response rate of 35.3%, which also reflects the researchers' strong interest in the topic and their close connection to FWF funding. All the more so when one considers that some projects had already ended 15 years before the survey.

The sample represents 31.8% of all projects that ended between 2009 and 2022 and 32.3% of the funding amount. The funding programmes are represented proportionately to their share of the base population (only the Schrödinger programme and Special Research Areas (SFBs) are slightly underrepresented, while the Richter programme is somewhat overrepresented[7]). The scientific disciplines are also represented almost as in the population: social and economic sciences, humanities/art and agricultural sciences/veterinary medicine are slightly overrepresented, and medicine/pharmacy is slightly underrepresented. The major research institutions are also represented in line with the population of all projects. However, as expected, older projects (completed before 2014) are slightly underrepresented and younger ones are slightly overrepresented. In most cases, however, the deviation is less than 2 percentage points. Thus, since the population as a whole is fairly well represented in the sample, **the survey data was not weighted**.

It is important to emphasise that this is a personal survey and not a project survey (because otherwise researchers would have had to fill out a questionnaire for each of their projects). The **answers therefore always refer to the sum of all projects of a principal investigator**. These were shown again at the beginning of the survey to clarify which of the researcher's projects fall within the observation period.

4.3. Results – FWF-Economic Impacts

4.3.1. Overview of economic impact

Researchers were first asked to assess the overall economic impact their FWF-funded research contributed to. They were asked to consider both direct and indirect impacts, e.g. via further applied research by others or other activities using their research to develop applications and uses (regardless of who funded them).

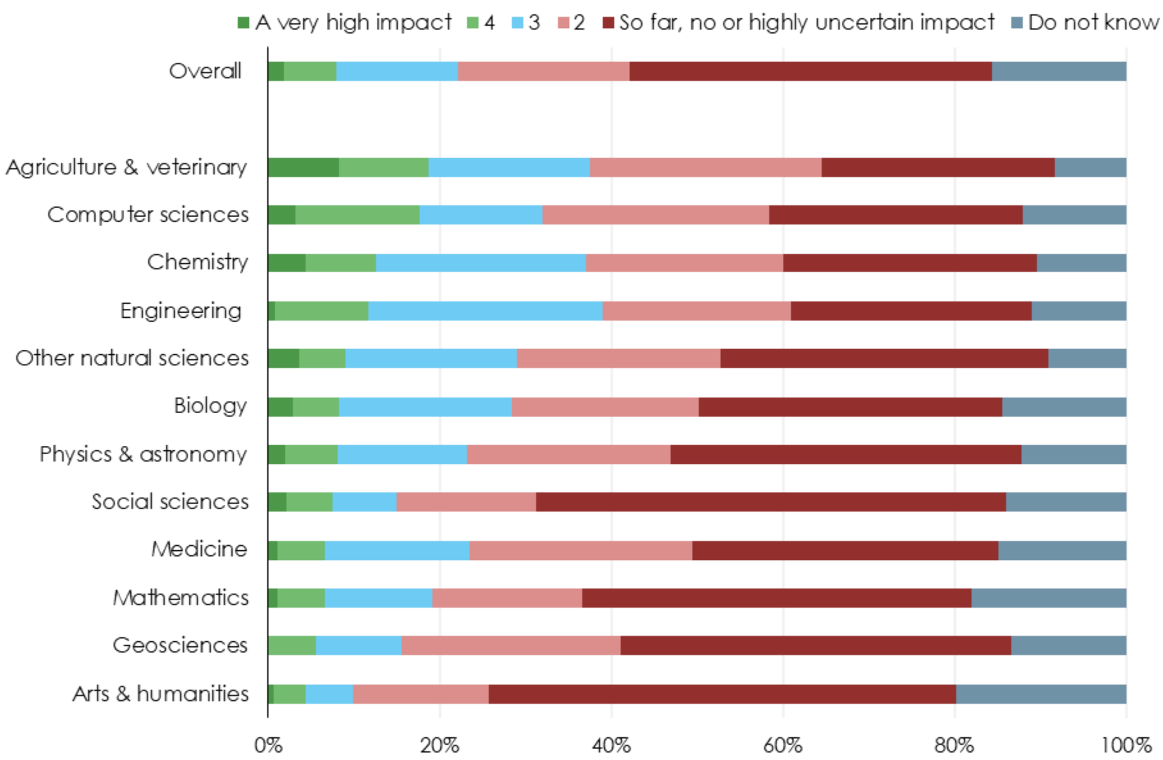
Overall, 8% stated that their research had a (very) high economic impact (see Figure 9) and 62% indicated that their research had a (highly) uncertain or no impact. The fact that the economic impact of the research financed by the FWF is difficult to assess is also reflected in the 16% who stated that they cannot answer this question or cannot assess the economic impact of their research. This is not surprising, as the FWF funds basic research projects, i.e. "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, **without any particular application or use in view**" (OECD, 2015, p. 45).

Researchers with projects in the field of agriculture & veterinary (19%), computer sciences (18%), and chemistry (13%) indicated most often that their FWF-funded research has had a

[7] In the case of the SFBs, this could be due to the fact that they are the oldest projects in the sample (see above).

(very) high economic impact (see Figure 9). In contrast, researchers who had projects in geoscience, social sciences (71% each) and arts & humanities (70%) most frequently stated that they perceive no or a (very) uncertain economic impact of their research, in line with previous research pointing to differences in the propensity to patent across fields of science (Trajtenberg et al., 1997)

Figure 9: **Rating of overall economic impact of FWF-funded project(s) by academic fields**



Source: Survey of FWF researchers 2024. n = 1,310 researchers.

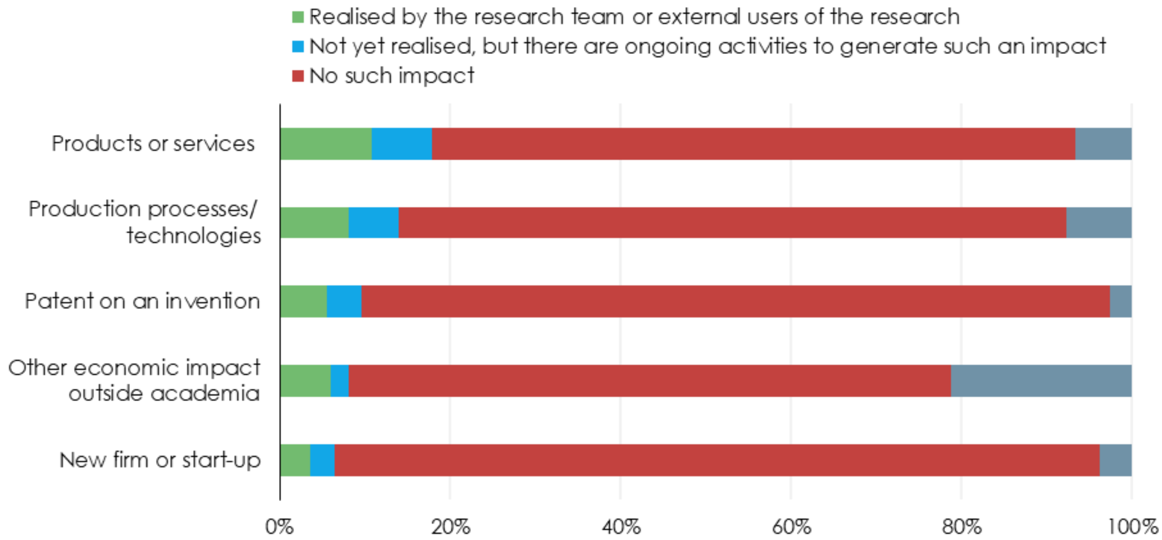
Furthermore, researchers were asked to assess if their FWF-funded project(s) could contribute to any of those specific economic impacts:

- **Patent** on an invention
- **Licence**, e.g. to use research result or patent (not software licence)
- New or improved **production processes** or technologies (incl. management practices) used in existing firm or organisation
- New or improved **products or services** (e.g. research tools, new materials, software, medical products) sold by existing firm or organisation
- New firm or **start-up**
- **Other economic impact** outside academia (open field for specification)

New firms or start-ups could commercialise any of the impacts mentioned in c) or d), but because we specified in c) or d) in "existing firms or organisations", any double counting is unlikely. For each economic effect, they could choose between 1) Yes, my research team or external users of my research were able to generate such an economic impact based on my FWF-funded research results, 2) the corresponding economic impact has not yet been realised, but there are ongoing activities or they could indicate that they perceive 3) no activities or developments in relation to the corresponding economic impact or 4) they do not know whether the research results of their FWF-funded projects are being used in this respect (see Figure 10).

Overall, **22% of all respondents** (n=309 researchers) stated that their FWF-funded research had contributed to at least one of the specific economic effects mentioned above. Of these, 18% stated that they could link at least one of the economic effects mentioned to their FWF-funded research. The remaining 5% of researchers who identified at least one economic effect stated that they could also identify some ongoing activities related to another of these specific economic effects. A further 10% had not yet observed any economic impact, but reported ongoing activities that might achieve one of these economic impacts. The remaining 67% of researchers indicated neither ongoing activities nor an economic effect resulting from their FWF-funded research (including those who do not know). This implies that about a third of project leaders who responded indicated a current or potential economic impact from their FWF-funded research, a surprisingly large share considering that FWF funds basic research only. Part of this may be explained by the high share of life sciences projects in FWF's funding, where basic research is closest to potential commercial applications (Powell & Owen-Smith, 1998).

Figure 10: **Realisation of a specific economic impact related to the researchers' FWF-funded project(s)**



Source: Survey of FWF researchers 2024. Multiple answers possible. For the economic impact 'licences' the case number was too low (n<30). n = 1,385 researchers.

Researchers were asked in more detail about the specific economic impacts that resulted from their FWF-funded projects. The following is a brief descriptive information on each of the six areas of economic impact, namely: patents, licences, new or improved products and production processes, and any other economic impact that was not specified in more detail and that researchers were free to define. This is supplemented by some examples of projects that were the basis for realising the respective economic impact. Wherever possible, a brief overview is also given of the commercial revenues that have resulted from the respective economic effect.

Patent

Among all surveyed researchers, 145 patents could be generated by the FWF-funded projects of the surveyed researchers who indicated a patent as economic impact (5% provided a number of the patents their research contributed to). However, the number of inventions protected by these patents is somewhat lower, as several patents in different jurisdictions can protect the same invention (for details, see section 5).

The patents have been filed at and granted most often by the European patent office, with Austrian medical and technical universities among the most frequently named application organisations (especially in Vienna). 14% of all researchers from the field of chemistry stated that a patent had resulted from their research (Ø 5%). Researchers from the field of medicine were the second most likely to realise a patent (10%), followed by researchers from the fields of biology (8%). All three are often likely to be related to the life sciences. Researchers from physics & astronomy (8%) are just behind.

Researchers were also asked if the patents their FWF-funded research contributed to has been sold and transferred (not licensed) to another organisation. Most stated that their research was *not* sold to another organisation (69%). If patents were sold, slightly more researchers indicated that patents were sold to an organisation in Austria (17%) than to one abroad (14%).

Table 2: **Status of patent: Sold and transferred (not licensed) to another organisation**

	Number of patents	In %
Organisation in Austria	16	17%
Organisation abroad	13	14%
Neither sold nor transferred to another organisation	66	69%
Total	95	100%

Source: Survey of FWF researchers 2024. n = 60 researchers.

Only a small number of researchers provided information on the commercial revenue of their patents (n=13 researchers responded for their total of 24 patents). For almost half of the patents that resulted from the FWF-funded research of these researchers, the commercial revenue was more than €0 but less than €100,000 (46%); for two patents, it was more than €100,000 but less than €1 million (8%); and for one patent, it was €0 (4%). For the remaining 42% of the patents, the researchers did not know the commercial return.

The FWF-funded research projects that have led to a patent are diverse. As described, these research projects can be primarily assigned to the natural sciences and medicine. This is illustrated by the following examples: One project developed a method for processing magnetic resonance signals. Another received a patent for a method to assess the risk of genetic defects in sperm or body tissue. Another group of researchers developed algorithms for better predicting human blood sugar levels. In yet another project, researchers discovered how to recombine proteins in plants, which promises great therapeutic benefits for a variety of diseases. And still others patented results in the field of engineering, such as inventions involving devices for suspending heavy loads.

According to the **FWF Researchfish survey**, 44 IPR activities were reported that arose from FWF-funded projects between 2016 and 2023. These include 11 patent applications, 18 published patent applications and 13 granted patents (all between 2017 and 2020). Eight have been licensed, commercialisation is still confidential for three, and 33 have not been licensed (as of the submission of the final project reports to the FWF).

Prior to 2019, 151 patents and 13 licences were reported to the FWF in the final reports between 2012 and 2018. However, some of these are patents from different regions that are apparently based on the same invention. Detailed analyses of the patent activities that were generated with input from FWF funding are provided in the next chapter 5, presenting also a total number of patents drawing directly on FWF-funded research, whether from the survey or from other sources.

Licences

Overall, 21 researchers (1% of all surveyed researchers) indicated to how many licences their research contributed to. In sum, at least 40 licences[8] could be generated by the FWF-funded projects of the researchers surveyed.

Most researchers who indicated licences as an economic output stated that it was a patent that was licensed (70%). The remaining 30% of these researchers stated that, in addition to a patent, know-how or the right to use innovative technical methods was also licensed. Within the fields of medicine (4%), biology (3%) and chemistry (3%) researchers stated most often that their research led to a licence (Ø 1%). Examples are research relating to new techniques, such as DNA methylation as an essential mechanism of epigenetic gene regulation with far-reaching significance for development and disease, or a method for the organic chemical production of peptides or proteins of any length.

When researchers provided information on commercial revenues in Austria (n=25 licences) almost half of the licences had revenues of above €0 but below €100,000 (46%), 29% had revenues of €0 and for a further 21% of these licences, the researchers did not know. For one licence, a researcher indicated a commercial revenue in Austria between €100,000 and less than €1 million (4% of all licences with revenue in Austria). When researchers provided information on the commercial turnover of licences abroad (n=25 licences), the researchers did not know the commercial revenue for almost half of the licences (46%) and for somewhat less than half, they indicated a commercial revenue of €0 (42%). In contrast to the commercial revenues in Austria, the researchers only reported commercial revenues from licences abroad of more than €0 but less than €100,000 for 8% of the licences. One licence had revenues between €100,000 and less than €1 million (4% of all licences with commercial revenues abroad), with this licence coming from a different researcher than the one who reported a licence in Austria with the same revenue level.

In addition, all researchers who indicate an economic impact (22% of all surveyed researchers) were asked whether their research institution or university regularly screens for potentially patentable or licensable results. 34% of those said that their research institution or university conducts such regular institutionalised screening, a further 26% said that they do not have such a policy, and 40% do not know (n=300).

New or improved production processes or technologies

In total, 6% of all surveyed researchers identified 144 new or improved production processes or technologies (including management practices) that were implemented in an existing firm or organisation. Most of them indicated that these production processes are used only in Austria (40% of all production processes), one fifth are used in another EU country (19%) and as many as 7% are used in a non-EU country (see Table 3). The new or improved production

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[8] This represents the most conservative estimate, as some respondents indicated that they had more than five (>5) licences, which is calculated as six. However, the exact number cannot be calculated from this data. Furthermore, not all researchers who indicated in the initial question that they had contributed to a licence later provided information on the number. This applies for the total amount of all following economic details if researchers selected the options of >5.

processes/technologies based on FWF-funded research are also used relatively frequently in all three regions (16%).

Overall, these production processes are used most frequently in Austria (47% of all production processes) and more frequently in EU countries (35%) than in non-EU countries (17%). While basic research results are known to flow across borders (see section 3), this indicates that the "home country" is likely to dominate, due to well known spillovers facilitated by geographic proximity (Abramovsky & Simpson, 2011; Rodríguez-Pose & Crescenzi, 2008).

Table 3: **Location of use of the new or improved production process/technology divided by the three areas Austria, other EU-countries and non-EU countries**

	Number of production processes	**In %**
Only in Austria	43	40%
Only in other EU countries	21	19%
Only in non-EU countries	8	7%
In Austria and other EU countries	16	15%
In Austria and non-EU countries	0	0%
In EU and non-EU countries	3	3%
In all three regions	17	16%
Total	108	100%

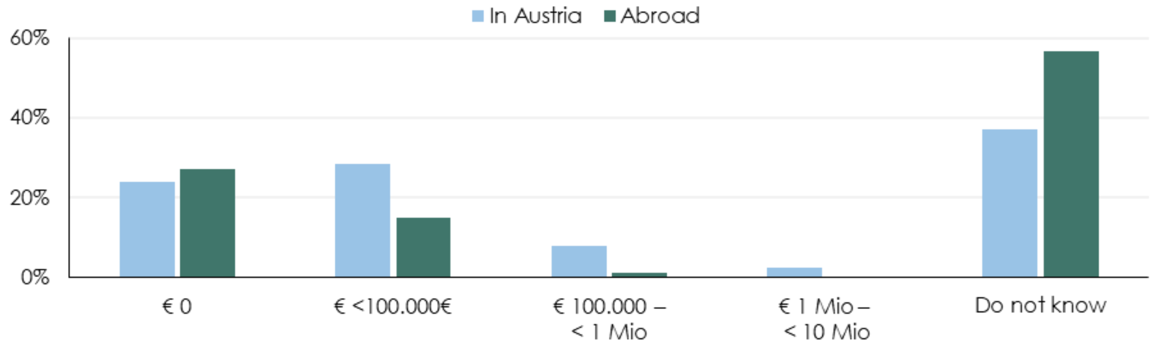
Source: Survey of FWF researchers 2024. Multiple choices possible. n =76 researchers, n = 108 production processes.

Researchers in the field of agriculture & veterinary (16%), ICTs (12%), engineering (9%), biology (8%), chemistry, and other natural sciences (7% each), stated most often that their FWF-funded research contributed to new or improved production processes or technologies (Ø 6%).

Examples of new or improved production processes/technologies that are used in all three areas are: a new programme for the systematic production of medicinal plants used in traditional European and Asian (Chinese) medicine (TCM); or software that supports the isolation of protein complexes and another innovative software tool that automatically creates digital 3D railway infrastructure from mobile map data. Another example is the development of new algorithms for archaeological research and GIS systems, as well as new methods for managing expectations to reduce investments with limited prospects. Two further interesting examples are in the field of social sciences and include the improvement and reorganisation of human resource management according to the findings of a gender-sensitive process design and, in the field of geosciences, the provision of satellite data that can be used to make predictions about the movement of the Sahara Desert. Both examples are only used in Austria and EU countries.

As can be seen in Figure 11, it is difficult for most researchers to estimate the commercial revenue or cost saving of the production process/technology that resulted from their research. For half (49%) of the production processes/technologies used by companies based in Austria, the researchers do not know what the commercial revenue was in 2022. If these production processes/technologies are used by companies based abroad, the researchers were unable to estimate the commercial revenue for an even higher proportion of products/services (60%). Furthermore, the researchers found that for around one-fifth of the production processes/technologies, the commercial revenue was more than €0, but below €100,000 (25% in Austria, 19% abroad), and that for one in ten of these production processes/technologies, the commercial revenue or cost saving was estimated to be between €100,000 and €1 million (10% in Austria, 11% abroad).

Figure 11: **Estimations of the commercial revenue (or cost saving) in 2022 of new or improved production processes/technologies for the firm located in Austria or abroad, proportion of processes/technologies**



Source: Survey of FWF researchers 2024. n = 75 researchers. $n_{(IAustria)}$ = 67 processes/technologies (without not applicable). $n_{(Abroad)}$ = 57 processes/technologies (without not applicable).

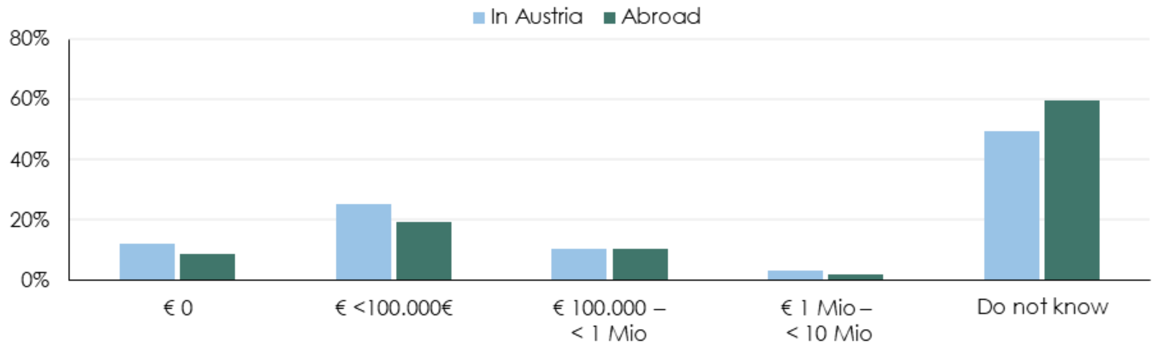
New or improved products or services

Most often researchers indicated that their FWF-funded research contributed to the development of a new or improved product or service. That could be, e.g., research tools, new materials, software or medical products which can be sold by an existing firm or an organisation. In total, at least 208 products or services resulted from the FWF-funded research of 9% of all surveyed researchers.

Nearly every fifth researcher from the field of computer sciences reported that their research contributed to a new or improved product or service (19% vs. Ø 9%). Furthermore, researchers from the field of engineering (16%), agriculture & veterinary (15%), medicine (12%), geosciences (11%), and mathematics (10%) stated that they contributed to a new or improved product or service most likely. Examples of products and services include an app for joint planning opportunities for the building industry; software that supports neuroscientific research in the pharmaceutical industry; the development of software for 3D printing; a wind tunnel for basic and applied biological research on birds; software for simulating the electrophysiology of the heart at the organ level; skin organoids that model human skin; AI-driven hardware and software for identifying cells and microorganisms. Examples outside the STEM fields include the production of renowned documentaries for National Geographic or the production of an edition of previously unavailable music from the 16th century, but also, in the field of law, a relational database for aviation law could be created.

As can be seen in Figure 12, it is difficult for most researchers to estimate the commercial revenue of the product or service that resulted from their research. For 37% of the products/services that are used by companies based in Austria, the researchers did not know what the commercial revenue was in 2022. For products or services that are used by companies abroad, researchers were unable to estimate the commercial revenue for an even higher proportion of products/services (39%). Furthermore, the researchers stated that for around one-fifth of the products/services, the commercial revenue was €0 (24% in Austria, 27% abroad). This may be because these products/services did not aim to generate commercial revenue, e.g. because they are open-source products. It may also be because these products/services did not generate any revenue in 2022. For one third of the products/services used by Austrian companies, the commercial revenue was more than €0, but below €100,000 (28% in Austria, 15% abroad). Overall, the estimated commercial revenue of the new and improved products/services is higher when they are used in Austria, but this may be mainly due to the fact that the commercial revenue is more difficult to estimate when these products/services are used abroad.

Figure 12: **Estimations of commercial revenue in 2022 of new or improved products or services for the firm located in Austria or abroad, proportion of products/services**



Source: Survey of FWF researchers 2024. n = 116 researchers. n(IAustria) = 113 products/services (without not applicable). n(Abroad) = 74 products/services (without not applicable).

According to the **FWF's Researchfish survey**, 288 technical products were generated from 309 FWF projects between 2013 and 2023. However, the distribution of reported products over the years is highly normalised, with a peak in 2019 and 2020 (59 and 55 respectively), while fewer than 10 were reported in the first and last year. This indicates that the reports are not complete and that the number of products created is therefore significantly underestimated.

Of the 288 products reported, 171 (59%) were in the software category, 66 (23%) in the web tools/applications category and 34 (12%) in the "new/improved technique/technology" category. The remaining 19 (7%) were in the areas of "detection devices", "new material/compound", "physical model/kit" and "systems, materials and instrumentation". 186 (65 %) of the products are open source, only 5 (2 %) are protected by copyright.

New firms and start-ups

In total, 3% of the surveyed researchers reported that their FWF-funded research contributed to 52 new firms/start-ups (both terms were mentioned in the survey to make sure respondents understand). Most of them successfully entered the market (71%). One-fifth were preparing for market entry (24%), and 4% already exited the market. For the majority of the start-ups the headquarter is located in Austria (86%), only for 4% it is located in in another EU country, and the remaining 10% of the firms/start-ups can be found in a non-EU country. This is much higher than for products and processes; for commercialisation of research via start-ups, often the researchers are directly involved, as only they master the critical knowledge base (Calcagnini et al., 2014; Zucker, Darby, & Armstrong, 2002; Zucker, Darby, & Torero, 2002). This in turn leads to start-ups often being founded close to the research locations of the researchers, as they often continue their research or will be unwilling to start a new business in an environment they do not know, in addition to the benefits of being close to recent (PhD) graduates in the case of universities.

Researchers were also asked to estimate the number of employees in these start-ups as of 31 December 2022. A total of 19 researchers provided a figure, resulting in a total of 215 employees for 24 start-ups. One researcher stated that two start-ups resulted from their research funded by the FWF, with one company having 30 employees and the second start-up having four employees. This means that the maximum number of employees resulting from the research of one principal investigator funded by the FWF is 34. At the same time, one researcher also stated that one of their research projects resulted in a one-person company. On average, 11 jobs were created if (at least one) start-up resulted from the FWF funded research (or 5.5 jobs on the median).

Most researchers provided information about the economic revenue for start-ups resulting from their research if those were based in Austria (n=28 start-ups). Information was provided for only three start-ups based abroad; for two out of those three start-ups researchers indicated that they do not know the economic return, and for the remaining start-up the economic return was estimated at €0. For start-ups in Austria, the picture is different: Here, researchers estimate that 35% of the start-ups could generate commercial revenues between €100,000 and €1 million in 2022. A further 27% of the start-ups are estimated to have generated revenues between €0 and €100,000, and the same proportion of start-ups (27%) are estimated to have generated revenues between €1 and €10 million. The researchers stated that only 4% of start-ups had a turnover of €0 and for 8% of companies they stated that they did not know.

Most often researchers within the fields of computer sciences (11%), engineering (6%), and geosciences (5%) have founded a start-up. Nevertheless, the start-ups are very diverse and range from STEM fields to the humanities. For example, one start-up is developing a new methodology for applying satellite data based on research-related Earth observations. Another company/start-up was founded based on innovative technologies in the fields of functional genetics and transcriptomics to enable the discovery of cancer drugs. Another company is working on 3D geometry processing software that is used in the dental, 3D visions and automotive sectors, with research funded by the FWF contributing to the mathematical foundations of the algorithms used in the software. Yet another company is developing software for the film industry also based on 3D reconstruction algorithms.

In addition, research in the field of gender equality led to the establishment of a gender equality consultancy, which helps to build a deep understanding of the topic in companies and NGOs. Another start-up developed an app that can play music for mental health and combines results from music therapy and neuroscience. FWF research contributed to understanding the effects of different acoustic frequency ranges on attention and cortical arousal. Another example is a company/start-up that has developed a model to predict the arrival of solar storms and is a non-profit start-up that makes the results available to the Austrian public and other interested parties around the world free of charge.

In the **FWF's Researchfish survey**, 16 spin-outs from 22 projects were reported. Thirteen of these are based in Austria, one each in Germany, Sweden and the United Kingdom. The first spin-out was founded before 2004 (before the start of FWF funding), the last in 2022. Two spin-outs are associations (in the arts), one of which no longer exists and the other does not appear to be very active at present. 14 are companies. At the time of reporting, most of them had 1-4 employees, two had 5-9 and one had 10-19 employees (the number of employees is not known for one, one was not yet operational and the two associations had no employees). According to the authors' research, 11 companies were definitely still operational in autumn 2024, one was probably still operational and the status of two could not be determined.

We have also examined the **Austrian Founder's Prize**, also known as the Phönix, which has been awarded annually since 2019 by the Ministry of Science and Research and the Ministry of Labour and Economic Affairs. Every year, an award is given to a start-up, a spin-off, a prototype project and a female entrepreneur. The prizes are awarded for all types of start-ups; they do not have to have a strong research focus (among others, an online farmers' market was honoured once). Nevertheless, FWF-funded research has contributed to 12 of the 20 prize winners to date, in various ways, directly or indirectly (with start-ups using technologies developed by other FWF funding; Table 4). Two are however identical, upnano received the prize for their prototype and as a spin-off. 4 out of 5 spin off prizes went to firms building on a knowledge base to which FWF contributed. Of course, FWF is or was not the only contributor, other public funding agencies such as the FFG or AWS are often also involved. However, FWF is usually important for the first relevant research results, for the knowledge base on which further applications build. Several are described later in the case studies, such as ParityQc, Quantum Technology Labs or Myllia Biotechnology, which draws on the Gene Scissor Technology.

Table 4: **Austria start-up prize „Phoenix" winners**

	Year	Category	Winner	FWF*
1	2023	Start-up	Inmox GmbH	
2	2023	Spin-off	Quantum Technology Laboratories GmbH	x
3	2023	Prototyp	Universität Graz, Abfall zu Abwasch	
4	2023	Female Entrepreneurs	Daniela Buchmayr, Sarcura GmbH	
5	2022	Start-up	Myllia Biotechnology GmbH	x
6	2022	Spin-off	UpNano GmbH	x
7	2022	Prototyp	TU Graz; ElektroPower	x
8	2022	Female Entrepreneurs	Karin Flekc, Vienna Textile Lab	
9	2021	Start-up	Lambda Wärmepumpen GmbH	
10	2021	Spin-off	AgroBiogel GmbH	
11	2021	Prototyp	CellEctric Biosciences GmbH	x
12	2021	Female Entrepreneurs	Julie Rosser, Pregenerate GmbH	x
13	2020	Start-up	markta GmbH	
14	2020	Spin-off	Parity Quantum Computing GmbH	x
15	2020	Prototyp	Universität für Bodenkultur Wien, CarboFeed	x
16	2020	Female Entrepreneurs	Evelyn Haslinger, Symflower GmbH	x
17	2019	Start-up	MacroArray Diagnostics GmbH	x
18	2019	Spin-off	Txture GmbH	x
19	2019	Prototyp	TU Wien Hochauflösender 3D Drucker (UpNano)	x
20	2019	Female Entrepreneurs	Eva Sigl, Andrea Heinzle, Qualizyme Diagnostics GmbH	

Source: https://www.gruendungspreis-phoenix.at/; FWF (Forschungsradar), own desk research. *Winners, to which FWF-funded research contributed directly or indirectly.

Table 5: **Firms drawing on FWF-funded knowledge headquartered in Austria**

Enzyan LEVERAGING THE POWER OF NATURE FOR SUSTAINABLE…	**Tamirna** A biotech company that specializes in the discovery and validation of…	
Farmdok Mobile app for production documentation in agriculture	**LIQUIFER Systems** Focuses on the positive synergies between Earth and Space Researc…	
QUANTRO Therapeutics Discovery and development of novel therapeutics targeting transcriptio…	**Evercyte** Developing human telomerized cells for cell based assays and producti…	**P4 Therapeutics GmbH**
MADx Develop, produce and distribute tests, instruments and software for…	**Procedural Design** We develop services for architects, 3D artists, game designers, film…	**Innotope**
A:head bio Next generation therapeutics for the treatment of brain disorders based…	**Rockfish Bio** Providing Senolytic Therapies for Age-Related Diseases and Disorders	**Spatial Services GmbH** Develops and implements geoinformation products and…
Datavisyn We develop data visualization solutions for applications in…	**kincon-biolabs.eu** KinCon biolabs is a biotech startup based in Innsbruck Austria	**b.geos GmbH** Develops value-added products, conducts basic research, provides…
Innophore Innophore - the enzyme & drug discovery company	**Alsix** We translate cutting edge academic RFÂ coil research into high end too…	**Rechenraum GmbH**
KML vision OG Working side by side with researchers to foster advancement…	**Numericor** We provide scientific services, consulting, contracted research…	**Quantum Technology Laboratories GmbH** Quantum Technology Laboratories • Vienna, Austria
Ecolyte Production and development of organic redox flow battery systems	**Miti Biosystems** Biotech company pursuing a unique approach for the discovery of highl…	**MetGIS** MetGIS combines exact weather models and terrain data and thus…

Source: FWF, Survey and desk research; Logos from Dealroom.cc database.

Other economic impact

Respondents could also report an economic effect that was not further defined in the list and describe it in their own words. In total, 3% of all surveyed researchers were able to identify at least 84 additional economic impacts to which their FWF-funded research contributed to.

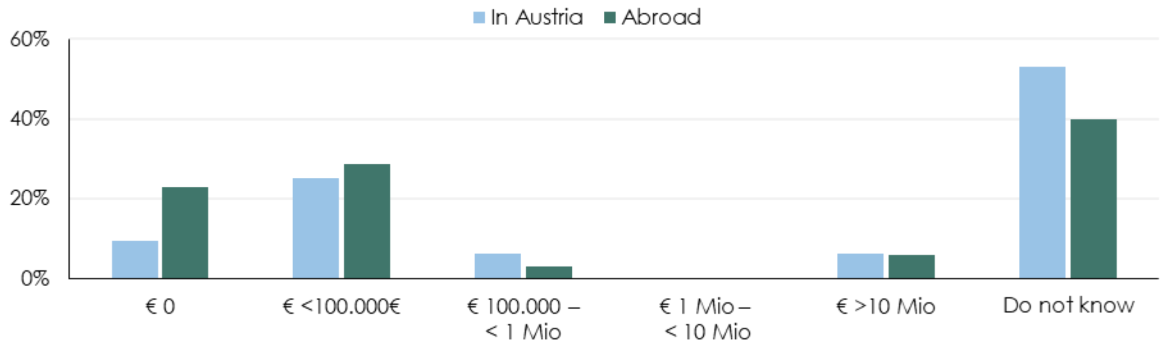
As can be seen in Figure 13, it is difficult for most researchers to estimate the commercial revenue of the other economic impact that resulted from their research. For more than half (53%) of the other economic impacts that are used by companies based in Austria, the researchers do not know what the commercial revenue was in 2022. Researchers who reported any 'other' economic effect abroad tended to estimate it more frequently at €0 revenue (23%) than when it was realised in Austria (9%). It is interesting to note that one researcher reported two projects that generated more than €10 million in commercial revenue both abroad and in Austria. A closer look at this example shows that this researcher contributed to corporate tax revenues and lower compliance costs for companies across Europe through an EU-wide tax consolidation, which has enabled two different projects to be realised.

Unlike the previous economic impacts, scientists from the field of social sciences (7%), and arts & humanities (5%) indicated most frequently to have another economic impact, followed by researchers working in the field of engineering (4%).

Examples of ‘other’ economic impacts described by researchers in the social sciences and humanities mentioned that their research contributed to an increase in tourism. Others mentioned consulting services that, for example, contributed to better quality of financial reporting in companies. The implementation of workshops was also repeatedly mentioned; for example, as part of FWF research or on the basis of this research, citizens were trained for citizen science, or teacher training was realised. Another impact described by researchers in these areas is that they were able to make a relevant contribution to the discussion on pension reform based on their research. It was sometimes mentioned that FWF-funded research was the source of inspiration, e.g. for a successful album produced by various artists or for textile patterns and production methods that triggered the production of special textiles in India and South America.

Examples of researchers who stated that their FWF-funded research had any ‘other’ non-academic economic impact, but no commercial income, include a researcher whose projects fall under both biology and the social sciences and who mentioned, among other things, that these research results contributed to the development of the SDGs indicators in sustainability policy. Another researcher, whose projects are in the arts & humanities and social sciences, mentioned a film that won an outstanding award at the Japan Film Festival, as well as an artist award and a book resulting from this research.

Figure 13: **Estimations of commercial revenue in 2022 of ‘other’ economic impacts used by firm located in Austria or abroad, proportion of products/services**



Source: Survey of FWF researchers 2024. n = 39 researchers. n(IAustria) = 32 other economic impact (without not applicable). n(Abroad) = 35 other economic impacts (without not applicable).

4.3.2. Steps towards realising the economic impact

Researchers who reported at least one concrete economic impact their FWF-funded research contributed to, were asked if they can identify how their research became relevant for the realisation of the respective economic impact and how many years this realisation took from the first research stages to the final application.

In the final section of this chapter, only those researchers who indicated that their research had not yet contributed to an economic impact but stated that "there are ongoing activities" (see Figure 10), provided an assessment of how close they thought the realisation of each impact was to final application or use.

How FWF-funded research became relevant for an economic impact

Researchers with FWF-funded projects were asked how their research achieved the economic impact they had previously stated. They could choose from a predefined list (see Figure 14) and describe in their own words in an open field how their research was able to achieve the respective economic effect.

The majority of researchers stated that their research achieved economic impact because of external users (72%, see Figure 14). The second most important way in which research funded by the FWF became relevant for achieving an economic impact was collaborative research and further development with firms (42%). This is followed by the researchers' own efforts to develop and commercialise the generated knowledge (38%). Furthermore, one in three researchers stated that (formal and informal) consultation with companies was important in order to achieve an economic impact based on their research (30%). Licensing by external users was rarely mentioned (7%).

Researchers also provided some additional input and examples of how their research became relevant for generating an economic impact. Many emphasised the importance of research-based training for students and staff in achieving economic effects. Not only is the training that takes place within FWF-funded projects often of fundamental importance for the further career steps of alumni (see also chapter 4.5), but it was also reported that former staff founded companies that are related to the results of FWF-funded research. Another example is that the research unit in a FWF-funded project of one of the researchers was integrated into a "federal agency" because this research was considered as important for Austria's critical infrastructure.

Another example is that the GitHub repository (an online forum) was important for making the research results accessible to others. Furthermore, making research results available for others as open-source software is a dissemination strategy that could also be categorised as "research results became known to external users" or "by own efforts". However, this is a concrete example of how research results can be made known in a way other than, for example, through a publication or a conference, and why no commercial income can result from it.

Figure 14: **Only those <u>with</u> a concrete economic impact: How FWF-funded research became relevant for achieving economic impact**

Source: Survey of FWF researchers 2024. Multiple answers possible. n = 303 researchers who indicated at least one economic impact.

When breaking down the results by academic discipline, it is particularly striking that researchers with FWF-funded projects in the fields of biology (48%), computer sciences (47%), engineering (47%) and chemistry (44%) mentioned joint research and development with companies more often than researchers in other fields (Ø 42%). Furthermore, researchers in the fields of computer sciences (37 %) and medicine (36%) report that they have made use of informal or formal advice from companies more often than average (Ø 30%). The licencing of research results is most frequently mentioned by researchers in the fields of chemistry (10%), medicine (10%), biology (9%), and computer sciences (8% vs. Ø 7%).

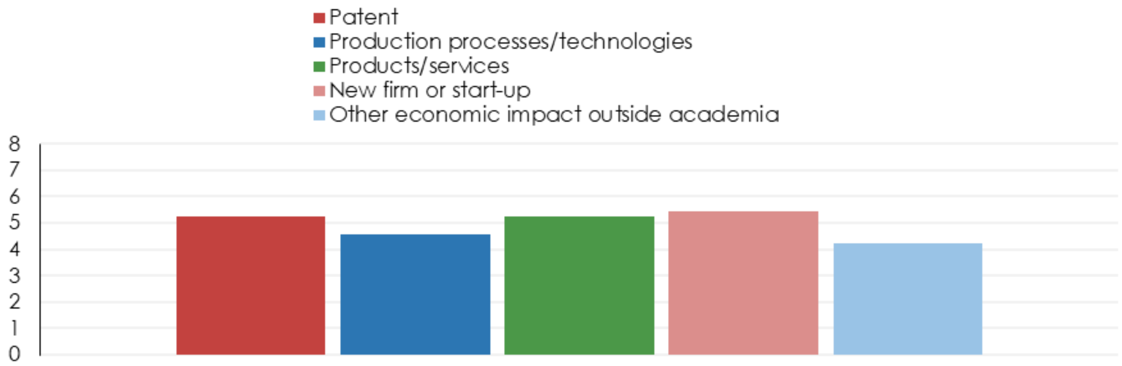
In addition, engineering (47%), computer sciences (45%), physics (44%), chemistry (41%) and medicine (38%) are disciplines in which researchers often report that they have made their own efforts to develop and commercialise knowledge in order to make their FWF-funded research relevant (Ø 38%) – but these are also the disciplines in which economic impacts are generally often realised.

By comparison, researchers who indicated that their FWF-funded research had an economic impact because their research results became known to external users (e.g. through a publication or a conference) were more likely to come from the fields of engineering (77%), arts & humanities (76%), social sciences (75%), biology (74%) and computer sciences (74% vs. Ø 72%).

Years it took from the first research results to the commercial impact(s)

Researchers who indicated specific economic impacts were asked to estimate how many years had passed between the first relevant research results and the indicated economic impacts (regardless of when the FWF funding took place). On average, it took five years for an economic impact to materialise across all different economic impacts, a little bit less than the 6-7 years reported in (Beise & Stahl, 1999; Mansfield, 1991, 1998). Only the 'other' economic impacts and new or improved production processes took a little less time to implement from basic research than the others (see Figure 15). The fact that the differences between the different forms are not very large is an interesting result that requires further investigation.

Figure 15: **Only those <u>with</u> a concrete economic impact: Number of years it took from the first relevant research results to the specific economic impact**



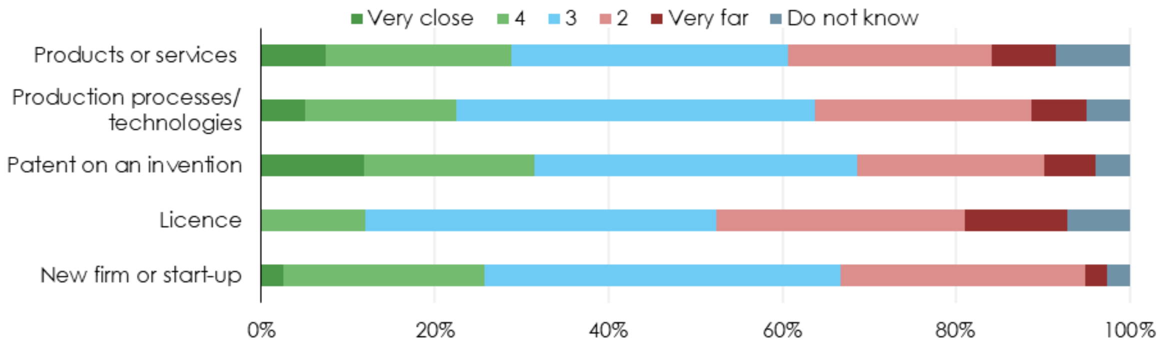
Source: Survey of FWF researchers 2024. For the economic impact 'licence' the case number was too low (n<30). n = 406 answers. One researcher could have more than one concrete economic impact.

Closeness to final economic impact

Researchers who indicated that they are aware of ongoing activities related to (at least) one specific economic impact were asked to assess how close or distant the final application or usage is.

Figure 16 shows that researchers who indicated that their FWF-funded research is about to be licensed are more likely to be in the initial phase or have just started the licencing process. Researchers whose research results are to be used to generate patents (32%) and products or services (28%) are more likely to be (very) close to the final step of application or use. In general, the differences are not very pronounced.

Figure 16: **Only those <u>with ongoing activities</u> to realise a concrete economic impact: Closeness of follow-up activities to the final application or use**



Source: Survey of FWF researchers 2024. For the economic impact 'other' economic impact the case number was too low (n<30). n = 330 researchers.

4.3.3. Barriers faced by researchers in achieving an economic impact

The following analysis includes only researchers who could *not* associate any specific economic impact with their FWF-funded research (see Figure 17).

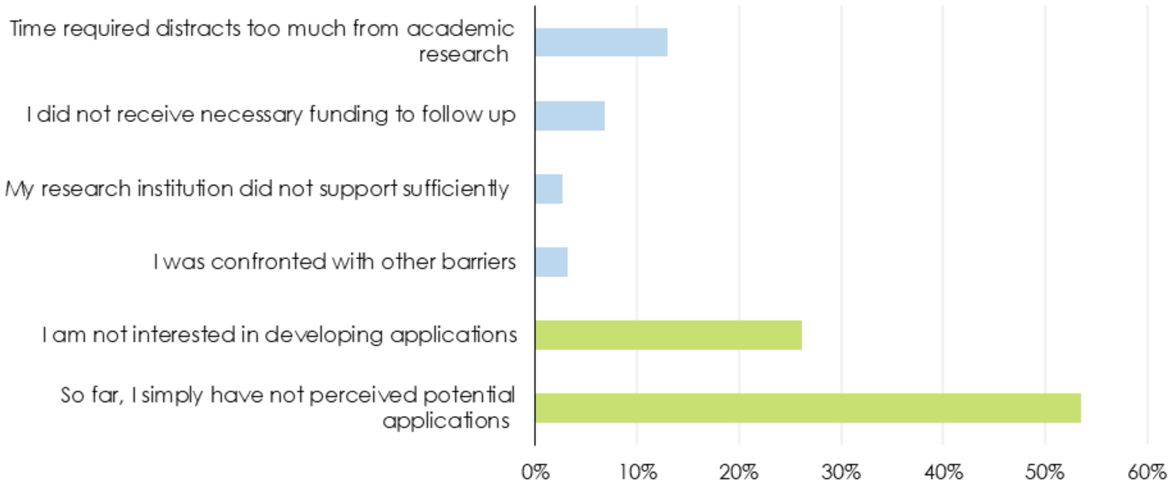
More than half of them stated that they simply did not perceive any potential applications of their research results (54%), and another quarter of these researchers stated that they were not interested in developing such applications (26%).

Those who wanted to achieve an economic impact but were unable to do so due to obstacles most likely cited that working on achieving an economic impact would distract them too much from their academic research (13%). Only a few identified a lack of support from their research organisation as an obstacle to realising their plans (3%).

It stands to reason that researchers from the fields of arts & humanities (41%) and social sciences (37%) were most often not interested in developing economic effects based on their FWF-funded research (Ø 26%). Researchers in the fields of geosciences (61%), agriculture & veterinary (61%), 'other' natural sciences (60%), chemistry (58%) and medicine (58%) are also more likely to state that they simply did not perceive potential applications (Ø 54%).

In contrast, researchers in the fields of engineering (17%) and chemistry (14%) report much more frequently than on average that they did not receive the necessary funds (Ø 7%).

Figure 17: **Only those <u>without</u> a concrete economic impact: Perceived barriers to develop economic applications and uses of FWF-funded research results**

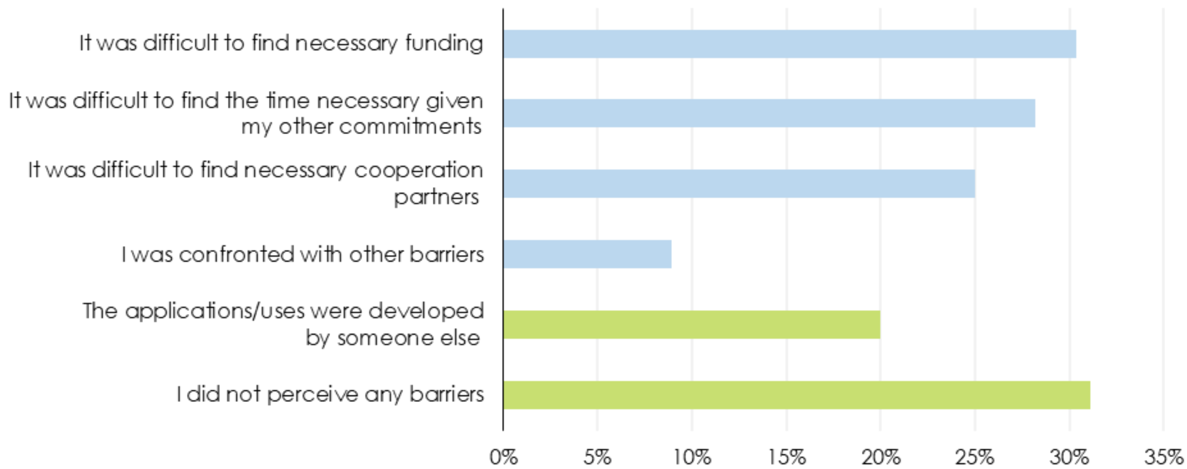


Source: Survey of FWF researchers 2024. Multiple answers possible. n = 1,039 researchers who did not report any concrete economic impact.

The following analysis only includes researchers who were able to identify a tangible economic impact based on their FWF-funded research (see Figure 18).

Not surprisingly, researchers who identified a concrete economic impact their research contributed to often stated that they had not perceived any of the obstacles listed (31%) or that others had developed the application (20%). But almost as often, even researchers whose research had an economic impact experienced a lack of funding (30%) and a lack of time due to other commitments (28%) as obstacles. One in four reported that it was difficult to find the necessary cooperation partners (25%).

Figure 18: **Only those <u>with</u> a concrete economic impact: Perceived barriers to develop economic applications and uses of FWF-funded research results**



Source: Survey of FWF researchers 2024. Multiple answers possible. n = 280 researchers who indicated any concrete economic impact.

4.4. Results – FWF-Societal Impacts

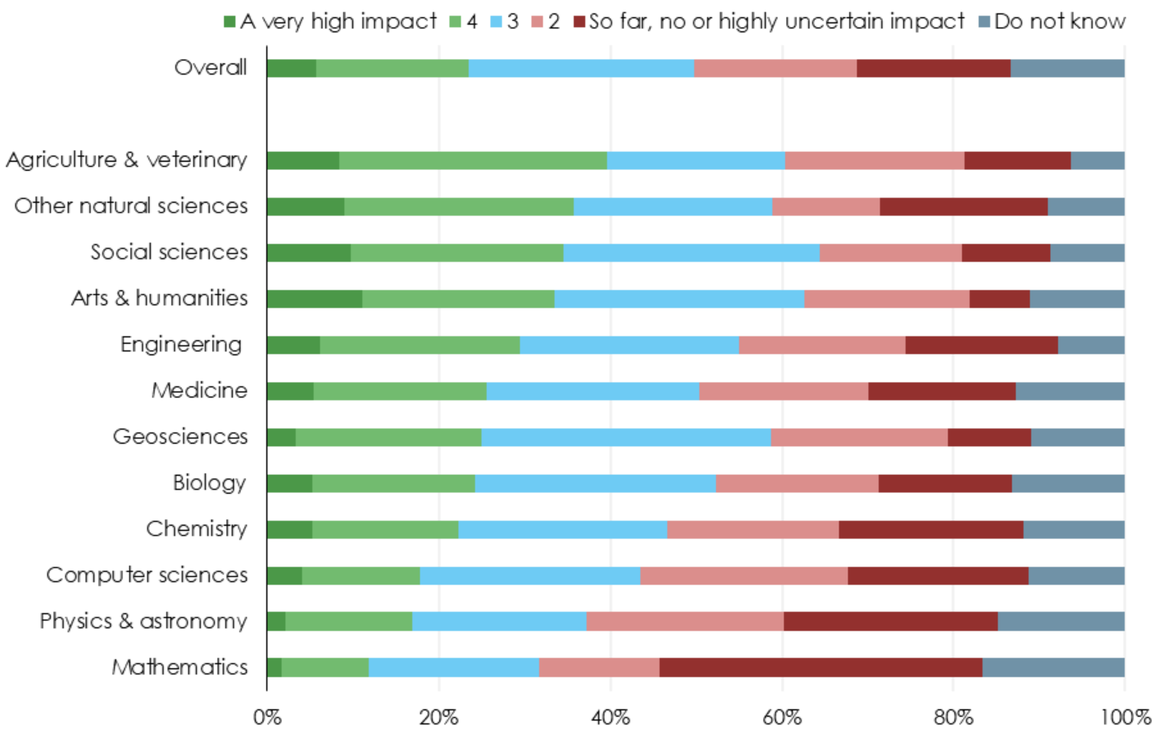
4.4.1. Overview of societal impact

The following section relates to possible societal impact contributions from FWF-funded research – that is, uses and applications outside of academia that transform or benefit society. Researchers should consider direct and indirect impacts, such as through further applied research by others or other activities that use their research to develop applications and uses (regardless of who funded it). It is possible that projects have both economic and societal impacts – for example, a medical product not only generates sales but also has an impact on health.

Overall, 24% stated that their research has a (very) large societal impact (see Figure 19). Compared to economic impact (see Figure 9), researchers were far more likely to report that their research had a societal impact. Nevertheless, 13% did not know whether their research project(s) had a societal impact, and 37% stated that it had no or a (very) uncertain societal impact.

Researchers with projects in the fields of agriculture & veterinary (39%), 'other' natural sciences (38%), social sciences (35%) and arts & humanities (33%) most frequently stated that their FWF-funded research has had a (very) high societal impact (see Figure 19). Researchers from the social sciences, and arts & humanities stated such an effect more often than those from engineering. By contrast, researchers from the fields of chemistry (22%), and computer sciences (18%) stated that their research has had a relatively high economic impact (see Figure 9), but a relatively low societal impact.

Figure 19: **Rating of overall societal impact of FWF-funded project(s) so far by academic fields**



Source: Survey of FWF researchers 2024. n = 1,330 researchers.

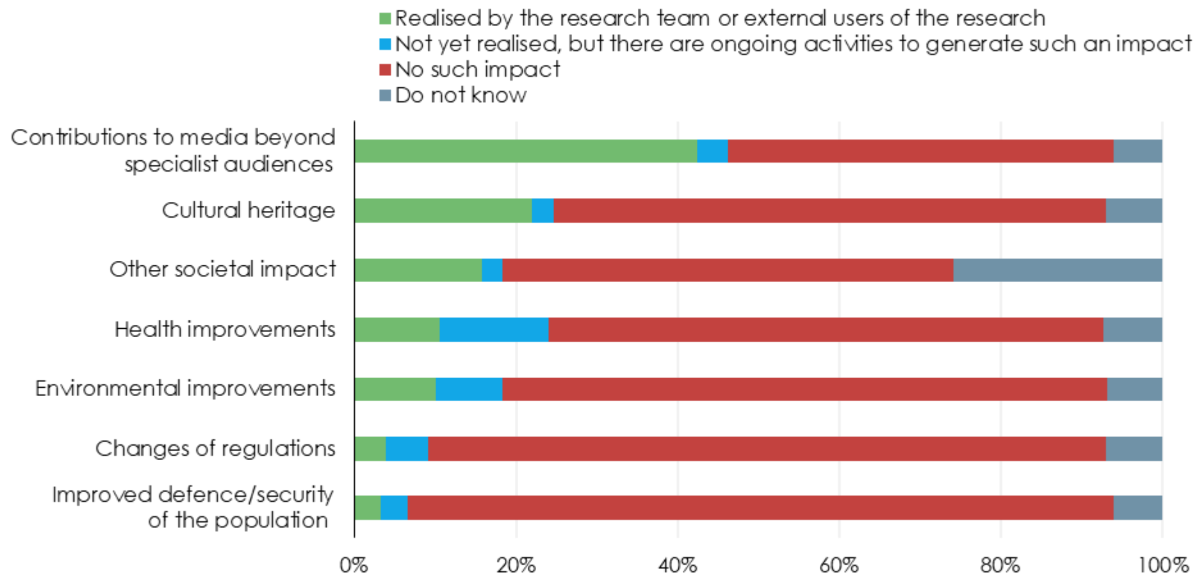
Additionally, researchers were asked to assess if their FWF-funded project(s) could contribute to any of those specific societal impacts:

a) **Environmental improvements** (e.g. protective measures against severe weather disasters, reduction of CO2, increased energy efficiency, habitat protection of endangered species, …)
b) **Health improvements** (e.g. medical interventions such as therapeutic interventions and diagnostics, health benefits of new drugs, …)
c) **Changes of regulations** (laws, decrees, norms, …)
d) Contribution to cultural heritage
e) Improved **defence/security** of the population
f) Contributions to **media** beyond specialist audiences (print, TV, podcast, film, blog, …)
g) **Other societal impact** outside academia (with an open field for specification)

For each societal impact, they could choose between 1) Yes, my research team or external users of my research were able to generate such a societal impact based on my FWF-funded research results, 2) the corresponding societal impact has not yet been realised, but there are ongoing activities or they could indicate that they 3) perceive no activities or developments in relation to the corresponding societal impact or 4) they do not know whether the research results of their FWF-funded projects are being used in this respect.

Overall, **58% of all respondents** (n=811 researchers) stated that their FWF-funded research has contributed to at least one of the specific societal effects mentioned above. Of these, 46% stated that they could link at least one of the societal effects mentioned to their FWF-funded research. The remaining 13% of researchers who reported at least one societal impact also indicated that they could additionally identify some ongoing activities related to another of these specific societal impacts. A further 14% could not yet identify any societal impact, but reported ongoing activities that could lead to one of the described societal impacts. The remaining 28% perceived neither ongoing activities nor a societal impact resulting from the FWF-funded research (including those who did not know).

Figure 20: **Realisation of a specific societal impact related to the researchers' FWF-funded project(s)**



Source: Survey of FWF researchers 2024. n = 1,386 researchers.

Researchers were asked to describe in their own words the specific societal impacts that resulted from their FWF-funded projects. The following is a condensed presentation of various examples of research projects for each of the seven areas of societal impacts. These are: regulatory changes, contributions to non-specialist media, cultural heritage, environmental improvements, health improvements, improved public defence/security, and 'other' societal impact as defined by the researchers themselves.

In addition, for each societal impact, the proportion of researchers indicating that their research had a societal impact at a) global, b) European Union/European Free Trade Association (EFTA) or c) Austrian geographical level is reported.

Changes of regulations

When researchers reported that their FWF-funded research had led to changes in regulation, they primarily mentioned new or revised laws in areas such as social benefits, environmental protection, and other specific policy domains. For example, one research project provided recommendations to political parties that influenced recent changes in electoral law. Additionally, a few studies influenced the development of new diagnostic and treatment guidelines issued by European and U.S. regulatory authorities. FWF-funded research also played a role in the implementation of anti-avoidance tax rules within the EU and OECD.

In the area of environmental regulation, FWF-funded research influenced revisions to Austria's Rules of the Air and the Act concerning Powers of the Military and led to changes in forest law regarding the definition of fire. Research also brought about notable changes in fisheries management and regulations affecting several Austrian lakes.

A few projects contributed to the creation of new norms or standards, such as modifications to the Austrian food pyramid and the establishment of a new standard file format, which has since been widely adopted by companies. Overall, the findings from some FWF-funded research projects have shaped policy debates and have been integrated by policymakers at European, national, and regional levels.

Furthermore, researchers were asked whether they could estimate the geographical scope of the improvement or change brought about by their research in terms of the respective societal impact. Of the researchers who indicated that their research had led to a change in regulations, one-third (31%) stated that the impact was noticeable at the global level. A similar proportion said the impact was only relevant at the Austrian level, and a quarter said the changed regulations mainly affected European Union/European Free Trade Association (EFTA) countries (25%). The remaining 15% said they did not know which geographic region would be primarily affected by the regulatory changes resulting from their research.

Contributions to media beyond specialist audiences

Researchers who indicated that their FWF-funded research contributed to public media frequently reported coverage across multiple media platforms. Many also noted that their research was featured not only in local and national outlets but also on an international scale. The majority of researchers highlighted coverage in newspapers, while some mentioned contributions to science magazines or books.

In addition to print media, numerous research projects were featured in radio or television broadcasts, as well as podcasts. Researchers were often interviewed about their FWF-funded work, with these interviews being disseminated across various media channels. In other instances, the research findings were referenced and discussed in the context of their broader public impact and significance.

Some researchers reported that their work was presented in panel discussions or public events, Examples mentioned that are aimed at a non-scientific audience are also the Austrian "Long Night of Research" lectures or science slam events. Contributions to social media were also mentioned, particularly in the form of YouTube videos.

A few projects were highlighted in documentaries, films or short films that were showcased in museum exhibitions, on television or via online streaming services. Some projects contributed to exhibitions, and a few were also integrated into theatrical or dance performances.

Researchers whose research contributed to a media coverage most frequently stated that it took place in Austria (37%). However, 32% of researchers also stated that their research led to a media report on a global level, while slightly fewer stated that their research was reported in EU/EFTA countries (27%, the remaining 3% did not know).

Cultural heritage

Researchers who reported that their FWF-funded research contributed to cultural heritage frequently highlighted their impact on both historical tangible and intangible culture.

Many projects focused on the conservation and documentation of archival materials and historic documents, significantly contributing to the preservation of historical tangible culture. This includes efforts in the recovery, preservation and collection of historical manuscripts, incunables, political documents, film materials, and audio recordings. In particular a significant number of projects aimed at protecting cultural heritage through digital conservation, such as creating databases or digital archives that offer global and free access to unique cultural objects for the broader public. Archaeological research was also highlighted, with projects dedicated to excavations and the protection and study of archaeological sites (see e.g. the case study in chapter 7.2).

Additionally, a few FWF-funded projects introduced important technological innovations. These included the application of advanced technologies like 3D laser scanning as new techniques in cultural heritage, and the development of sustainable and resistant data storage media to preserve cultural information for the long term.

Many researchers also highlighted significant contributions to the preservation and understanding of historical intangible culture. Several FWF-funded research projects provided valuable insights into heritage and culture by researching historical events and notable individuals, revealing new historical information.

Other researchers focused on the documentation and reconstruction of historic languages and dialect speech, as well as the collection of language data from underrepresented languages. Additionally, the documentation of cultural practices, such as historic printing techniques, played an important role in preserving intangible cultural practices.

Some researchers noted their contributions through contemporary events, such as museum exhibitions, as well as conferences and discussions that fostered intercultural exchange. A few research projects also produced contemporary materials, including books, films, and music compositions. Additionally, many researchers emphasized that their FWF-funded research contributes to cultural heritage by generating new scientific discoveries or technologies that will hold significance for future generations.

Most researchers who stated that their research has contributed to cultural heritage considered it to have had an impact on a global level (55%). About one-third of these researchers assigned it primarily to the EU/EFTA countries (30%), and 13% perceived an effect only in Austria (13%) (the remaining 1% of researchers did not know). Researchers sometimes assigned similar results in the fields of history, linguistics, or anthropology to different geographical levels. If the respective research concerns the interaction of different cultures or the history of human development, or if it leads to the creation of online databases, these projects were generally considered to have a global impact. Exhibitions, and linguistic or historical findings of a particular (e.g. German, Austrian) culture, on the other hand, are more likely to be assigned to the Austrian or European level.

Environmental improvements

Researchers who reported that their FWF-funded research led to environmental improvements most frequently highlighted contributions to biodiversity, such as protecting habitats for endangered species. They also emphasized efforts in nature conservation and the development of technologies that provide a deeper understanding of important organisms. Additionally, some projects focused on studying soil and fertilizers to promote sustainable agriculture and protect the environment.

Other significant environmental improvements included reducing CO2 emissions and optimizing material and energy use, often achieved through the development of new materials or more efficient and cleaner production processes. Furthermore, several projects aimed to enhance understanding and public awareness of climate change impacts, as well as to develop protective measures against severe weather events, such as models for better forecasting and monitoring of severe space weather impacts.

A few FWF-funded projects also concentrated on improving water quality, including research and monitoring efforts related to water pollution. In addition, the development of new tools and technologies in the traffic and construction sectors was highlighted. Some projects also had an educational impact, providing valuable information about environmental issues to students, teachers, and the general public.

Half of the researchers who stated that their research has contributed to environmental improvements cited a geographical impact at the global level (48%). A quarter of these researchers stated that their research mainly has an impact on EU/EFTA countries (25%), and 18% observed an impact mainly in Austria (the remaining 8% of researchers did not know). Researchers working in a similar research area have sometimes attributed different geographical impacts to their work. For example, while CO_2 reductions, new technologies for simulating environmental events or for removing toxic substances from soil and plants are particularly often seen as having an impact at the global level. Likewise, similar examples were also cited by researchers who see an impact only at the EU/EFTA level. At the Austrian level, the reduction in resource utilisation and the protection of special species are frequently described.

Health improvements

When researchers reported that their FWF-funded research had led to health improvements, they primarily cited advancements in treatments and diagnostics. For instance, some research led to better predictions of treatment responses and the development of improved monitoring methods. Additionally, several projects contributed to a better understanding of disease pathogenesis and the impact of various treatment methods. A few researchers also noted increased patient safety due to the use of advanced materials. Furthermore, some researchers highlighted health improvements achieved through the development of new drugs and therapeutic methods.

Many FWF-funded projects also led to the creation of improved technologies for disease detection. Examples include the enhancement of screening technologies for some diseases, the identification of new disease-relevant genes, and the development of novel sensors for biomarker detection.

In addition to these advancements, some researchers emphasized that their work contributed to raising public awareness of certain health issues, such as increasing empathy for dementia within society or highlighting pregnancy-associated diseases. A few projects also provided insights into the influence of lifestyle factors on health, particularly regarding dietary habits and nutritional health. Moreover, several projects highlighted improvements in food safety or even suggested a potential increase in quality-adjusted life years as a result of their FWF-funded research.

Most researchers whose FWF research has contributed to health-related social improvements stated that it has had an impact at the global level (68%). Furthermore, 15% of these researchers stated that their research primarily has had an impact at the EU level, and 11% stated that it only has had an impact in Austria (the remaining 6% of researchers did not know). It stands to reason that the treatment and diagnosis of diseases, the development of new drugs or the improvement of diagnostic techniques are more likely to have an impact at the global level.

Improved defence/security of the population

Several researchers indicated that their FWF-funded research has contributed to improvements in the security of the population. For instance, some projects focused on the development of new or enhanced technologies for protecting sensitive data, such as novel methods to safeguard systems against side-channel attacks and improvements in corporate cybersecurity, thereby enhancing public well-being in the digital realm.

One project developed advanced technology for monitoring potential threats in crowds, while another improved the simulation for predicting refugee movements, which can help to target humanitarian relief measures more effectively.

A few researchers highlighted their contributions to enhancing protection against space weather events and other natural hazards, such as more accurately identifying areas with high fire risk. Some also noted that their research has led to a deeper understanding of specific health risks and environmental improvements, both of which indirectly enhance population safety.

Additionally, a project reported improvements in population defence and security through the revision of a relevant law.

No examples of specific military technologies have been mentioned. One project was more concerned with revising the Military Authorisation Act, whereby the use of commercially developed products was at issue. Examples were mainly given of technologies, risk management methods and regulations that revolve around public health, environmental hazards, as well as data security.

Improvements in the area of increased public safety were predominantly seen as having an impact at the global level (56%). Around one fifth of researchers with impacts in the area of improved defence/security stated that these improvements only had an impact on EU/EFTA countries (19%). Only slightly fewer researchers stated that the impacts were only noticeable at the Austrian level (17%), with 8% of researchers stating that they did not know.

Other societal impact

Researchers who reported other societal impacts from their FWF-funded research primarily emphasized the educational benefits of their work. Many engaged in outreach activities, such as delivering lectures to primary and secondary school students and participating in programmes like Children's University. Others gave talks at high schools, universities, and public events to inspire interest and curiosity about their research and the scientific field. Additionally, some researchers conducted guided tours for children, university students, and the general public, while others offered summer internships for high school students. Some projects also provided courses in adult education. Several FWF-funded research projects contributed to the development of educational materials, including schoolbooks, online courses, and teaching aids.

Researchers also emphasized the training of master's and PhD students, who gained essential technical, scientific, and presentation skills, preparing them for successful careers in research and ultimately benefiting society. Additionally, several researchers noted that their work was cited in other publications or inspired further research.

Beyond academia, researchers shared their findings with activists, policymakers, and social groups, broadening the societal impact of their work. Some research findings were also showcased through exhibitions and public events, and some researchers noted that their work even inspired artists to create various art pieces.

Cultural and historical impacts were observed, with researchers raising awareness of contemporary societal issues. For example, a few researchers reported societal impacts through discussions on the status of women in contemporary society and highlighted the support of female scientists through FWF funding.

Some FWF-funded projects had a direct impact on local communities, such as through a participatory film production that strengthened community bonds. A few projects even led to the creation of initiatives focused on environmental issues or interreligious dialogue.

As with most societal impacts, researchers reporting 'other' societal impacts were most likely to report an impact at the global level (40%). Almost a third of researchers reported that their research had an impact mainly in Austria (27%), and the same proportion reported that their research had the more specific 'other' societal impact only in EU/EFTA countries (27%). The remaining 6% stated that they did not know.

Artistic and creative products

Between 2014 and 2023, 594 artistic or creative works were created as part of FWF projects, which were reported in the FWF researchfish survey when the final project reports were submitted. Artworks (146) were registered most frequently in this category, followed by 137 performances (music, dance, drama, etc.) and 117 artistic/creative exhibitions. In addition, 81 films/videos/animations, 49 artefacts (including digital), 46 compositions/scores, 10 creative writings and 8 images were reported. However, the vast majority of these results were also reported in 2018/19, meaning that the years before and after are probably significantly underreported. In 2018/19 alone, 245 works were reported, which is 41% of the entire period from 2014-2023. Not all artistic-creative products originate from artistic projects. In some cases, films, podcasts or exhibitions, for example, also originated from projects in other disciplines.

Some of the creative works submitted were described in great detail. The following figure shows the most frequently used words in these descriptions. As can be seen, "research", "data" and "technology" play at least as big a role here as artistic terms.

Figure 21: **Word Cloud from the descriptions of the reported creative product**

Source: FWF–Researchfish Survey at the end of projects.

4.4.2. Steps towards realising the societal impact

Researchers who named at least one concrete societal impact their FWF-funded research contributed to, were asked if they can identify how their research became relevant for the realisation of the respective societal impact and how many years this realisation took from the first research stages to the final application.

In the final section of this chapter, only those researchers who indicated that their research had not yet contributed to a societal impact but stated that "there are ongoing activities" (see

Figure 20), provided an assessment of how close or far away they think the societal follow-up activities are in terms of time.

How FWF-funded research became relevant for a societal impact

Researchers with FWF-funded projects were asked how their research achieved the societal impact they had previously stated. They could choose from a predefined list (see Figure 22) and describe in their own words in an open field how their research was able to achieve the respective societal effect.

Most researchers stated that their research became known through a using organisation (68%). The second most important way in which research funded by the FWF became relevant is by the researchers' own efforts to develop and apply the gained knowledge (66%). Far less researchers stated that collaborative research and further development with non-academic organisation helped to contribute to a societal impact (45%). And still one in five researchers reported that their research became used through an open-source platform (21%).

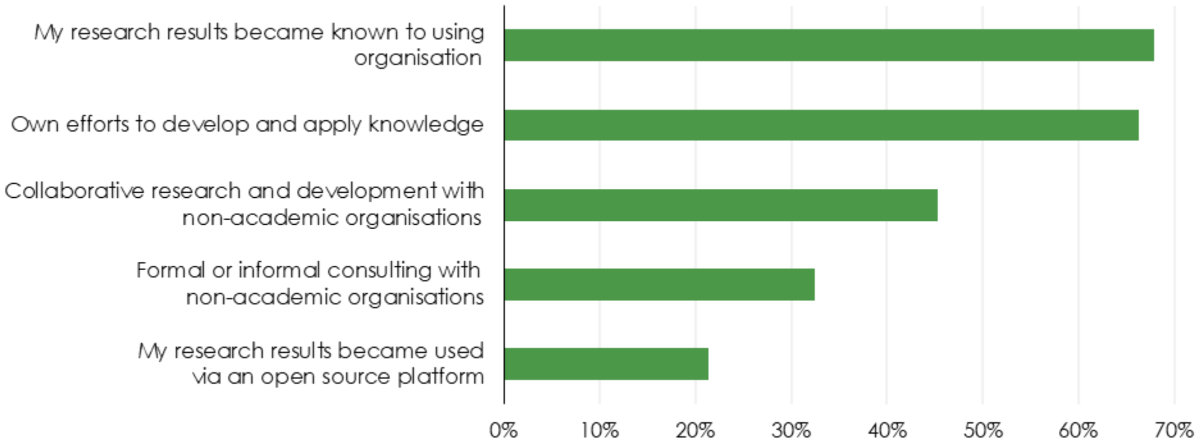
Researchers also provided some additional input and examples of how their research became relevant for a societal impact. They named a diverse array of media formats to disseminate their findings, including mass media outlets such as newspapers, podcasts, social media platforms like Twitter, and project-specific websites. Collaborations with newspapers and public broadcasters helped communicate research to wider audiences, while multilingual web journals, popular books, and documentary films offered more in-depth engagement. Additionally, press releases, high-impact journal publications, and online participation tools, such as CO2 calculators, provided both academic and non-academic platforms for presenting scientific results and fostering public involvement.

Many mentioned the importance of training and employment of Master and PhD students as well as staff exchanges with, for example, Erasmus programmes. But also, cooperations with schools and the involvement of the local population was mentioned as fundamental for the dissemination and application of knowledge.

Another area that was frequently mentioned was cooperation with other (international) organisations, campaigns or popular brands such as Fairtrade Austria, the Science Art Festival or the "Women in Science" campaign.

The benefits of open access formats and publications for the dissemination of results were repeatedly emphasised. The same applies to cooperation with museums and libraries for exhibitions with research-related art or findings. In addition, consulting services provided by researchers or giving lectures were also considered important for generating a societal impact.

Figure 22: **Only those with a concrete societal impact: How FWF-funded research became relevant for achieving societal impact**



Source: Survey of FWF researchers 2024. Multiple answers possible. n = 760 researchers who indicated at least one societal impact.

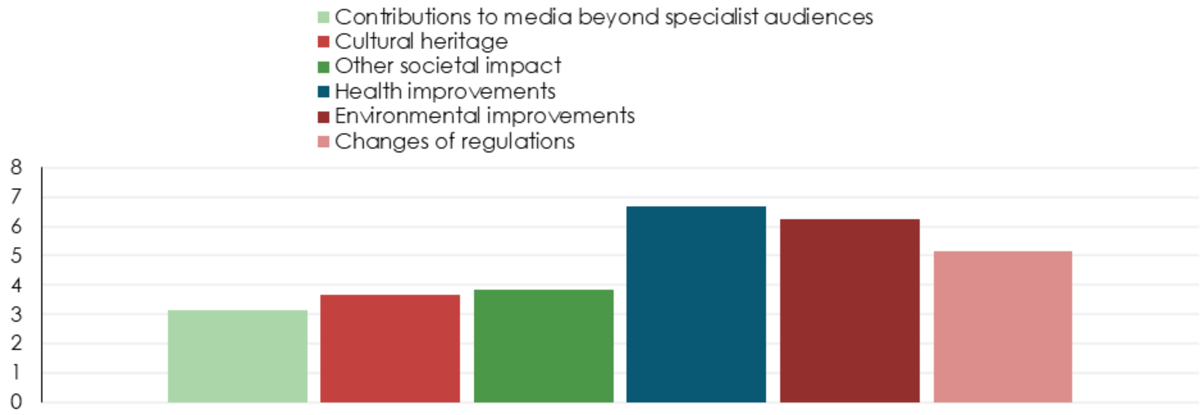
Researchers in arts & humanities (72%), computer sciences (71%) and physics (70%) were most likely to report that their own efforts to develop and apply knowledge were relevant (Ø 66%). For those in social sciences and engineering (58% each), arts & humanities (53%) and agriculture & veterinary (51%), collaborative research and development with non-academic partners is particularly important (Ø 45%). Not surprisingly, open-source platforms (e.g. GitHub, Bitbucket etc.) play a comparatively important role for researchers in computer sciences (38%) and mathematics (33%), but also for those in the arts & humanities, engineering and physics (26% each vs. Ø 21%).

Years it took from the first research results to the societal impact(s)

Researchers who indicated specific societal impacts were asked to estimate how many years had passed between the first relevant research results and the indicated societal impacts (regardless of when the FWF funding took place).

While the average duration for different economic impacts was quite similar (see Figure 15), the duration of realisation varies more among the different societal impacts. While the projects financed by the FWF usually end up in the media 3.1 years after the first relevant research results, it takes longer for the research to have a significant impact on health promotion on broad scale (Ø 6.7 years, see Figure 23).

Figure 23: **Only those with a concrete societal impact: Number of years it took from the first relevant research results until the specific societal impact**



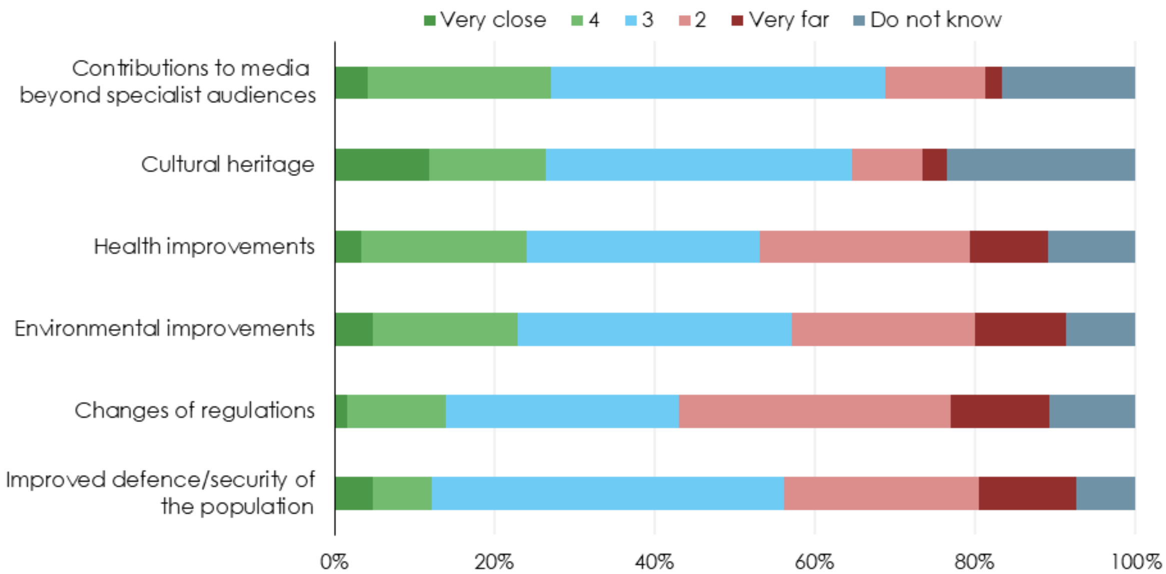
Source: Survey of FWF researchers 2024. For the societal impact 'improved defence/security of the population' the case number was too low (n<30). n=1,133 answers. One researcher could have more than one concrete economic impact.

Closeness to final societal impact

Researchers who indicated that they are aware of ongoing activities related to any specific societal impact were asked to assess of how close or far away they think the societal follow-up activities are in terms of time.

Figure 24 shows that researchers who indicated that their FWF-funded research is on the verge of making a contribution to the media are more likely to be realised soon (27% very close or close). While changes in regulations and a contribution to improved defence or security of the population are more in the initial phase or have just begun the realisation process.

Figure 24: **Only those with ongoing activities to realise a concrete societal impact: Closeness of follow-up activities to have an impact on society**



Source: Survey of FWF researchers 2024. For the 'other' societal impact the case number was too low (n<30). n = 468 researchers.

4.4.3. Barriers faced by researchers in achieving a societal impact

The following analysis includes only researchers who could identify that any specific societal impact resulted from their FWF-funded research (see Figure 25).

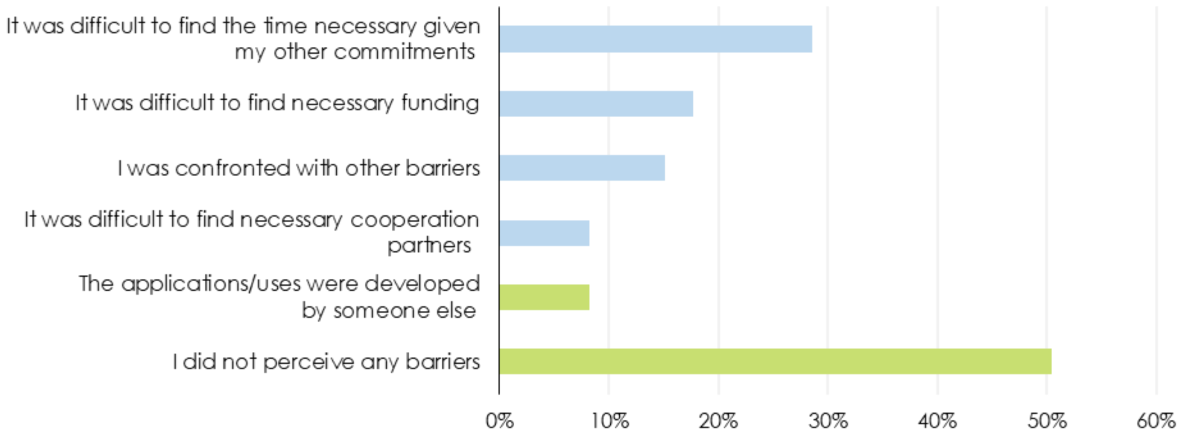
Not surprisingly, half of the researchers who were able to achieve a tangible societal impact stated that they had not perceived any of the obstacles listed (50%) or that others were using their research results to achieve such a societal impact (8%), and therefore they themselves did not. However, one-third of researchers whose research had a societal impact perceived a lack of time due to other commitments (29%) as an obstacle. In addition, 18% stated that it was difficult to find the necessary funding.

According to the researchers' own statements in the open response field, barriers to realise a societal impact based on their research results often arise from resistance from various interest groups that hinder the acceptance and implementation of research results, while societal taboos and ideological biases limit engagement with certain scientific topics. Furthermore, a lack of interest and willingness to adopt necessary reforms or technologies further exacerbates these challenges and often hinders progress in areas such as environmental sustainability and social inclusion.

However, there were also several cases in which difficulties within the institution or research group were reported. These ranged from unspecific statements that their own institute was not helpful or that certain regulations were a barrier, to specific examples of individual colleagues who stood out due to a lack of willingness to cooperate or discriminatory behaviour. Poor cooperation within one's own research group and with other relevant actors was repeatedly identified as another factor. Overall, institutional or structural barriers were mentioned very often, reflected in time-consuming bureaucratic requirements, financing problems or slow processing.

Researchers in computer sciences were more likely to report difficulties in finding the necessary collaborators (14 % vs. Ø 8%), as were researchers in chemistry, social sciences and medicine (all 10%). Those researchers with FWF-funded projects in the fields of physics (13%) and mathematics (11%) were more likely to report that their research had been used by others. Researchers in the fields of geosciences (59%), mathematics (56%), physics, biology and medicine (all 55%) were the least likely to perceive any obstacles (Ø 50%) to generate a societal impact.

Figure 25: **Only those <u>with</u> a concrete societal impact: Perceived barriers to achieving a societal impact from FWF-funded research results**



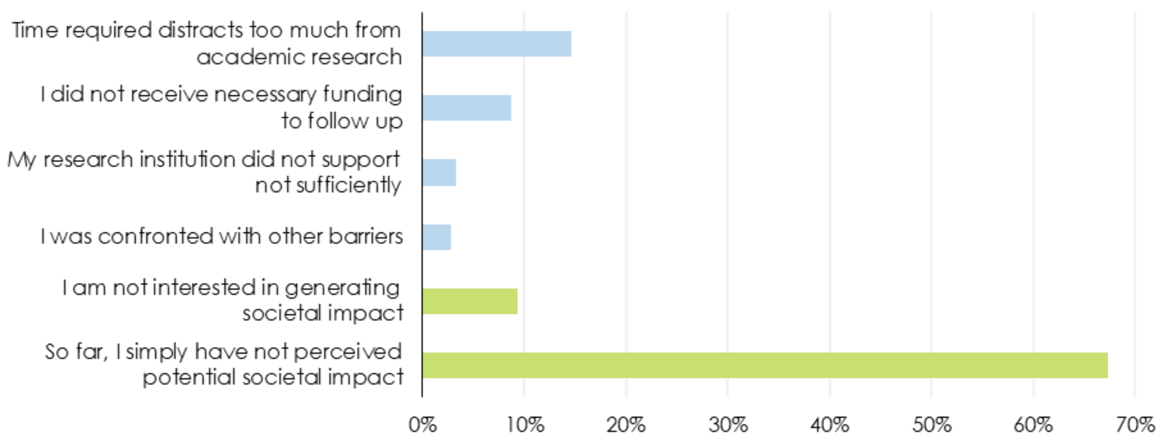
Source: Survey of FWF researchers 2024. Multiple answers possible. n = 752 researchers (who indicated at least one concrete societal impact).

The following analysis includes only researchers who could *not* associate any specific societal impact with their FWF-funded research (see Figure 26).

Two third of them stated that they simply did not perceive any potential to generate a societal impact based on their research results (67%), and only 9% indicated that they are not interested in having a societal impact with their FWF-funded research projects.

Those who wanted to achieve a societal impact but were unable to do so due to obstacles most likely cited that working on achieving a societal impact would distract them too much from their academic research (15%). Only few report that they had too less funding and only very few identified a lack of support from their research organisation as an obstacle to realising their plans (3%).

Figure 26: **Only those <u>without</u> a concrete societal impact: Perceived barriers to achieving a societal impact from FWF-funded research results**



Source: Survey of FWF researchers 2024. Multiple answers possible. n = 538 researchers (without a concrete societal impact).

4.5. Results – Impact through human resources

The educational and training function of FWF-funded research probably achieves some of the biggest economic and societal impacts in terms of building and applying knowledge for society and the economy. It requires people who have sufficient skills in a wide range of areas as well as in research and development.

Many researchers emphasised the importance of research-based training for students and young researchers in the context of FWF-funded projects. They stated that alumni and former team members are essential for the dissemination of knowledge and that the opportunities provided by FWF-funded research are often highly significant for further career steps of those researchers. In addition, the surveyed researchers also mentioned how academic staff financed by FWF projects later founded companies based on the results.

In this section, the answers of the surveyed researchers regarding their project team members of the FWF-funded projects they led between 2009 and 2022 are reported.

4.5.1. Knowledge transfer through job changes of former FWF-funded project team members

A knowledge transfer resulting from a change of workplace by researchers who have worked in FWF-funded research and are now employed in different areas is likely to have a high social and economic impact, but this is difficult to measure in practice in the absence of systematic "alumni" tracking, such as based on social security numbers (see for example Atrack, the graduate tracking of Austrian universities together with Statistics Austria, Statistics Austria 2022). The following section attempts to describe a pattern of the whereabouts of former FWF-funded project staff that suggests how the knowledge gained from working on FWF projects may have spread.

The researchers were asked whether they know in which area one of their (former) team members of their FWF-funded research are working at the time of the survey. In this way, an attempt can be made to identify a network of knowledge.

Researchers could select if their former team member's new jobs is: a) still at their own research team, b) is at another research team, but at the institution where the FWF-funded project was carried out, c) at another university/research institution, d) a for-profit company (e.g. a start-up) or e) a non-profit organisation (e.g. NGO), or f) in public administration. In addition, they should state if they work in the respective area in Austria or abroad.

Most frequently, the project leaders reported that their former team members in FWF-funded projects are now working at another university/research institution abroad (50%). However, 38% of project leaders also report that at least one former team member is working at another university or research institution in Austria.

If former team members remain in the research group of the principal investigator of FWF-funded projects, then this is particularly the case if the research group is in Austria: 43% of the project leaders know at least one team member who remained in Austria in their team, but only 12% of the project leaders stated that team members remained with them in their research group if these research groups are abroad.

On the other hand, it is relatively rare for someone to move to a different team within the same research institution: 32% of project leaders know of team members who have moved to a different team within an Austrian institution where their FWF-funded project was carried out, and 11% of project leaders stated that team members are currently working in a different research group but at the same institution if it is abroad.

Another popular field of work for former team members after their work on the FWF-funded project is the for-profit private sector (e.g., a company or start-up), with 40% of project leaders knowing of at least one team member who has remained in Austria working for a private company, while 18% know of team members who have gone to a company abroad.

Table 6: **Proportion of project leaders that know at least one of their former team members currently work in one of the listed working areas, divided by in Austria and abroad**

Former team members working …	In Austria	Abroad
… in the research group of the project leader	43%	12%
… in another research group at the institution where the project was carried out	32%	11%
… at another university/research institution	38%	50%
… at a for-profit company (e.g. a start-up)	40%	18%
… at a non-profit organisation (e.g. NGO)	10%	5%
… in public administration	20%	6%
other (unemployed …)	7%	3%

Source: Survey of FWF researchers 2024. Multiple answers possible. Researchers could also select "No" and "Don't know". The percentages relate to those who provided an answer for the respective area of work (varies by row). N=1,298 answered to at least one working area.

Working areas of former FWF-funded researchers by academic fields

The following percentages relate to the proportion of project managers who know where at least one former team member is currently employed. Researchers in the fields of agriculture & veterinary (53%), social sciences (46%), medicine (44%), arts & humanities (43%) and geosciences (42%) frequently **work at another university/research institution in Austria** (Ø 38%). Some team members from the fields of 'other' natural sciences (64%), biology (55%), physics (54%), computer sciences (53%), and mathematics (52%) more often went to another university/research institution **abroad** (Ø 50%).

For-profit companies in Austria (e.g. start-ups) seem to be most frequently chosen by at least one former team member in the fields of computer sciences (57%), physics (56%), agriculture (53%), chemistry (53%) and 'other' natural sciences (50% vs. Ø 40%). Furthermore, researchers who have worked on FWF-funded projects in the fields of computer sciences (28%), chemistry (26%) and physics (22%) are also particularly likely to work for a for-profit company **abroad** (Ø 18%). In addition, team members from the field of engineering are also among those who most often work for a company abroad (26%). Former team members from arts & humanities and social sciences are the least likely to work for a for-profit company.

In comparison, researchers from social science (28%) and arts & humanities (17%) are the most likely to work for **a non-profit organisation in Austria** (e.g. an NGO), and former team members from computer sciences (12%) are also more likely than average (Ø 10%) to work in this area of work, according to their former project leaders. If the non-profit organisation is based **abroad**, former team members from the fields of geosciences (16%), 'other' natural sciences (15%), social sciences (10%) and biology (7%) are more likely to have gone there (Ø 5%).[9]

Work in **public administration in Austria** (Ø 20%) seems to be attractive for former team members in agriculture & veterinary (42%) and geosciences (42%), as well as for researcher in 'other' natural science (28%), arts & humanities (25%), biology (24%), and social sciences (23%). When the workplace in public administration is **abroad** (Ø 6%), team members from the social sciences (11%), biology (8%), chemistry (8%) and geosciences (7%) have been particularly likely to go there, according to their former project leaders.

[9] The case number for agriculture & veterinary was too low for analysis by non-profit organisation (n<30).

Overall, it can be said that the former team members are broadly distributed across all possible areas of employment in Austria and abroad, even if it is always just 'at least one' person.

Working areas of former FWF-funded researchers who remained in Austria

While the above analysis only shows that *at least one* former team member moved to the specific working area, the second question takes proportions into account (see Table **7**7): project leaders (PI) funded by the FWF were asked to estimate the percentage of their former team members who have moved to a particular field – but only for those who continue to work in Austria.

Despite the higher accuracies regarding the percentage distribution, it must be borne in mind that only about half of all respondents provided a valid answer (n=680). However, what is still apparent is a broad affirmation of the results described above.

Among the former research team members who remained in Austria, the majority remained in the PI's former research team (26%) and an equal number have gone to another Austrian university or research institution (23%). In addition, a similar number have moved to an Austrian for-profit company (25%). It is much less common for those who remained in Austria to work for a different research group at the same Austrian institution where the FWF project was carried out (13%). And only a small proportion switched to public administration (7%) in Austria. Beyond that, only 3% went to a non-profit organisation or indicated an 'other' employment area, i.e. these team members are possibly not in employment (as far as the project leaders know).

Table 7: **Only those former team members currently working in Austria: Areas of work to which former members of FWF-funded project teams switched, estimated by project leaders in percentage shares**

	Ø proportion of former team members now working …
… in the research group of the project leader	26%
… at a for-profit company (e.g. a start-up)	25%
… at another university/research institution	23%
… in another research group at the institution where the project was carried out	13%
… in public administration	7%
… at a non-profit organisation (e.g. NGO)	3%
other (unemployed …)	3%

Source: Survey of FWF researchers 2024. Question items (area of work) were only shown if respondents selected "in Austria" before. n = 680. Only those researchers whose indications sum up to 100% in total.

Team members from the fields of medicine (29%), geosciences, biology and social sciences (28% each) more often than average **remained in the project leaders' research group** (Ø 26%) in Austria.

By comparison, former research team members in the fields of agriculture & veterinary (30%), arts & humanities (29%), and social sciences (26%) were more likely to transfer to **another Austrian university or research institution** (Ø 23%).

In particular, a large proportion of team members in the fields of chemistry (53%), physics (48%), computer sciences (36%), and mathematics (34%) move to a **for-profit company**, according to their project leaders (Ø 25%).

4.5.2. Number of academic degrees resulting from FWF-funded projects

Of all the researchers surveyed, the majority stated that their FWF-funded project(s) contributed to at least one degree in their own research group (81%). Only 14% of researchers stated that not even one team member of their project(s) completed a degree in the context of their project(s), and 5% stated that they do not know.

A total of 4,021 master's degrees were realised within the context of the surveyed FWF-funded projects. This is 3.1 master's degrees per surveyed project leader who answered to this question. In this question, the respondents were explicitly asked not to include any doctoral programmes in their calculations. Nevertheless, a total of 3,136 doctoral degrees could be realised based on the surveyed FWF-funded research projects, according to the project leaders. This corresponds to 2.3 PhD degrees per surveyed project leader. In addition, 835 habilitations were acquired in the context of or based on the results of the surveyed FWF-funded projects, i.e. 0.6 habilitations per surveyed project leader. Linking the number of Master degrees and PhDs to the survey results above on where former project team members currently work, this would imply that FWF-funded research projects have contributed to training about 1,750 people who now work in industry or start-ups, i.e. about 5% of employees in R&D departments of firms according to the R&D survey 2021 of Statistics Austria.[10]

Table 8: **Estimation by the project leaders: Number of degrees to which FWF-funded projects contributed (only in the own research group)**

Master	PhD*	Habilitation
∑ 4,021	∑ 3,136	∑ 835
Ø 3.1	Ø 2.3	Ø 0.6

Source: Survey of FWF researchers 2024. *Without doctoral colleges. Ø per researcher who answered to this question, including those who selected “None” and “Do not know”.

On average, projects in the field of biology contributed to the most master's degrees (4.6 master's degrees compared to 3.1 on average), followed by projects in the fields of chemistry and social sciences (4.1 each). In comparison, project leaders in arts & humanities (1.6) and mathematics (2.1) involved bachelor students who completed their master's degree on the basis of FWF-funded research less often.

Doctoral degrees based on FWF-funded projects also frequently come from the fields of chemistry (3.4 vs. Ø 2.3) and biology (2.9). Other disciplines that make a significant contribution to doctoral degrees within the framework of their FWF-funded research are physics (3.0), and computer sciences (2.8).

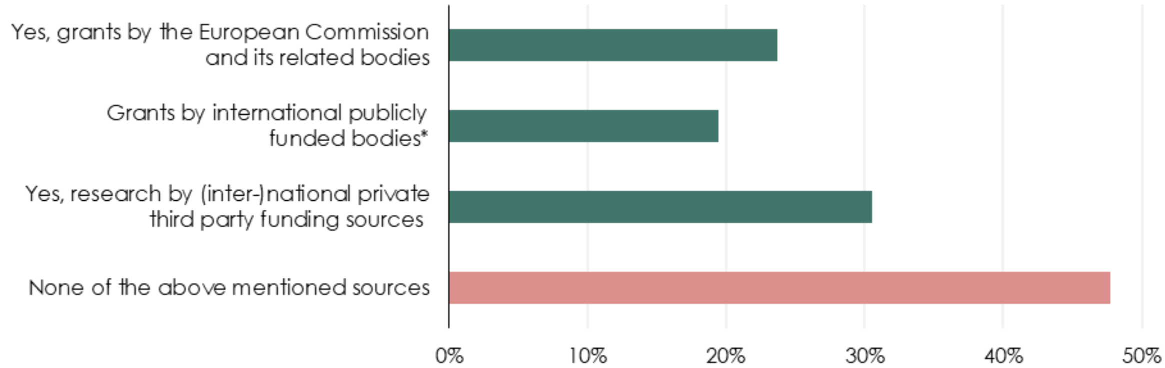
In contrast, research in the arts & humanities funded by the FWF is among the academic disciplines that led to habilitations more often than average (0.7 vs. Ø 0.6). However, researchers in the social sciences (0.8) and mathematics (0.7) were even more likely to complete a habilitation based on FWF projects than researchers in the arts & humanities. The number for medicine is the same (0.7) as for research in arts & humanities. A habilitation was generated least frequently in the ‘other’ natural sciences, engineering and agriculture (0.5 each).

[10] https://www.statistik.at/en/statistics/research-innovation-digitalisation/research-and-experimental-development-rd/rd-in-all-economic-sectors/rd-in-the-business-enterprise-sector

4.6. Further funding based on the results of the FWF-funded projects

International or national private follow-on funding can be regarded as an "economic impact" outside academia. Half of the researchers (48%) stated that they had not received any follow-on funding from either the European Commission or another international publicly funded institution or from a (inter-)national private third party (see Figure 27). Among those surveyed, funding from a private third-party is the most common type of follow-up funding after FWF-funded projects (31%). This is followed by funding for further research in the similar topic from the European Commission (24%) and grants from other international public funding bodies, which were still cited as a source of follow-on funding by 19% of the project leaders.

Figure 27: **Follow-up financing by different types of third parties based on the results of the FWF-funded projects**



Source: Survey of FWF researchers 2024. *other than the European Commission. By international and national private third-party funding sources, e.g., firms, foundations are meant. Multiple answers possible, "None of these" was exclusive. N = 1,318.

Project leaders from the field of physics (36%), 'other' natural sciences (34%), agriculture & veterinary (33%), and engineering (32%) were the most likely to receive European Commission funding (Ø 24%). In contrast, those in the arts & humanities (12%) and social sciences (22%) were less likely to report having received funding from the European Commission and its related bodies.

Once more, project leaders from the field of agriculture (38%), and 'other' natural sciences (27%), and from the field of geosciences (27%), most frequently report third-party funding from an international public funding organisation other than the European Commission. By contrast, project leaders in the fields of chemistry (13%), social sciences (16%), and mathematics (16%) are the least likely to report this (Ø 19%).

Private third-party funding is most likely to be reported by researchers in the fields of computer sciences (46%), medicine (44%), 'other' natural sciences (43%) and engineering (38%). And least often by project leaders of FWF-funded projects in the field of arts & humanities (23%), and social sciences (25%, Ø 31%).

Project leaders in the humanities (59%), social sciences (53%), mathematics (52%), and geosciences (52%) were most likely to report that they did not receive any of those third-party funding after their FWF-funded projects ended.

4.6.1. Amount of all the third-party funding incomes

The researchers were asked to estimate the amount of third-party funding that they could obtain for their research team(s) from the sources indicated (see Figure 27) because of the projects they have been conducting between 2009 and 2022 with FWF funding.

In total, researchers indicated an amount of third-party funding with a mean of € 711,484 and a median of € 350,000.

5. Direct and indirect use of FWF-funded research results in inventions

In this section, we first analyse self-reported use of FWF-funded research results for inventions, that is FWF-funded researchers directly applying their research to patented inventions. In the second step, we look at patents in the Lens database which cite publications that carry a funding acknowledgement to the FWF.

5.1. Analysis of direct use of FWF-funded results for inventive activity

The following information on patented inventions is based on information from both the survey we conducted and FWF's own data collection efforts, such as the information contained in the final project reports of FWF-funded researchers. In addition, we augmented the data by retrieving patents belonging to the same patent family, but not directly mentioned by FWF-funded researchers: an invention is often not protected by a single patent, but by several patents in different geographic jurisdictions.

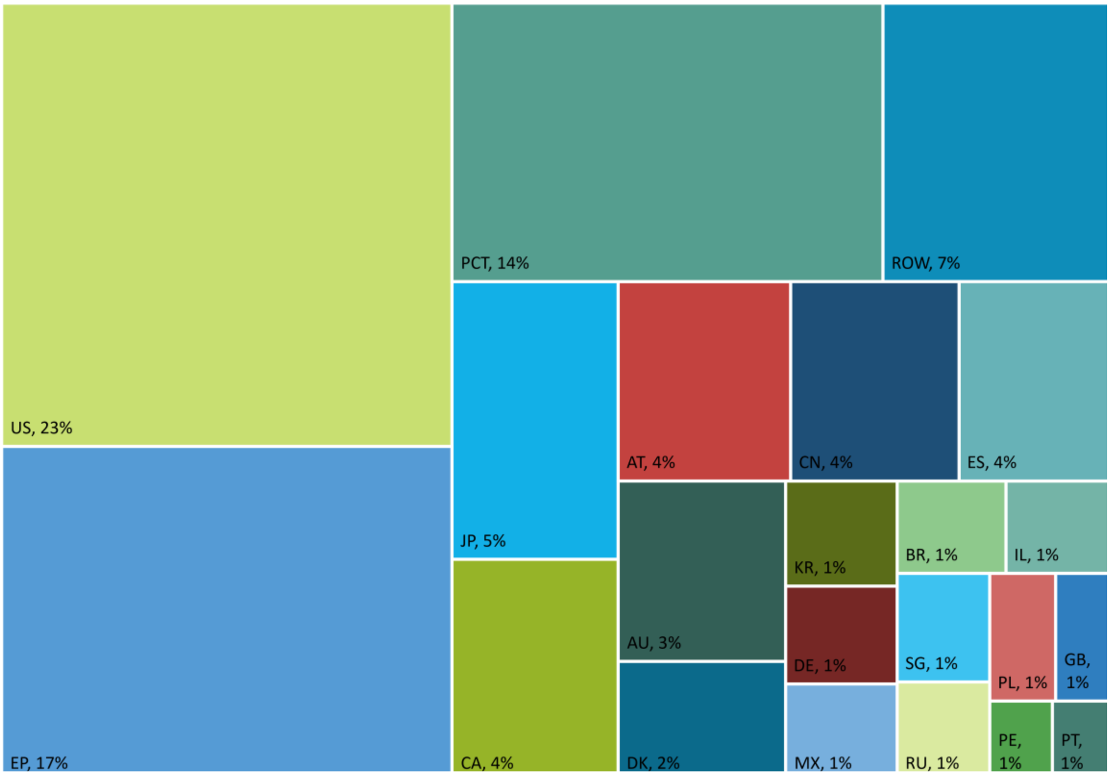
We use patents filed rather than granted due to the long time lags between patents filed and granted. Moreover, patents are an indicator of a potential application or use outside academia, a potential economic or societal impact. Filing a patent does not mean that the invention protected by it will actually ever be implemented in practice. Nevertheless, patent indicators are a central indicator of innovation activity (Nagaoka et al., 2010). In the following, we first show the number of total patent applications filed as a result of FWF-funded research, as well as their distribution over countries, time and technological classes. We refer to these patents as "FWF-patents" for the sake of brevity. As always, we don't exclude that research funded from other sources has also contributed to the patent, but we rely on the declaration of researchers of the patents as an outcome from their FWF-funded research. We then provide evidence to assess the quality of the patents, as measured by citations.

5.1.1. Quantity of patents based on FWF-funded research

Over a time period from 2000 to 2022, 1.025 patents have been filed directly based on FWF-funding, belonging to 189 unique inventions (Figure 28). Interestingly, the highest share of these patents has been filed at the USPTO, followed by the EPO. PCT refers to patents filed according to the Patent Cooperation Treaty. PCT patents are administered by the World Intellectual Property Organization. They allow inventors to seek patent protection in multiple countries simultaneously with a single application. Before they go on to the national registration, they can thus have more time to examine the viability of the invention. PCT patents are hence an indicator for potential future patents filed at national or regional patent offices such as the EPO.

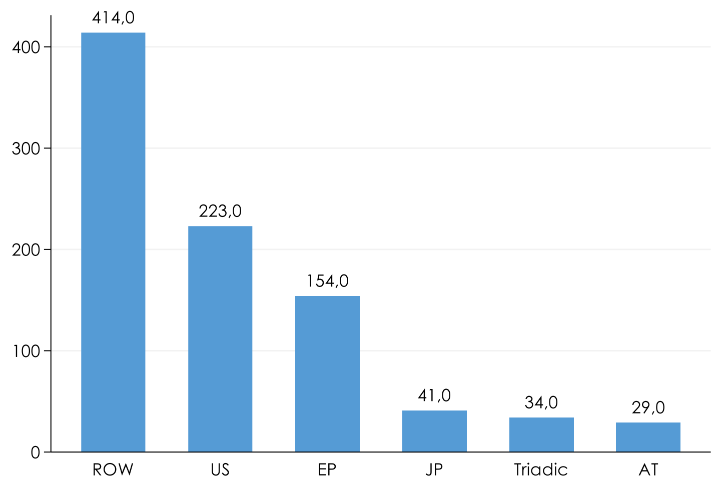
Restricting the timeframe to the survey period 2009-2022, we count 171 unique inventions leading to 861 patents at the patent offices listed in Figure 29.

Figure 28: **1.025 Patents filed based on FWF-funded research (“FWF-patents”), geographic distribution, total 2000-2022**



Source: FWF data (e.g. Final project reports), Survey, PATSTAT Autumn 2023, own calculation. All applications of a simple patent family are taken into account.[11] An invention can be registered in several (divisional) patent applications in one or more patent offices.

Figure 29: **FWF-patents filed per selected patent office, total 2009-2022**

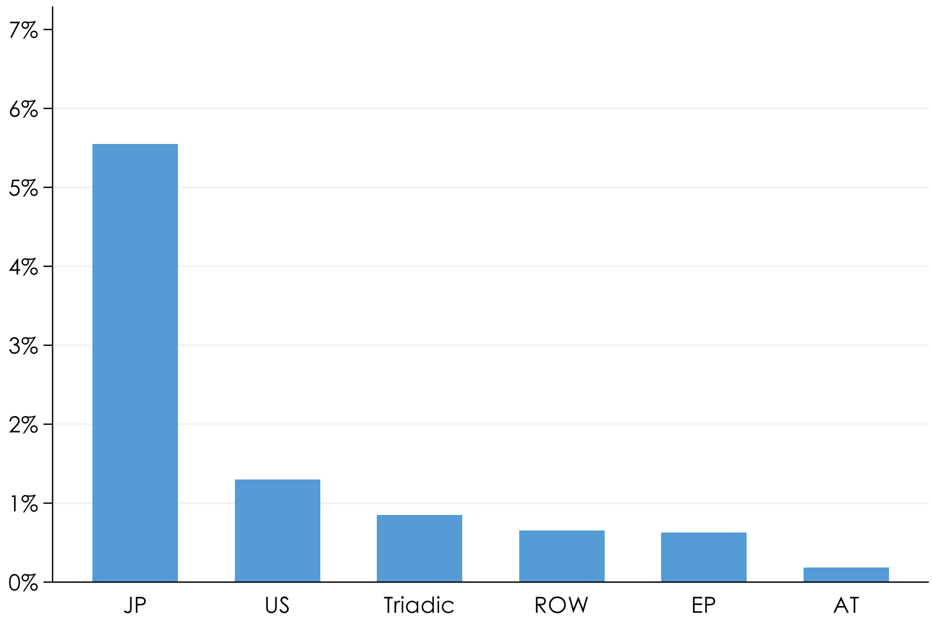


Source: FWF data (e.g. Final project reports), Survey, PATSTAT Autumn 2023, own calculation. ROW Rest of World. Triadic patents are patents filed at all three major “western” patent offices, USPTO, JPO, EPO. All applications of a simple patent family are taken into account. Triadic patent applications are counted both for the individual patent offices and for the triadic applications.

[11] A simple patent family contains applications for an invention (at different patent offices)

The next figure sets the FWF-patents in relation to the total number of patents filed by Austrian applicants (applicants residing in Austria). Of course these figures are low, as the FWF's goal is not to fund research that directly leads to patents. However, the higher share of FWF-patents in all triadic patents – patents registered at all three major patent offices – than in EPO patents, or Austrian patents, indicates already that FWF patents are on average patents with potentially broader commercialisiation opportunities. We will examine this more closely in the section on the quality of patents or inventions based on FWF-funded research.

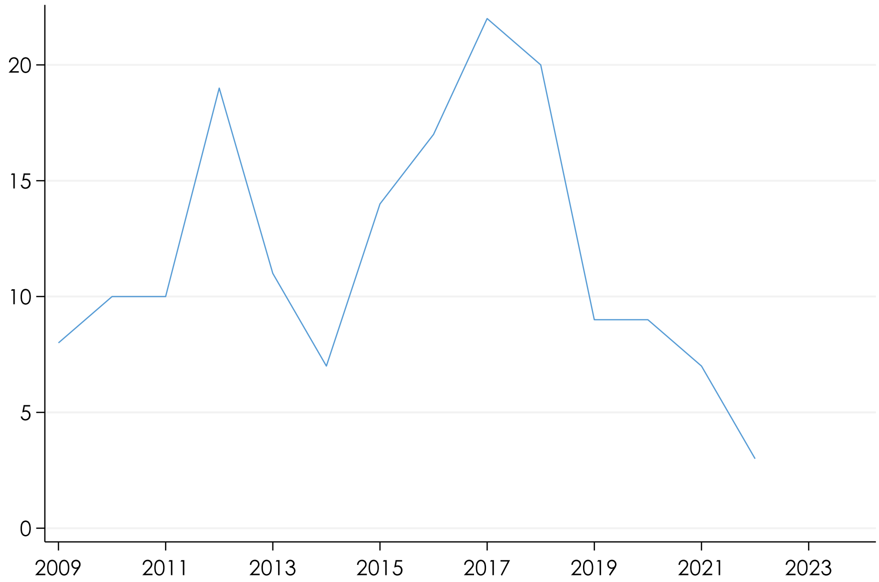
Figure 30: **Share of FWF-patents in total patents filed by Austrian applicants at selected patent offices, 2009-2022**



Source: FWF data (e.g. Final project reports), Survey, PATSTAT Autumn 2023, own calculation. ROW Rest of World. Triadic patents are patents filed at all three major "western" patent offices, USPTO, JPO, EPO. Triadic patent applications are counted both for the individual patent offices and for the triadic applications. All applications of a simple patent family are taken into account.

Figure 31 shows the distribution of the unique 167 inventions for which patents were filed over time. The decline at the end is a typical feature of patent data, as they only appear in the patent database with a time lag. There may also be a COVID-effect though, with empirical evidence pointing to a decline of innovation activities in Austria during COVID (Kügler et al., 2023; Reinstaller, 2021, 2022). On average, about 13 inventions come out directly from FWF-funding per year, in spite of FWF's quite "pure" basic research funding.

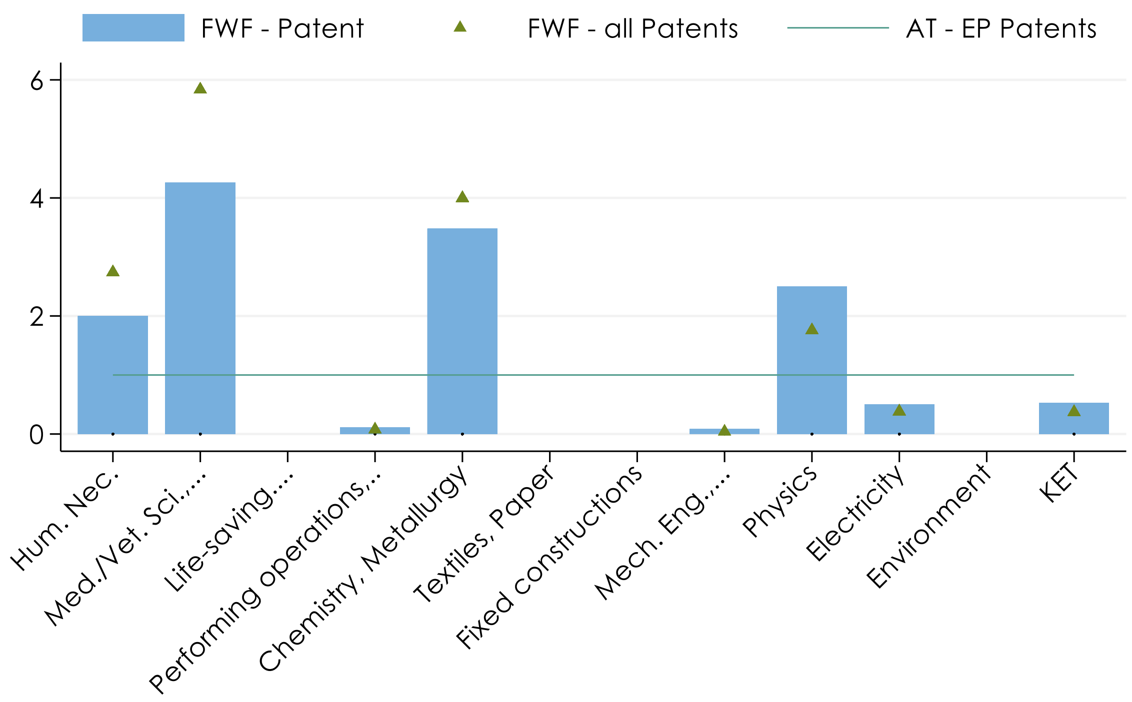
Figure 31: **Unique inventions for which FWF-patents were filed, per year 2009-2022**



Source: FWF data (e.g. Final project reports), Survey, PATSTAT Autumn 2023, own calculation. One application per simple patent family is counted. Patent is counted per first year of application within the family.

Figure 32 shows broad technological classes according to the IP classification of the WIPO, and the share of FWF-patents in all FWF-patents relative to the share of patents in that technological class by all Austrian application in total Austrian patents. This is a specialisation indicator, similar to the trade indicator revealed comparative advantage (RCA). FWF-patents are clearly more likely to be filed (RTA >1) in areas related to health & medicine, chemistry (with the important subclass biochemistry) and physics, reflecting the FWF's share of disciplines in funding (section 2) – a high share of medicine & natural sciences, whereas engineering takes a lower share, and engineering technological classes such as machine building, construction or electrical equipment all are clearly below 1 in the RTA indicator. The same holds true for key enabling technologies or environmental-related technologies.

Figure 32: **Share of FWF-patents in a technology class in all FWF-patents, relative to the share of patents by Austrian applicants in a technology class in all patents by Austrian applicants (=1) (revealed technological advantage, RTA), 2009-2023**



Source: FWF data (e.g. Final project reports), Survey, PATSTAT Autumn 2023, OECD (2020), IDEA et. Al (2012), own calculation. FWF – Patent: Patents that could be identified via FWF data or survey. FWF – all Patents: All applications of a simple patent family are taken into account. AT – EP Patents: Patents at the EPO from AT-applicants. Hum. Nec. = Human necessities (IPC Code A); Med./Vet. Sci.,... = Medical or veterinary science; Hygiene (IPC Code A61); Life-saving.... = Live saving; Fire fighting (IPC Code A62); Performing operations,..=Performing operations; Transporting (IPC Code B); Chemistry, Metallurgy (IPC Code C); Textiles, Paper (IPC Code D); Fixed constructions (IPC Code E); Mech. Eng.,... = Mechanical Engineering, Lighting, Heating, Weapons, Blasting (IPC Code F); Physics (IPC Code G); Electricity (IPC Code H); Environment = Environment-related Technologies; KET = Key Enabling Technologies.

5.1.2. Quality of patents based on FWF-funded research

Many patents are filed for inventions that are never commercialised, or are not even used or cited for follow-on inventions. Just looking at the numbers of patents protecting inventions can hence be a misleading exercise, in particular for assessing the FWF's impacts outside academia. To assess the use of patents by others, and hence their relevance or quality, citations from other patents are used (Jaffe & Trajtenberg, 2002; Unterlass et al., 2013). Table **9** compares patents directly based on FWF-funded research ("FWF-patents") with all patents filed at the EPO and at the USPTO in terms of citations received. Of course, the absolute numbers of patents filed are very different, but we see that FWF-patents are on average more often cited than company patents. At the EPO, FWF-patents achieve on average 15% more citations, at the USPTO it is even three times as many.

These differences come from the different ways the USPTO and the EPO work – at the USPTO, patent examiners try to integrate as many relevant references as possible, so that on average, USPTO patents come with more citations than EPO-based ones. The result of patents based on academic basic research being more relevant to follow-on inventions is not new. The existing empirical evidence (Poege et al., 2019; Trajtenberg et al., 1997) on science quality and the value of inventions, or on academic vs. firm patents, shows that patents based on basic research are – not surprisingly – technologically broader and usually protect inventions which are potentially more far-reaching, relevant for a broader set of follow-in inventions. This is in contrast with company patents, which may be more specific, protecting an incremental improvement (Henderson et al., 1998). The downside of course is that academic patents may be further away from commercialisation. The results are also in line with Austrian university patents (Arnold et al., 2022; Janger, Firgo, et al., 2017), and there is likely to be significant overlap.

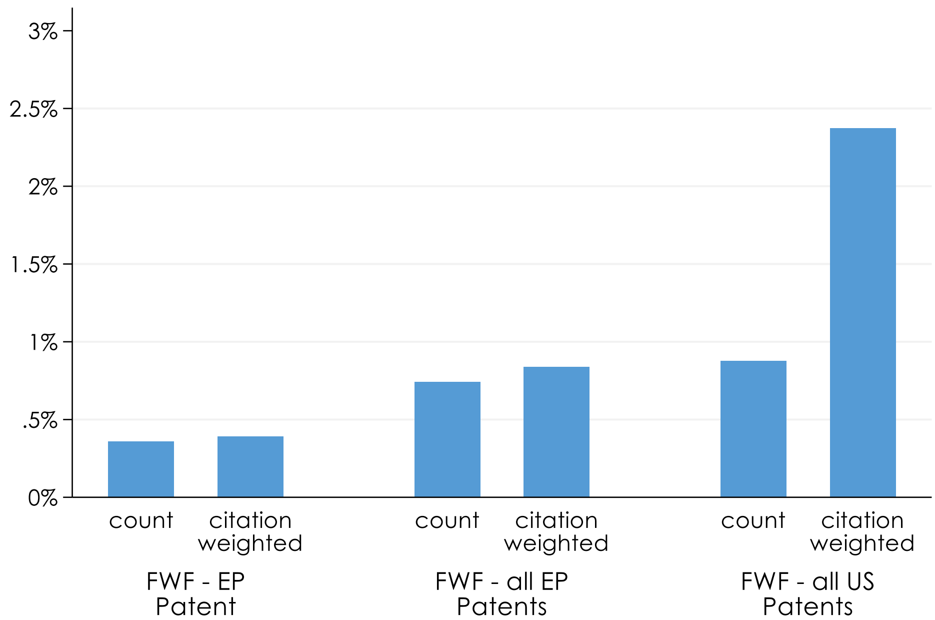
Table 9: **Quality of FWF-patents as measured by the number of citations from patents filed at all patent offices, 2009-2018**

	Patent office	Number of patents	Patents with at least 1 citation	Citations				
				Median	Average	p75	p95	Sum
FWF	EPO	128	37	0	1.84	1	13	236
FWF	USPTO	129	101	4	22.74	11	77	2,934
Company	EPO	16,445	5,893	0	1.60	1	8	26,248
Company	USPTO	14,583	11,963	3	7.85	9	28	114,462

Q: FWF data (e.g. Final project reports), Survey, PATSTAT Autumn 2023, ORBIS-IP, own calculation. All applications of a simple patent family are taken into account.

Using these differences in patent citations, the number of patents can be adjusted ("citation-adjusted patents), as another indicator of the importance or relevance of FWF-patents (Jaffe & Trajtenberg, 2002; Unterlass et al., 2013). We update the figures shown above (unweighted by citations) in the next figure and show that the share of FWF-patents in total patents increases substantially.

Figure 33: **Citation-weighted vs unweighted shares of FWF Patents in patents of all Austrian organisations, 2009-2018**



Source: FWF data (e.g. Final project reports), Survey, PATSTAT Autumn 2023, own calculation. FWF – EP Patent: EP Patents that could be identified via FWF data or survey. FWF – all EP Patents: All EP patent applications, that could be identified via simple patent families. FWF – all US Patents: All US patent applications, that could be identified via simple patent families.

Another way of looking at the quality of patents is to pick out the most highly cited ones, as in the following table. The table illustrates that patent citations can be heavily skewed, with few "superstar" patents such as the patent on gene scissors, while the broad majority of patents receives zero to one citations, as regards e.g. company patents.

Table 10**: Top FWF-patents**

Patent titel	Patent Office	Applicant	Inventor	Technology class (IPC)	Citations
Methods and compositions for RNA-directed target DNA modification and for RNA-directed modulation of transcription	WO	Univ California [US]; Univ Vienna [AT]; Doudna J. A [US]; Jinek M. [US]; Charpentier E. [US]; Chylinski K. [US]; Doudna C. J. H. [US]; Lim W.; Qi L.	Jinek M. [US]; Charpentier E. [US]; Chylinski K. [US]; Doudna C. J. H. [US]; Lim W.; Qi L.	Chemistry & Metallurgy	1480
Method for quantum computing	US	Raussendorf R. [DE]; Briegel H. [DE]	Raussendorf R. [DE]; Briegel H. [DE]	Physics	75
Glucose predictor based on regularization networks with adaptively chosen kernels and egularization parameters	US	Randloev J. [DK]; Mckennoch S. [DK]; Pereverzyev S. [AT]; Sampath S. [AT]; Novo Nordisk AS [DK]	Randloev J. [DK]; Mckennoch S. [DK]; Pereverzyev S. [AT]; Sampath S. [AT]	Human necessities; Physics	32
Three dimensional heterogeneously differentiated tissue culture	WO	IMBA Institut für Molekulare Biotechnologie GmbH [AT]	Knoblich J. [AT]; Lancester M. A [AT]	Human necessities; Chemistry & Metallurgy	32
Method, device and computer program product for determining an electromagnetic near-field of a field excitation source of an electrical system	US	Schoeberl J. [DE]; Koutschan C. [DE]; Paule P. [AT]; CST Computer Simulation Technology AG [DE]	Schoeberl J. [DE]; Koutschan C. [DE]; Paule P. [AT]	Physics	27
Quantumverarbeitungsvorrichtung und -verfahren	EP	Universität Innsbruck [AT]; Österreichische Akademie der Wissenschaft [AT]	Lechner W. [AT]; Hauke P. [AT]; Zoller P. [AT]	Physics	26
System, method and computer-accessible medium for learning an optimized variational network for medical image reconstruction	US	Universität New York [US]; TU Graz [AT]	Knoll F. [US]; Hammernik K. [AT]; Pock T. [AT]; Sodickson D. K. [US]	Physics	22
Organic ternary blends	WO	Imperial Innovations Ltd [GB]	Wadsworth A. [GB]; Nielsen C. [GB]; Holliday S. [GB]; Mcculloch I. [GB]; Kirkus M. [GB]; Baran D. [GB]; Ashraf S. [GB]	Chemistry & Metallurgy; Electricity	18
Monolayer of pbmcs or bone-marrow cells and uses thereof	WO	CEMM Forschungszentrum für Molekulare Medizin GmbH [AT]	Superti-Furga G. [AT]; Snijder B. [AT]; Vladimer G. I. [AT]	Chemistry & Metallurgy; Physics	18
UCP1 (thermogenin) - inducing agents for use in the treatment of a disorder of the energy homeostasis	WO	TU Graz [AT]; Scheideler M. [AT]; Karbiener M. [AT]; Amri E. [FR]; Ailhaud G. [FR]; Dani C. [FR]	Scheideler M. [AT]; Karbiener M. [AT]; Amri E. [FR]; Ailhaud G. [FR]; Dani C. [FR]	Chemistry & Metallurgy	17
Quantum imaging with undetected photons	US	Universität Wien [AT]; Österreichische Akademie der Wissenschaft [AT]	Zeilinger A. [AT]; Ramelow S. [AT]; Lapkiewicz R. [AT]; Borish V. [AT]; Barreto L. G. [AT]	Physics	16

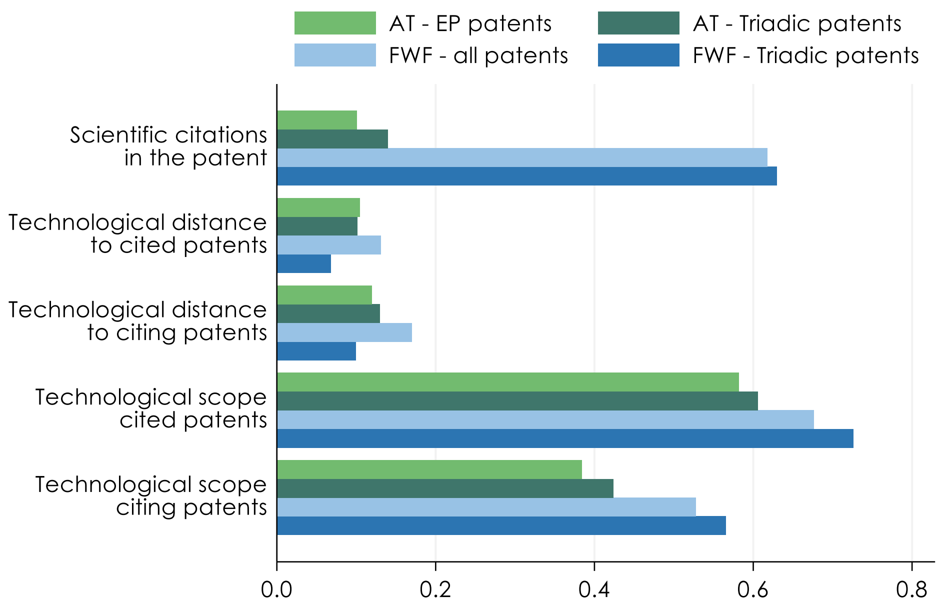
Source: FWF data (e.g. Final project reports), Survey, PATSTAT Autumn 2023, Espacenet, own calculation.

Further indicators to assess the quality of patents are the technological significance and the breadth of an invention. Technological significance essentially indicates how strongly inventions in a specific technological field are cited by inventions in other technological fields. The distance between the technological fields of the cited and citing patents can thus be calculated, providing insights into the level of general technological importance or significance of an invention. The greater the distance, the more the invention extends beyond its own technological field into others (distance to citing patents in the figure below). A variant of this distance measure involves a more detailed analysis of the spread or dispersion of the technological fields of the citing patents, regardless of the distance from the technological field of the cited patent (scope of citing patents in the figure below).

In contrast to technological significance, the technological breadth of patents focuses on those patents cited by the patent being analysed. The breadth of the knowledge base on which the patent is built can be determined by analysing the spread of the technological fields of the cited patents (scope of cited patents in the figure below) or by the distance to the technological fields of the cited patents (distance to cited patents in the figure below). This allows patent data to also be used to calculate the recombination of knowledge, which is considered an important feature of significant innovations.

In addition, the share of citations to scientific literature in all citations of a patent can be determined. This is a measure of how close to science the patent is, indicating as argued above broader patents with more general application possibilities. Figure 34 shows that FWF-patents score higher in all of these quality measurements than the total of all Austrian patents. Only FWF-triadic patents are lower concerning the technological distance.

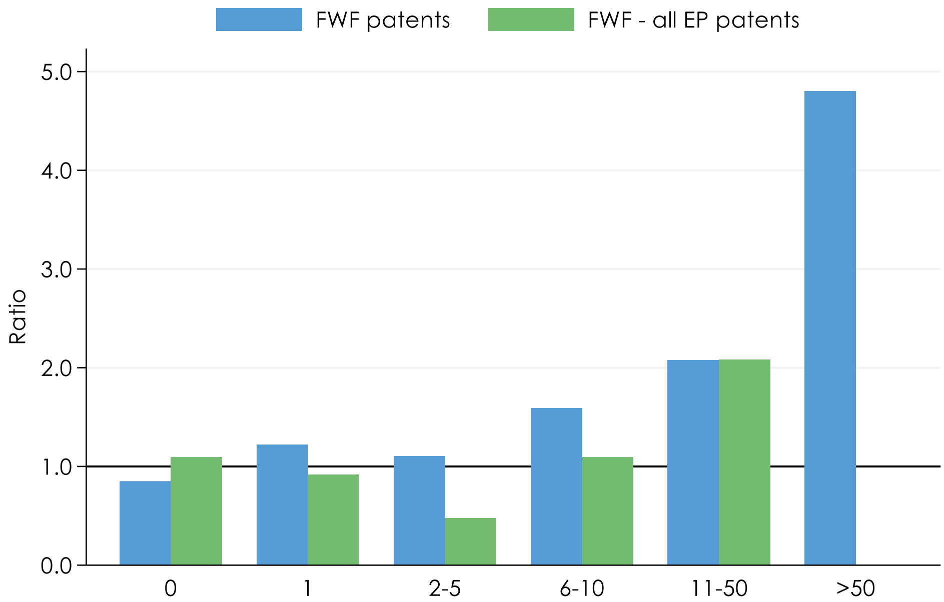
Figure 34: **Quality indicators for patents, based on FWF-funding vs. all Austrian applicants, mean 2009-2022: technological distance (significance) and scope (breadth)**



Source: FWF data (e.g. Final project reports), Survey, PATSTAT Autumn 2023, own calculation. Triadic patents are patents filed at all three major "western" patent offices, USPTO, JPO, EPO. FWF – all patents: All applications of a simple patent family are taken into account.

Finally, Figure 35 illustrates how FWF-patents are distributed over citation counts grouped as 0, 1, 2-5, 6-10, 11-50 and more than 50 citations per patent, relative to all Austrian patents. It can be seen that FWF patents are much more skewed towards a higher number of citations, achieving twice as many patents with citations 11-50 and close to five times more with more than 50 citations.

Figure 35: **Distribution Citation frequency of FWF-patents relative to all Austrian patents (2009-2020)**



Source: FWF data (e.g. Final project reports), Survey, PATSTAT Autumn 2023, own calculation. FWF – Patent: Patents that could be identified via FWF data or survey. FWF – all EP Patents: All EP patent applications, that could be identified via simple patent families. A number above 1 means that FWF has a higher share of patents in that citation frequency group than Austrian patents in total. I.e., FWF has a higher share of patents with 11-50 citations than Austrian patents in total.

5.2. Indirect use: citations of FWF-funded publications in patents

In this section, we look at any patents which cite FWF-journal articles (rather than at "FWF-patents"). The following analysis is conducted using "The Lens" database, a platform that integrates scholarly and patent literature from various sources.[12] As of April 2024, the database contained some 130 million patents that were filed with one of over 95 patent-granting authorities worldwide (incl. e.g. the EPO and the USPTO) and can be grouped into roughly 73 million simple patent families. Furthermore, The Lens contained approximately 270 million scholarly works, with 5.4 million of these being cited by at least one patent. The scholarly articles are sourced from Microsoft Academic, CrossRef, PubMed and OpenAlex (see The Lens, 2024). The Lens is said to cover nearly all patents filed globally in recent years, particularly those filed with the main leading patent-granting authorities. By combining scholarly literature from different sources, the Lens is also one of the largest databases for scholarly articles (see e.g. Penfold 2020). The database's unique feature, however, is that it links scholarly papers and patents, making it a valuable resource for the following analysis.

[12] https://www.lens.org/

We analyze scholarly work funded by the FWF, i.e., journal articles, conference proceedings, books, reports and other types of scholarly literature available in the Lens database, as well as the patents citing them. We do not group patents by families and include all patent filings regardless of their legal status, i.e., irrespective of whether they are pending, active, inactive or in any other legal status.[13] We examine FWF-funded scientific papers published in the observation period from the beginning of 2003 to the end of 2021 and all patents citing them that were published before January 2024.

While the coverage of scholarly work and patents in The Lens appears to be quite exhaustive, not all studies that originated from FWF-funded projects are listed as funded by the FWF. It seems that The Lens only lists those funding sources explicitly mentioned in the metadata of their data sources and does not include funding sources mentioned only in the acknowledgments[14]. An examination of the 100 FWF-funded research papers with most citations by other scholarly work shows that, while all but one of these research papers could be found in the Lens database, 36% of these studies are not included in the set of studies assessed below, even though The Lens indicates they are cited by at least one patent. This is because FWF-funding is not acknowledged in the paper, or Lens could not "read" the way FWF was spelt or indicated in the acknowledgements. The counts of FWF-funded studies cited by patents provided below, therefore, underestimate the actual numbers. An analysis of the project numbers corresponding to the included studies can indicate how representative the studied sample is of the full set of FWF-funded studies cited by patents.

Another caveat of this analysis is that patent citations to journal publications may not reflect a real knowledge flow, meaning that the inventor consciously reads the publication and uses the results for his or her invention. Patent citations can also be added "after the fact" by patent examiners.

5.2.1. Patent citations of FWF-funded scholarly work

General statistics

Of the 16,422 scholarly works funded by the FWF and published between 2003 and 2021, 2,255 or about a seventh (13.7%) were cited by at least one patent by December 2023, an astonishingly high number considering that the FWF funds basic research, i.e. "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view" (OECD, 2015, p. 45). By comparison, about 7.5% of ERC-funded papers were cited by patents between 2007-2016 (Munari et al., 2022). We can count almost 10,000 citations by patents for all FWF-funded research during this period. To put this figure into perspective, it corresponds to 12% of all 82,000 citations by patents of studies by institutions based in Austria in the same period. Given the small size of FWF research funding (about 5% of total R&D spending in the higher education and government sectors 2021), this indicates a disproportionate use of FWF-research results for patented inventions, all the more so as not all FWF-funded publications are properly referenced in The Lens (see above, 36% of the top 100 publications are not included in the analysed publications). However, we cannot take

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[13] In The Lens, the various patents belonging to the same patent family all receive the jurisdiction and the date of the first patent filing, often the US.

[14] For the study „A programmable dual-RNA-guided DNA endonuclease in adaptive bacterial immunity" by Jinek et al (2012), the publishing journal Science only provides funding sources in the form of unstructured text in the Acknowledgement section. PubMed only mentions the Howard Hughes Medical Institute as the funding source, which is why The Lens also lists the Howard Hughes Medical Institute as the only funding source.

account of the possible influence of other research funding sources, as explained above. About 30% of FWF projects lead to patent citations of the resulting journal articles, somewhat below the ERC (40%, Munari et al., 2022), although the share of various scientific disciplines would have to be taken account of.

The number of patent citations among the FWF-funded studies that were cited by at least one patent varies widely, with a mean of 4.8 patents per study and a median of 2. The h-index[15] of all FWF-funded scholarly work combined is 34 and the i10-index is 204, i.e., 204 FWF-funded studies were cited by at least 10 patents (every link between patent and study is counted only once, no matter how often the study is mentioned in a patent). As the data are not corrected for patent families (as explained, one invention may lead to several patents in different jurisdictions), these are most probably not all different patents, but indicates the geographical spread of patent applications citing FWF-funded studies.

When comparing these statistics to those of all scholarly work published by Austria-based institutions in 2003 to 2021 (see Table **11**: Statistics on patents citing FWF-funded scholarly work and scholarly work published by Austria-based institutions, patent citation counts), we can observe that the patent citation counts of FWF-funded scholarly work does not differ considerably from that of scholarly work from Austrian institutions, which is again surprising, given FWF's focus on basic research (e.g., half of all R&D at Austrian universities is applied research) and all the more so, as we know that The Lens does not cover all FWF-funded publications (see above). Among the studies by Austrian institutions there are also a few with extremely high patent citation counts while the vast majority is not cited by any patent in the first 2 years after publication, by maximum 1 patent in the first 5 years after publication and over the whole observation period by not more than a handful of patents.

Table 11: **Statistics on patents citing FWF-funded scholarly work and scholarly work published by Austria-based institutions, patent citation counts[16]**

	FWF-funded scholarly work			Scholarly work by Austrian institutions		
	Within 2 years	Within 5 years	Any time	Within 2 years	Within 5 years	Any time
Mean count	0.2	1.4	4.8	0.2	1.6	4.8
25%-percentile	0	0	1	0	0	1
Median count	0	1	2	0	1	2
75%-percentile	0	1	4	0	1	4
Max count	6	76	818	102	423	3488
h-index	4	14	34	10	26	71
i10-index	0	28	204	10	121	1520
Total count	441	2592	9973	3386	18089	81560
Avg. time till 1st citation	1707 days			1722 days		

Source: lens.org, calculations by authors. Note that The Lens does not identify all FWF-funded publications as such, 36% of the top 100 papers e.g. are cited by a patent but do not appear as FWF-funded in The Lens.

[15] The h-index is defined as the maximum value of h, such that at least h FWF-funded studies have each been cited at least h times.

[16] For the statistics on patent counts within 2 and 5 years after publication, all publications that are cited at any point in time are considered, hence e.g. the median of 0. The patent citation count within 5 years after publication only includes the 1911 patent-cited studies published between 2003 and 2018.

The considerably higher mean than median in the set of FWF-funded studies can be partly attributed to the fact that patent citations typically occur long after the publication of the study: the average time between publication of a study and the first patent citation is 1,707 days, i.e., more than 4.5 years. This is shorter than the 6.6 years reported in Ahmadpoor & Jones, (2017) for all US patents/publications, presumably because FWF-funded studies concentrate in life sciences, which often are closer to applications than articles in other fields of science.

Therefore, although the publication time frame set for the FWF-funded articles under study (2003 – 2022) allows for a minimum of 2 years after publication to obtain patent citations, the majority of patent-cited studies does not get cited by any patent within the first two years after publication (to compare, citations by research articles e.g. in the fields of Biology and Biochemistry reach their peak of citations about 2-3 years after publication, see Galiani and Gálvez, 2017). The difference between the median and mean in the full sample can therefore be attributed to the fact that the more recently published FWF-funded articles are far from their patent-citation peak. However, it is certainly also due to the typically heavily skewed citation pattern of publications, with few publications achieving the majority of (patent) citations (see e.g. Seglen, 1992) – FWF-funded research is no exception here.

Table 12: **Patents citing FWF-funded research and research from Austrian institutions at different distances (D = 1, D = 2 and D = 3)**

	# citing patents at max. D = 1	# citing patents at max. D = 2	# citing patents at max. D = 3
FWF-funded studies	9,165	29,789	58,486
Research from AT	62,061	197,363	477,748

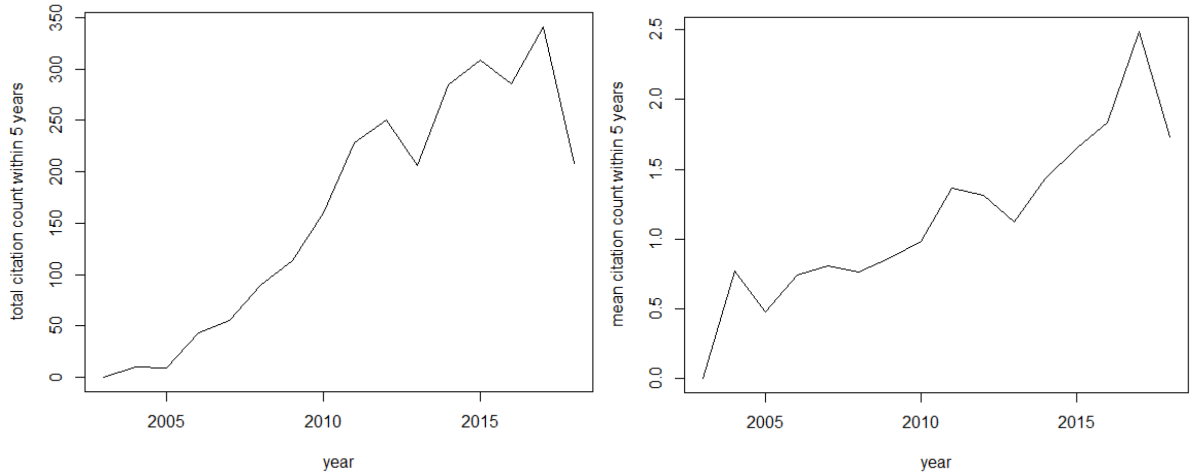
Source: The Lens.

Table 12 shows the average number of patents citing FWF-funded research and studies from Austrian institutions at different distances (D), where the set of patents at D = 1 encompasses all patents that directly cite FWF-funded work, patents at D = 2 are patents that cite patents which, in turn, cite FWF-funded/Austrian studies, and so on. Within a maximum distance of D = 2 from FWF-funded scholarly work, there are nearly 30,000 distinct patents, that is, there are about 3.3 times as many patents at a maximum distance of D = 2 compared to those directly citing FWF-funded work (AT: 3.2 times). The difference between a maximum distance of D = 2 and D = 3 around FWF-funded work is much smaller. There are slightly less than twice as many patents at a maximum distance of D = 3 compared to D = 2. This reveals a notable difference between FWF-funded research and research from Austrian institutions: for studies from Austrian institutions, there are 2.4 times as many patents at a maximum distance of D = 3 compared to D = 2.

Development of patent citations over time

To account for the fact that depending on their publication date, studies have a different time span in which they could be cited until December 2023, the development of patent citations over time is assessed based on the number of patent citations in the first five years after publication (Mariani et al, 2019). Figure 36 shows a strong increase in patent citations of FWF-funded research published between 2003 and 2018, both per publication and in total across all studies funded by the FWF. The decline in the last year is due to the fact that not all patents applied for in 2023 are yet in the database.

Figure 36: **Total patent citation count (left) and mean citation count per FWF-funded publication (right) in the first 5 years after publication, by publication year**[17]



Source: The Lens.

Top 10 most cited FWF-funded publications

In the following, we will examine the FWF-funded studies with respect to their research areas in order to determine those fields of science in which FWF-funded research was particularly frequently cited by patents. To this end, we first examine the FWF-funded studies that were cited most by patents and then look at the counts of FWF-funded and patent-cited scholarly work by field of science.

Table 13 shows the 10 FWF-funded studies that were most cited by patents. The two articles with by far the most patent citations are two articles which are cited in the reasoning of the 2020 Nobel Prize for Chemistry for Jennifer Doudna and Emmanuelle Charpentier, for developing the "gene scissors"[18]: "A programmable dual-RNA-guided DNA endonuclease in adaptive bacterial immunity" by Jinek et al. (2012) with 2,655 citations by patents, followed by " CRISPR RNA maturation by trans-encoded small RNA and host factor RNase III" (Deltcheva et al., 2011), with 818 citations from Lens-registered patents until December 2023. Note that these citations will not reflect entirely distinct inventions, as we have not consolidated them at the level of patent families.

The following studies achieve a considerably lower patent citation count, again in line with empirical work on the skewness of science. At first glance, it can already be seen that all these studies fall into the field of life sciences. On closer inspection, two larger clusters can be identified: there are several studies on genome sequencing published between 2011 and 2017 and a smaller cluster of three studies on cancer research; the remaining two studies are also in the field of life sciences, with one relating to neuroscience and one to retinal imaging.

[17] Years are counted from December to December as patent citation data was obtained in December 2023.

[18] https://www.nobelprize.org/uploads/2020/10/advanced-chemistryprize2020.pdf

Table 13: **FWF-funded studies published between 2003 and 2021 that were cited most by patents**[19]

Author(s)	Title	Journal	Field of Study[20]	Year	FWF-Pr.-No.	Patent Citations
M. Jinek , K. Chylinski , I. Fonfara , M. H Hauer , J. A. Doudna , E. Charpentier	*A programmable dual-RNA-guided DNA endonuclease in ad aptive bacterial immunity.*	*Science (New York, N.Y.), Vol. 337, Issue: 6096, pp. 816-821*	*Biology*	*2012*	*W 1207*	*2655*
E. Deltcheva, K. Chylinski, C. M. Sharma, K. Gonzales, Y. Chao, Z. A. Pirzada, M. R. Eckert, J. Vogel, E. Charpentier	CRISPR RNA maturation by trans-encoded small RNA and host factor RNase III	Nature, Vol. 471, Issue 7340, pp. 602-607	Biology	2011	P 17238	818
G. M. Frampton, A. Fichtenholtz, G. Otto, K. Wang, S. R. Downing, J. He, M. Schnall-Levin, J. White, E. M. Sanford, P. An, J. Sun, F. Juhn, K. W. Brennan, K. Iwanik, A. Maillet, J. Buell, E. White, M. Zhao, S. Balasubramanian, S. Terzic, T. Richards, V. Banning, L. Garcia, K. Mahoney, Z. Zwirko, A. Donahue, H. Beltran, J. M. Mosquera, M. A. Rubin, S. Dogan, C. V. Hedvat, M. F. Berger, L. Pusztai, M. Lechner, C. Boshoff, M. Jarosz, C. Vietz, A. N. Parker, V. A. Miller, J. S. Ross, J. Curran, M. T. Cronin, P. J. Stephens, D. Lipson, R. Yelensky	*Development and validation of a clinical cancer genomic profiling test based on massively parallel DNA sequencing*	*Nature biotechnology, Vol. 31, Issue 11, pp. 1023-1031*	*Biology*	*2013*	*J 2856*	*166*
D. Sint, L. Raso, M. Traugott	Advances in multiplex PCR: balancing primer efficiencies and improving detection success	Methods in ecology and evolution, Vol. 3, Issue 5, pp. 898-905	Biology	2012	P 20859	112
M. A. Lancaster, M. Rener, C. A. Martin, D. Wenzel, L. S. Bicknell, M. E. Hurles, T. Hofray, J. M. Penninger, A. P. Jackson, J. A. Knoblich	Cerebral organoids model human brain development and microcephaly	Nature, Vol. 501, Issue 7467, pp. 373-379	Biology	2013	I 552	101
J. Boulanger, L. Muresan, I. Tiemann-Boege	Massively parallel haplotyping on microscopic beads for the high-throughput phase analysis of single molecules	PloS one, Vol. 7, Issue 4	Biology	2012	M 1097	94

[19] To determine the studies with the most patent citations, we considered all studies in the Lens database where the FWF is listed as a funding source. Additionally, we included the 100 FWF-funded studies with the highest number of citations from other scholarly works, regardless of whether the FWF is mentioned as a funding source in the Lens (highlighted in gray in the table). This list might not be complete, as there may be FWF-funded studies with more than 69 patent citations that are neither among the top 100 studies most cited by other scholarly works nor listed with FWF as a funding source in the Lens. In the following analyses, just as in the analyses before this table, the studies among the 100 FWF-funded studies with the highest number of citations from other scholarly works, where FWF is not listed as a funding source in the Lens, are not added to the data obtained from the Lens.

[20] Microsoft Academic's fields of study are organized in a in a 6-level hierarchical system. The Lens provides the fields of study of scholarly works at different hierarchical levels to allow for subject-based search; each scholarly work is therefore assigned to more than one field of study (one per hierarchical level). To ensure a clear assignment of scholarly works to fields of study, we only include the highest level of study fields, where Microsoft Academic distinguishes between 19 fields of study (Färber and Lin, 2022).

Author(s)	Title	Journal	Field of Study[20]	Year	FWF-Pr.-No.	Patent Citations
O. Hantschel, U. Rix, U. Schmidt, T. Bürckstümmer, M. Kneidinger, G. Schütze, J. Colinge, K. L. Bennett, W. Ellmeier, P. Valent, G. Superti-Furga	The Btk tyrosine kinase is a major target of the Bcr-Abl inhibitor dasatinib	Proceedings of the National Academy of Sciences of the United States of America, Vol. 104, Issue 33, pp. 13283-13288	Chemistry	2007	P 18737 Y 163	92
P. Datlinger, C. Schmidl, A. F. Rendeiro, P. Traxler, J. Klughammer, L. C. Schuster, C. Bock	Pooled CRISPR screening with single-cell transcriptome read-out	Nature methods, Vol. 14, Issue 3, pp. 83774-301	Biology	2017	I 1626	83
S. Hauf, R. W. Cole, S. LaTerra, C. Zimmer, G. Schnapp, R. Walter, A. Heckel, J. van Meel, C. L Rieder, J.-M. Peters	*The small molecule Hesperadin reveals a role for Aurora B in correcting kinetochore-microtubule attachment and in maintaining the spindle assembly checkpoint*	*The Journal of cell biology, Vol. 161, Issue 2, pp. 281-294*	*Biology*	*2003*	…	*72*
E. Götzinger, M.I Pircher, C. K. Hitzenberger	High speed spectral domain polarization sensitive optical coherence tomography of the human retina	Optics express, Vol. 13, Issue 25, pp. 10217-10229	Physics	2005	P 16776	69

Source: The Lens.

Fields of science of patent cited research

Table 14 displays the shares of patent-cited scholarly work falling into different "fields of study" as identified by Microsoft Academic by means of a Natural Language Processing (NLP) procedure called concept discovery which was applied to all accessible text in a publication (Färber and Lin, 2022).[20] Table 14 shows the top 8 fields of study in terms of the share of patent-cited scientific papers falling into them, separately for all patent-cited scientific papers that were published worldwide, by an institution based in Austria and as part of an FWF-funded project. In all three cases, the respective top 8 fields of study cover at least 98% of all patent-cited scholarly studies.

Table 14: **Shares of patent-cited scholarly work published between 2003 and 2021 by fields of study as defined by Microsoft Academic**

	FWF-funded		AT		World	
	Field of Study	Share	Field of Study	Share	Field of Study	Share
1	Biology	57%	Biology	27%	Biology	23%
2	Chemistry	21%	Chemistry	20%	Chemistry	19%
3	Medicine	12%	Medicine	17%	Computer Science	16%
4	Computer Science	4%	Computer Science	15%	Medicine	16%
5	Materials Science	3%	Materials Science	10%	Materials Science	15%
6	Psychology	1%	Engineering	4%	Engineering	5%
7	Physics	1%	Physics	3%	Physics	3%
8	Mathematics	0.2%	Mathematics	2%	Mathematics	2%
9	Engineering	0.2%				
N	2,347		24,656		3,047,640	

Source: The Lens. (Note: The data contains all scholarly work that was cited by a patent before April 2024).

The predominance of the Life Sciences among patent-cited FWF-funded studies is evident not only regarding the FWF-funded studies with most patent citations (Table 13) but also when looking at the total of FWF-funded and patent-cited studies. While Life Science and Biology in particular dominate both among all patent-cited research published globally and as part of FWF-funded research, their prevalence is significantly higher within FWF-funded publications: Of the studies funded by the FWF, 57% are categorized under the field of biology; worldwide, the proportion of patent-cited studies falling into the field of biology is 23% (in AT: 27%).

A look at the other fields of study reveals that the much larger share in biology-related studies among those funded by the FWF is mainly attributed to an underrepresentation of technical fields such as computer science, material science and engineering, while there are not such striking differences in the share of medicine and chemistry patent-cited studies published worldwide and in the context of FWF-funded research. Some 16% of the patent-cited scholarly work published globally is categorized as computer-science-related, which is comparable to the share of computer science studies among patent-cited work in Austria (15%). Among the FWF-funded and patent-cited studies on the other hand, only 4% can be considered computer-science-related. Similarly striking is the difference in material science (FWF-studies: 3% vs. globally: 15%) and engineering (FWF-studies: 0.2% vs. globally: 5%), where the former appears to be generally underrepresented in patent-cited studies published by Austrian institutions.

Finally, we use a pre-trained Word2Vec model to cluster the FWF-funded and patent-cited studies based on title and abstract of each study. The Word2Vec algorithm converts words into vectors, where each word is represented by a vector of predefined length. The vectorization captures the context in which the represented word usually appears, and thereby its semantic and syntactic properties (Mikolov, et al., 2013). For clustering the FWF-funded studies, we use a Word2Vec model that was trained on Wikipedia and news articles (fasttext-wiki-news-subwords-300, available here: https://github.com/piskvorky/gensim-data/releases). For each FWF-funded and patent-cited study, all words appearing in the title and abstract are transformed into a vector as given by the pre-trained model and the FWF-funded study is then represented as the mean of all these vectors, which are then used to cluster the FWF-funded studies by means of a classical k-means clustering algorithm.

The optimal number of clusters is determined based on the silhouette value, a commonly used indicator comparing within-cluster distances and between-cluster distances (see e.g. Kodinariya and Makwana, 2013). Furthermore, we set the range of potential cluster numbers to 4 and 8 to keep the number of clusters manageable while at the same time allowing for some granularity in capturing diverse patterns within the data. The cluster names are then generated by asking ChatGPT to find a "short and general" title that summarizes the text of the 3 most central elements in each cluster.

When clustering FWF-funded and patent-cited studies by means of Word2Vec, a similar pattern emerges as in the previous two analyses regarding the dominance of Biology publications (see concentrated within the life sciences and particularly the field of Biology, with the cluster titles appearing to be quite specific and leaning towards Biology-related topics and particularly the fields of molecular and cell research, immunology and biomedicine.

5.2.2. Characteristics of patents citing FWF-funded scholarly work

In the following, we assess the characteristics of the patents that cite FWF-funded work. We start with an analysis of the patent offices where the patents were filed, followed by an assessment of the applicants that filed patents in the US (US Patent and Trademark Office USPTO) and with the European Patent Office (EPO). Finally, we also investigate the technological fields and the degree of multi-disciplinarity of the set of patents citing FWF-funded research.

Patent applicants

Table 15 shows the counts of patents citing FWF-funded research, broken down by the patent offices with which they were registered. Each patent citing one or more FWF-funded studies is counted only once, which is why the total number of patents in Table 15 differs from the number of patent citations in the previous section. We can observe that the vast majority (52%) of the patents citing FWF-funded research were filed with the US Patent and Trademark Office (USPTO), followed by the World Intellectual Property Organization (WIPO), where 32% of the patents were filed, and the EPO (10%). This differs greatly from the distribution of the patent offices of all patents available in the Lens database: of all patents available in the Lens, the largest share is filed in China, followed by Japan, the USPTO and the EPO.

Table 15: **Counts of patents that cite FWF-funded research**

USPTO	WIPO	EPO	AT	Local offices in Europe (w/o AT)	JP	China	Local offices in rest of world	**Total**
4586	2819	907	4	112	110	202	128	**8868**

Source: The Lens database. Note: each patent is only counted once, independently of how many FWF-funded studies it cites.

The following section takes a closer look at the applicants that have filed patents citing FWF studies with the USPTO or the EPO. By reducing the analysis to one patent office in each case, we ensure that we do not double-count a patent if it is filed with several patent offices.

Table 16 displays where the applicants of patents citing FWF-funded work are based, distinguishing between the main regions, as well as Austria and the four countries with the highest number of FWF-work-citing patents. There are 306 patents filed by groups of applicants from various countries, which are counted multiple times in Table 16, once for each of the respective countries; if an applicant group comprises multiple institutions from the same country, the patent is counted only once. Therefore, the counts in Table 16 indicate how many patents citing FWF-funded research have at least one applicant located in each country.

In most US-filed patents that cite FWF-funded work, at least one applicant is a US-based institution (71% - this figure is calculated relative to the count of patents filed in the US, see Table **15**), which can be partly attributed to the fact that the USPTO is located in the US; 524 patents (11%) are owned by at least one institution from the DACH region, 162 of which by Austrian institutions. Furthermore, there are several US-filed patents with applicants from Asia, particularly from Japan but also from China and South Korea among other countries. Given that we do not group them by families, the counts may include several patents belonging to the same patent family multiple times, even if they differ only by legal status. Moreover, because applications may be done by the headquarter of a multinational firm, the geographic shares may be misleading. E.g., a European or even Austrian research team could cite the FWF-study, but the patent coming out of the firm's research could be filed for in the US.

Table 16: **Patent citation counts by region of applicants (only patents filed in the US)**

Africa	Americas	Asia	AT	CH	DE	EU (w/o AT & DE)	Rest of Europe	JP	Oceania	US	Applicant unknown	**Total**
2	77	282	162	121	241	438	140	190	33	3268	22	**4976**

Source: The Lens.

Among the FWF-work-citing patents filed with the EPO (Table 16), we can observe more patents of European applicants than when looking at the patents filed with the USPTO, with 58% of the patents having at least one applicant from Europe, 51% having an applicant from the EU, 35% having one from the DACH region and 14% with at least one applicant from Austria. However, applicants from the US still play an important role: 34% of the FWF-work citing patents that were filed with the EPO have at least one US-based applicant. 41 of the FWF-work-citing patents filed with the EPO are from multi-national applicant groups.

Table 17: **Patent citation counts by region of applicant (only patents filed with the EPO)**

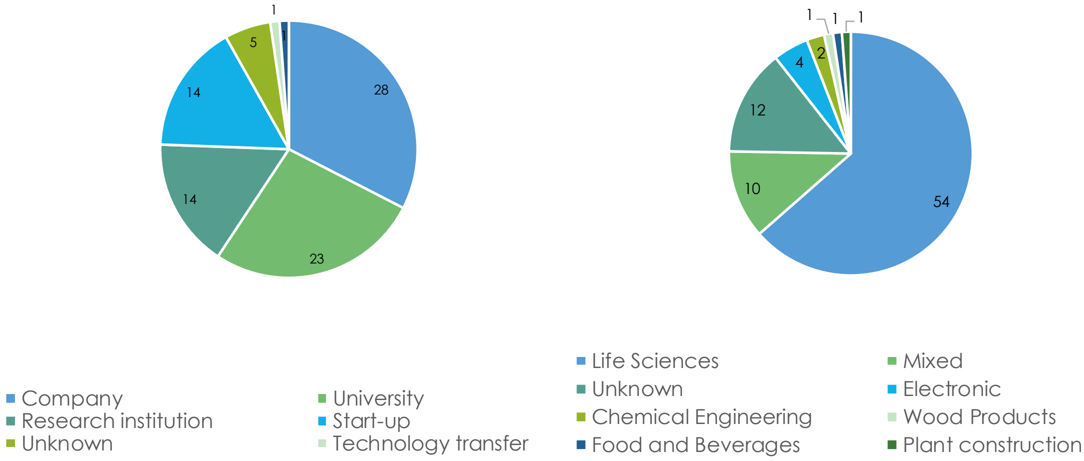
Africa	Americas	Asia	AT	CH	DE	EU (w/o AT & DE)	Rest of Europe	JP	Oceania	US	Applicant unknown	**Total**
3	19	47	127	42	151	183	22	53	3	310	3	**960**

Source: The Lens.

In the following, we take a closer look at the Austria-based applicants of patents that cite FWF-funded work and are filed with the EPO. We investigate these patents with respect to the type and field of activity of the applicant institution. Here, we consider all applicants, that is, if there is a larger group of Austrian institutions that apply for a patent together, each of them is considered for the analysis. The information on the institutions is obtained via an Internet search.

Figure 37 shows the composition of applicants by type (left) and by field of activity (right). Among the Austrian applicants of the EPO-filed patents citing FWF-funded work, approximately two thirds are universities (44%) or other research institutions (22%) and around 31% of the applicants are companies, one third of which are start-ups. Regarding the field of activity, the set of applicants is even more homogeneous with two thirds falling into the field of Life Science and 26% the group of applicants appears even more uniform, with two-thirds falling within the Life Science field and 26% classified as having a mixed field of activity (these are mainly non-specialized universities).

Figure 37: **Austria-based applicants of EPO-filed patents citing FWF-funded work by type (left circle) and field of activity (right circle)**



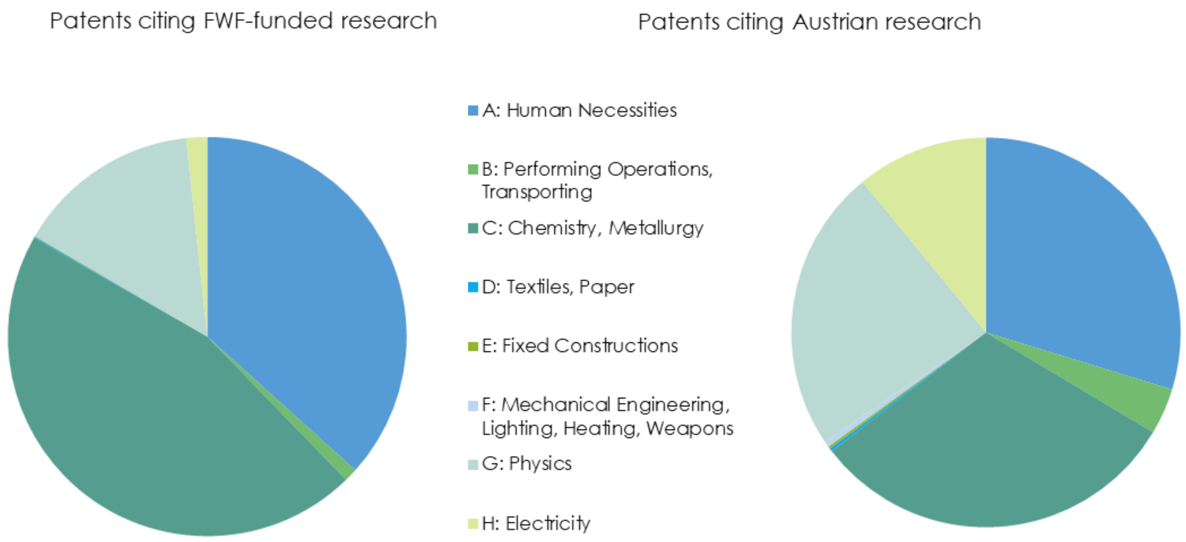
Source: Patstat/The Lens.

Technological fields of patents

In order to investigate the technological fields of the patents citing FWF-funded research we take a closer look at the International Patent Classification (IPC) assigned to the FWF-work-citing patents and compare them with those of the patents citing scholarly work published by Austrian institutions. The IPC is a hierarchical system used to classify patents based on the technological features of inventions; each patent is assigned one or more IPC codes indicating the field of the invention (WIPO, 2024).

We analyze the technological fields of the FWF-work-citing patents based on the least detailed level of the IPC codes assigned to them. This highest level of the IPC scheme consists of eight sections (A-H). If a patent is assigned to IPC codes that differ at the highest level, the patent is counted in each of these categories; if it is assigned to multiple subsections of one of the eight main sections (A-H), it is counted only once in the respective section.

Figure 38: **Highest level IPC codes of patents citing FWF-funded work and scholarly work from Austrian institutions**



Source: The Lens.

Figure 38 shows the composition of technological fields covered by patents that cite FWF-funded studies as well as that of patents citing research from Austrian institutions. We can observe that the patents citing FWF-funded scholarly work are much more concentrated in certain fields than those citing Austrian based research. Some 45% of the IPC 1-digit codes assigned to patents citing FWF-funded studies refer to the field of Chemistry and Metallurgy, 37% to the field of Human Necessities and around 15% to the field of Physics. Among the IPC codes assigned to patents citing scholarly work from Austrian institutions, the shares of the fields of Chemistry and Metallurgy, Human Necessities and Physics are of comparable size. Furthermore, there is a considerable number of patents that fall into the field of Electricity (11% of the assigned 1-digit IPC codes are of this field) and there are also some patents that are categorized as belonging to the field of Performing Operations and Transporting.

To further investigate the technological fields of patents citing FWF-funded work, we again use Word2Vec (Mikolov, 2013) to quantify the patents and then cluster them by means of classical k-means clustering as outlined in the previous section. Just as for the FWF-funded scholarly work, we cluster the patents based on title and abstract[1]. Additionally, we also cluster them based on the names/definitions of the IPC codes assigned to them at the 4th hierarchical level, i.e., the first 4 characters of the IPC codes (again, for each patent we include every 4-character code only once, independently of how many subcategories of this code are assigned to the patent). This latter approach helps assign every patent to one single group, while the analysis

[1] To handle patents that are not written in English, we translate all titles and abstracts to English using Microsoft Excel.

of the IPC classification above allows for one patent to be counted multiple times in different categories.

When clustering the patents that cite FWF-funded studies based on patent abstract and title (Table A 2), the cluster titles are sometimes very difficult to distinguish from one another. In contrast, the clusters obtained from the assigned patent classification appear to be more clearly distinguishable from one another. In this latter case, we can make out three large clusters of patent categories, namely microbiology and genetic engineering, material analysis and healthcare products.

Interdisciplinarity

In the following, we investigate the degree of interdisciplinarity of patents citing FWF-funded work. This is done by analyzing the patents citing FWF-funded work with regard to the average number of technological fields assigned to them and by analyzing the set of citing patents per FWF-funded scholarly work regarding the composition of their technological fields (both analyses are performed at the highest and second highest hierarchical level of the assigned IPC codes). Furthermore, we take a closer look at which technological fields are often linked through FWF-funded studies.

Patents citing FWF-funded research are, on average, assigned 1.57 IPC 1-digit codes and 1.78 IPC 2-digit codes. Patents citing research from Austrian institutions, on the other hand, are assigned 1.48 1-digit codes and 1.63 2-digit codes. Hence, it seems that FWF-funded research is cited more often by interdisciplinary patents compared to scholarly work from Austrian institutions is on average. For both FWF-funded research and research from Austrian institutions, the majority of citing patents are assigned either one or two different IPC 2-digit codes. Additionally, since around 2010, there has been a slight increase in the average number of 1- and 2-digit codes assigned to patents citing both FWF-funded research and research from Austrian institutions.

When looking at the composition of patents that cite FWF-funded scholarly work, we find that the sets of patents per study is assigned to on average 1.84 different technological fields at the 1-digit IPC level and 2.25 at the 2-digit level. For patents citing studies by Austrian institutions, we again find a lower degree of interdisciplinarity with 1.78 technological fields at the 1-digit IPC level and 2.10 at the 2-digit level. This may however also be due to a different propensity of technological fields to feature co-occurrences.

Finally, we assess which technological fields typically co-occur in sets of patents citing FWF-funded research. Table 18 shows that among the FWF-funded studies there are particularly many studies that are cited by sets of patents of which at least one is classified in the field Chemistry and Metallurgy and one that is assigned the IPC code for Human Necessities, this is the case for nearly half of the FWF-funded scholarly work that was cited by at least one patent in the study period. The much larger number of co-occurrences of these two technological fields can to a large degree be attributed to the fact that these two are also the dominating technological fields of patents citing FWF-funded studies. Additionally, there are also several co-occurrences of Physics and Human Necessities as well as between Physics and Chemistry, Metallurgy.

Table 18: **Co-occurring technological fields among patent sets citing FWF-funded scholarly work (shares of patent sets, N = 2,223)**

	Performing Operations, Transporting	Chemistry, Metallurgy	Textiles, Paper	Fixed Construc-tions	Mechanical Engineering, Lighting, Heating, Weapons	Physics	Elec-tricity
Human Necessities	2.5%	47.1%	0.4%	0.1%	0.1%	20.8%	1.7%
Performing Operations, Transporting		3.4%	0.3%	0.0%	0.1%	2.1%	0.7%
Chemistry, Metallurgy			0.4%	0.1%	0.1%	20.5%	1.4%
Textiles, Paper				-	-	0.1%	-
Fixed Constructions					-	0.0%	-
Mechanical Engineering, Lighting, Heating, Weapons						0.2%	0.2%
Physics							3.2%

Source: The Lens.

Table 19 finally shows the co-occurrences of technological fields in the sets of patents that cite research from Austrian institutions. The patterns look similar to those of FWF-funded research, only that there are more sets of patents citing studies from Austrian institutions that contain patents from the fields of Electricity and Physics as well as patents from Performing Operations, Transporting as well as Chemistry and Metallurgy or Physics.

Table 19: **Co-occurring technological fields among patent sets citing scholarly work by Austrian institutions (shares of patent sets, N = 23,862)**

	Performing Operations, Transporting	Chemistry, Metallurgy	Textiles, Paper	Fixed Construc-tions	Mechanical Engineering, Lighting, Heating, Weapons	Physics	Elec-tricity
Human Necessities	3.2%	30.2%	0.3%	0.1%	0.4%	16.4%	1.9%
Performing Operations, Transporting		6.1%	0.3%	0.2%	0.7%	4.9%	2.7%
Chemistry, Metallurgy			0.5%	0.2%	0.5%	15.7%	3.1%
Textiles, Paper				0.0%	0.0%	0.2%	0.1%
Fixed Constructions					0.1%	0.3%	0.1%
Mechanical Engineering, Lighting, Heating, Weapons						0.7%	0.6%
Physics							9.4%

Source: The Lens.

6. FWF-Impact through human resources

This section mainly works as a table of contents on where to find information on the impacts outside academia through human resources in the report. Due to data and resource limitations, it was not possible to elaborate in a more detailed way on the second big pillar of FWF's impacts outside academia, outside tacit and codified knowledge (see Figure 4).

The material collected in the report illustrates how FWF-funded research projects contribute to formal degrees of project staff and to gaining research skills which can be used outside academia.

- The survey results (4.5) provide information on how many formal degrees FWF contributed to, but also gives an idea about intersectoral and international career paths or mobility, with significant shares of researchers once involved in FWF-funded projects now working in sectors outside academia.
- That their knowledge or research skills can sometimes be key for knowledge transfer or commercialisation and valorisation of scientific research results, is shown both by the analysis of patents (5.1) and the case studies (7): when FWF-funded researchers appear as inventors on patent documents, or when FWF-trained researchers are key research staff in start-ups, the link between FWF-funding, human resources and impacts outside academia is clearly observable.
- The economic demand-side modelling (8.1) uses another dimension of FWF's funding of human resources: the economic effects of wages paid to researchers, leading to demand effects throughout the economy. Such effects are not special to the FWF, but because the share of wages in total funding is high, so are the related "impacts outside academia". Econometric supply-side estimations (8.2) statistically link FWF's impact on human capital to productivity.

Nevertheless, we clearly underestimate FWF's impact through human resources as data are mostly patchy, with the exception of the economic effects of wages paid. To fully capture FWF's contribution, longitudinal tracking of project members would have to be implemented. Even in this case, the question of the exact amount of contribution, and the role of other contributors, such as universities or other experiences, will remain open. To gain a better understanding on top of the tracking, interviews and surveys are hence commendable – only they can provide contribution analysis, tracing FWF's contribution to impacts. This will be done in the next section with case studies.

7. Case studies of the impact of FWF-funded basic research

In this section, we present first our methodological approach for our case studies and then four selected case studies on economic and societal impacts from FWF-funded basic research projects.

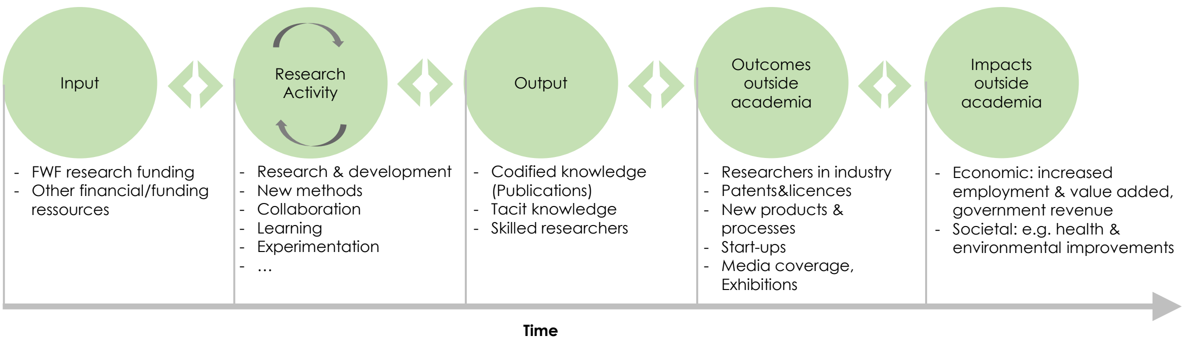
7.1. Methodological approach

7.1.1. Methodological background

The case studies presented here provides an analysis of impact pathways of the FWF funding using the approach of qualitative contribution analysis, which looks to establish "credible causal claims about the contribution an intervention is making to observed results" (Mayne, 2012, p. 270). Key is working out a theory of change or intervention logic, which outlines the possible impact path starting from the FWF-funded project to the economic and societal impact and the foundation of an impact history, taking into account framework conditions, other funding sources and the specifics of the relevant disciplines and fields of application. Such contribution-analysis based case studies have the advantage that they can trace in detail the mechanisms and transmission channels between basic research and successful applications. Our main source for making causal claims about the contribution of FWF-funding to the observed results are interviews with the involved researchers and other contributors or users of the research. This first-hand information source is best placed to assess the transmission of research to application and uses, visualised by the arrows connecting the inputs, outputs, outcomes and impacts in Figure 39, which shows a classic intervention logic framework and can be understood as a specific version of the general FWF impact pathways outlined in section 3.

Note that in the previous sections, e.g. in section 5 on the use of FWF publications in patents, it would be next to impossible to determine the precise contribution of an FWF-funded publication to the patent it is cited by, because the patent office or the inventors themselves would have to be interviewed or surveyed, which is unlikely to work because of non-response and would be very costly. In our case studies, we do not face the same problem, we can determine the contribution of FWF-funding to applications and uses precisely.

Figure 39: **Research impact pathway of FWF-funding**



Source: Authors based on https://www.ucd.ie/impacttoolkit/plan/impactjourney/.

The time lag between funding and the observation of economic impacts varies greatly (see also survey results in section 4). The longer or more complex the path, the more difficult it is to link the impact to the FWF input.

It can be assumed that the FWF not only stands at the beginning of a value chain of knowledge production, but also accompanies the development of science-based sectors (bio-pharma) over longer stretches. With possible exceptions in the area of highly knowledge-based sectors, only outputs and outcomes can be directly measured and linked to the FWF input. In addition, we assume that relevant impact dimensions and indicators for funded activities can at least be named (even if they cannot be quantified).

7.1.2. **Selection of case studies**

As part of the project, four distinct case studies were selected in collaboration with the FWF. These case studies were chosen to represent the diverse range of impacts and impact pathways, as well as the various disciplines supported by FWF funding. While the effects within academia provide insight into the broader impact of FWF funding, it is important to emphasize that the primary focus was on societal and economic impacts outside academia. Consequently, the selection was guided by the following criteria:

- Different disciplines
- Societal relevance outside academia
- Economic relevance outside academia

In addition, we did not choose to restrict examples only to Austria. FWF funds research projects, that may have economic or societal benefits outside Austria, as the selection criterion for funding is research quality and academic impact. This is the case for most funding of basic research projects, intended or unintended.

Table 20: **Overview of four case studies**

Case study	Focus of content
Quantum Ecosystem Austria	Since the 1970s, the FWF has significantly contributed to the development of Austrian quantum research and its international achievements. With the onset of the second quantum revolution in the 2000s, research results are increasingly being translated into technologies and, consequently, into practical applications. This case study focuses on the Austrian quantum ecosystem and its societal and economic impacts beyond academia, which, in the long run, can often be traced back to FWF funding.
Proxygen	The case study examines the role of FWF funding in the establishment of the biotechnology spin-off Proxygen. Proxygen was established in 2020 as a spin-off from the Winter lab at CeMM, Austrian Academy of Sciences. It focuses on screening methods for detecting new 'Molecular Glues' and the development of 'Molecular Glue Degraders', which are used to treat cancer and other life-threatening diseases.
CRISPR/Cas9 technology (Gene scissors)	The case study examines the role of FWF funding in the discovery and development of the CRISPR/Cas9 technology. Two pivotal papers, presenting the discovery of the CRISPR/Cas 9 technology, were outputs of FWF-funded projects/an FWF-funded doctoral programme. The case study therefore attempts to understand the impact of the CRISPR/cas9 technology on research, but also on the economy and society.
Park Elea-Velia	This case study examines the wide-ranging impacts of FWF-funded excavations conducted by Austrian archaeologists at the archaeological area of Velia, situated in the southern Italian province of Salerno.

Source: Authors.

7.1.3. Data sources

The following data sources can be mentioned for the development of the case studies:

- Desk research
- FWF Research Radar
- Patent data
- Semi-structured interviews

The data collection of the case study is based on desk research and interviews. This approach involves reviewing relevant documents, publications, and websites, gathering and analyzing information. This process provides an initial and essential insight into the subject of the case study.

Through interviews with the people involved (both FWF researchers as well as the "using" side, if not identical), it then traces the impact pathways, the importance of other research funding sources, framework conditions etc. Interviews are semi-structured and focused on what the FWF-funding enabled the re-searchers to do and how this led to impacts inside and outside academia. In total 13 online-interviews were conducted. Table 21 shows the number of interviews per case study.

Table 21: **Number of interviews**

Case study	Number of interviews
Quantum Ecosystem Austria	6
Proxygen	2
CRISPR/Cas9 technology (Gene scissors)	3
Park Elea-Velia	2

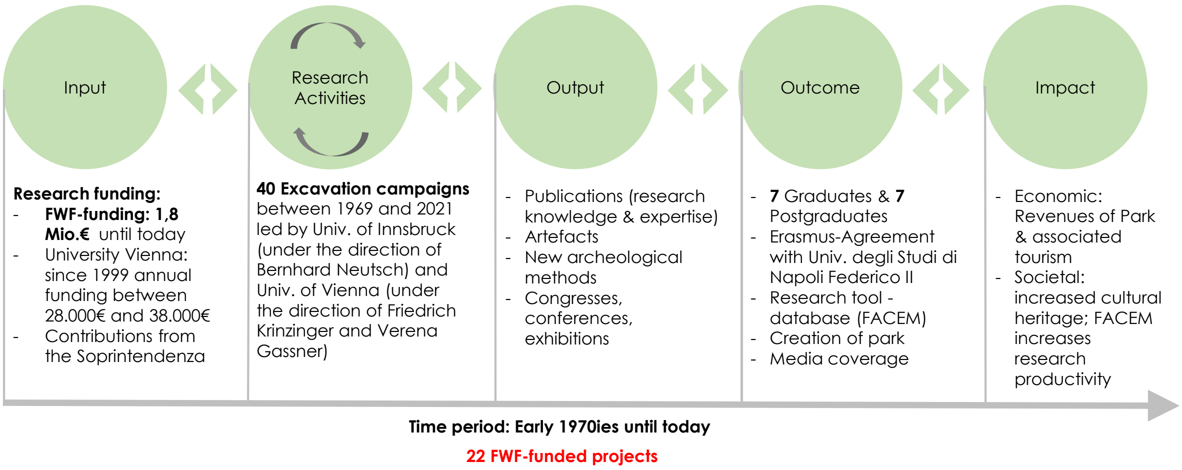
In addition, data related to FWF funding and its outputs (such as publications and patents) are analyzed alongside the interviews. The insights gained from the semi-structured interviews allow for the development of narratives that contextualize the figures on FWF funding and its resulting academic outputs and outcomes outside academia, including the number of publications, patents, and more.

7.2. Case study 1: Archeological Park Elea-Velia

7.2.1. Impact Pathway of the FWF-Funding

The excavations and research at Velia conducted by the University of Innsbruck in the 1970s under the leadership of Bernhard Neutsch, and later by the University of Vienna from the early 1990s under the direction of Friedrich Krinzinger and subsequently Verena Gassner, would not have been possible without the support of the FWF. The FWF's funding not only bolstered Austrian archaeological research and its international reputation but also significantly contributed to the development and preservation of cultural heritage, which is a vital aspect of European identity. Additionally, this support played a role in the economic strengthening of the southern Italian province of Salerno. Figure 40 presents a simplified model of the impact pathway of the FWF funding, which will be analyzed in the following sections.

Figure 40: **Impact-pathway of the FWF-Funding**

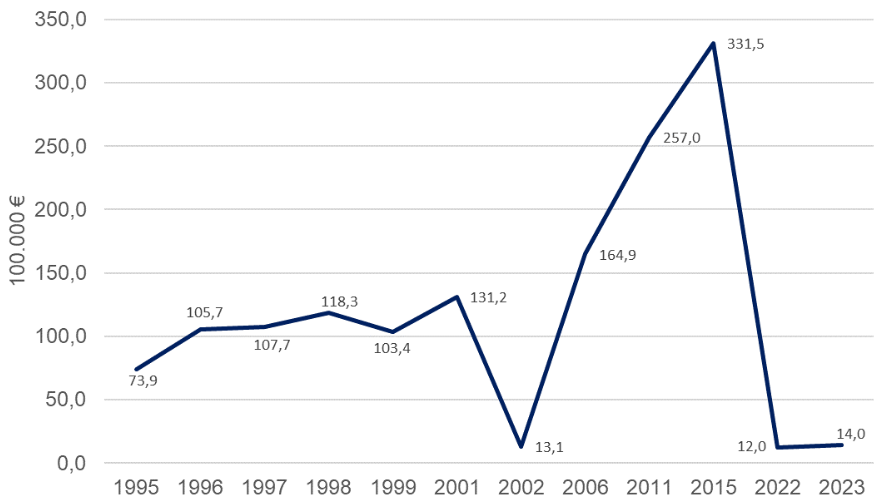


Source: Authors.

Input: The FWF-funding in numbers

Altogether, the FWF funded 21 projects in Velia between 1978 and 2019. The last two FWF-projects provided funding for book publications (Velia Studies IV). The total amount of funding provided by the FWF to projects in Velia reaches € 1.763.977. Figure 41 shows the funding amount over time, since 1995. Table 22 further shows the individual projects, the project running time and funding amount.

Figure 41**: FWF-funding for research projects in Velia since 1995 (in 100.000€)**



Source: https://www.fwf.ac.at/entdecken/forschungsradar.

Table 22: **FWF-funded projects at Velia**

Funding programme	Project Title	Principal Investigator (PI)	Project Runtime	Funding Amount
Book Publications	From Hyele to Velia. The finds.	V. Gassner	27.03.2023 - 26.03.2026	€ 14.000,00
Book Publications	From Hyele to Velia. Fortifications in their urban context	V. Gassner	20.07.2022 - 19.07.2025	€ 12.000,00
Lise Meitner	Ceramic production in the plain of Paestum	A. De Bonis	15.09.2016 – 14.09.2018	€ 159.620
PI Project	Urbanistic studies in the Eastern quarter of Velia - a hitherto unknown region of the town	V. Gassner	01.08.2015 - 31.01.2019	€ 331.508,00
PI Project	The sanctuary of Zeus at Velia	V. Gassner	2011 -2015	€ 256.979,00
PI Project	The sanctuaries of Velia on the ridge	V. Gassner	01.02.2006 - 31.12.2008	€ 164.866,00
Book Publications	Materielle Kultur und kulturelle Identität Eleas	V. Gassner	06.05.2002 - 03.09.2003	€ 13.081,00
PI Project	The fortifications of Velia	V. Gassner	2001 - 2005	€ 131.219,00
PI Project	The fortifications of Velia	F. Krinzinger	01.09.1999 - 14.04.2001	€ 103.408,00
Book Publications	Neue Forschungen in Velia I	F. Krinzinger	27.01.1998 - 20.05.1999	€ 10.915,00
PI Project	Archaeological research at Velia 1998	F. Krinzinger	11.07.1998 - 30.11.1999	€ 107.352,00
PI Project	Archäologische Forschungen in Velia	F. Krinzinger	01.06.1997 - 31.10.1998	€ 107.701,00
PI Project	Archäologische Forschungen in Velia	F. Krinzinger	01.07.1996 - 31.12.1997	€ 105.666,00
PI Project	Archäologische Forschungen in Velia	F. Krinzinger	03.07.1995 - 03.07.1996	€ 73.908,00

PI Project	Archäologische Forschungen in Velia 1994	F. Krinzinger	1994	€ 89.460,26
Research Project	Das Theater von Velia	F. Krinzinger	1993	€ 61.408,54
Research Project	Archäologische Forschungen in Velia. Insula II	F. Krinzinger	1992	€ 120.927,60
Research Project	Feldarchäologische Forschungen in Velia	F. Krinzinger	1989	€ 9.738,16
Research Project	Archäologische und baugeschichtliche Untersuchungen in Süditalien	B. Neutsch	1979	€ 16.788,05
Research Project	Archäologische und baugeschichtliche Untersuchungen in Süditalien — ELEA	B. Neutsch	1978	€ 18.894,94
Research Project	Archäologische und baugeschichtliche Untersuchungen in Süditalien	B. Neutsch	1976	€ 14.156,67

Source: https://www.fwf.ac.at/entdecken/forschungsradar.

In addition to the FWF funding, the archaeological team from the University of Vienna, initially led by Friedrich Krinzinger and later by Verena Gassner, received an annual budget ranging from €28,000 to €38,000 from the University of Vienna starting in 1999. This funding was allocated for depot rent and research activities at the site. Moreover, the Soprintendenza frequently supported the excavations by providing labor and other resources for the Austrian archaeological research team.

Activities

The funding of the Austrian Science Fund (FWF) and the above mentioned other funding resources has enabled extended research campaigns, allowing for more comprehensive excavation and analysis, many in close collaboration with the Soprintendenza dei Beni Archeologici delle Province Salerno e Avellino. In total 40 excavation campaigns were led by Austrian researchers between 1969 and 2021, from which the majority was financed through FWF funding.

This allowed researchers from the University of Vienna to undertake detailed analyses of artefacts and architectural structures uncovered at Velia. Their work includes the study of pottery, inscriptions, and other material culture, providing insights into the daily life, trade, and cultural practices of ancient Elea (Gassner and Trapichler, 2024).

The main focus areas and characteristics of these research activities can be summarized as follows:

- The Urban Development of Velia: One of the main focus areas is the study of the urban development of Velia. Researchers from the University of Vienna have collaborated with Italian archaeologists to map and analyse the city's layout, focusing on residential areas, public buildings, and the complex network of streets (Gassner et al., 2024).
- Artefacts and Daily Life: Numerous artefacts have been discovered, ranging from pottery and tools to coins and inscriptions. These items offer valuable information about the daily life, economy, and trade practices in Velia. For instance, the presence of imported goods indicates extensive trade networks (Gassner and Trapichler, 2024).

- Technological Applications in Archaeology: The University of Vienna has been at the forefront of applying advanced technologies (e.g. geophysical prospection) at Velia. This has enabled the discovery of previously unknown structures and provided a more comprehensive understanding of the site's layout and usage (Gassner et al. 2019).

Output and Outcomes

The collaborative projects funded by FWF and other funding sources led to the uncovering of different parts of the city Velia and the discovery of numerous artefacts (e.g. pottery, tools, coins). Additionally, the archaeometric analyses of the pottery carried out by the University of Vienna ultimately led to the creation of a database FACEM (https://facem.at/) (www.facem.at), which can be regarded as an academic as well as an output outside academia.[2] It is basically a research tool which can be used within and outside of academia by museums or specialists to identify the "provenance, distribution, and production technology of [Greek, Punic and Roman] ceramic finds", as the website facem.at states. As a research tool, it typically enhances research productivity and thus also increases the (soietal, in this case) returns to public funding of R&D.

It resulted in further numerous publications, conferences, and workshops, disseminating findings to a broader scholarly audience. Open access publications, funded also by the FWF, received a lot of positive feedback and helped in extending international exchange of researchers. Furthermore, the University Vienna has also been instrumental in organizing field schools and training programmes at Velia, offering students hands-on experience in archaeological excavation techniques and research methods. These educational initiatives have been crucial in training new generations of archaeologists. Overall, most of the FWF-funded projects in Velia, especially the ones from the 1990th ongoing, led to a dissertation or diploma thesis. A total of seven master's students and seven doctoral candidates focused between 1970th and early 2020th in their thesis on excavations and research in Velia (Gassner and Krinzinger, 2023). Furthermore, to commemorate the 50th anniversary of the excavations, Verena Gassner, Friedrich Krinzinger and Alexander Sokolicek published an anthology as part of a congress (50 anni di ricerche Austriache a Velia – 50 Jahre österreichische Forschung in Velia, Phoibos Verlag). The dissertation and diploma thesis as well as four book publications (Studies on Velia I-IV) were made possible by the FWF-funding. In the four FWF-funded book publications three under the lead of Verena Gassner and one of Fritz Krinzinger, the findings are summarized of the excavation work in Velia, detailing the processes and conclusions drawn.

[2] From the website facem.at: „**Facem** (= **Fa**brics of the **Ce**ntral **M**editerranean) is a database for specialists of Greek, Punic and Roman pottery. It aims to identify the provenance, distribution, and production technology of ceramic finds essential for the reconstruction and interpretation of broader socio-economic phenomena and ancient trade networks in the Mediterranean. FACEM's research methodology combines the examination of freshly broken ceramic samples at a macro- and microscopic level with archaeometric analyses. Since its first release in 2011, it has become a well-known research tool, supporting inter- and multidisciplinary scholarship by sharing thousands of high-resolution macro images and fabric descriptions"

Academic impacts

The involvement especially of the University of Vienna since the early 1990th and in the 1970th also of the University of Innsbruck, backed by the FWF-funding, has had a profound impact on the excavations and research at Velia. The contributions have enriched the academic understanding of the site and advanced archaeological methods.

Additionally, it strengthened the cooperation and exchange between Austrian and Italian researchers as well as the local population. When the Austrian work in Velia began in the early 1970s, these relations were far from frictionless, and scientific collaboration between the two countries first had to be established. The Institute for Classical Archaeology at the University of Innsbruck, and later at the University of Vienna, have developed a close and intensive collaboration with the Archaeological Monuments Office of the provinces of Salerno, Benevento, and Avellino, along with their respective directors (as well as with the University of Naples Federico II (especially with Prof. Giovanna Greco) and the University of Salerno (especially with Renata Cantilena oder Luigi Vecchio)   (see the forwords of Gottsmann and Schnetzer 2023 in the anthology published as part of the celebrations of the 50th anniversary of the excavations).

The collaborative projects, mainly together with Soprintendenza per i Beni Archeologici delle Province di Salerno e Avellino, have contributed greatly to mutual learning and understanding and to intensive cooperation between the University of Vienna and the two local Universities, namely the University Napoli Federico II and Salerno. The collaborations have also led to the invitation of Austrian researchers to congresses and collaborative publications, which has increased the visibility and international standing of Austrian researchers in this field. Also for students coming to research in Velia it was an excellent opportunity to get to know different living environments and the culture of Southern Italy. Apart from internships and training excavations for students from all three universities, the relationships were institutionalized through various scholarship programmes (Schnetzer, 2023).

Academic impacts of the FWF funding in brief

- International reputation and visibility of Austrian archaeological research
- Education and hand-on experience for students
- Promotion of dissertations and careers in archaeology
- Exchange and mutual learning through collaborative projects
- Enhancement of research possibilities and further development of methods

Economic impacts

The reputation and visibility of Austrian archaeological research led in the early 1990ths to the involvement of the archaeological research team under Friedrich Kinzinger in the feasibility study for the archaeological park.

The development of the archaeological park Elea-Velia has had a large impact on the tourism in the region. According to the management of the archaeological Parks of Paestum and Velia

(PAEVE), the park has been visited by approximately 507,000 people in 2023, with around 50,000 visitors in Velia. Furthermore, the number of employees of PAEVE is equal to 46 employees (management, archaeologists, technical officer, administrative assistant, engineers and operators between carers and supervision), of which 16 are in service at Velia. Additionally, the PAEVE park cooperates with external partners, which are not part of the PAEVE staff, however, support the park if needed. The total number of these external partners is 38, of which 10 are in service at Velia. In total, the PAEVE park generated in 2023 revenue of €2,4million (from entry fees and goiods and services sold at the park area), from this 115.104€ can be traced back to the entrance fee of Velia. This economic impact has been enhanced by the formation of the Cilento and Vallo di Diano National Park and the dedication to the site as UNESCO World Heritage. The National Park and therefore also the archaeological site is best visited in summer and therefore also strengthen local companies during this time.

Economic impacts of the FWF funding in brief

- Revenue of the park
- Creation of workplaces at the site
- Strengthening local companies and tourism industry in the region (number of visitors per year)

Societal and environmental impacts

The most significant societal contribution of the FWF-funded projects in Velia is arguably the development and preservation of a cultural asset that spans thousands of years. The archaeological site is a key element of the regional history of southern Italy and, by extension, a vital part of European heritage. Insights gained from the excavations and research greatly enhance our understanding of history and are made accessible to the public through site visits and special exhibitions. The significance of the archaeological park as a cultural heritage site is further highlighted by the designation of the Cilento and Vallo di Diano National Park, which encompasses the archaeological sites, as a UNESCO World Heritage Site in 1998. Therefore, the park also plays a crucial role in environmental protection due to its location within the national park. Reports on the park and the archaeological excavations were also broadcast on the regional Italian television (e.g. Sereno Variabile) as well as published in the Italian newspapers. Furthermore, the database FACEM may impact the work of other archaeologists everywhere, including Austria, and therefore also archaeological sites and museums, even outside academia, leading to further contributions to cultural heritage. It also makes research more productive, increasing the benefits of publicly funded research and archaeological activities.

Societal impacts of the FWF funding in brief

- ·• Contribution to cultural heritage - UNESCO World Heritage; research tool FACEM
- ·• Contributions to media beyond specialist audiences (print, TV, podcast, film, blog, … especially in the Italian regional television/newspaper)

- ·• Environmental improvements

The archaeological area of Velia looks back at a long history of excavation and research and has developed into a historical park that attracts researchers and visitors from around the world. The Austrian involvement in Velia date back to the 1970s and has shaped the site significantly over the years. Within multiple projects funded by the FWF, researchers of the University of Innsbruck and later the University of Vienna have studied the urban development of Velia as well as numerous artefacts, ranging from pottery and tools to coins and inscriptions.

Besides the knowledge gains, the projects supported the education of the next generation of archaeologists and promoted international cooperation and mutual learning. The presence of Austrian researchers in Velia also increased the international standing of Austria in the scientific community, with many publications and dissemination of findings to an international audience. Also in the future the research in Velia will continue and the historic park will serve as a touristic as well as educational site.

7.3. Case study 2: Proxygen – a Biotech Company

7.3.1. Context

Proxygen is a biotech start-up based in Vienna. Its fundamental mechanisms are largely the result of the work conducted by the researcher Georg Winter. During his tenure as a postdoctoral researcher under Dr. James Bradner at the Dana Farber Cancer Institute at Harvard Medical School in Boston, he conducted research in the field of biochemistry, building upon his doctoral studies at the University of Vienna. He devised a generalisable pharmacological solution to in vivo target protein degradation and employed this strategy in the study of leukemic gene regulation (CeMM, n.d.). His research findings were published in Science and other academic journals, and subsequently led to the establishment of the US company C4 Therapeu-tics (https://ir.c4therapeutics.com/), which is now also listed on Nasdaq. The scientific competition in this field was already considerable at the time, with a substantial body of basic research already in place. Key mechanisms were understood and considered to have been sufficiently researched, and the first major pharmaceutical companies announced their interest. Consequently, the original basic problem became an engineering problem. The focus in this area was therefore more on clinically testing the knowledge gained, transferring it into scalable technologies and thus bringing it into application.

Upon his recruitment to CeMM as group leader (https://cemm.at/research/groups/georg-winter-group) in 2016 and subsequent return to Austria, Georg Winter continued to work on methods for target protein degradation, but shifted his research focus away from the approach initially pursued in Boston. He began exploring a relatively unexplored approach, namely the utilisation of molecular glues (see also infobox below). Although molecular glues offer a novel and promising approach to target protein degradation, their discovery has thus far been fortuitous. Their mechanisms remain poorly understood, limiting their potential for targeted development as anti-cancer agents.

Info-Box: Molecular glues for targeted protein degradation

Starting point: The body is engaged in a continuous process of protein synthesis and degradation. Protein synthesis involves the creation of new proteins, while protein degradation encompasses the removal of proteins that have become inactive or mutated. In the event of a cell being unable to de-grade specific proteins, the accumulation of these proteins can result in the development of diseases such as cancer. By employing targeted protein degradation, researchers are leveraging the cell's intrinsic mechanisms to degrade an array of previously intractable protein classes (Bristol Myers Squibb, n.d.).

Molecular Glues in short: The advent of molecular glues has opened up new possibilities for targeted protein degradation and for identifying potential treatments for some of the estimated 85% of targets in the protein-coding genome that are currently considered "undruggable" (BMG Labtech, 2024).

Major challenges: A significant challenge in the field of molecular glues is the lack of a systematic approach to their discovery. Unlike other areas of research, the development of molecular glues has been largely driven by serendipity, with no established strategies for rational design or development with the specific purpose of inducing degradation (Hjerpe, n.d.).

Area of application: Molecular glues have the potential to influence protein-protein interactions, thereby opening new avenues for therapeutic strategies targeting disease-causing proteins. The theoretical scope for their application is vast, as they offer novel routes to the development of small molecule drugs in a wide range of disease areas, including cancer, neurodegenerative disease and autoimmune conditions (Garber 2024).

7.3.1. Context

Situated in the southern Italian province of Salerno, around 50km south of another important archaeological site, Paestum, lies the archaeological area of Velia (https://museopaestum.cultura.gov.it/?lang=en). The city, first called Hyele and later Elea, was estab-lished around 540 BC by Greek immigrants from Phocaea, present-day Turkey. Around the 5th century BC, Elea was a significant centre of philosophy and trade, most known for being the location of the Eleatic school of philosophy, which was established by Parmenides and his pupil Zeno (Parco Archeo-logico di Paestum e Velia I, n. d.). Today, the Velia archaeological region serves as a historical park that draws visitors, academics, and students from all over the world. With ruins of temples, one theatre, two thermal baths and homes remaining, the park provides a thorough look into Greek and Roman urban life.

While the interest and documentation of Velia date back to the 19th century, with first mappings of the city walls and layout, systematic excavations were initiated early in the 20th century. The first excavations in the 1920s and 1930s were carried out by Superintendent Amedeo Maiuri. These early efforts were focused mainly on the higher part of the city, where more of the buildings and structures were still visible above the surface. From 1949 onwards Superintendents Pellegrino Claudio Sestieri and Mario Napoli continued working where Amedeo Maiuri left off and started investigating also the lower parts. Uncovering several structures in the lower part, Sestieri made a significant contribution to the knowledge of the expansion of the urban organization of this area (Gassner et al., 2024). When Mario Napoli took over the superintendence in 1960, he was able to quickly create a comprehensive research programme based on clearly formulated hypotheses, which aimed above all to clarify topographical questions. In this period, great strides could be accomplished through a more methodical and cooperative approach to archaeological investigation. In the 1960ies and 1970ies researchers like M. Napoli ana-lysed the urban planning and uncovered the well-known Porta Rosa, an ancient Greek gateway, which connected the Southern and the Northern part of the city (Parco Archeologico di Paestum e Velia II, n. d.).

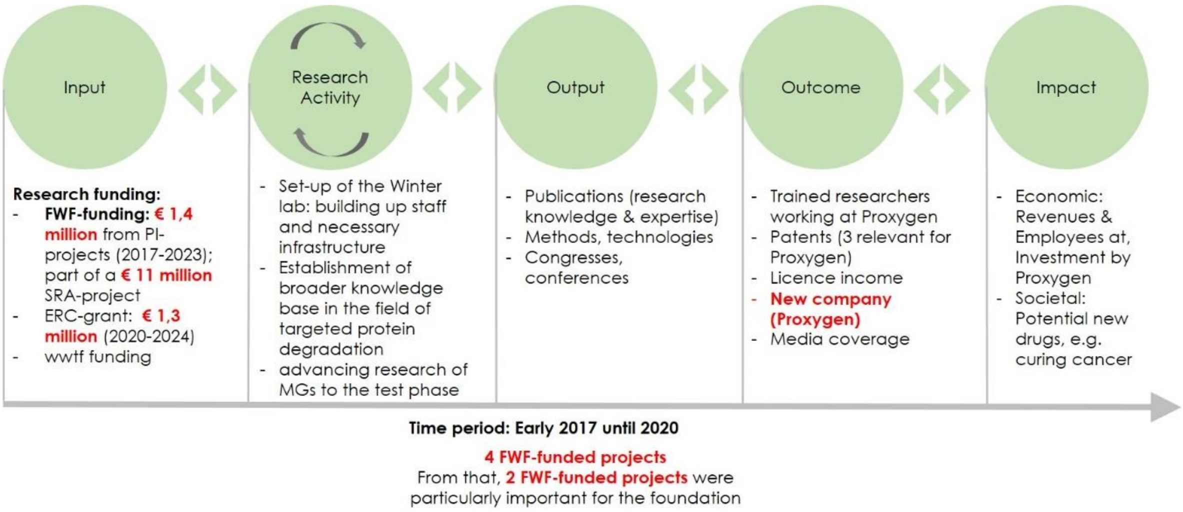
In 1969, Mario Napoli invited Bernhard Neutsch, then at the University of Mannheim, from 1971 professor of archaeology at the University of Innsbruck, to research in Velia. This was the starting point for Austrian involvement at the excavations in Velia, which was later on continued with projects of Fritz Krinzinger and later Verena Gassner, both researchers from the University of Vienna. These institutions have contributed through academic partnerships, providing both expertise and resources. Graduate students and researchers from these universities have participated in fieldwork, bringing fresh perspectives and contributing to the site's ongoing research initiatives. Especially the University of Vienna has been strongly involved in Velia ever since and have played a significant role in the excavations and research activities at the archaeological area of Velia. Their involvement has provided crucial support in terms of expertise, funding, and collaborative projects that have furthered the understanding and preservation of this ancient site. Beyond these contributions, the University of Vienna was instrumental in the establishment of the archaeological historical park, particularly through its important role together with the Università degli Studi di Napoli Federico II in the feasibility study conducted by the Soprintendenza in the early 1990s (Gassner et al., 2024). This partnership was a foundational step in the park's creation.

As a result, and with Italy's acknowledgement of the region's historical and cultural value Velia gradual-ly evolved from an excavation site into a designated historical park. Velia's protection was greatly aid-ed by the creation of the Cilento and Vallo di Diano National Park in 1991, including the archaeological areas of Paestum and Velia. This classification served to both protect the site from intrusions and to emphasize its significance in relation to Italy's cultural legacy as a whole. In 1998, the entire area, including Velia, was designated a UNESCO World Heritage Site (Parco Archeologico di Paestum e Velia II, n. d.).

7.3.2. Impact Pathway of the FWF-Funding

The FWF funding played a crucial role in the establishment of the Winter Lab, enabling the development of expertise in targeted protein degradation, which was essential for the foundation of Proxygen. This chapter therefore outlines the impact pathway of the FWF funding in detail. Figure 42 presents a simplified model of the impact pathway of the FWF funding, which will be analyzed in the following sections.

Figure 42: **Impact pathway of the FWF-funding**



Source: Authors.

Input: FWF-funding in numbers

Between 2016 and the establishment of the company, the Winter lab was engaged in three FWF-principal investigator projects and one special research area (SFB) project. In addition to FWF funding, it also received ERC funding and smaller grants from the Vienna Science and Technology Fund (wwtf) and the Austrian Research Promotion Agency (FFG). During this period, all funding was directed towards the field of targeted protein degradation, although not exclusively towards the discovery and research of molecular glues. The individual findings derived from these various projects collectively contributed to the company's establishment. Nevertheless, three projects can be identified as pivotal to the successful spin-off. These include two FWF-principal Investigator projects and one ERC-grant:

- FWF: Charting and Disrupting the Gene-Regulatory Function of CDK6 (P 30271))
- FWF: Development of c-RAF degraders to probe KRAS mutant cancers ((P 32125))
- ERC-Grant: Glue2Degrade (€ 1,3 million between 2020 – 2024; https://cordis.europa.eu/project/id/851478)

Table 23 presents a list of the individual FWF-funded projects, accompanied by the amounts of funding received and the research output achieved. In total, the Winter lab received from 2017 until 2023 approximately € 1,4 million from FWF Principal Investigator projects (PI-projects). Additional it is involved in a special research area project (SFB) with a funding amount of more than € 11 million. Considering the three projects that played a central role in the foundation of Proxygen, it can be estimated, as highlighted in the interview with Georg Winter, that approximately an amount of € 800.00 of research funding indirectly contributed to the company's establishment, of which about € 600.000 can be attributed to the FWF.

Table 23: **FWF-funded projects**

Funding Programme	Project Title	Funding Amount in €	Project Runtime	Output	Comment
PI Projects	Charting and Disrupting the Gene-Regulatory Function of CDK6 (P 30271)	398.558	2017 – 2020	Publications: 5 Citations: 370	Funding was pivotal for the foundation of Proxygen
PI Projects	Chemical Dissection of the Super Elongation Complex (P 31690)	401.816	2019 – 2023	Publications: 18 Citations: 301 Funding: 2	
PI Projects	Development of c-RAF degraders to probe KRAS mutant cancers (P 32125)	557.338	2019 – 2023	Publications: 18 Citations: 319	Funding was pivotal for the foundation of Proxygen
Participation in the Special Research Areas	Targeted protein degradation - from small mole-cules to complex organelles (F 79)	11.192.255	2020 – 2028	Publications: 2 Citations: 12	

Source: JR-POLICIES based on data from FWF Research Radar, https://www.fwf.ac.at/en/discover/research-radar .

Activities

It would be incorrect to assert that Proxygen emerged in a linear fashion as a research outcome from a single research project. The transition from research to the establishment of a company is not a straightforward process, whereby promising results from a research project could be readily transferred to a start-up. This also applied to the Proxygen spin-off: The foundation of the company was based on the combination of various findings from different scientific studies and research projects:

The above listed FWF funding was instrumental to set up the Winter lab (especially the two PI projects highlighted pivotal), both in terms of building up staff and laying the foundation for building up necessary infrastructure. And it helped the lab to establish a broader knowledge base in the field of targeted protein degradation: At the time of Georg Winter's appointment as principal investigator in 2016, the scientific competition in the field of MGs was still manageable. While the field of heterobifunctional molecules had already reached a considerable level of advancement, necessitating the availability of a well-equipped chemistry laboratory of a certain size to remain competitive, MGs were still in their infancy. During this period, the Winter lab was in the process of being established. The laboratory was not yet operational and the necessary chemical laboratory infrastructure was not accessible. This enabled the group to exploit with the means at its disposal the time lag created by the lack of competitors in the market regarding MGs. The primary objective was to develop methodologies for the identification of novel MGs and the characterisation of their mechanisms, modes of action and active ingredients.

Finally together with the research base of the FWF-funding regarding targeted protein degradation, the ERC-grant enabled the mechanism underlying the discovery and development of a 'molecular glue degrader' to be elucidated to such a degree that it could be transferred to the test phase and ultimately scaled up.

In addition to the scientific findings, other factors also played a decisive role in the founding of the company, including the optimal timing, the involvement and attraction of relevant talent, the availability of funding opportunities, the accessibility of infrastructure, the founders' willingness and ability to invest time beyond their usual professional activities and the prevailing market conditions. CeMM provides in this respect important supportive framework conditions. The provision of infrastructures, including incubator spaces, in conjunction with consulting services, facilitates the smooth implementation of spin-off processes.

Output/Outcomes

Although the FWF-funded projects were not primarily oriented towards the discovery and investigation of molecular glues, they helped to set up the lab and thus resulted in the development of methods and scientific insights that could be applied to this field. This again resulted in publications, some of them in high-calibre journals . In total, the output of the three FWF PI-projects listed in the table above are 41 publications, which got cited 990 times so far, and two publications from the Special Research Area project, one was published by Georg Winter. From that the two FWF PI projects, which form a significant part of the research foundation for Proxygen, resulted in 23 publications that have been cited 689 times (see Table 23). Later the laboratory expanded, now including also synthetic chemistry. The ERC-grant enabled the group to prioritise the biological aspects and mechanical understanding of the MGs, thereby gaining a competitive advantage. This ultimately led to patent applications. Proxygen is based on these three patents. The patents are listed below:

- Oxazole and thioazole-type cullin ring ubiquitin ligase compounds and uses thereof
- Heterocyclic cullin ring ubiquitin ligase compounds and uses thereof
- Method for identifying a chemical compound or agent inducing ubiquitination of a protein of interest

In addition to publications, the FWF-funded projects also resulted in the development of highly qualified skilled labour. PhD students were employed through the FWF-funded projects and trained as experts in this field of research (as outlined above). One of these PhD students, who joined the Winter lab via the first FWF-funded Principal investigator project, initially joined Proxygen as Head of Biology with its formation and is now serving as Chief Technology Officer (CTO). Additionally, also a technical assistant – before part of the Winter Lab – joined the company from the very beginning.

Academic impacts

The presence of highly qualified minds represents a crucial factor in determining success, as does the availability of a well-equipped, cutting-edge infrastructure. With the formation of the Winter lab and the success of its initial publications, its international reputation and visibility in the field of molecular glues for targeted protein degradation grew rapidly. This contributed to the group’s growth in attractiveness for postdoctoral researchers and led to the influx of experienced international scientists into the group. One postdoc from Spain could be recruited relatively at the start of the Winter lab. A critical mass of highly qualified professionals was successfully established, significantly enhancing the Winter Lab's attractiveness for international collaborations. Since its establishment, the Winter Lab has developed extensive networks at both European and international levels, advanced its research to the highest standards, and made substantial contributions to providing ground-breaking insights into fundamental societal challenges, such as advancing cancer research.

Academic impacts of the FWF funding in brief

- International reputation and visibility of Austrian research in the field of molecular glues for tar-geted protein degradation
- Building a critical mass
- Promotion of dissertations and careers
- Recruiting national & international experts
- Education and hand-on experience for students
- Enhancement of research possibilities and further development of methods

Economic impacts

Building on the FWF-funded research, three patents were eventually filed through research conducted as part of the ERC grant, laying the foundation for the establishment of Proxygen. These patents were initially licensed by the company, providing economic returns to CeMM. However, the even more substantial economic impact, to which the FWF funding significantly contributed, is the founding of the company itself. Since its inception in 2020, the company has grown to 28 employees and generated an estimated revenue of over 7,5 Mio. € in 2023. It has secured key strategic partners and is on the verge of entering clinical trial phase 1 with its first product (see also Table 24).

Table 24: **Key information on Proxygen**

	Information on the company
Founders	Georg Winter, Matthias Brand, Stefan Kubicek and Giulio Superti-Furga
Spin-off from	Research Center for Molecular Medicine (CeMM) of the Austrian Academy of Science (23 % shareholding)
Founding year	2020

Location	Siemensstr. 89, 1210 Vienna, Austria
Number of employees	2023: 28 employees Some employees are also based in Germany and France and work remotely
Field of activity	Biotechnology research: Screening methods for detecting new 'Molecular Glues' and the development of 'Molecular Glue Degraders', which are used to treat cancer and other life-threatening diseases
Products	Most advanced product is approximately 12 to 18 months from clinical trial phase 1
Current Funding	• Austria Wirtschaftsservice Gesellschaft mbH (aws) • Austrian Research Promotion Agency (FFG) • Private investors and industry bilateral cooperation (e.g. Merck KGaA, Boehringer Ingelheim, MSD)
Total Revenue 2023	>7.5m EUR
Prize	Boehringer Ingelheim Innovation Prize (2020)

Source: JR-POLICIES based on Proxygen, 2024; aws, 2020; Pharmaceutical Technology, 2023; dealroom (https://dealroom.co/); qualitative interviews & internet research.

Economic impacts of the FWF funding in brief

- Licensing of three patents from the Winter lab
- Formation of Proxygen, including training of researchers working there
- Revenues & Job creation through the spin-off
- Increase in attractiveness of Austria as a biotech hub through positive press coverage and international high-profile partnerships

Societal impacts

In addition to the economic impact of FWF funding, there are already indications of potential societal benefits. The development of molecular glues could facilitate the treatment and neutralisation of disease-causing proteins, which are currently challenging or impossible to drug. This could have a significant societal impact, despite the lengthy and costly preclinical and clinical development phases that would be required.

Societal impacts of the FWF funding in brief

- Future impact: contribution to make disease-driving proteins druggable that were considered to be undruggable
- Positive perception of science and biotech delivering remedies to counteract general science disenchantment (New medicine made in Austria)

7.4. Case study 3: Austrian Quantum Ecosystem

This case study is not about a single research project or a single impact, but about FWF's contribution to a whole new ecosystem, namely the "Quantum ecosystem". The term ecosystem has been borrowed from natural ecosystems to also describe social ecosystems, to define "a dynamic structure of different, loosely coupled societal, research and economic actors. They form a network and interact through shared technologies, languages and institutions[3]". It has also been applied to innovation: "*An innovation ecosystem is the evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors*." (Granstrand & Holgersson, 2020, p. 1) As this case study will show, the quantum ecosystem in Austria is not just an emerging academic field, but an emerging innovation ecosystem, with actors in basic and applied research as well as start-ups commercialising the scientific knowledge base. The case study therefore outlines, how the FWF-funding supported the formation of an Austrian quantum research base, which can be seen as a breeding ground for the development of the Austrian Quantum Ecosystem.

7.4.1. Context

The theoretical foundations of quantum physics were laid in the early 20th century with Max Planck's quantum hypothesis. Planck formulated this hypothesis because classical physics had reached its limits, particularly in describing light and the structure of matter. Quantum ideas sought to explain individual phenomena such as blackbody radiation, the photoelectric effect, for which Albert Einstein received the Nobel Prize, and solar emission spectra. Building on this knowledge and the technology developed in classical mechanics, the Austrian physicist Erwin Schrödinger invented wave mechanics and introduced the Schrödinger equation in 1925. This equation became a cornerstone of wave mechanics and an essential part of quantum theory. Schrödinger's work won him the Nobel Prize in Physics in 1933, which he shared with Paul Dirac. This foundation, and subsequent fundamental achievements by other physicists, laid the groundwork for the first quantum revolution in the 1950s and 1960s (Tegmark and Wheeler, 2001).

During the first quantum revolution, physicists learned to exploit quantum paradoxes that had emerged since the early 20th century. Technologies such as the transistor, the atomic clock and the nuclear magnetic resonance used in MRI scans can be traced back to new quantum ideas about the behaviour of electrons in metals and other materials. Another major quantum invention by optical physicists of the time was the laser, which is now used in applications ranging from laser pointers to barcode scan-ners and life-saving medical techniques (Garisto, 2022).

Although scientists were using their understanding of quantum mechanics to invent new technologies and tools, the term "quantum" was not commonly used in public descriptions of

[3] See Gabler Banklexikon https://www.gabler-banklexikon.de/definition/oekosystem-99853.

these developments. This was largely because the first quantum revolution did not fully exploit the potential of quantum mechanics, as the field was not yet fully explored (Garisto, 2022).

In Austria, quantum research gained significant momentum during the first quantum revolution. The University of Vienna, Vienna University of Technology, University of Innsbruck and the Austrian Acad-emy of Sciences were key players in creating an environment conducive to advanced research in physics. This period saw the establishment of major research programmes and the influx of talented physicists such as Herbert Pietschmann, Reinhold Bertlmann, Helmut Rauch, Anton Zeilinger, Rainer Blatt and Peter Zoller. These physicists made both theoretical and experimental contributions to the growing field of quantum mechanics. The work of Anton Zeilinger's PhD supervisor Helmut Rauch, as well as Zeilinger's own contributions had a major impact on experimental research in quantum physics in Aus-tria and worldwide. Their experiments provided some of the clearest demonstrations of fundamental quantum phenomena and helped to establish the principles of quantum mechanics within the scientific community. Anton Zeilinger's pioneering work on quantum entanglement and quantum teleportation brought him international acclaim and provided the first conclusive evidence of quantum entanglement. Zeilinger is often referred to as the "father of quantum teleportation". In recognition of his work, he received the 2022 Nobel Prize in Physics together with Alain Aspect and John F. Clauser[4].

The second quantum revolution began in the early 21st century and continues today. Scientists and businesses are not only exploiting the insights of quantum theory, but also actively controlling quan-tum effects, opening up a wide range of new possibilities in various areas of quantum research. To-day, quantum research is broadly categorized into four pillars: 1) Quantum communication and quan-tum cryptography; 2) Quantum computing and quantum algorithms; 3) Quantum simulation; 4) Quantum metrology and sensor technology.

With the beginning of the second quantum revolution, the research landscape in Austria has expanded considerably. In 2003, the Institute for Quantum Optics and Quantum Information (IQOQI) of the Austri-an Academy of Sciences was founded. The institute is located in Vienna and Innsbruck and is closely linked to the University of Vienna and the University of Innsbruck. In the same year, the Austrian Insti-tute of Technology (AIT) established a research group in the field of quantum communication and cryp-tology. Furthermore Institute of Science and Technology Austria (ISTA), which was founded in 2006, and the University of Linz are also success-fully involved in quantum research today. Thanks to the strong research landscape and the commit-ment of the public sector, a quantum ecosystem has gradually developed in Austria since the 2000s.

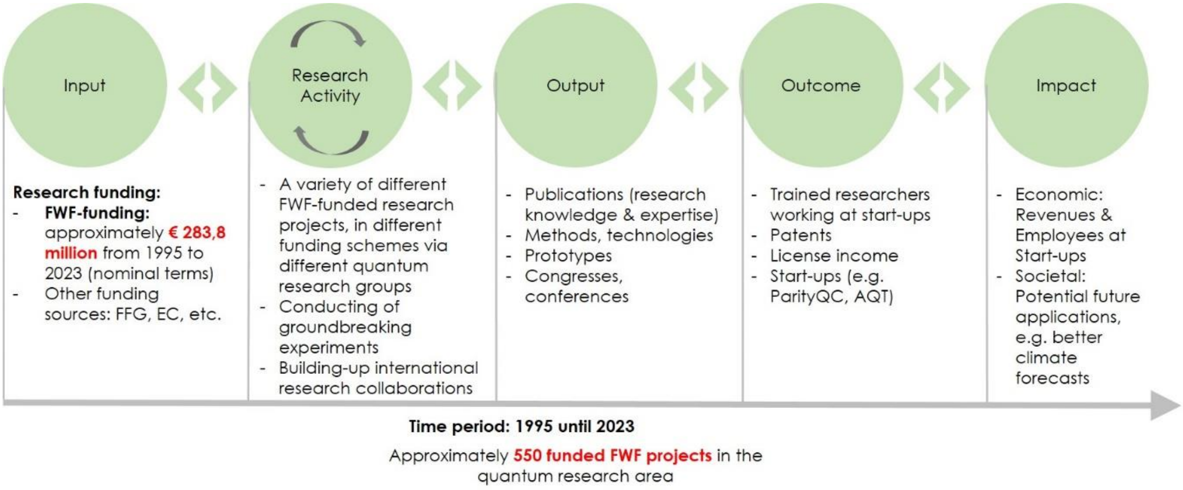
7.4.2. Impact Pathway of the FWF-Funding

The Austrian Science Fund (FWF) contributed to the advancement of Austrian quantum research over the past decades. From this research basis a national quantum ecosystem has begun to emerge, in-volving stakeholders from various sectors. This chapter outlines the impact pathway of the FWF funding. The aim is to capture both the macro and micro perspectives.

[4] https://www.nobelprize.org/prizes/physics/2022/summary/

On the macro level, it is demonstrated how FWF funding has contributed to the development of the research community in the field of quantum research since the 1970s, playing a key role in the establishment of an Austrian quantum ecosystem. At the same time, concrete examples are used to illustrate how and to what extent FWF funding has supported groundbreaking discoveries, which have either already had an economic and societal impact or are expected to do so in the near future.

Figure 43: **Impact pathway of the FWF-funding**



Source: Authors.

Input: The FWF quantum funding by numbers

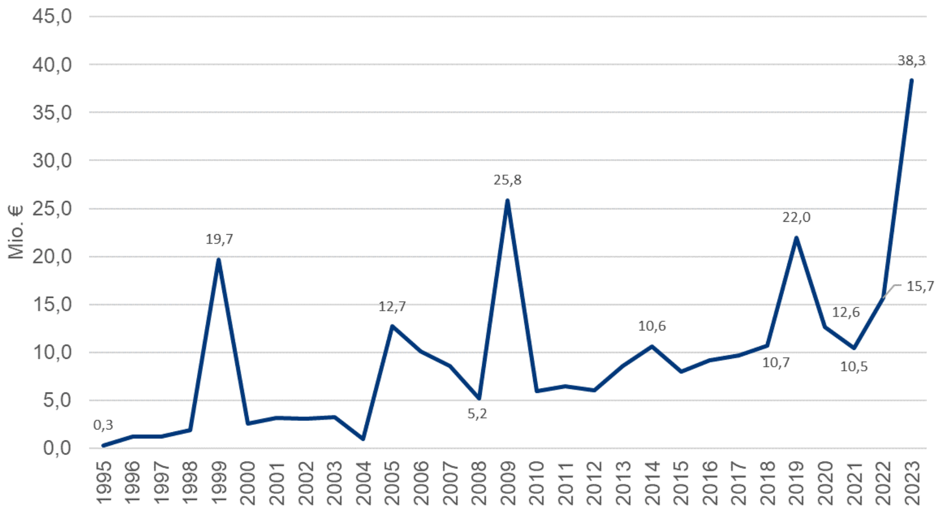
Since its foundation in 1968, the FWF has continuously invested in the development and expansion of Austrian quantum research through various funding programmes. Figure 44 shows FWF funding from 1995 to 2023. In total the FWF has spent approximately €283,8 million in nominal terms in this time period on the development and expansion of Austrian quantum research and funded more than 550 quantum projects. The figures mentioned in this section are based on data from the FWF Research Radar and do not claim to be exhaustive. They serve as a guideline and provide a sense of the scale of FWF funding from 1995 to 2023, without asserting to cover all FWF-funded projects in the field of quantum research comprehensively.[5]

Figure 44 shows FWF funding of various research programmes from 1995 to 2023. The outliers in 1999, 2005, 2009 and 2019 are due, among other things, to the “Special Research Areas” (Spezialforschungsbereiche SFB) in the field of quantum research launched in these years, each with a funding volume of more than €10 million (in 2005, the funding volume of the special

[5] Using the search function of the FWF Research Radar, the term "Quanten*" was researched, resulting in a list of all projects that included the term "Quanten" in the title, keywords, discipline, or abstract (a total of 907 projects). Subsequently, all projects not classified within the natural or technical sciences were filtered out (6 projects). For the 305 projects where "Quanten" was mentioned only once in the abstract, a random review was conducted, revealing that these projects are not at the core of quantum research. Due to time constraints, not all abstracts of the 305 projects could be reviewed; therefore, it was decided to exclude all 305 projects from the analysis. In total, 596 FWF-funded projects from various programs between 1995 and 2023 were included in the evaluations.

research area was just under €10 million), while the strong outlier in 2023 is due to the Cluster of Excellence "Quantum Science Austria" (quantA) launched under the leadership of Gregor Weihs from the University of Innsbruck. This already indicates the great importance that the FWF attaches to quantum research and its role in driving the second quantum revolution. Unsurprisingly, the seven largest Austrian research institutions in the field of quantum research received the largest share of FWF funding in the period from 1995 to 2024 (approx. 90%). Within the seven big players, the University of Innsbruck ranks first in terms of FWF funding received, ahead of the Vienna University of Technology and the University of Vienna.

Figure 44: **FWF funding of quantum research projects of various research programmes per year since 1995**

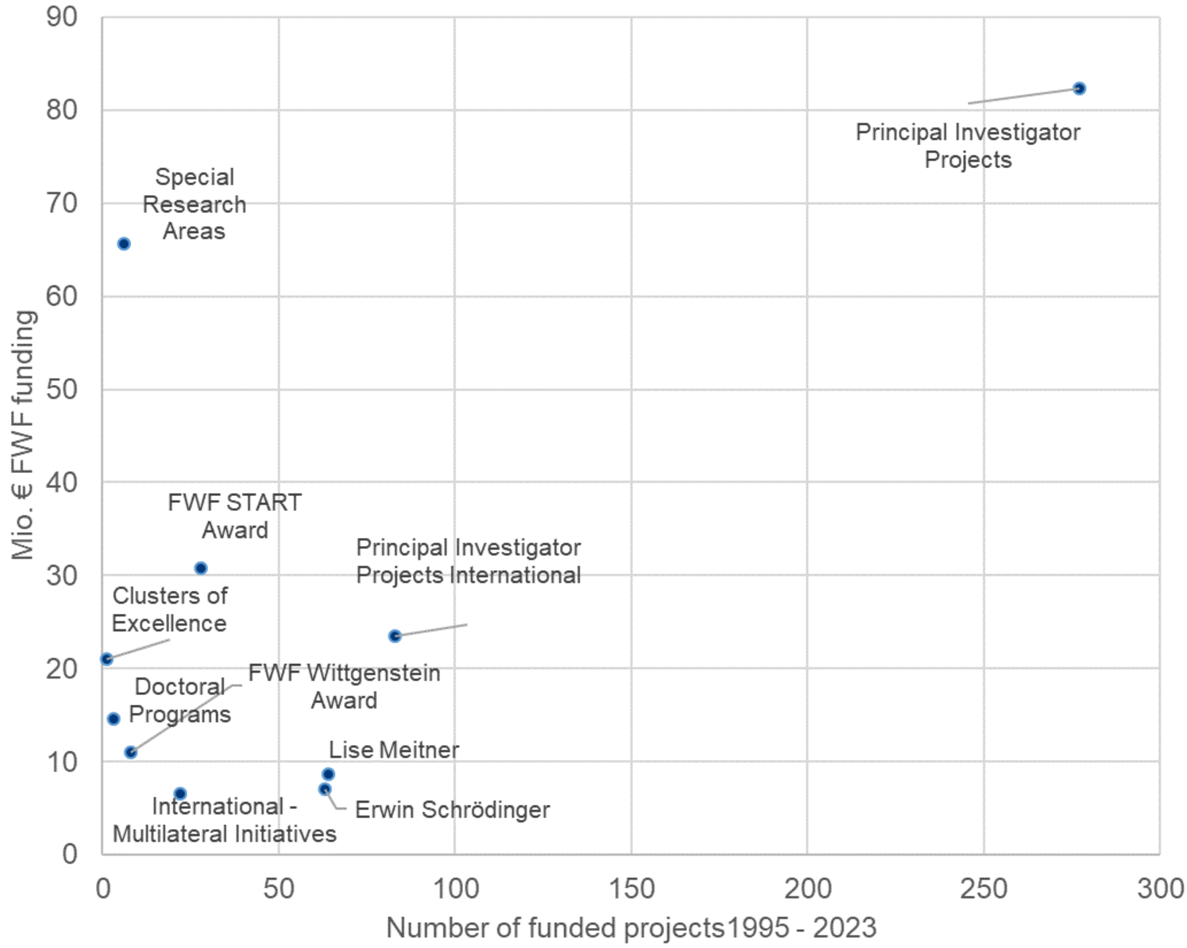


Source: JR-POLICIES based on data from the FWF research radar.

Figure 45 shows the amount of FWF funding in relation to the number of funded projects in the individual FWF funding programmes. The figure shows that the FWF invested in the period from 1995 until 2024 the highest volume of funds in quantum research through the "Principal Investigator" funding programme (approximately 12 projects per year), followed by the "Special Research Areas" funding programme (about one project every decade), the "FWF START Award" funding programme (approximately one per year), the "Principal Investigator International" funding programme and the "Cluster of Excellence" funding programme. In particular the FWF's "Special Research Areas" and "Clusters of Excellence" funding programmes have provided Austrian quantum research with large amounts of funding relative to the number of projects. The six Special Research Areas funded by the FWF between 1995 and 2023 , together with the Cluster of Excellence quantA, accounted for €86.6 million, more than the amount spent on the Principal Investigator funding programme (€82.2 million).

Note that FWF funds bottom-up, based on the quality of proposals, in both structural funding pro-grammes such as the Special Research Areas and in individual research funding programmes. Hence, there was not ex-ante decision to invest more in quantum research than in other fields, but the quality of the proposals made the difference.

Figure 45: **Number of FWF-funded quantum projects in relation to FWF-funding amount**



Source: Authors based on data from the FWF research radar.

On the national level, beside the FWF and FFG funding, the Quantum Austria initiative is worth mentioning. From 2021 until 2026 Austria provides a total of €107 million from the Recovery and Resilience Facility through the Quantum Austria initiative. This initiative is jointly implemented by the FWF and the FFG and aims to promote quantum research and the development of quantum technologies and technologies in the field of next-generation HPC (high-performance computing).

At the European level the two most relevant funding initiatives in regard to quantum technologies are Horizon Europe and Digital Europe. The Quantum Flagship is an initiative funded through Horizon Eu-rope whose goal is to foster fundamental research and development. The Quantum Flagship plays an important role for the Austrian quantum ecosystem. This initiative was launched in 2018 and will run for ten years. In the first phase (2018 to 2023), 20 projects have been approved, six of which involve Austrian participation. Two of these projects are coordinated by Austrian research institutions (University of Innsbruck, Austrian Institute of Technology).

Beside the Quantum Flagship the Digital Europe Programme plays an important role on the European level to foster quantum research and technologies. The European Quantum Communication Infrastruc-ture (EuroQCI) initiative is funded under the Digital Europe Programme. It aims to build a secure quantum communication infrastructure that will span the whole EU, including its overseas territories (Quantum Flagship n.d.). QCI-CAT is the Austrian project in the framework of the European Commis-sion's EuroQCI initiative funded by Digital Europe and managed by the FFG. The project is led by the AIT, but also includes industry partners, universities, public authorities and QTlabs from the quantum start-up scene. Austria has demonstrated a continuous commitment to advancing collaboration in the field of quantum technology on the European level by joining the European Declaration on Quantum Technologies.

When adding up the funding amounts from the various programmes mentioned above, a total estimate of approximately € 400 million emerges, which has been invested in Austrian quantum research (both basic and applied research) over the past 30 years. While this funding sum may seem considerable at first glance, a comparison with the funding volumes of other European quantum initiatives reveals similar magnitudes over much shorter timeframes. For instance, Bavaria has committed € 300 million over a five-year period since 2021 to the "Munich Quantum Valley" (https://www.munich-quantum-valley.de/de/) (Bayrisches Staatsministerium für Wissenschaft und Kunst 2021), while or Lower Saxony has invested € 245 million in the "Quantum Valley Lower Saxony" (https://www.qvls-q1.de/de/) in recent years (Niedersachsen 2021). Both German federal states have invested a roughly similar amount to Austria's investment over the last 30 years, but within a significantly shorter timeframe (3-5 years). Other countries, such as the UK and the Netherlands, have also invested substantial amounts in quantum research and the development of quantum technologies in recent years. For example, UK recently announced, that they will invest approximately € 120 million into the five UK Quantum Technology Hubs (idox 2024) and additional € 45 million especially for the further development of the quantum computer (Gov.UK 2024). The Netherlands plans to invest from 2021 until 2027 € 615 million into quantum research and the development of quantum technologies via its public-private foundation "Quantum Delta" (https://quantumdelta.nl/ - coordinates the national agenda regarding quantum technologies (NAQT - https://qutech.nl/wp-content/uploads/2019/09/NAQT-2019-EN.pdf) (Bundesministerium für Forschung und Bildung 2021). These examples highlight the growing importance that other European countries have placed on quantum research and the development of quantum technologies in recent years, while Austria adopted a more cautious stance.

Activities

Austria has a well-established quantum research community, highlighted by distinguished researchers such as Nobel laureate Anton Zeilinger. The most important basic and applied research organisations in the field of quantum research and technologies are located in

Vienna, Klosterneuburg, Innsbruck and Linz. Among these, Vienna and Innsbruck stand out as important hotspots for quantum research. Especially, the University of Vienna and the Vienna University of Technology, which includes the Atomic Institute, and the University of Innsbruck have played a central role in Austrian quantum research from the very beginning. The Institute for Quantum Optics and Quantum Information (IQOQI), based in Vienna and Innsbruck, was founded in November 2003 as an independent research institute of the Austrian Academy of Sciences with strong links to the Universities of Innsbruck and Vienna. In 2003, the AIT also established a research group in the field of quantum communication and cryptology, and in 2006 the ISTA was founded, which also houses several research groups in the quantum field today. The emergence of new research institutions and groups since the 2000s highlights the increasing importance attributed to quantum research and technologies in the context of the second quantum revolution at the international, European, and national levels. It was estimated in the interviews that via the FWF Cluster of Excellence quantA approximately 700 quantum researchers at national level are contributing to this scientific success. The table below shows the research organisations, the number of research groups and the number of research and technical staff per group. The numbers were requested directly from the institutions.[6]

Table 25: **Austrian Quantum research groups***

Organisation	No of research groups (approx.)	No of research and technical staff (approx.)	Quantum research focus
University of Vienna	10 (6 experimental, 4 theoretical groups)	123	Strong in the field of quantum communication and cryptology
IQOQI Vienna	9	87	Strong in the field of quantum communication and quantum computing
Technical University of Vienna	32	303 (290 research and 13 technical staff)	Strong in the field of quantum metrology and sensor technology, quantum modelling and simulation, design and engineering of quantum systems, quantum many-body systems physics, photon-ics and nanoelectronics
AIT	1	35	Strong in the field of quantum communication and cryptology
ISTA	9	66	Strong in the field of quantum computing

[6] Due to limited time resources, the University of Linz was unable to respond to our inquiry. As a result, the figures were researched on the university's website, and therefore, no claim to completeness can be made. The same holds for the AIT.

University of Innsbruck	15	60	Strong in the field of quantum computing and quantum rpeaters
IQOQI Innsbruck	6	64	Strong in the field of quantum computing and quantum re-peaters
University of Linz	2	31	Strong in the field of quantum metrology and sensor technology

Source: Authors based on internet research. *The approximate number of research and technical staff is outlined for each organisation individually. Double counting between institutions has not been taken into account. This applies particularly to the University of Vienna, the Technical University of Vienna and the IQOQI Vienna as well as for the University of Innsbruck and the IQOQI Innsbruck. Researchers might be employed at two of the listed organisations.

The strength of the Austrian quantum research community is due both to the efforts of the researchers themselves and to substantial support from the public sector (FWF, FFG, EU). Especially basic research activities, to a large extent with the support of FWF- and EU-funding – were conducted from the outset at a high level and with the necessary freedom that fundamental research requires (thinking outside the box). Groundbreaking experiments were carried out, and the required research infrastructure, as well as international research collaborations, were established and expanded. Concurrent research activities often interacted with one another, with preceding projects frequently laid the foundation for subsequent research efforts.

In most cases, it would be therefore inaccurate to claim that significant research findings (e.g. ground-breaking experiments, spin-offs from significant research findings) emerge in a linear manner as the result of a single research project. The foundation of the AQT company as a spin-off from the University of Innsbruck was supported by various research projects funded by different research funding organisations (FWF, FFG, EU, non-EU). While the FWF played a role through the funding of the Special Research Area F40 (F40 Foundations and Applications of Quantum Science coordinated by Rainer Blatt), it was not a central one. Rather, the Special Research Area served as one piece in the early days of the development of the ion trap among many: It helped to build a necessary foundation that facilitated further development. A key advantage of SRA projects is their long-term nature (previously 10 years (in three phases), now 8 years (in two phases), at the time). Additionally, the SRA promoted networking and exchange activities, which opened up new perspectives.

In contrast, the spin-off Parity Architecture developed within an FWF PI-project, which developed into the company ParityQC, followed a significantly more straightforward path. Wolfgang Lechner, at the IQOQI Innsbruck at that time, conducted an FWF-funded PI-project with the project title "Ultracold Atoms and Molecules: From Defect Dynamics to Quantum Glass" from 2013 until 2016. Although the project was not directly related to quantum computers, it provided him with the opportunity to allocate resources towards a simultaneously emerging groundbreaking idea for an alternative approach to quantum computing. Previous research on quantum computers had highlighted the scalability limitations of these systems to the researcher. This realization eventually inspired the development of a new approach and an innovative method for constructing and operating quantum computers. The development of this approach, which resulted in a scientific paper and a patent, formed the scientific basis for the company ParityQC. Furthermore, in 2017 Wolfgang Lechner received the prestigious and highly remunerated FWF-Start-Prize for the Project “ParityQC: Parity Constraints as a Quantum Computing Toolbox”. The funding of the FWF-Start-Prize amounted € 1,16 million. This funding allowed him to further develop his concept of the Parity Architecture.

Output/Outcomes

The numerous research activities and experiments funded by the FWF and other public funding sources (e.g. ERC, FFG) in the field of Austrian quantum research are most prominently reflected in groundbreaking scientific achievements. At this point, special mention is given to experiments carried out by Anton Zeilinger and his team in 2012 and 2017 in the field of quantum teleportation and quantum entanglement, that have also attracted considerable media attention. For this work, Zeilinger was awarded the 2022 Nobel Prize in Physics, together with physicists Alain Aspect and John Clauser.

In addition to the media-highlighted research outputs accessible to a broader public, the FWF-funded activities in quantum research and technologies have resulted in numerous scientific publications, which have been presented at international conferences and congresses. Promising methods and techniques have also been patented. Moreover, several prototypes have been developed through these projects or because previous projects yielded relevant research findings that could serve as a foundation for further work[7], including the prototype of an industrial ion trap quantum computer and quantum chips from the University of Innsbruck, a quantum radar from ISTA, and various QKD prototypes from AIT.

Since 2012, Austria has seen an increasing number of start-ups focusing on quantum technologies: The first Austrian company to focus on quantum technologies was founded in 2012, Crystalline Mirror Solutions (CMS) as a spin-off of the University of Vienna and the Vienna Centre for Quantum Science and Technology (VCQ). Since then, six other quantum technology start-ups have emerged on the Austrian start-up scene. Qtlabs is a spin-off of IQOQI Vienna and QUBO one of the University of Vienna. In 2024, Qtlabs founders Rupert Ursin and Thomas Scheidl, together with Felix Tiefenbacher and Thomas Heine, founded a subsidiary of Qtlabs and named it Quantum Industries GmbH. AQT, ParityQC and QND are spin-offs of the University of Innsbruck and IQOQI Innsbruck (see also key information on the spin-offs depicted in Table 26).

All of these spin-offs can be traced back to Austrian research institutions in the quantum field and thus also to a greater or lesser extent to FWF funding. The history of the ParityQC origins illustrates this point remarkably well. The FWF project, from which the company originated, resulted in 19 publications with a total of 636 citations. The most recent paper, published in the prestigious journal Science Advances, discussed a new approach involving a parity

[7] Examples for prototypes are: a) prototype of an industrial ion trap quantum computer, University of Innsbruck (mainly from resources of the University of Innsbruck, however a previous FWF SRA-project served among other projects as foundational work); b) quantum radar, ISTA (ERC Starting Grant QUNNECT and resources from ISTA; if FWF-resources played a role in building up the basic knowledge to build the radar is not known)

architecture for quantum computers. This paper quickly garnered significant attention within the international quantum community, accounting for 165 of the 636 citations. Based on this paper, a patent application was filed almost simultaneously. Shortly after the publication and presentation of the paper at an international conference, Wolfgang Lechner received an offer from one of the world's largest companies, seeking to acquire the patent rights. By that time, the researcher had already decided to spin off the developed architecture into a new company. In 2020 ParityQC was founded as a spin-off of the University of Innsbruck and IQOQI Innsbruck.

The foundation of AQT can be attributed to some extent to the FWF-funded SRA-project (F40). The research group around Rainer Blatt at the University of Innsbruck acquired fundamental knowledge about ion traps, which, in conjunction with other research projects, served as the foundation of AQT. In total, the SRA led to an output of 136 publications with 14.354 citations, from which 11 publications had ion traps as their topic. However, the construction of a prototype ion trap relied heavily on practical engineering expertise in manufacturing processes and was carried out in the institute's workshop, funded by the university. Several industry partners showed strong interest in the ion trap prototyp, which ultimately led to the founding of AQT in 2018 with two employees.

Table 26: **Spin-offs from Austrian quantum research**

Name of Start-up, founding year and city of location	Founders	Field of activity	Important remarks
Crystalline Mirror Solutions (CMS) | founded 2012 | Vienna	Univ.-Prof. Dr. Markus Aspelmeyer and Gar-ret Cole from Universi-ty of Vienna/IQOQI Vienna	Spin-off of fundamental quantum optics research from the University of Vienna, pioneering substrate-transferred crystalline coatings for the development of ultrastable interferometers, mid-infrared cavity ring-down systems, and laser-based manufacturing	Was acquired by Thorlabs Inc. in De-cember 2019 and rebranded as Thorlabs Crystalline Solutions
Quantum Technology La-boratories GmbH (Qtlabs) | founded 2017 | Vienna https://www.qtlabs.at/	Dr. Thomas Scheidl, and Dr. Rupert Ursin ogether with Dr. Fabian Steinlech-ner and Mag. Sam L. Tschernitz	qtlabs develops de-signs and prototypes for the technical im-plementation of quantum encryption into other business infrastructure.	Hardware based company; entered already the market with its products
Alpine Quantum Technolo-gies (AQT) | founded 2018 | Innsbruck	Prof. Rainer Blatt, Prof. Peter Zoller and Dr. Thomas Monz	AQT is an Innsbruck-based quantum computer technology developer working on general-purpose quantum information processors based on scalable	Hardware based company; entered already the market with its products

		trapped-ions platforms. Its solutions combine unmatched physical performance, extraordinary qubit control, and demonstrated optical networkability.	
Parity Quantum Computing GmbH (Parity QC) | found-ed 2020 | Innsbruck https://parityqc.com/	Wolfgang Lechner and Magdalena Hauser, as a spin-off from the University of Innsbruck	ParityQC is the world's only quantum architecture compa-ny. It develops blue-prints and an operat-ing system for highly scalable quantum computers, with ap-plications ranging from solving optimi-zation problems on NISQ devices to general-purpose, error-corrected quan-tum computing.	Software based company; entered already the market with its products
Quantum Industries GmbH | founded 2023 | Vienna | 8 employees https://www.quantum-industries.eu/	Dr. Thomas Scheidl, Dr. Rupert Ursin, Felix Tiefenbacher, Thomas Heine	quantumcryptographic solution based on entangled photons	Sister company of Qtlabs; hardware based company; entered already the market with its products
Qubo Technology GmbH | founded 2023 | Vienna https://www.qubo.technology/	Prof. Dr. Borivoje Dakic, Prof. Dr. Philip Walther, Dr. Stefan Fürnsinn	quantum cryptography in the field of payments security	
QND - Quantum Network Design GmbH | founded 2024 | Innsbruck	Prof. Dr. Dür	Development of software to simulate large quantum communication networks	

Source: JR-Policies based on internet research.

Academic Impact

The considerable amount of funds that the FWF has invested in the development and expansion of Austrian quantum research since its foundation have had a continuously visible impact since today. The University of Innsbruck has become a hotspot for quantum computing and quantum repeaters, while institutions such as the University of Vienna, the University of Linz, IQOQI and ISTA are internationally recognised in the fields of quantum communication, quantum cryptography and quantum sensors. The FWF funding have contributed significantly to this success. It played a central role in the establishment of research groups and therefore in strengthening the Austrian quantum research com-munity, the promotion of Austrian quantum research and the positioning of Austria among international competitors, as can be seen from the above analysis of the FWF Research Radar data. In particular, as has been noted in one of the qualitative interviews, the first FWF-funded Special Research Area on quantum research (F15) at the beginning of the 2000s increased the visibility and attractiveness of Austria as a research location and motivated highly qualified international scientists to carry out their research in Austria. Furthermore the FWF-funded Cluster of Excellence QuantA will play a key role in ensuring that Austria can continue to position itself as a globally recognised and renowned centre for quantum physics; interviewees stated that to maintain its position in quantum research and continue to be recognized as a strong scientific partner at both European and international levels, the public sector in Austria needs to invest continuously and substantially in quantum research and the development of quantum technologies. As outlined in the section "Input: The FWF Quantum Funding by Numbers," several European countries have recently launched large-scale quantum initiatives, which can serve as significant pull factors for highly qualified Austrian quantum researchers. According to interview partners, Austrian researchers in the field of quantum technologies are internationally renowned; they are popular candidates when international institutions are recruiting. The qualitative interviews highlighted that attractive offers from abroad present strong incentives in this respect. In the past, this has led Austrian professionals to accept appealing opportunities abroad. For instance, it was noted in the qualitative interviews that some highly qualified quantum researchers were recently recruited from the University of Innsbruck by other international or European institutions.

Academic impacts of the FWF funding in brief

- International reputation and visibility of Austrian quantum research
- Building a critical mass
- Promotion of dissertations and careers
- Recruiting national & international experts
- Education and hand-on experience for students
- Enhancement of research possibilities and further development of methods

Economic Impact

Over the past 50 years, FWF funding has played a crucial role in establishing a strong and internationally renowned foundation for quantum research in Austria. In recent years, this has led to the emergence of the first quantum spin-offs. It can therefore be assumed that the various FWF-funded projects have contributed to the knowledge base of the spin-offs listed in Table 26 to varying degrees.

For instance, ParityQC clearly emerged from the resources provided by an FWF-funded PI-project, while AQT, as revealed in the qualitative interview, shows only peripheral connections to FWF funding. In this case, university funding and other funding sources (such as the EU and FFG) were the primary drivers for the spin-off. The same holds for the spin-off Quantum Technology Laboratories (Qtlabs): The FWF-funding played a minor role.

Nonetheless, relatively concrete statements can be made about the economic impact of FWF funding. This can be clearly illustrated by the example of ParityQC. The company was founded in early 2020 and had six employees by the end of the year. The first two employees of ParityQC were initially employed in the research group of Wolfgang Lechner at the University of Innsbruck. Today, ParityQC employs a total of 60 people and operates from its headquarter in Innsbruck and two additional locations, namely Hamburg and London. The headquarter in Innsbruck and the site in Hamburg, both have 30 employees each. The site in London is currently still under development. In recent years, ParityQC has been able to attract graduates from Austrian universities on a regular basis. For graduates in physics, computer science, and mathematics, the company offers the opportunity to remain in the Innsbruck area rather than relocating due to a lack of local job opportunities. Additionally, due to its reputation and the critical mass it has now achieved, the ParityQC also attracts highly qualified international professionals (pull effect). A major success that significantly contributed to the company's reputation was winning two projects in 2022, with a total value of € 208 million, within a larger DLR contract comprising five projects. Moreover, from the outset, the company secured paying customers, first in international markets (Asia, America) and then in Europe, and generates significant revenue with its products.

As the interview with AQT founder Thomas Monz revealed, the company is already showing visible economic success. Initially, it was assumed that demand for ion traps would be low due to the niche market, and the company would not grow significantly beyond its two employees. However, the company soon expanded its product range to include items such as stabilization systems, optomechanical solutions, and other components. These solutions are part of the quantum computer developed by AQT in 2023, which is based on ion trap technology. The quantum computer itself, roughly the size of an IKEA built-in wardrobe, has already been sold twice: one system was delivered to the Leibniz Supercomputing Centre of the Bavarian Academy of Sciences, and another to Poland. As a result, the company now employs 30 people.

Table 27: **Spin-offs from Austrian quantum research, number of employees and revenues**

Name of Start-up, founding year and city of location	Employees	Important prizes
Quantum Technology Laboratories GmbH (Qtlabs) | founded 2017 | Vienna https://www.qtlabs.at/	2024: 34 (16 Post-Docs, 3 PhD students)	Austrian Start-up Prize Phönix
Alpine Quantum Technologies (AQT) | founded 2018 | Innsbruck	2024: 30 (18 Post-docs, from which 9 are from the Universi-ty of Innsbruck)	
Parity Quantum Computing GmbH (Parity QC) | founded 2020 | Innsbruck https://parityqc.com/	2024: 60 (30 in Innsbruck and 30 in Ham-burg)	FWF-early career grant START for Wolfgang

		Lechner; Austrian Start-up Prize Phönix
Quantum Industries GmbH | founded 2023 | Vienna | 8 employees https://www.quantum-industries.eu/		
Qubo Technology GmbH | founded 2023 | Vienna https://www.qubo.technology/	2024: 9	Science & Business Award 2024
QND - Quantum Network Design GmbH | founded 2024 | Innsbruck	2024: 2 to 10 employees	

Source: JR-Policies based on internet research.

Additionally, the establishment of the first quantum technology companies over the past 20 years has gradually led to the development of an Austrian quantum ecosystem. The ecosystems encompass a diverse range of entities, including basic and applied research organiza-tions, government research agencies, tech giants, quantum technology start-ups, and supporting organizations such as hubs. Additionally, increasingly well established SMEs and large corporations are also focusing on quantum technologies and their potential as well as on technologies that support the development of quantum technologies (and vice versa) (e.g. lasers, cryostats, electronics). The qualitative interviews showed the importance of involving a wide range of companies in initiatives to promote quantum solutions in industry. In general, companies need to be made more aware of the potential offered by quantum implementations in the future. It is essential that Austrian companies are up to date with developments in the quantum field in order to make the best use of the potential. However, it was not easy to determine through online research which Austrian companies are already working on quantum technologies. One prominent example can be mentioned: Infineon cooperates with the University of Innsbruck in the field of quantum computers.

Furthermore, these developments have also captured the attention of the public sector, leading to the launch of various national quantum initiatives over the past decade. These initiatives aim not only to advance quantum research but also to establish a foundation for start-ups focused on quantum tech-nologies (e.g., the EU Quantum Flagship, Quantum Austria). In addition, government bodies have an important role to play in raising awareness of quantum technologies in private sector companies. In this respect have the qualitative interviews highlighted the importance of getting the public administration on board with quantum innovations. This is not limited to the role of public administration in funding, but also in procurement and as a first user of quantum technologies, especially in areas such as cybersecurity. In addition, public authorities play a role as associate partners in quantum communications projects. Figure 46 depicts the main actors of this ecosystem by city in Austria.

Figure 46: **The Austrian quantum ecosystem: Research organisations, private companies, hubs**[8]

Source: JR-Policies based Data collected through qualitative interviews and internet research, map designed by Freepik and adapted by JR-POLICIES.

[8] There are also various well established companies in Austria, which work in the field of quantum (e.g. Infineon, Anton Paar, EV Group (see Hübel 2018). However, only sparse information is publicly available on the companies and their involvement in quantum. Therefore, due to the lack of concrete information none of them is listed in the figure.

Table 28: **The Austrian Quantum Ecosystem (Table to Figure 46)**

Vienna	
Research organisations:	*Supporting companies:*
University of Vienna	Gradient Zero (2019 | https://gradient0.com/)
Technical University of Vienna	Nutshell Quantum-Safe (2022 | https://www.nutshell-qs.com/) (not only supporting, will be incorporated in the near future into the Swiss company IDQ)
IQOQI Vienna (ÖAW)	QDeep Tech (2024 | https://qdeeptech.com/company/)
Austrian Institute of Technology (AIT)	
Private companies:	*Hubs/networking organisations:*
Qtlabs (2017 | https://www.qtlabs.at/)	Vienna Center for Quantum Science and Technology (VCQ - https://vcq.quantum.at/)[1]
Quantum Industries (2023 | https://www.quantum-industries.eu/)	Working Group Quanten[2] of the platform Photonics Austria (https://www.photonics-austria.at/en/wg-quantum-2/)
QMware (https://www.qm-ware.com/de/ | subsidiary of a German quantum technology company) – hybrid quantum cloud services	Quantum Connect[4] (https://platform.quantum-connect.ai/main-english/)
Qubo Technology (2023 | https://www.qubo.technology/)	
Klosterneuburg	
Research organisations:	Institute of Science and Technology (ISTA)
Innsbruck	
Research organisations	*Private organisations:*
University of Innsbruck	Alpine Quantum Technologies (2018 | https://www.aqt.eu/)
IQOQI Innsbruck (ÖAW)	ParityQC (2020 | https://parityqc.com/)
quantA (Cluster of Excellence, lead Gregor Weihs University of Innsbruck) (https://www.quantumscience.at/about)	QND – Quantum Network Design (2024)
Linz	
Research organisations	
Johannes Kepler University Linz	Research Center for Non Destructive Testing GmbH (Recendt | https://www.recendt.at/de/)
Graz & Weiz	
Research organisations	
Silicon Austria Labs GmbH (https://silicon-austria-labs.com/)	Working Group Quanten of the platform Photonics Austria3 (https://www.photonics-austria.at/en/wg-quantum-2/)

Source: JR-Policies based Data collected through qualitative interviews and internet research, map designed by Freepik and adapted by JR-POLICIES.) The VQC is one of the largest quantum hubs in Europe, comprising 31 research groups from the University of Vienna, the TU Wien, the Austrian Academy of Sciences, and the Institute of Science and Technology Austria. 2) The working group Quanten promotes the networking of research organisations and industry to strengthen the European quantum industry. 4) Quantum Connect is an Austrian association for Quantum technologies in Austria. It provides a platform for research organisations and industry with the purpose of knowledge and technology ex-change.

Economic impacts of the FWF funding in brief

- ·Training of skilled researchers working in industry
- ·Formation of spin-offs, partly based on patents emerging from FWF-funded research
- ·Revenues & Job creation through the spin-offs
- ·High reputation of spin-offs on the European and international level and therefore increase in attractiveness of Austria as workplace for highly qualified international skilled labour
- ·Increasing engagement of well established Austrian companies in quantum technologies (e.g. Infineon)

Societal Impact

In addition to the economic impact of FWF funding, the most visible social benefit is the increasing interest in quantum research among the general public. Qualitative interviews revealed that the ongoing advancement of quantum technologies is expected to have significant social impacts. It is anticipated that quantum computers, due to their immense computational power, will transform the world in many ways. The enhancement of processes, operations, and calculations currently achieved with more powerful hardware will be elevated to a new level with quantum computers. This will enable, among other things, the development of better models and more accurate predictions, whether in terms of climate forecasting or early detection of serious diseases

Societal impacts of the FWF funding in brief

- Arousing interest in quantum research among the general public
- Many potential future applications, such as better climate forecasts

7.5. Case study 4: CRISPR-Cas9 – the „Gene Scissors“

7.5.1. Context

The CRISPR/Cas9 technology (see also Info-Box below) has quickly established itself as a widely used genome-editing tool across various applications due to its simplicity and effectiveness, earning the Nobel Prize. Important ad-vancements in the development and research of this technology were made at the Max Perutz Labs at the University of Vienna within the Vienna BioCenter. Here, Emmanuelle Charpentier conducted research from 2002 to 2009 with her team in the field of RNA. She and her team gained significant attention in the research community with a publication in 2011 (Max Perutz Labs Vienna n.d). In this work, the team discovered the so-called tracrRNA, which forms duplexes with the repeats of long precursor forms of crRNAs, thereby activating the process that cleaves the long pre-crRNAs into individual sequences capable of guiding Cas9 to its targets (Deltcheva et al. 2011). Building on this, Emmanuelle Charpentier's team, together with Jennifer Doudna's team at the University of California, published a second groundbreaking study a year later (Jinek, Chylinski et al. 2012). This study revealed the exact molecular mechanism of the type II CRISPR-Cas9 system. It was a two-component system (a duplex of tracrRNA-crRNA or a single guide RNA plus the Cas9 enzyme). The breakthrough of this system was that it was not only relatively user-friendly, but also could be "programmed" by scientists to bind and cleave any DNA sequence of interest. The study concludes with the sentence: „We propose an alternative methodology based on RNA-programmed Cas9 that could offer considerable potential for gene-targeting and genome-editing applications.“ (Jinek, Chylinski et al. p. 820, 2012)

This sentence indicates the significance attributed to this technology from the very beginning. The au-thors were proven correct; the CRISPR/Cas9 technology has now become a standard tool for genome editing in the biomedical field. It is seen as a promising instrument for understanding and effectively treating genetic hereditary diseases and cancers. Additionally, its great potential for agriculture and adapting crops to new climatic conditions is anticipated. Emmanuelle Charpentier and Jennifer Doudna were awarded the prestigious Nobel Prize in 2020 for their work on CRISPR/Cas9 technology, among many other honors (Max Perutz Labs Vienna n.d)[9].

[9] https://www.nobelprize.org/prizes/chemistry/2020/summary/

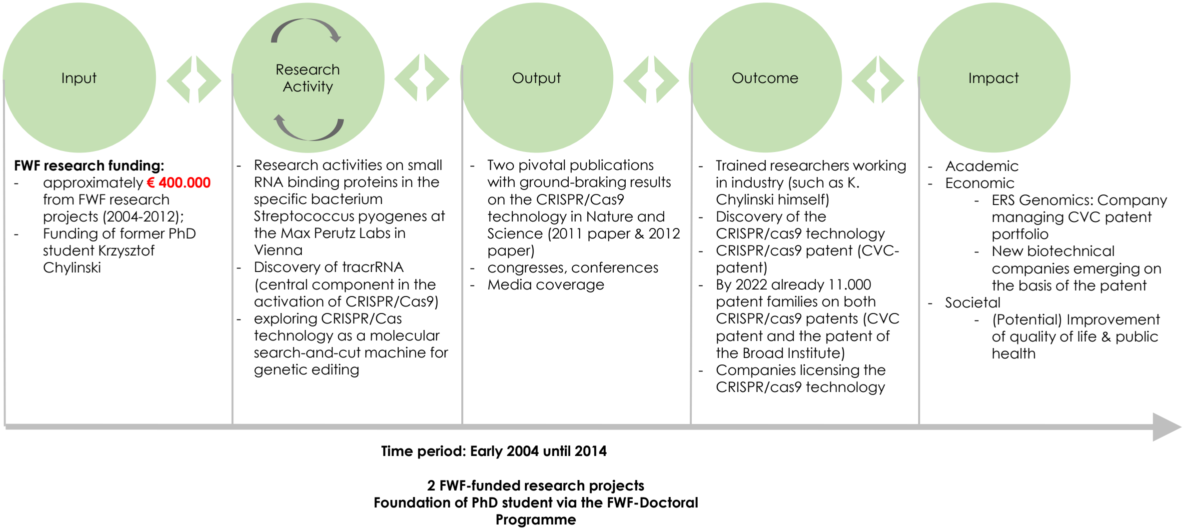
Info-Box: CRISPR-Cas9

CRISPR stands for Clustered Regularly Interspaced Short Palindromic Repeats. It is essentially a part of the immune system of many bacteria, and allows bacteria to fight off viruses and plasmids. Bacteria have naturally integrated fragments of foreign DNA into their own genome, in the regions called repeat-spacer arrays. When these are then transcribed and processed into short RNA (crRNA) which matches foreign DNA that are further bound to Cas (CRISPR associated) proteins. If a viral material, which has the same sequence of DNA as previously integrated into the bacteria, enters it is recognized and the Cas-protein cuts the viral genetic material thus stopping the spread of the virus in the bacteria. This process occurring naturally in bacteria has been harnessed by scientists to precisely recognize DNA and cut it at a specific location, which is an essential molecular tool for genetic engineering. It allows for a range of genetic modifications, like changing parts of the DNA or individual nucleotides. This works as follows: A Cas9 protein connected to a short RNA molecule is introduced into a cell. This RNA molecule finds the part of the DNA it matches. The Cas9 protein then cuts the DNA at the sequence bound to the RNA. The cell then tries to fix this so called double stranded DNA break, often introducing mistakes leading to functional gene deletions. If so called template DNA, containing a desired mutation, was brought into the cell together with CRISPR/Cas9 it can be used by the DNA damage repair machinery to introduce a desired mutation or insertion into the genome. (Max Perutz Labs Vienna n.d.; vfa n.d)

7.5.2. Impact Pathway of the FWF-funding

The FWF funding played a considerable role in the discovery of the CRISPR/Cas9-technology. As mentioned above, key steps in research of this technology were made at the Max Perutz Labs at the University of Vienna within the Vienna BioCenter. As a result, the University of Vienna holds a small part of the foundational CRISPR/Cas9 patent family. This chapter outlines how the FWF funding contributed to the development of the CRISPR/Cas9-technology and how the technology revolutionized academic research, but also the pharmaceutical and the biotech-industry. A special focus is placed on the Austrian biotech-industry. It is very likely that CRISPR/Cas9-technlogy will make a significant contribution to improving health and quality of life in the future. Figure 47 presents a simplified model of the impact pathway of the FWF funding, which will be analyzed in the following sections.

Figure 47: **Impact pathway of the FWF-funding**



Source: Authors.

Input: FWF-funding in numbers

During her time as a postdoc and later as a research group leader at the Max F. Perutz Laboratories of the University of Vienna and the Medical University of Vienna, Emmanuelle Charpentier received funding from two FWF-supported projects. Furthermore, her PhD student Krzysztof Chylinski was employed at the University of Vienna through the FWF Doctoral Programme on RNA Biology led by Andrea Barta from 2007 until 2021. The first project of PI Emmanuelle Charpentier ran from 2004 to 2008, followed by a second project from 2009 to 2012. At the beginning of the funding period for the second project ("Innate immune responses to Streptococcus pyogenes"), Emmanuelle Charpentier was already at Umeå University, coordinating the project from Sweden. Her contract at the Max F. Perutz Laborato-ries ended in 2009. Krzysztof Chylinski, one of her former doctoral students, remained employed at the University of Vienna through the FWF Doctoral Programm. In total, the two FWF projects with Emmanuelle Charpentier as PI secured €362.891in FWF funding (see

Table **29**).

Of course, as in other case studies, FWF was not the only provider of research funding; other organisations that contributed funding to the 2011 paper are e.g. EU FP6, FFG, Swedish Research Council, DFG.[10] For the 2012 paper, e.g. the HHMI (Howard Hughes Medical Institute), University of Vienna, University of Umeå.[11]

[10] Full list: https://www.nature.com/articles/nature09886#Ack1

[11] Full list: https://www.science.org/doi/full/10.1126/science.1225829#acknowledgments

Table 29: **FWF-funding and output regarding the development of the CRISPR/cas9-technology**

Funding Programme	Project Title	Funding Amount in €	Project Runtime	Output
PI-Project	Regulation of virulence by a regu-latory RNA in GAS – PI: Emmanuelle Charpentier	147.074€	2004 – 2008	9 Publications 2.216 citations
International - Multilateral Initiatives	Innate immune responses to Strep-tococcus pyogenes – PI: Em-manuelle Charpentier	215.817€	2009 – 2012	
Doctoral Programmes	RNA Biology – PI: Andrea Barta	Total: 9.034.512€ The PhD of Krzysztof Chylin-ski was financed via this pro-gramme	2007 – 2021	349 publications 49.338 citations The breakthrough publication from 2012 on the CRISPR/cas9 technology is an output of this programme

Source: Authors based on data from FWF Research Radar.

Activities

In her research time in Vienna (2002 -2009) Emmanuelle Charpentier focused, among others, on researching regulatory ribonucleic acids (RNA) in bacteria. A portion of her research in Vienna, likely one of the most important for the discovery of the CRISPR/Cas9-technology, was funded among other things also through FWF grants (see table above). Unlike DNA, which serves as the storage form of genetic material, RNA represents the active form of genes. Part of her research initially concentrated on investigating small RNAs in the specific bacterium Streptococcus pyogenes. In 2011, Charpentier and her team published a ground-breaking study in the esteemed journal Nature, describing tracrRNA, in conjunction with CRISPR RNA and Cas9, as a central component in the activation of CRISPR-Cas in Streptococcus pyogenes and other bacteria (Deltcheva et al. 2011).

Alongside US biochemist Jennifer Doudna, she and her team began exploring CRISPR-Cas as a potential technology, aiming to harness this molecular search-and-cut machine for genetic editing (Kurier Wissenschaft 2020). CRISPR-Cas was originally discovered in the 2000s as an adaptive immune system in bacteria and archaea to defend against viral attacks (Max-Planck-Gesellschaft 2020). This is where the research of Emmanuelle Charpentier and Jennifer Doudna and their teams began. In the course of their work the relevance of the CRISPR/cas9 technology as a genome editing tool became apparent. At that time, Emmanuelle Charpentier was no longer at the Max F. Perutz Laboratories but was working at Umeå University in Sweden. One of her former doctoral students, Krzysztof Chylinski, remained at the University of Vienna (funded via the FWF Doctoral Programmes) and continued to collaborate with Charentier and her team in Umeå on the gene scissors. He conducted crucial work for the CRISPR/Cas9 technology (Illetschko 2017).

A year later, the researchers were able to demonstrate in a highly acclaimed paper that CRISPR/Cas9 is a three-component system composed of Cas9 enzyme together with tracrRNA and CRISPR RNA, that can be further reduced into Cas9 and a single guide RNA, capable of making sequence-specific cuts in DNA (see Jinek et al. 2012). The system was then used as a precise genetic tool that can correct faulty DNA, similar to a word processing software that edits or corrects typographical errors in a document (Max-Planck-Gesellschaft 2020). The 2012 paper (see Jinek et al. 2012) was quickly celebrated as a scientific breakthrough. The University of California submitted a patent application to the US Patent Office with Emmanuelle Charpentier, Jennifer Doudna Martin Jinek and Krzysztof Chylinski as co-inventors. A share of this patent is also held by the University of Vienna. The reason for this is, that Krzysztof Chylinski, who is listed as co-inventor of the patent, was at that time employed as a PhD-student at the University of Vienna.

Output/Outcomes

Through the two FWF-funded research projects, Emmanuelle Charpentier and her team achieved ground-breaking results in CRISPR/Cas9 technology. The first FWF-funded PI-project („Regulation of virulence by a regulatory RNA in GAS") produced a total of nine publications with 2,216 citations. Within the framework of this project, one of the two pivotal publications appeared in the journal "Nature" in 2011[12], followed by the second publication with Jennifer Doudna in "Science" in 2012[13]. This publication can be considered, in part, as an output of the FWF Doctoral Programme on RNA Biology. Krzysztof Chylinski shares first authorship with Martin Jinek from the University of California. In each of the following two years, Krzysztof Chylinski co-authored three further papers focusing on CRISPR/Cas and the CRISPR/Cas9 technology within FWF Doctoral Programme[14]. In these, the authors explored Cas9 enzymes and tracrRNA-CRISPR RNAs from other bacterial species, contributing to the toolbox of alternative CRISPR/Cas9 technologies. However, the major breakthrough came with the 2012-paper. The research published in this paper served as the basis for the subsequently filed patent: "US10988782B2 Methods and compositions for RNA-directed target DNA modification and for RNA-directed modulation of transcription". Just a few months later, a research group led by Feng Zhang at the Broad Institute of MIT also filed a patent related to the application of CRISPR/Cas9

[12] Deltcheva E, Chylinski K, Sharma CM, Gonzales K, Chao Y, Pirzada ZA, Eckert MR, Vogel J, Charpentier E. CRISPR RNA maturation by trans-encoded small RNA and host factor RNase III. Nature 2011; 471:602–7.

[13] Jinek M, Chylinski K, Fonfara I, Hauer M, Doudna JA, Charpentier E. A programmable dual-RNA-guided DNA endonuclease in adaptive bacterial immunity. Science 2012; 337:816–21.

[14] Chylinski K, Le Rhun A, Charpentier E. The tracrRNA and Cas9 families of type II CRISPR-Cas immunity systems. RNA Biol. 2013 May;10(5):726-37. doi: 10.4161/rna.24321. Epub 2013 Apr 5. PMID: 23563642; PMCID: PMC3737331.

Chylinski K., Makarova K. S., Charpentier E., Koonin E. V., Classification and evolution of type II CRISPR-Cas systems, Nucleic Acids Research, Volume 42, Issue 10, 2 June 2014, Pages 6091–6105, https://doi.org/10.1093/nar/gku241 technology. This sparked a patent dispute (see also the information box on the patent dispute below), which remains unresolved in the United States to this day.

However, this dispute did not deter either the scientific community or the industry from utilizing the ground-breaking CRISPR/Cas9 technology in their work. Within a short period, the CRISPR/Cas9 technique became globally adopted, opening entirely new avenues in the life sciences. According to the former Swiss economic research company Centredoc, there were already more than 11.000 patent families related to CRISPR technologies by 2022 building on the patent of the University of California and the University of Vienna or the patent of the Broad Institute of MIT (Ledford 2022). T In general, the initial patents for the CRISPR/Cas9 technology held by both parties are regarded as foundational and far-reaching, meaning that companies may be obligated to license these foundational patents regardless of the outcome of the patent dispute (Ledford 2022).

CRISPR/Cas9 technology also revolutionized the work of science and increasingly that of industry in Austria. As revealed in qualitative interviews, just a few years after the publication of the second pivot-al paper in 2012, the majority of research groups at the Vienna BioCenter (https://www.viennabiocenter.org/) began using the CRISPR/Cas9 technology for their research efforts, further developing, improving, and refining it. These advancements were documented and recorded through publications and, in some cases, associated patents. The Elling lab of Institute of Molecular Biotechnology (IMBA), for example, has worked intensively in recent years on the technical improvement of CRISPR/Cas9 technology and has developed also together with Krzysztof Chylinski various modifications of the technology. These improvements were mainly financed via internal resources of the ÖAW, FFG grant for VBCF and cooperation with pharmaceutical companies:

- CRISPR-UMI (2017, publication, no patent): facilitates extremely robust and sensitive screens by tracking single mutants within a population of cells (IMBA 2017)
- CRISPR-Switch (2019, publication and patent): can be understood as a refinement of CRISPR/Cas9 technology, enabling genes to be turned off in a defined temporal sequence. It optimizes the guide-RNA which is used editing (sgRNA) and can then be employed with a much higher degree of precision (Chylinski et a., 2019). It was developed together with Krzysztof Chylinski and the Vienna Biocenter Core Facilities GmbH. (ÖAW 2019)
- VBC-score (2020, publication): Identification of guide RNAs with optimal activities to inactivate genes is important for both research purposes as well as therapeutic applications. Using machine learning, researchers at IMBA and IMP developed a new CRISPR tool that predicts effective guide RNAs with unprecedented precision (Vienna BioCenter 2020) and still today is considered the best tool for sgRNA selection (see Lukasiak, S. et al. 2024).
- CRISPR-StAR (publication in press, patented): Pooled genetic screens require large cell populations for robust screening readouts. With CRISPR-StAR, the Elling lab developed a new screening paradigm that empowers genetic screening in more challenging model systems such as in organoids as well as in vivo.

Info-Box: Patent dispute

The revolutionary nature and immense importance of CRISPR/Cas9 technology, both economically and socially, is further highlighted by the ongoing patent dispute between the University of California/University of Vienna/Emmanuelle Charpentier and the Broad Institute of MIT. Emmanuelle Charpentier and Jennifer Doudna filed their patent for the CRISPR/Cas9 technology through the University of California, University of Vienna and Emmannuelle Charpentier as a private person in 2012. A few months later, Feng Zhang from the Broad Institute of MIT and Harvard in Cam-bridge, Massachusetts, filed a patent for the application of CRISPR/Cas9 in so-called eukaryotes (organisms whose cells contain a membrane-bound nucleus). The Broad Institute urgently sought patent protection, leading to a dispute that remains unresolved, at least in the United States. In 2022, the US Patent Office rejected the claims of the University of California/University of Vienna and granted the patent to the Broad Institute, as the office determined that the Broad Institute was at the forefront of applying CRISPR/Cas9 to eukaryotic cells. The Broad Institute's team had expanded CRISPR/Cas9 technology to such an extent that it warranted a separate patent. This decision is currently being contested by the University of California/University of Vienna, which is attempting to demonstrate that they also conducted research on applications in eukaryotic cells. In Europe, the patent was granted to the University of California/University of Vienna because the Broad Institute omitted one of the inventors from the original application during the follow-up filing. (Illetschko 2020; Ledford 2022; Infor-mationsdienst Gentechnik 2022)

Academic impact

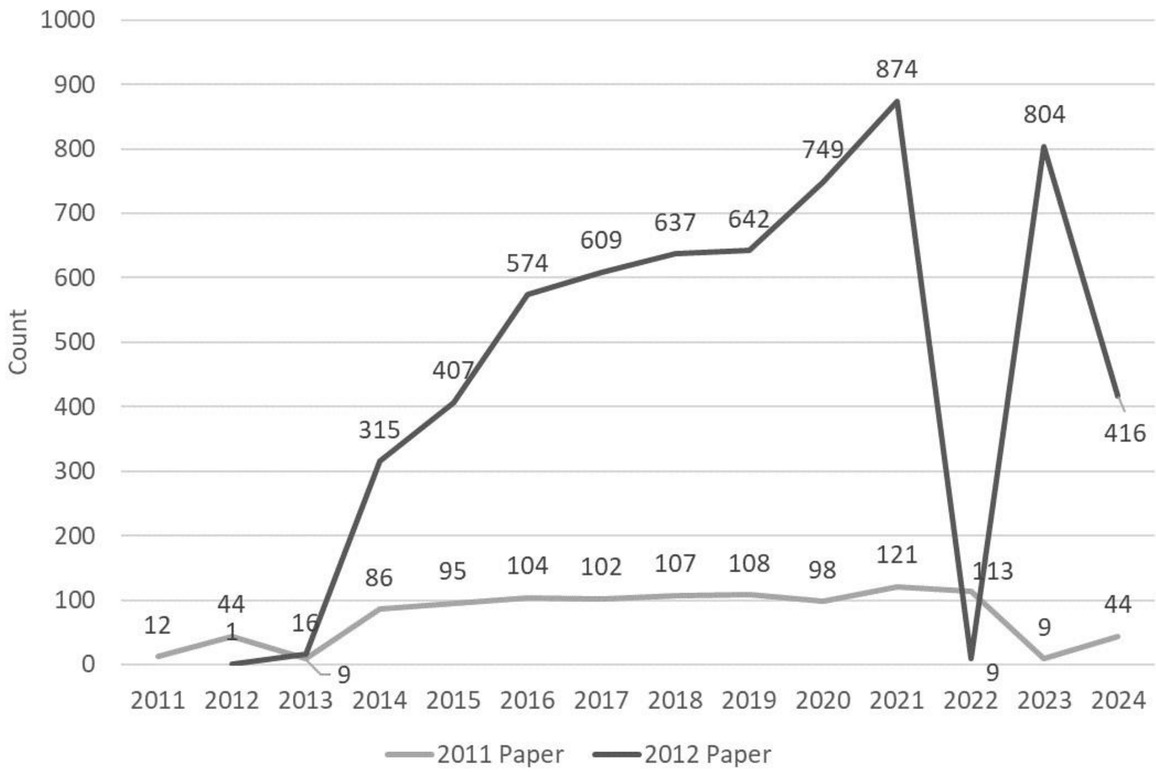
In the decade following the publications of the two decisive papers on CRISPR/Cas9 the technology was not only very quickly used for research activities, but also has been continuously improved. While the initial technology was described to be not so precise, in some cases leading to unwanted damages to other parts of the genome, subsequent research has led to a fine-tuning of the technology making it more precise and safer to use in e.g. therapeutic applications. So called Cas9-fusions made it possible to now inactivate certain genes but also to reactivate them using transcriptional regulators in technologies called CRISPRi and CRISPRa. Further methods were developed to introduce new genetic variants through base-editing or prime editing. Base-editing is an innovation allowing for some applications of this technology in medicine (Illetschko, 2022). CRISPR/Cas9-based tools are used in basic research for protein labelling, genetic sequence visualization and, importantly, for creation of genetically engineered cellular, animal and plant models for research, including medical applications.

All these technologies are utilized by research labs in Austria for advancement of basic research projects, but, as noted above, further important advancements in the realm of CRISPR technologies were also achieved by scientists working in Austria (e.g. CRISPR-UMI, CRISPR-Switch, CRISPR-StAR). Work of laboratories of Johannes Zuber (IMP) and Ulrich Elling (IMBA) concentrated on improving so called CRISPR-Screens – high throughput genetic tools used for studying e.g. drug mechanisms, gene essentiality, cancer vulnerabilities, drug resistance, among others. Another example from Austria is work of the lab of Anna Obenauf on so called CATCH system, based on CRISPRa technology allowing to study resistance in cancer.

This increased the visibility and reputation of Austrian research in the field of RNA and contributed to the fact that the Vienna BioCenter (https://www.viennabiocenter.org/), which comprises important research organisations in the field of life sciences (GMI, IMBA, IMP, Max Perutz Labs, Ce-MESS and Faculty of Life Sciences), has become a magnet for highly qualified scientists from all over the world.

Furthermore, the extent to which this technology has revolutionized research is evident in the rapid adoption by research groups across various disciplines (e.g. medicine, microbiology, pharmacy, agricultural science) allowing for new insights and research advancements. The CRISPR/Cas9 technology has reduced the complexity of genome editing and made it more cost efficient, which means that many more research labs are now doing genome editing. At the Vienna BioCenter, as well as at the Universities and in IST Austria, as revealed in an interview and mentioned above, it took only a few years for the technology to become mainstream, with the majority of research groups incorporating it into their research activities – an indication for the fact that this technology and its application spread very quickly. The impact on the scientific community is also underlined by the fact that the two original pivotal publications (Deltcheva et al., 2011; Jinek, Chylinski et al., 2012) has been cited over a few thousand times since their publications. The 2012 paper (Jinek, Chylinski et al., 2012) has been cited according to PubMed since 2012 6.053 times (see Figure 2), according to the Science journal even 11.579 times. The citation metrics of the Science Journal are based on the service Cited-by by Crossref. Not only citations in the medical and biotechnological field are counted here (as it is the case with PubMed), but from all scientific fields that have cited the paper. (see metrics https://www.science.org/doi/10.1126/science.1225829 and https://www.crossref.org/documentation/cited-by/). The 2011 paper (Deltcheva et al., 2011) has been cited since 2011 in total 1.052 times according to PubMed. The numbers show the importance of the two papers for academic research. Especially when looking at Figure 2 it gets obvious how quickly the results from the 2012 paper have spread and have been up-taken by other papers.

Figure 48: **Citations of the two pivotal papers published in 2011 and 2012 on the discovery of the CRISPR/cas9-technology**



Source: Authors, based on data from PubMed.

Table 30 Table **30**: Count of publications concerning CRISPR-technologies (PubMed search)further outlines worldwide publications on CRISPR-technologies since 2002 (source PubMed). The table clearly shows that engagement with the CRISPR-technology began prior to the publication of the pivotal 2011 and 2012 papers of Charpentier and her team, but initial interest was relatively modest. Between 2002 and 2011 (a period of nine years), only 153 publications on this topic were released worldwide. After the publication of the ground-breaking papers (in 2011 and 2012), the number of publications on CRISPR technologies quadrupled globally, and this occurred within just four years. Since 2014, as shown in Table 2, the topic has been highly prominent in research. Table 30 also illustrates how the CRISPR-technology has spread within the biotechnology research community in Vienna. Between 2011 and 2014, 14 papers were published with authors affiliated with organisations located in Vienna, and four years later, the number of publications increased almost sixfold.

Table 30: **Count of publications concerning CRISPR-technologies (PubMed search)**

Publications concerning CRISPR technologies (count)	2002 - 2011	2011 - 2014	2015 - 2018	2019 - 2022	2023 - 2024
Affiliation worldwide	153	639	12.081	22.138	14.640
Affiliation in Vienna	0	14	82	211	93

Source: Authors based on data from FWF Research Radar.

The wide use of the technology in scientific research allows for breakthroughs that would not have been possible prior. The possibility to easily modify cell-lines in animals which are then used for then testing therapies is one instance of this. Using genetically modified animals in drug testing can lead to a drastic shortening of research times and increased efficacy and safety. This of course also has great societal impacts, as the quicker availability of new medicines can save lives.

Academic impacts of the FWF funding in brief

- Building a critical mass
- Promotion of dissertations and careers
- Recruiting national & international experts
- International reputation and visibility of Austrian in the field of RNA
- Large reception in international scientific publications
- Improvement of research possibilities and tools and development of new methods

Economic Impact

The discovery of CRISPR/Cas9 technology has had far-reaching effects not only on academic re-search but also on industry, particularly in the pharmaceutical, biotech, and agricultural sectors. By demonstrating that the technology is applicable to eukaryotic cells—cells with a nucleus—a wide range of applications and business models emerged. This includes applications in agricultural biotechnology and medical therapies for humans. Companies that utilize CRISPR/Cas9 technology to develop, either directly or indirectly, products or therapies require a license for the patent. In Europe, the patent dispute has already been resolved in favour of the University of California/University of Vienna, while it remains unresolved in the United States. According to patent experts, the value of such a patent is estimated to be in the billions (Informationsdienst Gentechnik 2022).

In 2014, Emmanuelle Charpentier co-founded ERS Genomics in Dublin, Ireland (https://ersgenomics.com/licensing/). The company manages the CRISPR patent portfolio, also known as the CVC portfolio (University of California-Berkeley, University of Vienna, and Emmanuelle Charpentier), and licenses the CRISPR/Cas9 technology to companies involved in the development and commercialization of CRISPR/Cas9 technology, products, and services.

According to the ERS Genomics website, over 100 companies worldwide licensed the CRISPR/Cas9 technology for their operations in 2021. The patent portfolio broadly covers five areas for which CRISPR/Cas9 patents exist:

- Pharmaceutical & Biotechnology (e.g. target discovery and validation, high-throughput screening, diagnostics, development of therapeutic proteins and vaccines, animal models of disease, internal R&D)
- Contract research organisations, contract manufacturing organisations and tool providers (e.g. Cell lines for laboratory research and/or manufacturing, Animal models for laboratory re-search and/or manufacturing, Discovery and screening of novel drug targets
- Companion animal and veterinary applications (e.g. CRISPR based animal therapeutics, Manufacturing of therapeutic proteins and vaccines)
- Agriculture and livestock applications (e.g. All internal R&D for trait discovery and development, creation and commercialization of modified strains for food and feed)
- Industrial & Synthetic Biology Applications (e.g. internal R&D of microbial, fungal, and algal strains, metabolic pathway engineering, strain optimization)

It can be assumed that in Austria, particularly biotech companies are working with CRISPR/Cas9 technology in the field of researching genetic disorders, cancer immunotherapy, and gene therapies. Officially, companies provide only sporadic publicly available information on this topic. For instance, it is known that Boehringer Ingelheim is using CRISPR/Cas9 technology-derived models in their R&D work (https://pubmed.ncbi.nlm.nih.gov/35883003/). But also smaller biotech companies utilize the technology. The company Myllia Biotechnology GmbH (https://myllia.com/crop-seq-technology/), holds a license for the CRISPR/Cas9 technology according to a 2020 announcement from ERS Genomics, (ERS Genomics 2020). Myllia Biotechnology GmbH was established in 2018 as a spin-off from CeMM, originally under the name Aelian Biotechnology. The company combines CRISPR screening with single-cell RNA sequencing, leveraging two transformative technologies to enable genetic screening for complex phenotypes.

Another example of an Austrian company that utilizes CRISPR/Cas9 technology is Biomay AG (https://www.biomay.com/). Biomay was involved in the creation of Casgevy by developing production process based on the CRISPR/Cas9 technology. Casgevy is a therapy for sickle cell disease and Beta thalassaemia developed by Charpentier's company, CRISPR Therapeutics (https://crisprtx.com/) and by Vertex (https://www.vrtx.com/). Vertex also has a subsidiary in Vienna, working with the CRISPR/Cas9 technology. The Casgevy therapy has been conditionally authorized for use in the European Union. The cells of a patient are modified and transplanted into a patient, which has long-lasting therapeutic effects. Biomay is FDA-approved as a producer of Cas9 for the use in medications such as Casgevy. Vertex (also in Vienna) is currently setting up to treat patients with the therapy.

It can also be assumed that the biotech spin-offs from the Vienna BioCenter are more likely to employ CRISPR/Cas9 technologies in their research efforts as well as in the development of their products and therapies, particularly in the fields of genetic disorders and cancer immunotherapy. As mentioned earlier, the CRISPR/Cas9 technology has quickly established itself as the standard among the research groups within the Vienna BioCenter. In recent years, several spin-offs have emerged from these re-search organizations (e.g. Quantro (founded 2019; https://quantro-tx.com/); Ahead:bio (founded 2019; https://aheadbio.com/); Heartbeat:bio (founded 2021; https://heartbeat.bio/); Viverita Discovery (founded 2024; no homepage yet)). Heartbeat:bio has reported back that it is using CRISPR technolo-gy to genetically modify iPS cells to generate human 3D disease models of the heart.

For the other two companies, Quantro and Ahead:bio, internet searches provide sparse or no infor-mation on whether these companies apply CRISPR/Cas9 technology in their work. However, it can be assumed with a high degree of probability. This is supported by job profiles in the companies' job postings, where experience with gene-editing methods such as CRISPR/Cas9 is listed as advantageous. Additionally, Ulrich Elling, founder of the recently established Viverita Discovery FlexCo noted in an interview that his firm is based on the CRISPR-Switch and -StAR technology, as well as CRISPR/Cas9 technologies. He plans to license both patents in the future.

Economic impacts of the FWF funding in brief

- Fundamentally, contribution to the discovery of a new research/production tool that can be used by many firms in Austria and worldwide
- Formation of various Biotech-spin-offs making use of the CRISPR/cas9 technology; job creation (about 110 employees in the firms mentioned)
- Formation of CROs providing CRISPR/Cas9-related services (e.g. the Canadian company Synthego or the US-American company Revvity)
- Facilitating R&D by use of genetic engineering in Big Pharma and Biotech
- Increase in attractiveness of Austria as a biotech hub through positive press coverage and inter-national high-profile partnerships

Societal Impacts

The societal impact of the CRISPR/Cas9 technology is far-reaching and encompasses different areas, first and foremost the public health and the improvement of quality of life through improvements in a better understanding of diseases and faster discovery of new drugs. Currently, there is a successful therapy utilizing CRISPR/Cas9 technology available on the market. This is the Casgevy therapy developed by CRISPR Therapeutics and Vertex for sickle cell disease and beta thalassemia. Currently, it is a highly intricate and costly yet effective therapy.

There is also a lot of research going on in immunotherapy for cancer and HIV, where clinical trials have been promising (see for example Hussein et al. 2023). Modifying animals whose organs are used for transplants, such as pigs, is another application that could have massive societal benefits. With many people on long waiting lists for transplants, organs from animals such as pigs offer an alternative. CRIPR/Cas9 can make this safer by removing animal-specific viruses from the genome to reduce the risk of infection in humans after organ transfer (European Animal Research Association n.d.).

Genome editing is also being used in drug discovery for drugs that are not based on CRISPR technology, but use CRISPR in the research process. CRISPR/Cas9 is therefore also an essential tool that is contributing to advances in medicine that can have a huge impact on health and well-being.

The technology could also have a huge impact on agriculture in the future. CRISPR/Cas9 could be used to precisely modify crops to make them more adaptable to changing climates. In order for this to be implemented on a larger scale in Europe, it would be important not to consider CRISPR editing as genetic modification, as the mutations caused by this technology are small and could occur naturally in nature by chance. The EU is currently discussing a reform of its genetic engineering laws. Such a re-form would permit the breeding of plants using CRISPR/Cas9 technology (EASAC 2024).

In addition, the funding of basic research in biochemistry has increased public interest in these technologies. Public interest in technologies such as CRISPR/cas9 can help to popularize science and counter scepticism about science that hinders scientific progress.

On a critical note, it also has to be mentioned that – as opposed to the somatic gene therapy –the CRISPR/Cas9 technology could also be used for human germline modification: 2019 it got public that Chinese researchers used CRISPR/cas9 technology to rewrite the DNA in sisters' embryos to make the children immune to HIV. This human germline modification led to a worldwide outcry and a discussion about ethical values broke out. Most countries, but actually not all, forbid germline modification. Due to worldwide pressure, the Chinese researcher who played a central role in this was sentenced to three years in prison.

Societal impacts of the FWF funding in brief

- Considerable improvement of health and well-being
- Increasing food security through making crops more resistant to climate change
- Popularising science

8. Overall economic impact

While the preceding sections looked at specific, observable economic impacts of FWF-funding such as start-ups, patents or researchers trained within FWF-projects now working in industry, this section uses modelling tools and econometric approaches to establish links between FWF-funding and economic impacts. The first part focuses on shorter-term impacts arising from FWF-induced spending flows, the second part on medium- to longer-term structural impacts on productivity. While both approaches have advantages and drawbacks (section 3), for the public rate of return to FWF funding, it does not matter where additional taxes come from – e.g., from higher demand by wages spent by PhD researchers or from (long-term) growth in value added due to higher productivity of firms.

8.1. Shorter-term impacts from FWF-based spending flows

The FWF's grants and the projects financed by those grants are connected with the broad economy via a variety of effects, for example:

- The grants are spent on wages of researchers, as well as non-personnel costs (inputs and investments)[15]. Wages are linked to consumer spending, inputs and investment to output and employment in the providing firms, leading to demand effects.
- Successful projects can lead to the creation of startups, or their results can be commercialized as patents or licences, directly providing employment and generating value added. This constitutes in principle one of several supply effects, but will also lead to demand effects e.g. via additional exports or investment.
- Researchers gain experience and acquire skills that can be profitably employed, thus raising the economy's competitiveness, another supply effect.

The first two of these examples will be investigated below, based on information provided by the FWF as well as the results from a survey among the principal investigators funded by FWF (section 4). Analysing short-term economic benefits of FWF-funding suffers less from international spillovers and is not plagued by long time lags between basic research and its economic application. We follow in this approach the calculation of the economic impact of the American Research and Recovery Act (ARRA), which was also done using an input output model (Lane, 2009) and situate ourselves among recent literature pointing to the high business cycle stabilisation effects of R&D support (Brautzsch et al., 2015) equivalent to private consumption support schemes. Economic effects are certain to arise, independent of research results.

The third is less tractable: former studies have tried to estimate the effects of higher qualification in an economy (see, e.g. (Janger, Firgo, et al., 2017, for a survey). However, such analyses typically look at the total effect of employees' qualification; so, whereas a university system, for example, can be investigated in this manner, as (most) employees with tertiary education

[15] The FWF data base distinguishes between personnel and non-personnel costs. We assume that non-personnel expenditure is used for investment (new machines, equipment software, etc.) as well as operating costs (inputs); in the simulations, we assume a 50:50 share between investment and operating expenses.

will have passed through such a system, this is much harder in the case of FWF-funded projects, because only a small minority of all tertiary graduates will have been part of such a project. To break out their share of the total "tertiary dividend", then, is a tougher case.

8.1.1. Economic impact from FWF grants' wagens and non-personnel costs

The sums disbursed by FWF amounted to more than 240 Mio. € in 2022. All but 5 Mio. € of which went to Austrian recipients / research institutions. This was almost 75% more than was paid out in 2009, even if it remains small compared with similar research funding organisations in Switzerland or Germany, after controlling for country size[16], or with Austria's funding agency for applied research, the FFG, which disbursed approx. 780 Mio. € according to its yearly report 2023. Around 80% of the FWF funding constitute wage costs for researchers and staff.

Table 31: **Volume of FWF grants, 2009-2022**

Year	Wage costs covered by FWF - Austria	Wage costs covered by FWF - Abroad	Other costs covered by FWF - Austria	Other costs covered by FWF - Abroad
2009	105.62	0.60	31.61	2.12
2010	114.42	0.71	31.76	1.97
2011	116.19	1.40	34.34	1.32
2012	127.24	1.41	33.38	1.67
2013	134.87	2.15	36.66	1.68
2014	141.60	4.18	37.08	1.00
2015	146.70	4.69	36.37	1.03
2016	148.19	4.18	35.83	0.63
2017	151.25	4.82	35.86	0.36
2018	157.89	4.16	37.12	0.60
2019	160.59	4.18	38.61	0.91
2020	183.01	4.09	36.24	0.85
2021	184.89	3.78	36.83	0.91
2022	195.78	3.43	41.04	1.55

Source: FWF. receive more than half of the grants, followed by Tyrolean and Styrian institutions with around 12% each.

[16] See https://fti-monitor.forwit.at/B/B.2, indicator on project-based funding of basic research.

Table 32: **Regional shares of FWF grants 2011-2022**

Province	Share in FWF grants 2011-2022
Burgenland	0%
Carinthia	1%
Lower Austria	3%
Upper Austria	4%
Salzburg	4%
Styria	13%
Tyrol	12%
Vorarlberg	0%
Vienna	56%
Abroad	7%
Total	**100%**

Source: FWF; WIFO calculation.

We use the economic model ASCANIO to analyse the economic linkages of these grants. In principle, any government spending (indeed, all spending) leads to economic input-output linkages. In FWF's case, the effects are likely to be high, as the wage share of the funding is high. Typical FWF-wages for PhDs (2.300 € per month before taxes in 2022) and post-docs (4.061 € - 4.454 €) will also be mostly spent rather than saved. Moreover, while economic spending effects can and will be achieved by other forms of government spending, in terms of the additionality of FWF funding it can be argued that it directly leads to additional jobs for PhDs and post-docs – in particular PhD-positions depend on FWF funding. If a project proposal is not positively evaluated by FWF, there are few potential alternatives in the Austrian funding landscape: while smaller science funding agencies do exist in Austria (such as WWTF in Vienna, or the OeNB's jubilee anniversary fund focusing on social sciences), FWF is the main funder of basic research projects. At the European level, it is even tougher to get ERC funding than FWF funding (ERC success rates are about half of those of the FWF), so that the ERC is not a real alternative once FWF-funding has been declined. And while we don't model human capital effects directly – impact of FWF-funding on increased knowledge and skills of researchers – we have seen in the survey and in the case studies that many FWF-funded researchers do obtain training that leads them to further productive careers in academia or industry. The short-term economic impact effects of FWF-grants based on spending flows are hence likely to form a lower bound.

In the following, we briefly describe the model ASCANIO, which is a regional Input-Output model at the level of Austrian provinces. It distinguishes 65 sectors and commodities in the 9 Austrian provinces (and 43 countries, the EU27 among them), allowing to track the economic ramification between regions and sectors (for details see the Appendix 12.2). The linkages encompass **direct** effects (at the level of the analysed firms and products), **indirect** effects (in the production process, intermediate inputs are used to produce firm output and products; these inputs are purchased from other firms, which in turn use their own inputs, etc., leading to indirect effects) as well as **induced** effects (in the direct and indirect stages of the economic cycle, income and profits are generated, which are associated with household consumption and firm investment to replenish depreciated capital). While direct effects can be deduced from the information provided by the FWF and the survey results, indirect and induced effects have to be simulated using appropriate models.

Although most projects were conducted at universities, we did not use sector P85 *Education* to "produce" the projects, but put them in sector N72 *Scientific research and development*, as this sector's "production technology" is arguably much more appropriate for FWF-funded projects[17]).

8.1.2. Economic impact from products and processes in established firms and from start-up creation

Information on financial disbursement of FWF grants is readily available from funding statistics. Information on the economic impacts in the form of e.g. turnover of new or improved products or cost savings from production processes at established firms as well as turnover or employment at start-ups follows from both the survey conducted within this project and information provided by FWF-funded researchers in their final project report to FWF (see section 4 for a description). About a third of all project leaders of projects ending between 2009 and 2022 are covered by the survey, data from the FWF *researchfish* database (see section 4) is centred on 2018-2020 (section 4). Data by Dealroom[18]) on startup employment complement the data gained. We did not use survey data on the income from patents or licences, as the data were too patchy.

Questions on employment and turnover in start-ups were part of the survey: employment was provided as headcount; for turnover, ranges were given. Rather than using the broad turnover ranges provided in the survey (100k/1,000k/10,000k) we imputed the turnover numbers from data in the startup database Dealroom, which yields a plausible and robust turnover of 100k per employee. Using this as an estimate for firms without exact numbers, we arrived at total sales of 42.5 Mio. €, produced by 435 employees. Summarizing the internet presentations of the surveyed firms, we estimate that a majority (61%) of the turnover was made from software[19]),

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[17] The importance of this choice stems from the fact that the economic linkages, both sectoral and regional, depend on the goods and services used in the production process – they determine which sectors in which region provide the inputs and investment goods. As universities' "production process" is heavily geared towards teaching and administration, the R&D sector's input and investment structures are certainly a much better proxy for FWF projects.

[18] A "*Global data platform for intelligence on startups, innovation, high-growth companies, ecosystems and investment strategies*", see https://dealroom.co/

[19] This overwhelming majority of software does not in the least reflect the share of the field "informatics" computer science in FWF projects: in fact, only a small amount of FWF funding goes into this scientific field. Often, however, products that emerge from FWF projects (in whatever field) constitute "software", from visualization software in Pharmaceutics to Quantum computing platforms in Physics. Lacking detailed information, we assume that the type of product determines the production process, not the type of firm (i.e., if a pharmaceutical firm develops specific software, its inputs resemble those of software firms rather than those of pharmaceutical firms). In IO analysis, this is called the "commodity technology assumption", and is usually preferred over the "industry technology assumption" (in which all goods produced by a sector are produced with the same average sector-specific technology)

with pharmaceutical products a distant second (28%). Other types of products were of minor importance.

Table 33: **Key variables of surveyed firms by product (2-digit CPA[20]), 2022**

	Employees	Turnover	Share of total turnover
C21 Pharmacy	118	11,800	28%
C26 Electronics/optical equipment	30	2,227	5%
C28 machinery	17	1,700	4%
J62 Software	261	25,873	61%
M70 Consultancy	2	200	0%
M72 R&D Services	7	700	2%
Total	**435**	**42,502**	**100%**

Source: own survey & Dealroom.

Not surprisingly, the regional pattern of the firms quite closely follows the regional pattern of FWF grants: again it is Vienna, which hosts the majority of the firms (60%), followed by Styria and Tyrol with 15%.

Table 34**: Turnover of surveyed firms by Province, 2022**

Province	Share in Firm Turnover 2022
Burgenland	-
Carinthia	-
Lower Austria	4%
Upper Austria	5%
Salzburg	-
Styria	15%
Tyrol	16%
Vorarlberg	-
Vienna	60%
Total	**100%**

Source: own survey & Dealroom.

To assess the economic linkages of these firms, we treated their output as additional exports of the respective goods. For one, this ensures the most appropriate "production process". The treatment as exports is justified, because most of the products are expected to be "new-to-the-world" (or at least "new-to-the-market"), thus they either constitute genuine exports, or, if

[20] The statistical classification of products by activity, abbreviated as **CPA,** is the classification of products (goods and services) in the European Union. The **CPA** product categories are related to the economic activities of the statistical classification of economic activities (**NACE**). (see https://ec.europa.eu/eurostat/web/cpa)

they are sold domestically, they do not directly compete with similar, domestic products. From what we know about the firms' activities, this seems to be the dominant case.

Additionally, participants were asked about new or improved products and production processes in third-party established firms which are based on the results and outcomes of FWF-funded projects (section 4.3). Again, respondents were not required to provide exact numbers but range estimates; they were very similar, with a (very broad) range of 4.1 – 45.3 Mio. € for products and 4.3 – 45.8 Mio. € for production processes. Simulations were performed for the lower and upper bounds; lacking information on the regional and sectoral dimensions of the products and processes, we assumed the same region-sector-pattern as in the case of firms. However, we will not report regional or sectoral disaggregations of the simulation results[21]).

In terms of the "additionality" of FWF funding, or the economic effects accruing to FWF funding via the use of research results in firms, products, or production processes, there is an important difference with regard to the economic effects accruing to FWF funding via funding wages of researchers and other project costs. While FWF's funding can significantly contribute to the knowledge base of these impacts, commercialisation usually requires many additional efforts. Firms often need to undertake additional research, innovation and investment activities before scientific discoveries made through basic research can be applied to concrete uses. In established firms, such activities are likely to be funded by firms' own funds as well as potentially public support from agencies funding research closer to the market, such as the FFG (Austrian Research Promotion Agency). In start-ups, venture capital funds will be used, as well as public support from the likes of FFG, AWS (the Austrian Promotional Bank which e.g. funds start-ups) or EU-level agencies such as the EIC (European Innovation Council). Our analysis of firms and our case studies testify to the importance of additional funding sources necessary to turn results from basic research into applications and uses. It would hence be misleading to take the economic effects of these impacts as returns to FWF funding only – FWF funding is usually part of a broader range of funding sources, even if it is likely to be crucial in terms of the knowledge base which makes the impacts possible in the first place.

At the same time, as stressed before, our data on economic impacts associated with FWF funding is incomplete. According to the survey in section 4, half of the respondents which indicated that their research contributed to new or improved production processes at established firms could not put a number on any revenues or cost savings. The same holds true for 40% of the respondents for new or improved products at established firms, 42% for patents and 21% for licences. Moreover, our survey captured about a third of relevant project leaders; even if survey response was biased towards those with impacts, we are likely to have missed a substantial share of the economic impacts of FWF funding. Moreover, we do not attempt any monetarisation of societal impacts, which would be done in a fully-fledged cost-benefit analysis but is outside the scope of this study.

[21] The Austrian totals, i.e. summed over all regions and sectors, are quite stable with respect to the exact regional and sectoral pattern; in any case, uncertainty from the fact that values are given in ranges only certainly far surpasses the uncertainty stemming from assumptions about regional-sectoral distribution.

Hence, to some extent, the lack of accounting for all public and other funding sources for the economic impact of FWF-funded research results is compensated by missing a considerable part of the the economic impacts in the first place.

8.1.3. Results

Using the regional IO-model ASCANIO, we estimated the economic effects connected with the demand aspects of FWF grants and the related firms (with respect to turnover as well as products and production processes in third-party established firms or start-ups) in the survey. We refrained from extrapolating the survey results to the whole population of related firms in light of the discussion above; rather, such extrapolation can be made on the basis of these results but needs to account for the additional funding sources necessary to commercialise basic research.

In total, i.e. via direct, indirect and induced channels, the 196 Mio. € of wages and non-personnel costs financed in 2022 by FWF are associated with 410 mio. € of Austrian Value added (Table 35), providing around 5,600 jobs (of which around 3,000 directly in FWF-financed projects). Taxes and Social Security Contributions add up to a total of 190 Mio. €; via fiscal transfers, almost 20 Mio. € each flow to communities and provinces, and more than 60 Mio. € to the federal budget (plus 100 mio. € of Social Security Contributions).

Table 35: **Estimated economic linkages of FWF projects' spending and results, in Mio. €, 2022**

	Variable	Wages&other costs financed by FWF projects	Spinoffs & startups	Products & Processes in established firms	
				Lower	Upper
National accounts:	Output/Turnover	430	110	20	230
	Value Added	410	60	10	120
	Wages	250	25	5	60
	Employees (Heads)	5,600	670	140	1,420
	Employees (FTE)	4,550	560	120	1,190
Taxes and social security:	Personal & Firm Income Tax	54	6	1	13
	Social Security Contributions	96	11	2	24
	VAT - Value Added Taxes	43	5	1	11
Tax distribution:	Province level	18	2	0	5
	community level	18	2	0	4
	federal level	61	7	2	16

Source: WIFO calculations with ASCANIO.

The (non-extrapolated) model estimates for the firm linkages (with sales of 42.5 Mio. €, see Table 29) amount to 60 Mio. € of Austrian value added, generating around 670 jobs. Taxes and social security amounts to more than 20 Mio. €. Assuming that the two thirds of the firms, that did not respond to the survey, have a similiar impact, we find that the (direct and indirect) contribution to the Austrian GDP would be around 200 Mio. €.

The (rather broad) range estimates for the direct, indirect and induced impact of products and production processes at established third-party firms (4.3-45.8 mio. €, see above) amount to 10-120 Mio. € of value added, filling some 140-1,400 jobs. To give a less uncertain result: If we assume that the actual value lies at the lower third of the range between 10 and 120 Mio.€ (45 Mio.€) and if we extrapolate that to the total set of firms (of which 30% took part in the survey), the contribution to value added at the national level would be around 130 mio.€ and 1.400 jobs.

All these numbers are annual estimates; in the case of wages and other costs financed by projects, these effects are quite directly linked to (annual) FWF payments. In the case of output or turnover by established firms (products/processes), spinoffs and start-ups, they have a longer time horizon, with FWF-subsidised research at the beginning of the (potential) revenue streams; the numbers presented in the table correspond to the revenues reported for one year, 2022.

Additionally, but more indirectly, project leaders in the survey indicated that about a quarter of the staff in their research projects now works in industry, leading to the number of 1,600 researchers in industry from the pool of MSc and PhD graduates with FWF project experience (see section 4). Their specific impact cannot be estimated quantitatively in this context, but as a very rough, first approximation, we can try to estimate their combined wages: with average annual researcher wages of 47.800 €[22], the total annual volume of wages amounts to around 80 Mio €, which – including employers' Social Security Contributions – implies a contribution to Austrian Value Added (and GDP) of more than 90 Mio €. Additionally, these wages are associated with 14 Mio € of taxes (income and payroll taxes), as well as 30 Mio € of total Social Security Contributions (paid by employers resp. employees).

In all, FWF projects – either directly or via their long-term impacts on researchers and firms – are linked to a remarkable "economic footprint", which, however it is measured, compares very favourably with the FWF's grants and subsidies. Taking the lower bound of all estimates and adding up the taxes and social security contributions of Table 35 leads to tax revenues and social security contributions of € 219 million In the year 2022, merely € 17 million below the FWF funding 2022 spent in Austria (€ 236 million). Adding the € 44 million from researchers working in industry (yielding in total € 263 million), or extrapolating to some extent the information on firms and start-ups gained in the survey, would imply that the FWF is entirely self-financing itself from spending impacts alone, not taking account of longer-term structural impacts stemming from increased productivity due to better human capital and an increased knowledge base – **the return for the taxpayer would be positive even without considering structural supply effects.** Based on the results from table 33 and the researchers working in industry, a lower bound for the short-term return would be 1 € of FWF funding to be associated with 1,1 € of tax revenues and social security contributions. 1 € of FWF funding would also be associated with 2,37 € of output or turnover (first line of table 33) in the lower bound, very similar to the result of Azoulay

[22] see https://www.kununu.com/at/gehalt/forscher-in-29583

et al. (2019), 1 $ of NIH funding relates to 2,34 $ of drug sales, although the methodologies are very different. This is just meant to provide an order of magnitude. Compared to value added, the relationship would be 1 € to 2-2,5 €. Note that these results cannot be interpreted as causal relationships. Even if lower in reality, they would however still need to be added to longer-term supply-side effects (section 8.2).

Regional aspects

With good information on the regional distribution of FWF grants and firms, we can also provide estimates for the regional effects of value added:

Table 36: **Regional distribution of FWF grants and their economic linkages**

Province	FWF grants 2022	VA effects of FWF grants	firm turnover	VA effects of firm turnover
Burgenland	-	6	-	1
Carinthia	2.1	12	-	1
Lower Austria	7.0	41	1.6	5
Upper Austria	10.5	35	2.3	5
Salzburg	10.7	23	-	2
Styria	33.9	54	6.4	7
Tyrol	29.5	42	6.8	6
Vorarlberg	0.2	6	-	1
Vienna	142.8	189	25.8	27
Total	**236.8**	**408**	**42.8**	**57**

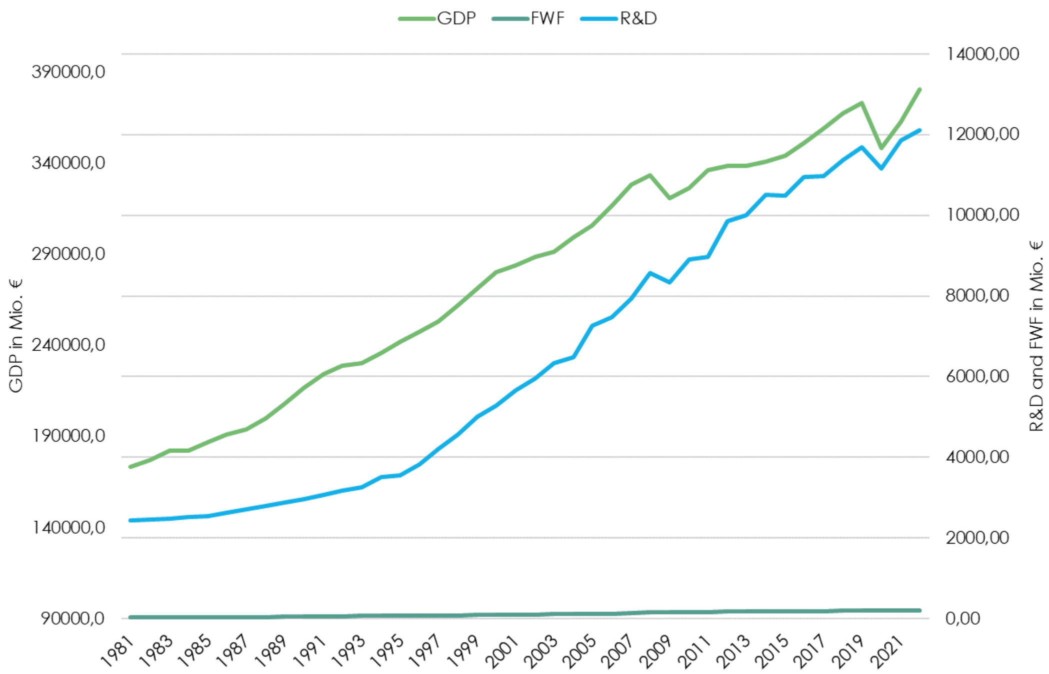
Source: WIFO calculations with ASCANIO.

Like project volumes and firm turnover, the value added effects are geared towards the capital: the regional economy of Vienna is simulated with almost half of the national effects; inter-regional trade linkages (as well as commuting, inter-regional shopping and tourism, etc), however, lead to a broadening of the regional impacts: provinces with no or low direct impact nevertheless receive some of the indirect and induced effects of grants and firms.

8.2. Medium-term structural impacts

To examine the potential economic supply-side effect of the projects funded by the FWF, we use two different state-of-the-art methodological approaches. The first, structural vector autoregression (SVAR) makes use of the long time series for FWF funding and economic variables available for Austria. The second, system-GMM estimation of dynamic panel data, exploits shorter time series on FWF-type funding among a variety of countries. Before we present the results of the analysis, we illustrate the differences in economic magnitudes analysed. Figure **39**Figure 49 juxtaposes data on Austrian GDP over time (1981-2022, left axis) with total R&D expenditure and FWF disbursements (right axis). While total R&D expenditures are roughly about 3% of GDP, FWF-disbursements are only about 0.05% of GDP. While we will take the logarithmic values of the data series in our estimations, it will be interesting to see whether such a small share of activities can directly impact GDP dynamics. Moreover, there are no structural breaks in the series on FWF funding.

Figure 49: **GDP, R&D expenditures and FWF disbursements in Mio. €, 1981-2022**



Source: AMECO, Statistics Austria, FWF. All series are adjusted for inflation using the GDP deflator.

8.2.1. Estimates based on time-series estimation[23]

In this methodological approach, we use vector autoregression models (VAR) first developed by Sims (1980) to analyse several long time series of economy-wide and FWF data. A recent example for an application to the impact of public R&D spending on productivity is Ciaffi et al., 2024. In a VAR, variables are specified as a linear function of a certain amount of their own lags and of those of other variables, generalising univariate autoregressive equations by allowing for more than one variable. The so-called impulse response function shows the impact of one variable on another, but cannot be causally interpreted. A structural vector autoregression model (SVAR) places restrictions on the contemporaneous correlations between variables and can hence be used in principle for causal inference (Stock & Watson, 2001). The restrictions are placed using assumptions based on economic theory, so that the robustness or quality of these restrictions depends on the appropriateness of these assumptions. Nevertheless, SVARs are nowadays a workhorse tool to examine the relationships between multiple time series.

We use the STATA SVAR package to implement the estimations and draw on data from the European AMECO database which provides long time series on macro-economic data such as GDP or hours worked. FWF funding data 1981-2022 are provided by the FWF. All data are in real terms using the GDP deflator and in logarithmic form.

Table 37**: Descriptive statistics of the variables used in the estimations**

	FWF funding (Mio. €)	**Real GDP (Mio. €)**	**GDP per hour (€)**	**Tertiary attainment (in % of 25-64y)**	**Researchers in higher education**	**All researchers**	**Journal Publi-cations**	**Patents**	**Patent citations**
Availability	1981-2022	1981-2022	1981-2022	1981-2022*	1998-2021*	1998-2021*	2004-2022	1999-2022	1999-2022
Mean	112	253235	37	8,0	10481	35806	3578	7	104
Median	104	250348	38	6,5	11496	35276	4233	5	36
Std deviation	60	92692	12	4,6	3721	11506	1390	7	260
Max	206	396632	53	18,4	16230	56533	5228	23	1357
Min	34	94130	14	2,8	1389	18715	1234	0	0

Source: FWF, AMECO, Statistics Austria, Patstat. *Missing years are interpolated.

In the most simple application, we directly specify FWF funding to be linked to GDP or, as a productivity proxy, GDP per hour worked. To provide the necessary restrictions to identify the causal impact from FWF funding on the dependent variable, we specify the matrix that includes the restrictions placed on the contemporaneous correlations between the variables as follows:

$$\begin{bmatrix} 1 & -\alpha \\ -0.0004 & 1 \end{bmatrix} \begin{bmatrix} GDP_t \\ FWF\_funding_t \end{bmatrix}$$

[23] We thank Christian Glocker for valuable advice on implementing the structural vector autoregressions.

In a simplified notation without lags, this specification implies solving the following system of equations

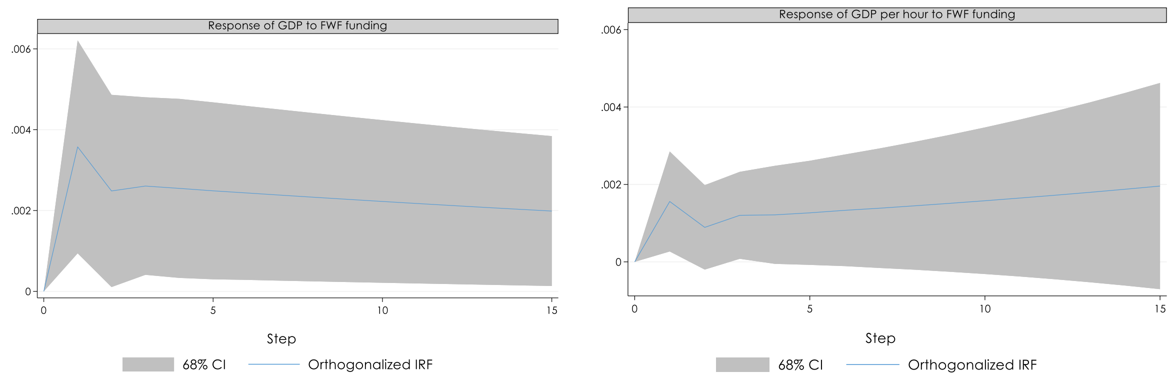
$$GDP_t = \alpha \; FWF\_funding_t \tag{1}$$

$$FWF\_funding_t = 0.0004 \; GDP_t \tag{2}$$

We restrict FWF funding to be equal to its average share of GDP over the time period 1981-2022, which is 0.04%; just setting it to zero does not change the results. α is our coefficient of interest. Usually, the contemporaneous coefficient at time t is of less interest than the delayed responses of GDP to FWF Funding, as depicted by the impulse response functions in Figure 50. The response of GDP with 68% confidence (mean plus/minus one standard deviation) to an impulse of 1% more FWF funding is at the beginning at 0,7%, petering out at about 0,3% in later years. The results barely change when using an exogenous time trend and/or restricting the sample to before 2020, the first year of the pandemic.

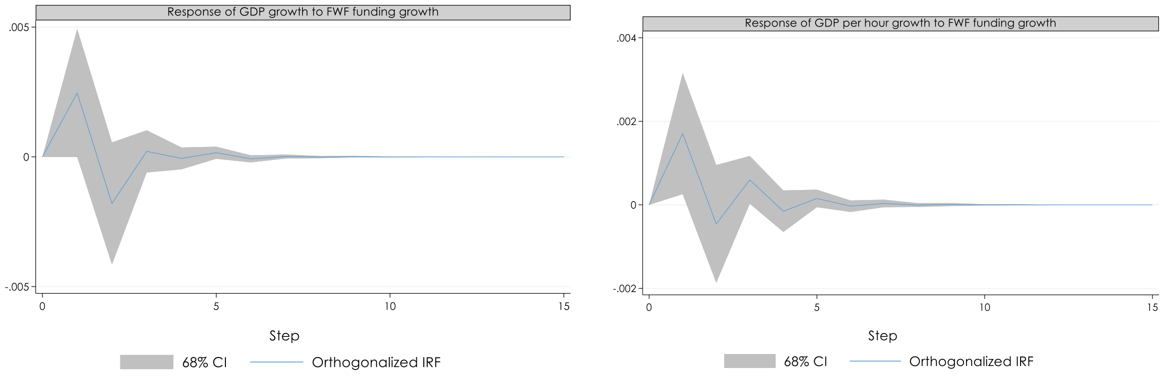
Real GDP per hour worked is our key variable of interest, as it is a proxy of productivity or improvement of the supply-side of the economy. We specify that there is no contemporaneous relationship between FWF funding and GDP per hour as FWF funding is unlikely to be influenced contemporaneously by the evolution of GDP per hour worked. GDP per hour only shows a small positive significant response to FWF funding at the beginning, when restricting the time span to before the pandemic (Figure 50).When we look at growth rates rather than levels, for GDP a similar picture emerges in terms of a weak response to the FWF impulse (Figure 51).

Figure 50: **Response of GDP and GDP per hour to FWF funding impulse**



Source: data from AMECO database and FWF for the period 1981-2022 (left hand panel) and 1981-2019 (right hand panel). Structural vector autoregression using default lags. Orthogonalised Impulse Response Function (IRF).

Figure 51: **Response of GDP and GDP per hour growth to FWF funding growth**



Source: data from AMECO database and FWF for the period 1981-2022 (left hand panel) and 1981-2019 (right hand panel). Structural vector autoregression using default lags. Orthogonalised Impulse Response Function (IRF).

In the following steps, we do not directly relate FWF to GDP per hour, but specify an intermediary variable that we know from the preceding sections of this report is affected on the one hand by FWF-funded projects, and that on the other hand is likely to affect economic performance. This is also the background of the approach by Azoulay et al., 2019, to determine economic impacts from NIH funding – they look at NIH's impact on disease-specific patents rather than at any direct link between NIH spending and economic effects.

We have seen in the preceding sections that FWF-funded research projects lead to flows of additional trained researchers, journal publications and patented inventions. Trained researchers increase the stock of human capital, which is a key driver of economic growth (Mankiw et al., 1992); R&D expenditures increase the stock of knowledge, while new journal publications are a proxy for the amount of the increase of the stock of general knowledge, while patented inventions proxy the increase of the stock of technological knowledge. Both drive economic growth in advanced, knowledge-based economies (Aghion & Howitt, 2009). We hence specify as "intermediaries" the following variables: the tertiary graduation rate among the population aged 25-64 from Statistics Austria as an admittedly imperfect proxy for researchers, but available for a long time, the number of researchers in the total economy and in higher education only, total R&D expenditures, the journal publications associated with FWF projects and the flow of patents identified in section 5.1. We need to specify restrictions for the following matrix

$$\begin{bmatrix} 1 & -\alpha & -\beta \\ -\gamma & 1 & -\delta \\ -\omega & -\varphi & 1 \end{bmatrix} \begin{bmatrix} GDP\ per\ hour_t \\ "Intermediary"_t \\ FWF\_funding_t \end{bmatrix}$$

to solve the following system of equations:

$$GDP\ per\ hour_t = \alpha\ "Intermediary"_t + \beta\ FWF\_funding_t \tag{3}$$

$$"Intermediary"_t = \gamma\ GDP\ p.h._t + \delta\ FWF\_funding_t \tag{4}$$

$$FWF\_funding_t = \omega\ GDP\ p.h._t + \varphi\ "Intermediary"_t \tag{5}$$

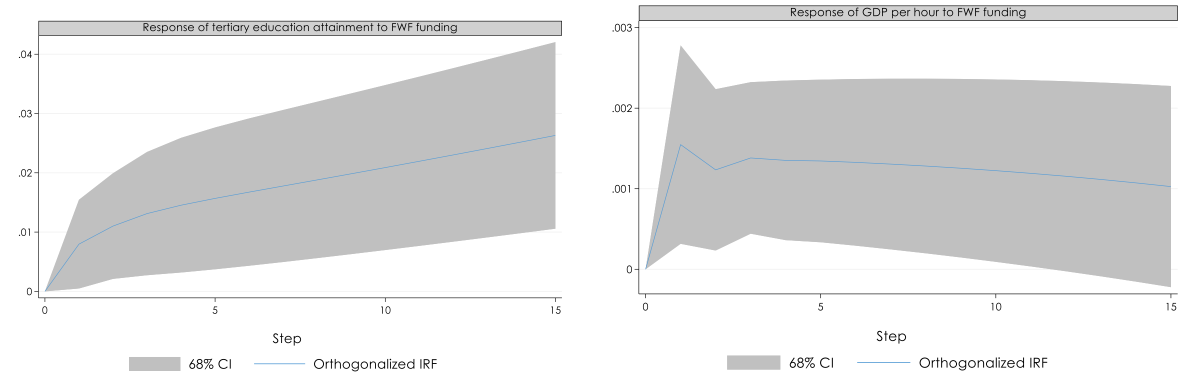
We set β in all equations to zero, as above. Moreover, we set ω to 0.0004 or 0 (little impact on results) and φ to 0, as the FWF's budget is unlikely to be affected contemporaneously by additional researchers, journal publications or patents (additional researchers are likely to lead to higher FWF budgets over time though, as doing research in the face of decreasing success rates would lead to researchers leaving).

For the first structural relationship, we investigate the impact of FWF funding on additional researchers (tertiary graduation rate) which in turn affects GDP per hour. We restrict α to the elasticity of GDP per hour to human capital as found by Mankiw et al., 1992, namely 0.33 (not restricting does not significantly change the results), to give the following matrix:

$$\begin{bmatrix} 1 & -0.33 & 0 \\ -\gamma & 1 & -\delta \\ -0.0004 & -0 & 1 \end{bmatrix} \begin{bmatrix} GDP\ per\ hour_t \\ Tertiary\ education_t \\ FWF\_funding_t \end{bmatrix}$$

The response of tertiary education to an impulse from FWF funding is clearly positive (left-hand panel of Figure 52) and also the intermediated response of GDP per hour to FWF funding is positive (right-hand panel of Figure 52). Calculating again the unit response of the response of GDP per hour to FWF funding using the coefficients of the impulse response functions, we obtain that, e.g. a 1% increase of FWF funding is associated with a 0.22 to 0.34% response of GDP per hour in the fifth year after the shock which peters out over time, at about year 10 there is no more significant response.

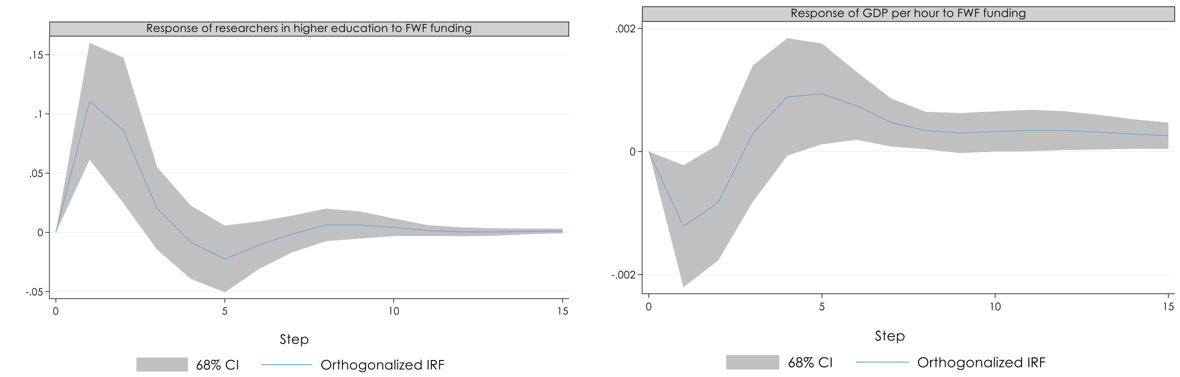
Figure 52: **Response of GDP per hour to FWF funding via human capital (tertiary education attainment)**



Source: data from AMECO, FWF & Statistics Austria for the period 1981-2019. Structural vector autoregression using default lags. Orthogonalised Impulse Response Function (IRF).

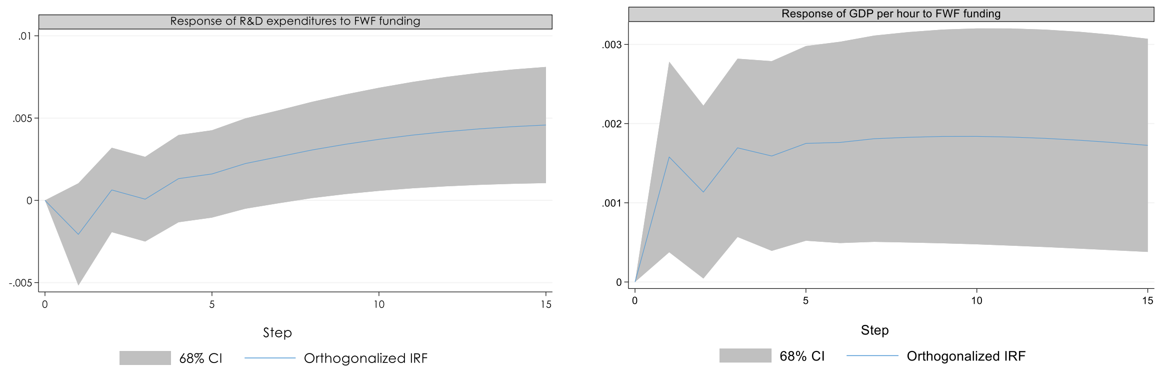
As an alternative, we use the number of researchers in the higher education sector over time. This time series is shorter, starting from 1998. Strictly speaking, this is not anymore a proxy for general human capital – working through PhDs, post-docs funded by FWF which are not necessarily working in academia – but for research activities. The responses to FWF funding of GDP per hour are negative at first, but then turning positive, which would be in line with standard theory that basic research first reduces production capacity (because people do research that is not immediately useful for production), but then increases it. Total R&D expenditures (Figure 54) also proxy research activities and show a positive response over time, with a similar unit response of about 0.35% in the fifth year of the shock.

Figure 53: **Response of GDP per hour to FWF funding via researchers in higher education**



Source: data from AMECO, FWF & Statistics Austria for the period 1998-2019. Structural vector autoregression using default lags. Orthogonalised Impulse Response Function (IRF).

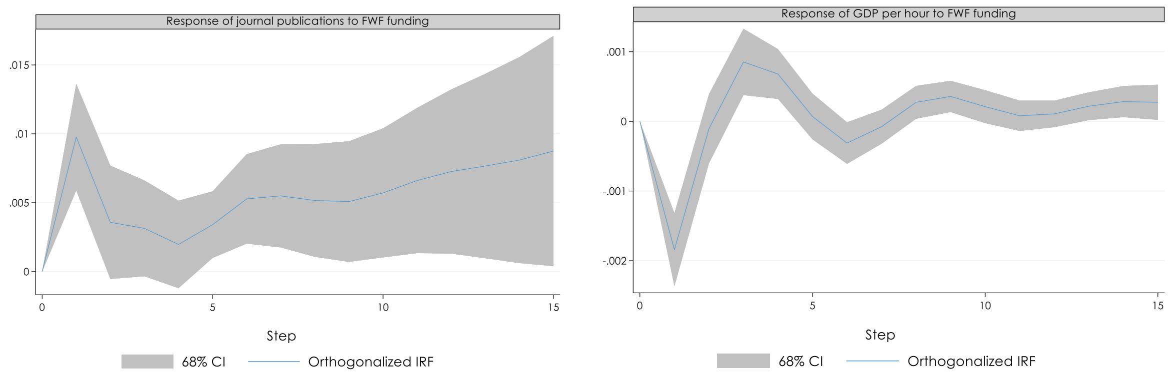
Figure 54: **Response of GDP per hour to FWF funding via R&D expenditures**



Source: data from AMECO, FWF & Statistics Austria for the period 1981-2019. Structural vector autoregression using default lags. Orthogonalised Impulse Response Function (IRF).

Next, we examine FWF-funded journal publications, a key FWF-output metric that proxies the growth of knowledge due to FWF funding. In this case, we use the second lag of FWF funding, to allow some time for funding to turn into publications. The responses are similar, with the unit response to FWF funding again similar at its peak in the third year at close to 0.3%.

Figure 55: **Response of GDP per hour to FWF funding via journal publications**



Source: data from AMECO, FWF for the period 2004-2019. Structural vector autoregression using default lags; FWF funding lagged by two periods. Orthogonalised Impulse Response Function (IRF).

Lastly, we use the number of patents based on FWF-funded research or patent citations to these patents. The results are however not significantly different from zero. The patent time series is too erratic and short and may in addition be characterised by many missings, as there is an underestimation of FWF patents as outlined in section 4.

In summary, using different variables and specifications, we find evidence that FWF funding is associated with a positive effect on productivity measured by GDP per hour in the environment of 0.2-0.3% of GDP per hour per percent increase of FWF funding, after several years into the shock, slowly fading out over time. Assuming a linearly increasing impact, a 10% FWF funding increase would be associated with a 2-3% increase of GDP per hour, which is quite large considering the small amount of FWF funding. The coefficients themselves are similar to the results in the literature (section 3), although difficult to compare. However, as stated, these results should be interpreted cautiously, as the data quality is limited and there are no really comparable international studies. Impulse response functions are shown with 68%-level of confidence (1 standard deviation), a very strict 95%-confidence interval would lead to more insignificant responses. Next, we examine panel data as a complement to time series data.

8.2.2. Estimates based on dynamic panel data

In this section, we take advantage of internationally available data in the Austrian RTI monitor[24] on FWF-“type” funding and further variables which can explain productivity, such as R&D expenditures, human resources, publications and patents. Because of the inclusion of Switzerland, we cannot use AMECO data however on GDP per hour worked, but use GDP per capita instead, which is a less good approximation of productivity. The data on competitive grant funding of basic research are compiled for the Austrian RTI monitor based on Janger et al. (2019). All in all, we have nine countries (Austria, Denmark, Finland, Germany, Netherlands, Sweden, Switzerland, UK, USA) for the time period 2009-2023. Because of the pandemic, as above we restrict the data to before 2020 though.

Table 38: **Variables used in the estimation, 2009-2022**

	FWF-type funding per capita (in €)	R&D spending in the higher education and government sector per capita (in €)	R&D spending in the business sector per capita (in €)	Tertiary attainment (% of 30-34y)	Citable documents per 1.000 of population	Patent applications	Real GDP per capita (in 1.000 €)
Mean	61	380	867	40	2,85	8.722	48
p50	56	369	876	42	2,65	3.318	47
SD	24	137	342	8	1,05	11.534	9
Max	126	791	1.974	56	5,98	39.737	91
Min	22	142	277	21	1,37	904	33

Source: Austrian RTI monitor, AMECO, World Bank.

While we cannot estimate an Austrian-specific coefficient, the international data gives us the option to use a panel data estimator to control for unobserved fixed effects. Given that GDP per capita is likely to be in part explained by past realisations, we use a lagged dependent variable. As normal panel data would be biased because of the use of a lagged dependent variable, we use the dynamic panel data estimator developed originally by Arellano & Bond (1991). Kiviet, (2020) provides a detailed discussion on appropriate model specification. The dynamic panel estimator uses lagged values of the regressors as instruments. We use the STATA xtabond package to implement the estimations.

[24] https://fti-monitor.forwit.at/O/system

We need to specify which variables are strictly exogenous (ones dependent on neither current nor past errors), predetermined or weakly exogenous (potentially correlated with past errors) and which are endogenous variables (potentially correlated with past and present errors). There are no strictly exogenous variables, as past realisations of GDP may be correlated with current funding for research and hence also current publications, and with tertiary graduates as well (as economic development is known to drive up the tertiary graduation rate). As endogenous we specify business R&D, which is known to be cyclical, and hence also the number of patents. We use time fixed effects and robust standard errors.

In a nutshell, in our baseline specification we estimate

$$GDP\_capita_{i,t} = \alpha_1 GDP\_capita_{i,t-1} + x_{i,t}\beta_1 + w_{i,t}\beta_2 + v_i + \epsilon_{i,t}$$

with *i = 1,…N* referring to countries in our sample, *t = 1,…,*T_i to the number of years 2009-2019 in our sample. $GDP\_capita_{i,t-1}$ is our lagged dependent variable (LDV). $\epsilon_{i,t}$ are the observation-specific errors (for each country in each year). $x_{i,t}$ contains the strictly exogenous explanatory variables, $w_{i,t}$ contains the predetermined or weakly exogenous variables as well as the endogenous explanatory variables as explained above.

Table 39 summarises two regression results, one without the number of patents, the other one with it. FWF-type funding is significant at the 10% level (p-value of 0.065). 1% of additional funding is associated with an increase of GDP per capita of between 0.017 to 0.058%. Again assuming a linearly increasing impact, a 10% increase of FWF-funding would be associated with an increase of GDP per capita by about 0.2 to 0.6%. The results are not strictly comparable to the results in 8.21., as we use GDP per capita here rather than GDP per hour, and the coefficient is an average effect across countries, not specific to Austria. Interestingly, publications – as a proxy for the stock of knowledge – are highly significant. In regressions not shown here, we explained the number of publications using the same methodology by FWF-type funding (and other variables) and find a highly significant effect of FWF-type funding on publications. In terms of structure, this is similar to our analysis in the preceding section, where we let FWF-funding affect GDP per hour via publications or human capital as well.

The number of countries is also limited (dynamic panel data estimation, with the Arellano-Bond-estimator, works best with many panel units and a short time series). The results must hence be interpreted with caution. As outlined throughout the report, we know however that there are many FWF impacts outside of academia which can affect productivity. Our results must also be seen against the background of practically no study available that attempts to econometrically estimate the impact of competitive publicly funded grants for basic research. Azoulay et al.'s 2019 paper works with NIH data, where about half is applied / translational research[25] rather than basic research. Akcigit et al., 2021 paper looks at basic research activities by firms.

We conclude from section 8.2 that we can see indications in the data for productivity effects of FWF-funding, or FWF-type funding. However, better data would certainly allow for more precise estimations – the topic of the next and concluding section 9.

Table 39**: Regression results from dynamic panel data, 2010-2019**

		(1)	(2)
VARIABLES		Base model	With patents
GDP per capita lagged	Lagged dependent variable	0.780***	0.780***
Publications	Predetermined	0.239***	0.239***
Tertiary graduates	Predetermined	0.000228	0.000230
R&D in Higher Education & Government sector	Predetermined	0.00342	0.00330
FWF_type - funding	Predetermined	0.0377*	0.0376*
Number of patent applications	Endogenous		-0.000957
R&D in the business sector	Endogenous	0.0210**	0.0211**
Constant		0.723***	0.730*
Observations		87	87
Number of countries		9	9
Year FE		YES	YES
Robust Errors		YES	YES
Wald chi2		6212	5066

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

25 https://nexus.od.nih.gov/all/2023/10/31/trends-in-nih-supported-basic-translational-and-clinical-research-fys-2009-2022/

9. Conclusions and recommendations on measurement

The report has produced a rich illustration of the impacts of FWF outside academia. A detailed summary of the results is provided by the executive summary. In a nutshell, Martin & Salter's conclusion (2001, p. 527) from 23 years ago is 100% true for the FWF: *"In short, the overall conclusions emerging from the surveys and case studies are that: i the economic benefits from basic research are both real and substantial; ii they come in a variety of forms; and iii the key issue is not so much whether the benefits are there but how best to organise the national research and innovation system to make the most effective use of them."*

While this could be another report, we highlight here the dearth of venture capital in Austria, inhibiting growth by spin-offs drawing on FWF-funded knowledge. Would only one such firm develop into a large profitable research-intensive firm, the returns to FWF-funding – and to other funding sources of spin-offs or start-ups – would increase dramatically. The overall economic (and societal) long-term effect of FWF funding will depend on economic (and societal) framework conditions. Nevertheless, we show here that FWF is already self-financing itself even in the short term. This comes against a background of considerably incomplete data, but we also need to take into account that FWF is often not the only contributor to impacts outside academia. Some of the incompleteness is due to our own limited resources – for example, we did not do a survey among firms and could not invest the time necessary in the various subtopics as would have been necessary.

But better data are clearly needed. What FWF needs is a systematic mechanism to account for impacts which arise later, several years after the project has ended.

A first measure would be to make sure that **FWF-funding is uniformly acknowledged** in journal publications – there should be strict information delivered to project leaders and participants at the beginning. Acknowledgement rules could concern not just publications, but also other impacts, such as spin-offs, to acknowledge FWF-funding even from the past.

A second concerns data collection through questionnaires. The FWF should develop a **standardised questionnaire** based on the Researchfish survey, which would be **sent out at the end of the project and again some time later** (e.g. three years later) to capture updates. The Researchfish survey is a good starting point, but it focuses on outcomes and not (explicitly) on impacts. If possible, individual fields should be defined more precisely and/or queried more accurately.

For example, "collaborations and partnerships" could more clearly indicate whether only academic or all possible collaborations are meant, and if necessary, the answers should at least distinguish between academic and for-profit organisations (or other types of organisations). On the other hand, the whole block of questions could probably be shortened a bit. The "next destination" chapter is very imprecise about which people should be reported on, e.g. all those involved in the project or only those who have left the team, or those randomly selected by the PI? The open-ended information on "Influence on Policy, Practice, Patients and the Public" makes it clear that very, very different activities have been registered here. The types of activity queried are also neither very precise nor comprehensive enough. Often, suspected or possible influences were reported here, but no proven ones (e.g. a set of rules was changed). Similar improvements can also be made in the other parts.

The survey developed within this project is often clearer and more systematic as regards collecting impacts outside academia (see annex 12.3) and could inform future efforts by the FWF to better measure impacts outside academia. As far as we know, surveys asking researchers on impacts outside academia are rare.

On top of surveys, a third measure, **tracking initiatives**, would be particularly valuable, especially for project staff who did a PhD as part of their FWF-funded research (doc.funds, but also in other projects). The best way to do this would be to cooperate with the universities, which would have to include a field in their data sets (students, staff) if a person is (directly or indirectly) FWF-funded. Ideally, the universities would also mark all participants in doctoral schools in their data, regardless of who funds them. Since the universities record the social security numbers of all students and employees, at least Statistics Austria can link this data with other administrative data (e.g. labour market) and make it available via the AMDC[26] for research purposes (see Statistik Austria 2022). This would allow comparisons of individual doctoral degrees without funding, doctoral schools in general with doctoral degrees that were completed as part of an FWF project or with participants in a doctoral school funded by doc-funds. Such control groups would also make it easier to determine any impact. The linkage with further register data is limited in that only individuals who remained in Austria are recorded and that the labour market data do not provide any information about the specific activities of the person, only about the industry of the employer. However, since the universities also collect email addresses at graduation, former funded scholars could also be more easily addressed for a survey if they are flagged as former scholars in the universities' databases.

Alternatively, the FWF would have to record the national social security number of all persons who are to be tracked (if this is possible under data protection law, presumably only on a voluntary basis). Statistics Austria could then link the data of the individuals with other data and make it accessible for scientific purposes via AMDC. However, ideal comparison group approaches would then no longer be possible.

On top of measurement itself, FWF could also **change the way it presents impacts**. As an example, it could include impacts on its dashboard website, creating dedicated pages e.g. for spin-offs, as NASA does (https://spinoff.nasa.gov/). Such public presentation would increase the visibility of FWF and **contribute to the awareness of researchers to report impacts to the FWF, creating a double dividend**.

[26] Austrian Micro Data Center

10. References

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  - Gerhard Streicher: economic modelling section 8.1
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  - Angelika Sauer-Malin: case studies section 7
  - Michael Ploder: survey conception
  - Lisa Schön: case studies section 7
  - Yamna Krasny: Research assistance

12. Annex

12.1. Annex for indirect use of FWF-funded publications in inventions

Table A 1: **FWF-study-clusters as obtained by clustering based on abstract and title**

Clustering based on abstract and title:

	Count of FWF-funded studies	Share of FWF-funded studies
Cluster 0: Molecular Biology	632	30%
Cluster 1: Allergy Immunotherapy and Immune Regulation	75	4%
Cluster 2: Fungal Physiology and Protein Engineering	609	29%
Cluster 3: Immunomodulation and Therapeutic Applications of Bioactive Peptides	365	17%
Cluster 4: Multidisciplinary Biomedical Research	428	20%

Table A 2: **Patent clusters as obtained by clustering based on abstract and title as well as based on IPC/CPC patent classifications**

Clustering based on abstract and title:

	Count of patents	Share of patents
Cluster 0: Innovative Biotherapeutics and Immunomodulation	1908	21%
Cluster 1: Biotechnological Therapies and Antibody Production	2042	23%
Cluster 2: Therapeutic Innovations and Molecular Insights in Cancer Treatment	2772	31%
Cluster 3: Advancements in Medical Technologies: Labeling, Electromagnetic Therapy, and Wearable Biomonitoring	1561	18%
Cluster 4: Biochemical Innovations in Immunomodulation and Peptide Synthesis	602	7%

Table A 3: Patent clustering based on IPC/CPC patent classifications:

	Count of patents	Share of patents
Cluster 0: Microbiology and Genetic Engineering	2,842	32%
Cluster 1: Material Analysis	2,548	29%
Cluster 2: Medical Procedures	145	2%
Cluster 3: Healthcare Products	2,727	31%
Cluster 4: Peptide Chemistry	433	5%
Cluster 5: Chemical Synthesis	190	2%

12.2. The regional Input-Output models ADAGIO and ASCANIO

ADAGIO, A DynAmic Global Input Output model, is part of a family of regional models with a common modelling philosophy; a philosophy which might be described as "Dynamic New Keynesian": although not „General Equilibrium" in the usual sense, this model type (which might be called „EIO" – econometric Input Output modeling – or "DYNK" – Dynamic New Keynesian) shows important aspects of equilibrium behavior. The dynamic aspect differentiates „DYNK" from the static CGE long-term equilibrium. This feature is most developed in the consumption block, where a dynamic optimization model of households is applied. But it equally applies to the equilibrium in the capital market as well as to the macroeconomic closure via a well defined path for the public deficit.

The „New Keynesian" aspect is represented by the existence of a log-run full employment equilibrium, which will not be reached in the short run, due to institutional rigidities. These rigidities include liquidity constraints for consumers (deviation from the Permanent Income hypothesis), wage bargaining (deviation from the competitive labor market) and imperfect competition.

The DYNK model is an input-output model in the sense that it is inherently a demand driven model. However, it is a much more powerful model for impact assessment than the static IO quantity and price models due to the following features:

- The price and the quantity side of the input-output model are linked in different ways, demand reacts to prices and the price of labor reacts to demand.
- Prices in the DYNK model are not identical for all users as in the IO price model, but user-specific due to its proper account of margins, taxes and subsidies, and import shares that are different for each user.
- Consumption, investment and exports (i.e. the main categories of final demand) are endogenous and not exogenous as in the IO quantity model, explained by consumer behavior (demand system), regional import demand (differentiated by intermediate and final use) and producer behavior (K,L,E,M model with M split up into domestic and imported).
- Aggregates of the column of IO coefficients (total intermediates, energy goods, value added components) are endogenous and explained in the K,L,E,M model, whereas in the IO price model they are taken as exogenous.

While the DYNK approach shows several similarities with computable general equilibrium (CGE) models, it also deviates from specifications in CGE models in some important aspects. Output is demand driven and the supply side is represented with the help of a cost function that also comprises total factor productivity (TFP). The growth of TFP is the most important long-term supply side force in that sense in the DYNK model. Contrary to some CGE applications, exports are also fully demand driven via foreign demand in the DYNK approach (demand for imports in one country corresponds to demand for exports in other countries).

Members of this family of regional models are ASCANIO (a model of the 9 Austrian provinces), FIDELIO (a model of the EU27, developed for and with the IPTS, the Institute for Prospective Technology Studies in Sevilla (see Kratena et al., 2013, 2017), and ADAGIO, a model based on on the WIOD data base [27]).

Prices are determined endogenously: based on output prices (which are determined in the production block), purchaser prices are derived by taking into account commodity taxes (and subsidies) as well as trade and transport margins. For international trade, the model takes account of the cif/fob correction by explicitly incorporating international trade and transport costs[28]).

- The production technology: for all sectors, we assume a $KLEM_mM_d$-technology, that is, we distinguish between 5 factors of production: Capital, labour, energy, domestically produced intermediates, and imported intermediates. Together, the capital and labour share make up value added; the aggregate of energy and intermediates (both domestically produced and imported) constitutes the use of intermediates. These factor shares, together with the Output Price, are modelled within a TRANSLOG framework.
- Wages are set under a Wage bargaining assumption, taking into account sectoral productivity, the general price level, and the unemployment rate. In the wage and employment block, three skill levels – low, medium, high – are distinguished.
- Consumption by households: based on the COICOP classification, we distinguish between 15 groups of consumption goods; 2 of them are treated as "durable consumption goods" (housing and vehicles), the rest as "non-durables" (food, clothing, furniture and equipment, health, communication, recreation and accommodation, financial services, electricity and heating, private transport, public transport, appliances, other consumption goods, as well as a category "durable depending", which captures the running and maintenance outlays for the durable consumption goods). Durables are modelled in a stock-flow-model, whereas the non-durables are dealt with in an AIDS-type model. The consumption block distinguishes between 5 types of households, based on their wealth (5 quintiles). Current consumption is determined by current income as well as the stock of wealth. Accumulation of wealth is modelled in an intertemporal framework.

Basic energy prices (crude oil, coal) are exogenous. All other prices are endogenous, starting from output prices (as defined in the TRANSLOG specification of sectoral production technology; this is the price at the factory door), and adding trade and transport margins (national as well as international) and commodity taxes (which, in the case of imports, can include import duties) to finally arrive at purchaser prices (the prices relevant for the respective users; even within the same region, different users can –an typically will – face different prices

[27] [1] The WIOD project compiled Supply and Use Tables for 40 countries (the EU27 plus 13 major economies from outside Europe. WIOD was conducted within the 7th EU-framework project 'WIOD: World Input-Output Database: Construction and Applications' (www.wiod.org) under Theme 8: Socio-Economic Sciences and Humanities, Grant agreement no. 225 281.

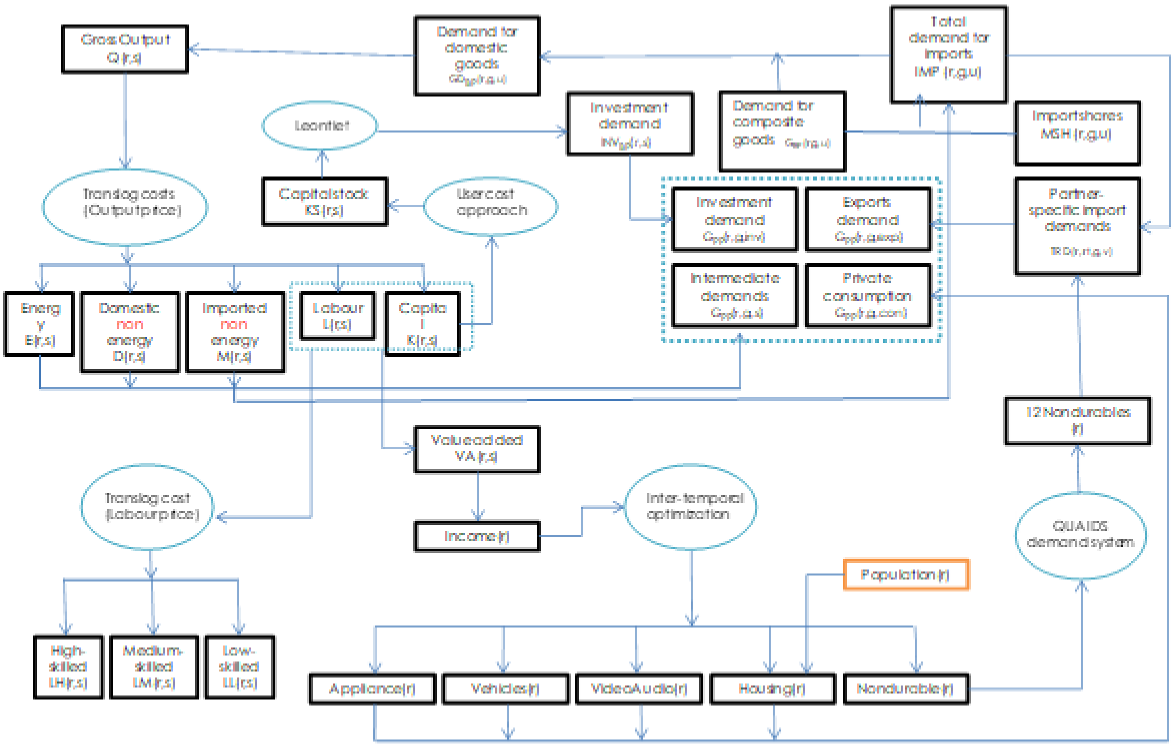
[28] [2] For details on the estimation of consistent international trade and transport margins, see Streicher and Stehrer (2014)

for the same commodity. The main reason for this is different commodity taxes (intermediate consumption mostly faces low or no commodity taxes, because these are typically defined as "value-added taxes": intermediate users can reclaim most input taxes that they have paid), but probably also different trade and transport margins.

For an extensive and in-depth treatment of all parts of the model, see Kratena/Streicher (2009) and Kratena et al (2013, 2017).

ADAGIO is first and foremost a demand-driven model: demand will be satisfied immediately, excess (or inadequate) demand is not allowed. Supply-side constraints, however, enter the scene indirectly via the price model: if an economy becomes overly tight, wages will go up, taking with them output prices – and, consequently, all prices derived from them – which are all other prices. Demand for this sector's (or economy's) products will, therefore, be dampened. In fact, and unless forced (by, for example, overly devaluing the exogenous exchange rate, or an overly lax target path for the budget deficit), conditions for overheating will not arise in the first place. In other words, ADAGIO is not a business cycle model, but rather a tool for following medium- to long-term developments.

Figure 56: **ADAGIO's model structure**



Source: Kratena et al (2013)

To sum up: ADAGIO is an Input-Output model with econometrically estimated behavioural equations. These include Translog specifications for the production side (where, based on input prices and technology, factor and investment demand as well as output prices are determined) and a (quadratic) AIDS specification for consumption demand (based on appropriate purchaser prices). Additional econometric equations determine wages and skill shares (the model distinguishes between 3 skill levels in labour demand).

ADAGIO builds on Supply-Use tables: these tables describe the economy in term of commodity flows: which sectors of the economy produce which commodities (Supply) resp. who consumes these commodities (Use. If the consumers are sectors, then this is called intermediate use: sectors need products from other sectors in their own production processes. Final consumption, on the other hand, is what might be called the "raison d'être" of economic activity: it consists of consumption by private households and government, investment by sectors, changes in inventory, and exports. Supply-Use tables (SUTs for short) are the basis for Input-Output tables (IOTs): whereas SUTs distinguish between producers and consumers on the one hand and commodities on the other, IOTs show directly the flow between sectors and users (with only implicit distinction between commodities: in SUTs, a sector can (and usually will) produce more than one commodity, which can be "traded" separately. In IOTs, it is only total flows between economic agents, without distinction by type of commodity. IOTs are usually calculated from SUTs; however, going from SUTs to IOTs involves a loss of information – therefore, it is not possible to reverse this process).

The Supply-Use tables are based on the set of regions included in the WIOD project and encompasses 43 Countries plus a Rest-of-the-World. In the current version of ADAGIO, however, the data base itself is no longer taken from WIOD, as the update of this data base was discontinued in 2017 (the most recent year in WIOD is 2014). Instead, ADAGIO is based on Supply-Use-Tables adapted from EUROSTAT (for the EU27/8) and OECD (for the remaining countries). The current base year of the model is 2017/18.

In December 2016, an update became available, now covering 43 countries (Croatia as a new member state was added; also, Switzerland and Norway were taken in, now ensuring almost complete coverage of the European continent (excluding only the eastern states apart from Russia).

Literature:

KRATENA, K., STREICHER, G., SALOTTI, S., SOMMER, M., VALDERAS JARAMILLO, J. M. (2017): FIDELIO 2: Overview and theoretical foundations of the second version of the Fully Interregional Dynamic Econometric Long-term Input-Output model for the EU-27, Publications Office of the European Union 2017

STREICHER, G. and STEHRER, R.: Whither Panama? Constructing a consistent and balanced world SUT system including international trade and transport margins; Economic Systems Research, Vol 27/2 (2015), p 213-237

12.3. Questionnaire of the survey among Principal Investigators[1]

Start page

Contribution of FWF-funded research to economic and societal impacts

The Austrian Institute of Economic Research (WIFO), the Institute for Advanced Studies (IHS) and Joanneum Research Policies conduct this online survey amongst former principle investigators of FWF-funded projects to understand the contribution of FWF funding to the economy and society. It is part of a study commissioned by the FWF. While basic research is usually undertaken without any application or use in view, it is well known that it leads – often by chance – to many applications and uses, even many years after the actual research has taken place.

In this survey, we are not "evaluating" the contribution of individual projects or researchers to such applications and uses. We want to find out to what extent FWF funding as a whole generates impacts outside of academia in addition to the gain in scientific knowledge.

To avoid double counting, only former principle investigators of already completed FWF projects are invited to take part in the survey; heads of subgroups (e.g. SFBs) are not addressed separately.

Your participation in this first-of-its-kind survey will provide invaluable insights into the contribution of FWF-funded research to any applications and uses. Researchers, policy-makers and the wider public will gain a much more comprehensive understanding of the benefits of funding basic research.

Participation in this survey is voluntary.

- ☐ *I hereby confirm that I have read and understood the privacy statement. I authorise the project consortium (WIFO, IHS, JOANNEUM) to process and use my data in this questionnaire for scientific purposes as explained in the privacy statement*.

[1] The layout of the questionnaire presented here differs from the original online layout, e.g. in terms of font, size, line and page breaks. Filter guides are shown here but are automatically (hidden) online.

Intro Page

For this survey, we define research impacts **as direct or indirect**, intended or unintended applications or uses of fundamental research **outside of academia**. This also includes the training of researchers who have left academia.

The survey asks about the contributions of FWF-funded research completed between 2009 and 2022 to the following two types of impact:

SECTION A **Economic impact:** an effect on, change or benefit to the economy

SECTION B **Societal impact:** an effect on, change or benefit to society, art & culture, public policy or services, health, the environment or quality of life beyond academia

According to our information, you have **led** the following FWF-funded project(s) that **ended between 2009 and 2022**:

Information on your FWF funded projects:
According to our information, you have led the following projects since 2009:

- Project number, Title, Start, End (import from FWF data)
- Project number, Title, Start, End (import from FWF data)
- Project number, Title, Start, End (import from FWF data)
- …..

This questionnaire refers to all of these projects.
We now ask first about the economic impact, and in the second part of the questionnaire about the societal impact.

Section A – Economic impacts

The following questions cover possible contributions of your FWF-funded research to economic impacts. Please consider both direct and indirect impacts, e.g. via further applied research by others or other activities using your research to develop applications and uses (regardless who funded them).

1. Has your FWF-funded research made a relevant direct or indirect contribution to any of the following economic impacts?

	Yes, by my research team or external users of my research	Not yet, but there are ongoing activities to generate such an impact	No	Don't know
Patent on an invention	O	O	O	O
Licence, e.g. to use research result or patent (not software licence)	O	O	O	O
New or improved production processes or technologies (incl. management practices) used in existing firm or organisation	O	O	O	O
New or improved products or services (e.g. research tools, new materials, software, medical products) sold by existing firm or organisation	O	O	O	O
New firm or start-up	O	O	O	O
Other economic impact outside academia (please specify) ______________	O	O	O	O

Filter: Only "Not yet, but there are ongoing activities to generate such an impact" in the Q1

2. How close to the final application or use do you think the follow-up activities are?
In case of more than one impact per category, please think about the in your view most important impact.

Filter: Only those selected before are displayed	Very far				Very close	Don't know
Patent on an invention	O	O	O	O	O	O
Licence, e.g. to use research result or patent (not software licence)	O	O	O	O	O	O
New or improved production processes or technologies (incl. management practices) used in existing firm or organisation	O	O	O	O	O	O
New or improved products or services (e.g. research tools, new materials, software, medical products) sold by existing firm or organisation	O	O	O	O	O	O
New firm or start-up	O	O	O	O	O	O
Other economic impact outside academia (as specified above)	O	O	O	O	O	O

Filter: If any economic impact and >1 project:

3. Which of the FWF-funded projects you have led and that ended since 2009 has contributed the most to the economic impact you have indicated?
According to our information, you have led the following project(s) that ended since 2009:

- o Project name, duration (import from FWF data)
- o Project number, Title, Start, End (import from FWF data)
- o Project number, Title, Start, End (import from FWF data)
- o …

Filter: If any economic impact

4. Do you happen to know roughly how many years it took from the first research stages to the commercial impact(s)?

If you indicate more than one impact per category, please think of the most important impact in your opinion.

Filter: Only those selected before are displayed	Approx. years
Patent on an invention	___
Licence, e.g. to use research result or patent (not software licence)	___
New or improved production processes or technologies (incl. management practices) used in existing firm or organisation	___
New or improved products or services (e.g. research tools, new materials, software, medical products) sold by existing firm or organisation	___
New firm or start-up	___
Other economic impact outside academia (as specified above)	___

Filter: If any economic impact

5. How has the FWF-funded research you led become relevant for an economic impact?

Multiple answers possible.

- ☐ Own efforts to develop and commercialise knowledge
- ☐ Collaborative research and development with firms
- ☐ Formal or informal consulting with firms
- ☐ Licensing of my research results by external users
- ☐ My research results became known to external users (e.g. via a publication or conference)
- ☐ Other (please specify) ______________________________
- ☐ Don't know

Details per economic impact

Filter: If patents as economic impact was selected

Patents

6. To how many patents has your FWF-funded research contributed?

- o 1
- o 2
- o 3
- o 4
- o 5
- o 6
- o 7
- o 8
- o 9
- o 10
- o >10

7. If known, please provide further details on patents your FWF funded research contributed to

Filter: As many as indicated above (max 10 patents)

8. [Details for the] 1. Patent:

Patent Status:

- Filed at please specify the patent office ____
- Granted by please specify the patent office ____

Patent number: ____

Inventor(s): ____

Applicant organisation and country: ____

URL related to this patent (if any):

____

9. Has this patent been sold and transferred (not licensed) to another organisation?

- Yes, to an organisation in Austria
- Yes, to an organisation abroad
- No

10. [Details for the] 2. Patent:

... depending on the selected number of patents, the same was displayed for each patent.

11. Please roughly estimate the commercial revenue from this patent for…

1. Patent:

- 0 €
- < 100.000 €
- 100.000 – < 1 Mio €
- 1 Mio € – < 10 Mio €
- >= 10 Mio €
- Don't know

2. Patent:

... depending on the selected number of patents, the same was displayed for each patent.

Filter: If licences as economic impact was selected

Licences

12. To how many licences (e.g. for the use of research results or patents, not software licences) has your FWF-funded research contributed?

- 1
- 2
- 3
- 4
- 5
- >5

13. If known, please provide further details on licences your FWF-funded research contributed to.

Filter: As many as indicated above (max 5 licences)

14. [Details for the] 1. Licence:

Licence holder, country: ____
URL related to this licence (if any): __________________________________

13. What is being licensed?

- a patent
- other, namely: ____

14. [Details for the] 2. Licence:

... depending on the selected number of licences, the same was displayed for each licence.

15. Please roughly estimate the commercial revenue 2022 from this licence for…

1. Licence

	… firm(s) located in Austria	… firm(s) located abroad
0€	O	O
< 100.000€	O	O
100.000 – < 1 Mio €	O	O
1 Mio € – <10 Mio €	O	O
>= 10 Mio €	O	O
Don't know	O	O

2. Licence

... depending on the selected number of licences, the same was displayed for each licence.

Filter: If improved products as economic impact was selected

New or improved products

16. To how many new or improved products has your FWF-funded research contributed?

- o 1
- o 2
- o 3
- o 4
- o 5
- o >5

17. If known, please provide further details on the product(s) your FWF-funded research contributed to.

Filter: As many as indicated above (max 5)

18. [Details for the] 1. Product:

Product name: ______________________________

Please provide a brief description of the product: ______________________________

URL related to this product (if any):

____

Name and country of firm producing this product: ______________________________

19. [Details for the] 2. Product:

... depending on the selected number of products, the same was displayed for each product.

20. Please roughly estimate the commercial revenue 2022 from this new or improved product for…

1. Product

	… firm(s) located in Austria	… firm(s) located abroad
0€	O	O
< 100.000€	O	O
100.000 – < 1 Mio €	O	O
1 Mio € – <10 Mio €	O	O
>= 10 Mio €	O	O
Don't know	O	O

2. Product

... depending on the selected number of products, the same was displayed for each product.

Filter: If improved production process as economic impact was selected

New or improved production process

21. To how many new or improved production processes has your FWF-funded research contributed?

- o 1
- o 2
- o 3
- o 4
- o 5
- o >5

22. If known, please provide further details on this new or improved productions process(es) your FWF funded research contributed to.

Filter: As many as indicated above (max 5)

23. [Details for the] 1. New or improved production process

Please describe briefly this new or improved production process and its added value, e.g. lower cost production, higher quality production, more environmentally friendly production:

____

24. Where is this new or improved production process used? Multiple answers possible.

- ☐ In Austria
- ☐ In other EU countries
- ☐ In non-EU countries

Example(s) of users applying this production process: ______________________

URL related to this product process (if any): ________________________________

25. [Details for the] 2. New or improved production process

... depending on the selected number of production processes, the same was displayed for each production process.

26. Please roughly estimate the commercial revenue 2022 from this new or improved product for…

1. Production process

	… firm(s) located in Austria	… firm(s) located abroad
0€	O	O
< 100.000€	O	O
100.000 – < 1 Mio €	O	O
1 Mio € – <10 Mio €	O	O
>= 10 Mio €	O	O
Don't know	O	O

2. Production process

... depending on the selected number of production processes, the same was displayed for each production process.

Filter: If firm/start-up as economic impact was selected

New Firms or Start-Ups

27. To how many new firms or start-ups has your FWF-funded research contributed?

- o 1
- o 2
- o 3
- o 4
- o 5
- o >5

28. If known, please provide further details on the new or improved medical products/drugs your FWF funded research contributed to.

Filter: As many as indicated above (max 5)

29. [Details for the] 1. New firm or start-up:

Name of the firm/start-up: ________________________________

What aims the new firm/start to sell: ________________________________

What was the contribution of your FWF-funded research: ________________________

URL of the new firm/start-up (if any): ________________________________

30. Status of the new firm/start-up:

- o preparing for market entry
- o has successfully entered the market
- o has exited the market

31. Where is the headquarter of the new firm/start-up located?

- o in Austria
- o in another EU country
- o in a non-EU country

32. [Details for the] 2. New firm or start-up:

... depending on the selected number of firms/start-ups, the same was displayed for each firm/start-up.

1. New firm or start-up:

33. Approximate number of employees as of 31.12.2022 ca. __________ employees

34. Please roughly estimate the commercial revenue 2022 from this firm/start-up if…

	… firm(s) located in Austria	… firm(s) located abroad
0€	O	O
< 100.000€	O	O
100.000 – < 1 Mio €	O	O
1 Mio € – <10 Mio €	O	O
>= 10 Mio €	O	O
Don't know	O	O

2. Firm/start-up

... depending on the selected number of firms/start-ups, the same was displayed for each firm/start-up.

Filter: If 'other' economic impact was selected

Other economic impact

37. To how many other economic impacts has your FWF-funded research contributed?

- O 1
- O 2
- O 3
- O 4
- O 5
- O >5

38. If known, please provide further details on the other economic impact your FWF funded research contributed to.

Filter: As many as indicated above (max 5)

39. [Details for the] 1. Other economic impact:

Please describe this other economic impact briefly: ____

URL related to this other economic impact (if any): ________________________________

40. [Details for the] 2. Other economic impact:

... depending on the selected number of other economic impacts, the same was displayed for each other economic impact.

1. Other economic impact:

41. Please roughly estimate the commercial revenue 2022 from this other economic impact for…

	… firm(s) located in Austria	… firm(s) located abroad
0€	O	O
< 100.000€	O	O
100.000 – < 1 Mio €	O	O
1 Mio € – <10 Mio €	O	O
>= 10 Mio €	O	O
Don't know	O	O

2. Other economic impact

... depending on the selected number of other economic impacts, the same was displayed for each other economic impact.

End of Section A – Economic Impacts

Filter: If any economic impact

42. Did you perceive any barriers to develop economic applications and uses of your research results?

Multiple answers possible.

- ☐ Yes, it was difficult to find necessary cooperation partners
- ☐ Yes, it was difficult to find necessary funding
- ☐ Yes, it was difficult to find the time necessary given my other commitments
- ☐ Yes, I was confronted with other barriers, please specify ______________________________
- ☐ No, the applications or uses were developed by someone else using my research
- ☐ No, I did not perceive any barriers

Filter: Without any economic impact

43. Did you perceive opportunities to develop economic applications and uses of your research results, but could not follow up due to barriers?

Multiple answers possible.

- ☐ Yes, my research institution did not sufficiently support developing applications
- ☐ Yes, I did not receive necessary funding to follow up
- ☐ Yes, the time necessary would have been too much of a distraction from academic research
- ☐ Yes, I was confronted with other barriers, please specify ______________________________
- ☐ No, I am not interested in developing applications
- ☐ No, so far, I simply have not perceived potential applications

Filter: If any economic impact

44. Does your research institution/university have a regular screening for potentially patentable or licencable findings?

- o Yes
- o No
- o Don't know

Filter: If any economic impact

45. If you would like to add anything about the economic impact of your FWF-funded research, please indicate this here:

____

Section B – Societal impacts

The following questions cover possible contributions of your FWF-funded research to societal impacts – i.e. uses and applications <u>outside of academia</u> which change or provide a benefit to society. You may enter economic impacts again to describe their societal impacts – e.g. a medical product does not just generate turnover but also has an impact on health. Please consider both <u>direct and indirect</u> impacts, e.g. via further applied research by others or other activities using your research to develop applications and uses (regardless who funded them).

46. Has your FWF-funded research made a relevant contribution to any of the following societal impacts?

For each dimension below, please consider the most important impact.

	Yes, by my research team or external users of my research	Not yet, but there are ongoing activities to generate such an impact	No	Don't know
Environmental improvements (e.g. protective measures against severe weather disasters, reduction of CO2, increased energy efficiency, habitat protection of endangered species, …)	○	○	○	○
Health improvements (e.g. medical interventions such as therapeutic interventions and diagnostics, health benefits of new drugs, …)	○	○	○	○
Changes of regulations (laws, decrees, norms, …)	○	○	○	○
Contribution to cultural heritage	○	○	○	○
Improved defence/security of the population	○	○	○	○
Contributions to media beyond specialist audiences (print, TV, podcast, film, blog, …)	○	○	○	○
Other societal impact outside academia (please specify) __________	○	○	○	○

Filter: Only “Not yet, but there are ongoing activities to generate such an impact“ in Q46

47. How close to the final societal impact do you think the follow-up activities are?
In case of more than one impact per category, please think about the in your view most important impact.

Filter: Only those selected before are displayed	Very far				Very close	Don't know
Environmental improvements (e.g. protective measures against severe weather disasters, reduction of CO2, increased energy efficiency, habitat protection of endangered species, …)	○	○	○	○	○	○
Health improvements (e.g. medical interventions such as therapeutic interventions and diagnostics, health benefits of new drugs, …)	○	○	○	○	○	○
Changes of regulations (laws, decrees, norms, …)	○	○	○	○	○	○
Contribution to cultural heritage	○	○	○	○	○	○
Improved defence/security of the population	○	○	○	○	○	○
Contributions to media beyond specialist audiences (print, TV, podcast, film, blog, …)	○	○	○	○	○	○
Other societal impact outside academia (please specify) ___________	○	○	○	○	○	○

Filter: If any economic impact and >1 project:

48. Which of the FWF-funded projects you have led and that ended since 2009 made the most significant contribution to the societal impacts you indicated?
According to our information, you have led the following project(s) that ended since 2009:

- o Project name, Title, Start, End (import from FWF data)
- o Project number, Title, Start, End (import from FWF data)
- o Project number, Title, Start, End (import from FWF data)
- o …

Filter: If any societal impact

49. What was/is the geographical scope of the improvement or change in the area of …?

Filter: Only those selected before are displayed	Predominantly to Austria	Predominantly to EU/EFTA countries	Global	Don't know
Environmental improvements	O	O	O	O
Health improvements	O	O	O	O
Changes of regulations	O	O	O	O
Contribution to cultural heritage	O	O	O	O
Improved defence / security of the population	O	O	O	O
Contributions to media beyond specialist audiences	O	O	O	O
Other societal impact outside academia (specified above)	O	O	O	O

Filter: If any societal impact

50. Do you happen to know roughly how many years it took from the first relevant research results to the societal impact (regardless of when FWF funding happened)?

In case of more than one impact per category, please think about the in your view most important impact.

Filter: Only those selected before are displayed	Approx. years
Environmental improvements	___
Health improvements	___
Changes of regulations	___
Contribution to cultural heritage	___
Improved defence / security of the population	___
Contributions to media beyond specialist audiences	___
Other societal impact outside academia (specified above)	___

Filter: If environmental improvement

51. Environmental improvement:

Please briefly describe this impact, including any numeric measures if available (e.g. reduction in tons of CO_2)

____
____
____

Filter: If health improvement

52. Health improvement:

Please briefly describe this impact, including any numeric measures if available (e.g. gain in quality adjusted life years)

____
____
____

Filter:Iif changes of regulation

53. Changes of regulation:

Please briefly describe this impact, including any numeric measures if available.

____

____

____

Filter: If cultural heritage

54. Contribution to cultural heritage:

Please briefly describe this impact, including any numeric measures if available.

____

____

____

Filter: If improved defence/security

55. Improved defence/security:

Please briefly describe this impact, including any numeric measures if available.

____

____

____

Filter: If contributions to media

56. Contributions to media:

Please briefly describe this impact, including any numeric measures if available.

____

____

____

Filter: If other societal impact

57. Other societal impact:

Please briefly describe this impact, including any numeric measures if available.

____

____

____

Filter: If any societal impact

58. How has your FWF-funded research become relevant for a societal impact?

Multiple answers possible.

- ☐ Own efforts to develop and apply knowledge
- ☐ Collaborative research and development with non-academic organisations
- ☐ Formal or informal consulting with non-academic organisations such as firms, public administration, NGOs, hospitals, …
- ☐ My research results became known to using organisation (e.g. via publication or conference)
- ☐ My research results became used via an open-source platform (e.g., GitHub, Bitbucket etc.)
- ☐ Other (please specify) ____

Filter: If any societal impact

59. Did you perceive any barriers to generate societal impact of your research results?

Multiple answers possible.

- ☐ Yes, it was difficult to find necessary cooperation partners
- ☐ Yes, it was difficult to find necessary funding
- ☐ Yes, it was difficult to find the time necessary given my other commitments
- ☐ Yes, I was confronted with other barriers, please specify ______________________________
- ☐ No, the societal impact was generated by someone else using my research
- ☐ No, I did not perceive any barriers

Filter: If no societal impact

60. Did you perceive opportunities to generate societal impact of your research results, but could not follow up due to barriers?

Multiple answers possible.

- ☐ Yes, my research institution did not sufficiently support generating societal impact
- ☐ Yes, I did not receive necessary funding to follow up
- ☐ Yes, the time necessary would have been too much of a distraction from academic research
- ☐ Yes, I was confronted with other barriers, please specify ______________________________
- ☐ No, I am not interested in generating societal impact
- ☐ No, so far, I simply have not perceived potential societal impact

Filter: If any societal impact

61. If you would like to add anything about the <u>societal impact</u> of your FWF-funded research, please indicate this here:

Section C – Human Resources

In this final section, we ask about the project team members of the FWF-funded projects you led. Please only consider projects covered in this survey (completed between 2009 and 2022).

62. Please roughly estimate to how many academic degrees your FWF-funded projects have contributed to <u>in your own research group:</u>

Please do not consider doctoral colleges in this question.

approx. (#) ___ Master
approx. (#) ___ Dr/PhD
approx. (#) ___ Habilitation (or equivalent)

- o None
- o Don't know

63. Are any of your former FWF-funded project team members currently working…

	Yes, in Austria	Yes, abroad	No	Don't know
… for your research group	☐	☐	☐	☐
… in another research group at the institution where the project was carried out	☐	☐	☐	☐
… at another university/research institution	☐	☐	☐	☐
… at a for-profit company (start-ups, …)	☐	☐	☐	☐
… at a non-profit organisation (NGO, …)	☐	☐	☐	☐
… in public administration	☐	☐	☐	☐
other (unemployed …)	☐	☐	☐	☐

Filter: If anywhere "Yes, in Austria" is checked

64. Please roughly estimate the share of your former FWF-funded project team members currently working <u>in Austria</u>…

Filter: only displayed if selected above	Approx.
… your research group	___%
… in another research group at the institution where the project was carried out	___%
… at another university/research institution in Austria	___%
… at a for-profit company (start-ups, …)	___%
at a non-profit organisation (NGO, ….)	___%
… in public administration	___%
other (unemployed...)	___%

Further Funding

65. Based on the results of the FWF-funded projects you led, were you able to obtain any of the following types of third-party funding?

Multiple answers possible.

- ☐ Yes, grants by the European Commission and its related bodies
- ☐ Grants by international publicly funded bodies (other than the EC)
- ☐ Yes, research by national or international private third party funding sources (e.g. firms, foundations)
- ☐ None of the above-mentioned sources

Filter If any third-party funding income

66. Please estimate the amount of all the third-party funding incomes you indicated (share for your research team) based on your FWF-funded projects since <u>2009</u>:

Approximately ____________€

Closing Question

67. In general, how would you rate the overall economic and societal impacts of your FWF-funded project(s) so far?

Please consider both direct and indirect impacts outside of academia – via further research by others or other activities using your research.

	So far, no or highly uncertain impact				A very high impact	Don't know
Economic impacts	O	O	O	O	O	O
Societal impacts	O	O	O	O	O	O

Feedback

68. We are aware that a questionnaire cannot capture the impact of research in detail for every project.

If you have any additions, comments or critical remarks regarding the impact of your research (or the questionnaire), please let us know here!

____

____

Thank you very much for your valuable time!

The results of this study will be published on the FWF website (expected in the second half of 2024).

If you would like to be informed about the publication, please enter an email here: ____________________