GLOBAL YOUNG ACADEMY

Back to basics: researchers' perception on the global state of funding for fundamental research

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Brief overview

It is not always easy to see the importance of science that is conducted without a clear product or applied problem in mind, and yet, discoveries from such fundamental or 'blue sky' research have transformed society and greatly enriched the human experience. Society is faced with problems that threaten our very existence and yet the benefits of science are being challenged. How should fundamental research be justified at such a time? To address this question, we need greater public and governmental understanding of how fundamental research — the pursuit of knowledge and understanding of humanity or the natural world without consideration of an end product — forms the crucial foundation of innovation. Typically, applied research and its outcomes build on decades of much less visible fundamental and use-inspired research findings, much like the visible portion of an iceberg rests upon the massive foundation beneath the surface.

The United Nations (UN) General Assembly has proclaimed 2022 as the International Year of Basic Sciences for Sustainable Development. This call recognises that fundamental research is essential for implementing the Agenda 2030 with its 17 Sustainable Development Goals (SDGs).

This report presents results from an international online survey demonstrating that researchers around the world perceive a decrease in support for fundamental science in the context of increased support for applied research. As a result, their decisions about the direction of research programmes have changed. Here, we highlight how researchers see changes in patterns of funding and research directions over a decade, and the impact this may have on innovation and our future generations of scientists.

Our respondents come from 64 different countries. Although heterogeneity in a sample can sometimes be a challenge, in this case, it provides unique insights into the different factors that influence decisions about the type of research we engage in. Despite distinct experiences, backgrounds, and cultural reference points, clear messages come through regarding the emphasis and value of fundamental research. The ability to create innovation and build capacity in the future requires greater investment in fundamental research and a wider appreciation of the crucial role it plays in our capacity to respond to global challenges.

Acknowledgements

The development of this report benefited greatly from discussions and input from other members of the Global Young Academy (GYA) working group on The Importance of Fundamental Research. Some members of our group developed an in-depth Canada-specific report (1). The current report focuses on survey data from our global sample but draws heavily on the template of the Canadian report. In particular, we have included quotes and infographics developed during this first phase of the project and previously used in Baum, et al. (1). We would also like to recognise the efforts of members and alumni of the Global Young Academy to disseminate the survey, which enabled us to get responses from 64 countries.

We appreciate the support of our research assistants: Megan Dodd, Kristina Tietjen, and Sarah Friesen for assisting the design and dissemination of the online survey, and supporting analyses and plotting of the survey data; Emily Bent, Wo Su Zhang, Margery Pardey, and Corrine Giorgetti for communicating the online survey to researchers around the world and responding to their questions about the work, and Mirko Consiglio for assistance with final figures. We also extend our thanks to fellow GYA alumnus Kai Chan and to Gerald Singh (both University of British Columbia) for advice about designing effective online surveys, and to Kate Campbell for producing four infographics related to this project as well as the graphics in the introductory section illustrating why fundamental research is important. We acknowledge the help of Amir Gat, Head of Budgeting for Research at the Council for Higher Education, Israel.

We extend our sincere thanks to Anna-Maria Gramatté for her ongoing outstanding support of our working group activities, and the entire Global Young Academy Office team for their work supporting the academy members.

We greatly appreciate the time given by members of the global research community, who engaged enthusiastically with our online survey, providing us with these insights into perceptions of a wide range of researchers on fundamental research support and illuminating the importance of this topic. Finally, we gratefully acknowledge the financial support of the Global Young Academy.

1. Introduction: fundamental research is the basis of innovation

Scientific discovery forms the basis of much of our daily lives. What is less obvious is that the numerous applications that directly benefit society, from medical imaging, cancer treatment, vaccine development, through to water purification/sanitization and global positioning systems, are primarily based on a crucial foundation of fundamental or 'blue sky' research.

Although types of research can be classified in different ways, a common distinction reflects the degree to which the project aims to increase understanding and achieve practical outcomes. In this classification system, there are three major research categories that can lead to important advances (**Figure 1**):

- ***Fundamental research*** is a study in the pursuit of knowledge and understanding of humanity or the natural world. It is executed without consideration of an end product, and instead asks questions, such as how and why proteins fold and make complex shapes that affect chemical reactions in living organisms, or how our brains work. Fundamental research is also referred to as basic research, blue-sky research, or curiosity-driven research.
- ***Use-inspired research*** strives to understand phenomena and processes required to address long-term societal challenges. For example, research into chemical interactions inspired by challenges of unclean water.
- ***Applied research*** seeks to use existing knowledge – discovered through fundamental or use-inspired research – to develop practical solutions to specific challenges, such as the development of an antiviral medication that targets a particular protein in a virus.

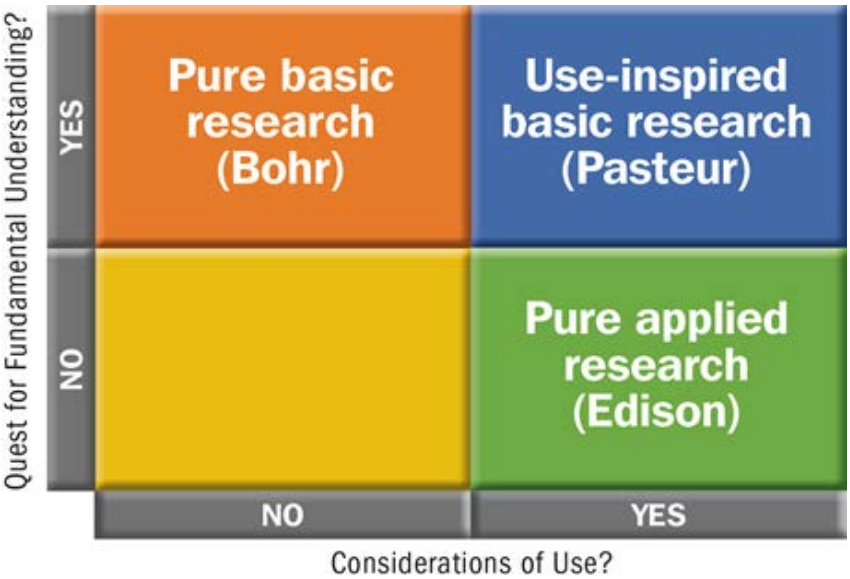


Figure 1. Donald Stokes' Quadrant Model of Scientific Research demonstrates the differences between research that is clearly motivated by curiosity (exemplified by Bohr's quest to understand the structure of the atom) and strongly applied research (represented by Edison's determination to develop commercial electric lighting) (2). Stokes introduced the term 'Pasteur's quadrant' to represent use-inspired research, based on Pasteur's commitment to both understand microbiological processes, and control their effects on human lives and products (2).Reprinted with permission from (1).

There is a flow of information between research in these different categories, with knowledge from one sector informing and inspiring advances in others. Some researchers work purely on questions that fit in

one of these categories, whereas many others have a combination of research foci in their work. Applied research with direct practical benefits for society cannot happen in isolation. Typically, applied research and its outcomes build on decades of fundamental and use-inspired research findings. In addition, there are also situations where fundamental research discoveries have serendipitously resulted in immediate applied outcomes. Although each research category is crucial, there is uneven visibility to the public in their importance. The explicit goals of applied research to achieve tangible economic or social benefits make the argument for public and political support apparent whereas it is often harder to demonstrate the crucial role that fundamental research plays in achieving these outcomes.

We previously published a report on the Canadian landscape of research funding in which we articulated four main justifications for the importance of fundamental research (1). Here, we reiterate these as the underpinnings of this report.

First, fundamental research is the foundation of innovation. It forms the necessary base of a pyramid that has applied research at the top. If funds are directed exclusively to applied research, then a law of diminishing returns will eventually apply. As the foundation erodes, we will see a decrease in new scientific applications, technologies, and products. Baum, et al. (1) presented a compelling case for this, based on changes in Canadian research funding for different categories of research.

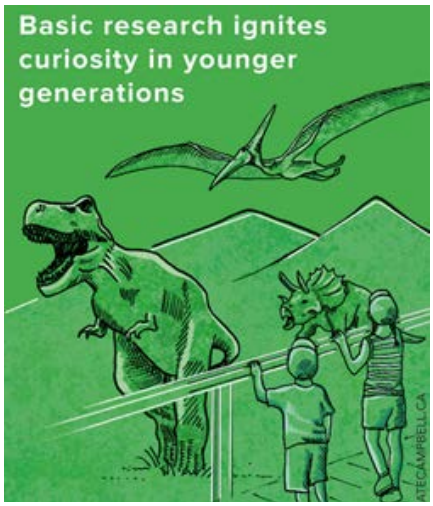
Applied research and fundamental research are both important. These research sectors should not be in competition. Instead, they are mutually dependent, with applied research drawing upon new theories and inspiration from fundamental research, while innovative tools emerging from applied work may enable discoveries in the realm of fundamental research. Support for only one kind of research is less effective than funding a range of research. If, due to a lack of resources, applied science is prioritised at the cost of fundamental research, there are long-term consequences for innovation.

"To equate the useful with the applied is to display the same level of understanding as the child who thinks that the hands are the most important parts of a watch because they are the ones that tell the time."
(J.A. Kay and C.H.L. Smith, Economist and Physicist at Oxford University, 1985)

Second, although the original goal of fundamental research is to advance knowledge without a direct end product in mind, there are many demonstrations that fundamental research can lead to ground-breaking practical applications. For example, fundamental chemistry research on Nuclear Magnetic Resonance (NMR) spectroscopy led to the development of Magnetic Resonance Imaging (MRI) and functional MRI, now widely used for both clinical imaging and research (3). Similarly, our ability to accurately navigate using GPS readings relies on Einstein's theories of special and general relativity (4). Lasers developed in fundamental research programmes are used for applications ranging from film projectors to medical diagnosis and surgery (5).

Current applied research foundations are based on past investment in fundamental research. Developments in solar energy and other renewable energy sources are critically dependent on fundamental discoveries in materials science (6) and fluid dynamics (7); fundamental research on the distribution of contaminants in the environment identified plastic microbeads in many aquatic ecosystems, highlighting this critical problem (8).
These advances each build on decades of fundamental science, from which applied outcomes are numerous, wide-reaching, largely unexpected and even unforeseeable.

"To feed applied science by starving basic science is like economising on the foundations of a building so that it may be built higher. It is only a matter of time before the whole edifice crumbles."
(George Porter, Nobel Laureate, 1986)



Third, curiosity is crucial for innovation, and fundamental research inspires our next generation to engage in critical, creative and innovative thinking (9, 10). Children start out curious about why the world is the way it is, and for many researchers, developing and answering curiosity-driven questions creates a much greater dedication to research than whether it has an immediate application (11). That such people choose research careers ensures there is a firm basis for future innovation. This, in turn, requires confidence in the availability and adequacy of fundamental research funding. A perceived devaluation of fundamental research may lead to a drop in new researchers engaging in careers focused on fundamental research and potentially in scientific careers in general. This would undermine the potential for all three categories of research to progress (12). Strong funding support and a high value on fundamental research gives nations the edge in inspiring, attracting and developing future generations of scientists (13). In sum, fundamental research inspires the next generation and provides essential training for their future careers, which can balance fundamental, use-inspired, and applied research endeavours (12).

Fourth, we need fundamental research to increase our understanding of the universe and our place within it. This creates a perpetual momentum, expanding both knowledge and the eagerness to learn more. The fuel for this positive cycle is fundamental science.

The many innovations based on findings that were motivated by pure curiosity demonstrate the importance of satisfying this basic human need for knowledge. As Marie Skłodowska Curie, who led the discovery of radium, which still forms the basis for life-saving therapies, said, "this is a proof that scientific work must not be considered from the point of view of the direct usefulness of it. It must be done for

itself, for the beauty of science" (14).
The United Nations has proclaimed 2022 as the International year of International Year of Basic Sciences for Sustainable Development. This is a clear recognition of the important role fundamental research holds in finding solutions to global problems.

The **objective** of this report is to present the findings of a global survey exploring the perceptions of a diverse group of researchers about the status of funding and value placed on fundamental research. This includes voices from low- and middle-income countries that are typically not heard. The perceived value placed on fundamental research in different contexts around the world will determine our future innovation, in that it influences the direction of research laboratories, the maintenance and attraction of researchers to fundamental science, and our collective potential for the future.

2. What researchers say about the global state of fundamental research

2.1 Querying the international research community

We conducted an online survey entitled 'Perceptions of Funding for Fundamental Research' between May 2016 and May 2017. This survey measured researchers' perceptions of funding trends in the country where they work, and their outlook on the research funding landscape for fundamental and applied research. The survey was open to researchers from all disciplines across the numerate and natural sciences, social sciences, humanities, engineering, medicine, as well as of all career stages, with the proviso that participants had to have some experience in applying for research funding, which usually meant that they were at least at the post-doctoral stage of their career.

The survey gathered detailed information to address questions in five major areas:

1) **Research focus:**
   Has the type of research (fundamental, use-inspired, applied) that researchers conduct changed over the past decade? If so, why, and what are researchers' views on these changes?
2) **Government priorities:**
   How important do researchers believe fundamental research is to their government, and do they believe any type of research has become a higher priority in the past decade?
3) **Grant success rates:**
   Have perceived success rates for fundamental, use-inspired, or applied research grants changed over the past decade?
4) **Practical applications and external partnerships:**
   What is the perceived value of suggesting practical applications and including external partnerships to grant success? Has the level of external partnerships changed for researchers over the past decade? If so, why, and what are researchers' views on these changes?
5) **Future research funding:**
   Do researchers believe that available funding for fundamental, use-inspired, or applied research will change in the next five years, and what impact will these funding changes have on the likelihood of the next generation to pursue careers in research?

In total, 2,918 researchers from 64 different countries (33 low- and middle-income (LMI) and 31 high-income (HI) countries[1]) completed the survey. Of these, 1,303 participants were from Canada, reflecting the strength of our network for dissemination in this region. Given this distribution, we therefore prepared an initial report that focused specifically on Canada (1). For this report, to avoid the over-representation of views from Canada (which have already been analysed in full, see (1)), we randomly selected 350 Canadian respondents for inclusion, which is the same number of responses as the next most prevalent country (Australia) (Figure 2.1A). However, our reach was also global, with ~14% of responses coming from researchers in low- and middle-income countries that are often silent on questions of fundamental research. We note, however, that the distribution of our respondents was not even, with greater representation of Australia and Canada than other regions of similar wealth, including Europe and the USA, and we had much lower response rates from low- and middle-income countries in general.

Our respondents represented many different disciplines: 54% of the LMI and 48% of the HI responses came from either the physical sciences, with the remaining responses spread amongst the medical and life sciences (24% LMI and 25% HI), engineering (8% LMI and 9% HI), social sciences and humanities (4% LMI and 11% HI), and interdisciplinary research (8% LMI and 7% HI; Figure 2.1B)[2].

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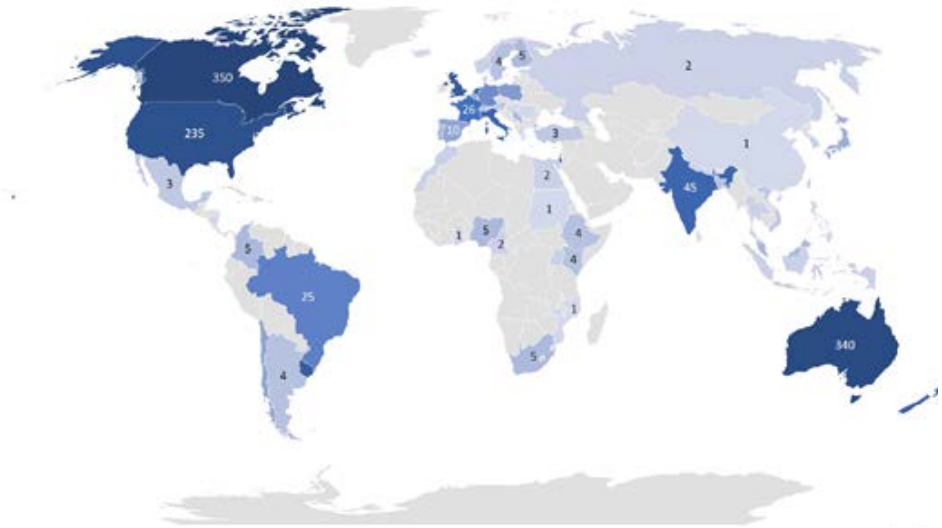

Figure 2.1 A) Number of respondents by country.

1 Following the Development Assistance Committee (DAC) list of official development assistance (ODA) recipients for 2014–2017 from the Organisation for Economic Co-operation and Development (OECD).
2 Note some HI/LMI percentages (throughout) do not add up exactly to 100% due to rounding.

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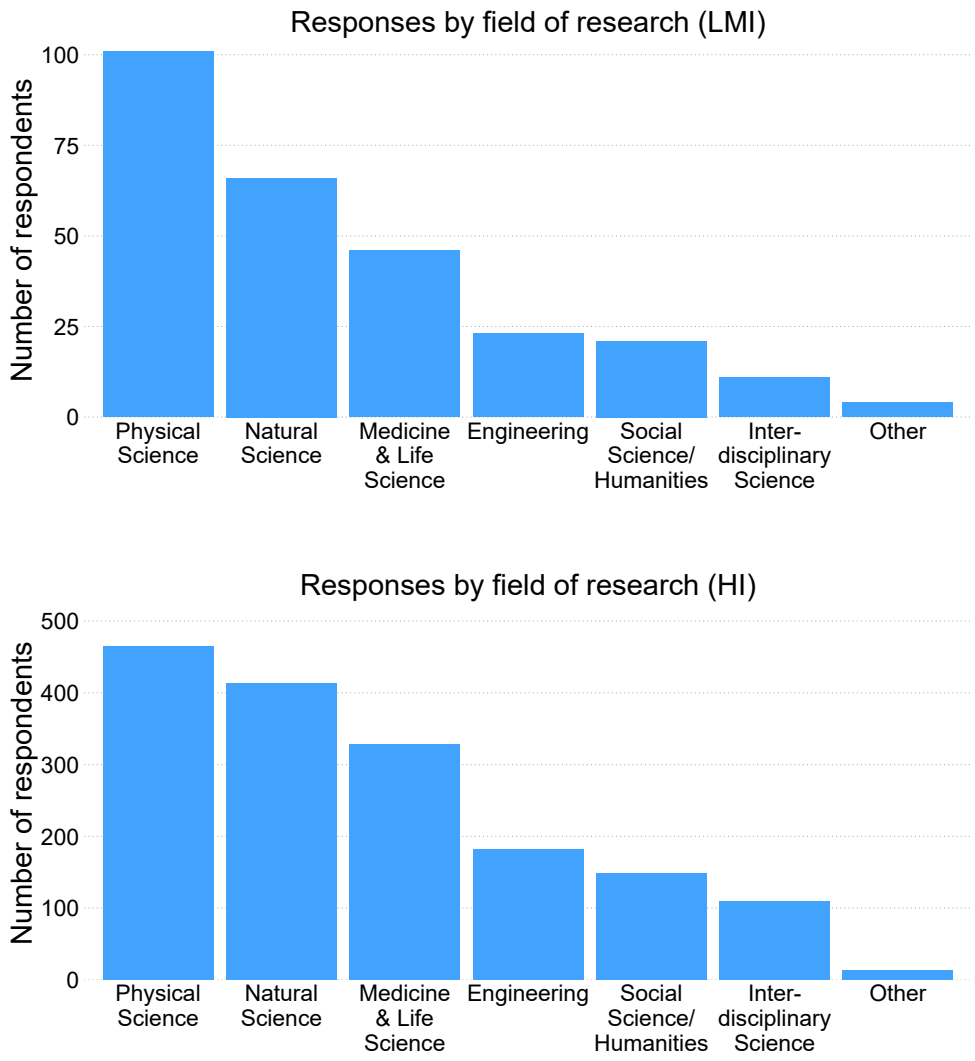

Figure 2.1 B) Number of respondents by field of research (top: low-middle-income countries (LMI); bottom: high-income countries (HI); Note the differences in y-axis scales).

The vast majority of respondents (92% LMI and 91% HI) were senior academics. Researchers were categorised by career stage, with senior researchers having more than ten years' experience applying for research grants since completion of their PhD (51% LMI and 62% HI), and early-career academics being those with between five and ten years of post-PhD experience (41% LMI and 29% HI; Figure 2.2). The remaining of the responses came from post-doctoral researchers (7% LMI and 7% HI) or non-academic researchers (1% LMI and 3% HI). Overall, 69% of the respondents were male (65% of LMI respondents and 70% of HI respondents), 30% were female (35% LMI; 29% HI) and 1% either did not input their gender or selected 'other' (0% LMI; 1% HI).

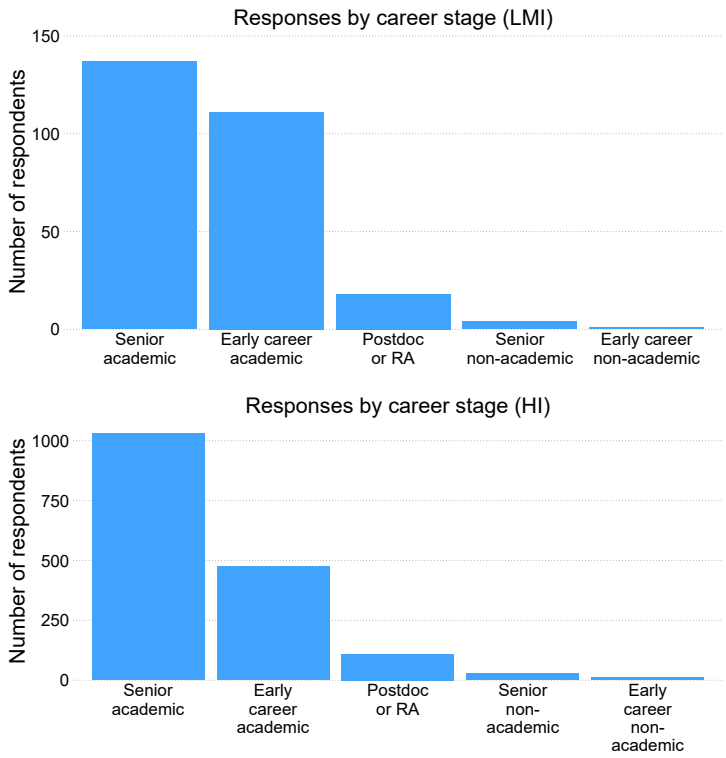

Figure 2.2 Number of respondents by career stage (top: LMI; bottom: HI; Note the differences in y-axis scales).

Here, we present aggregate data across countries, fields, and career stages to illustrate cross-cutting themes that emerged in our analyses. We do not have enough data (except for Canadian researchers, hence the separate report presented in (1)) to permit regional or discipline-specific analyses. However, the data presented here demonstrate that researchers globally, across disciplines, agree that fundamental science must be supported effectively to sustain potential for future innovation.

2.2 Research focus: researchers are increasingly shying away from fundamental research

The focus of many (45%) senior academics' research programmes had changed substantially over the five years preceding their participation in the survey, with the most commonly reported change being a shift away from fundamental research and towards use-inspired or applied research (Figure 2.3A). Whereas 73% of respondents report that between 2006 and 2010 their research programmes were dominated (i.e., half or more of their programme) by fundamental research (68% LMI; 74% HI), 61% of respondents report this to be the case between 2011 and 2015 (60% LMI; 61% HI; Figure 2.3A). Both use-inspired and applied research filled this gap. Research programmes dominated by use-inspired or applied research rose from 11% (15% LMI; 11% HI) and 15% (14% LMI; 16% HI), respectively, in the period 2006–2010, to 19% (24% LMI; 18% HI) and 21% (15% LMI; 22% HI) in the period 2011–2015 (Figure 2.3A).

Between the periods 2006–2010 and 2011–2015, the proportion of researchers who report only conducting fundamental research decreased from 22% (17% LMI; 23% HI) to 18% (13% LMI; 19% HI), and those who report no use-inspired or applied research declined from 22% (17% LMI; 23% HI) to 18% (13% LMI; 19% HI; Figure 2.3A). In general, most researchers conduct a mix of fundamental,

use-inspired, and applied research. This may reflect the close connection between the different types of research, or the pressure that researchers feel to include more than 'just' fundamental science for the purposes of funding (see below).

Sixty-nine percent (55% LMI; 71% HI) of respondents cited changes to available research funding as the reason for shifting the focus of their research programmes (Figure 2.3B), indicating that perceived funding priorities between 2006 and 2015 effectively pushed researchers away from fundamental research. Fifty-four percent (63% LMI; 53% HI) of researchers cited changing research interests, and 34% (28% LMI; 35% HI) cited career changes as their reason for shifting research foci (Figure 2.3B). Note that some respondents indicated multiple reasons for shifting their research focus.

Overall, the opinions of researchers whose focus had shifted on the impacts of these changes were divided. Sixty percent (74% LMI; 58% HI) of researchers regarded the shift in their research programme emphasis as slightly or very positive, whereas 16% (8% LMI; 17% HI) of researchers viewed the change as slightly negative (Figure 2.3C). Five percent (2% LMI; 6% HI) regarded the changes as very negative.

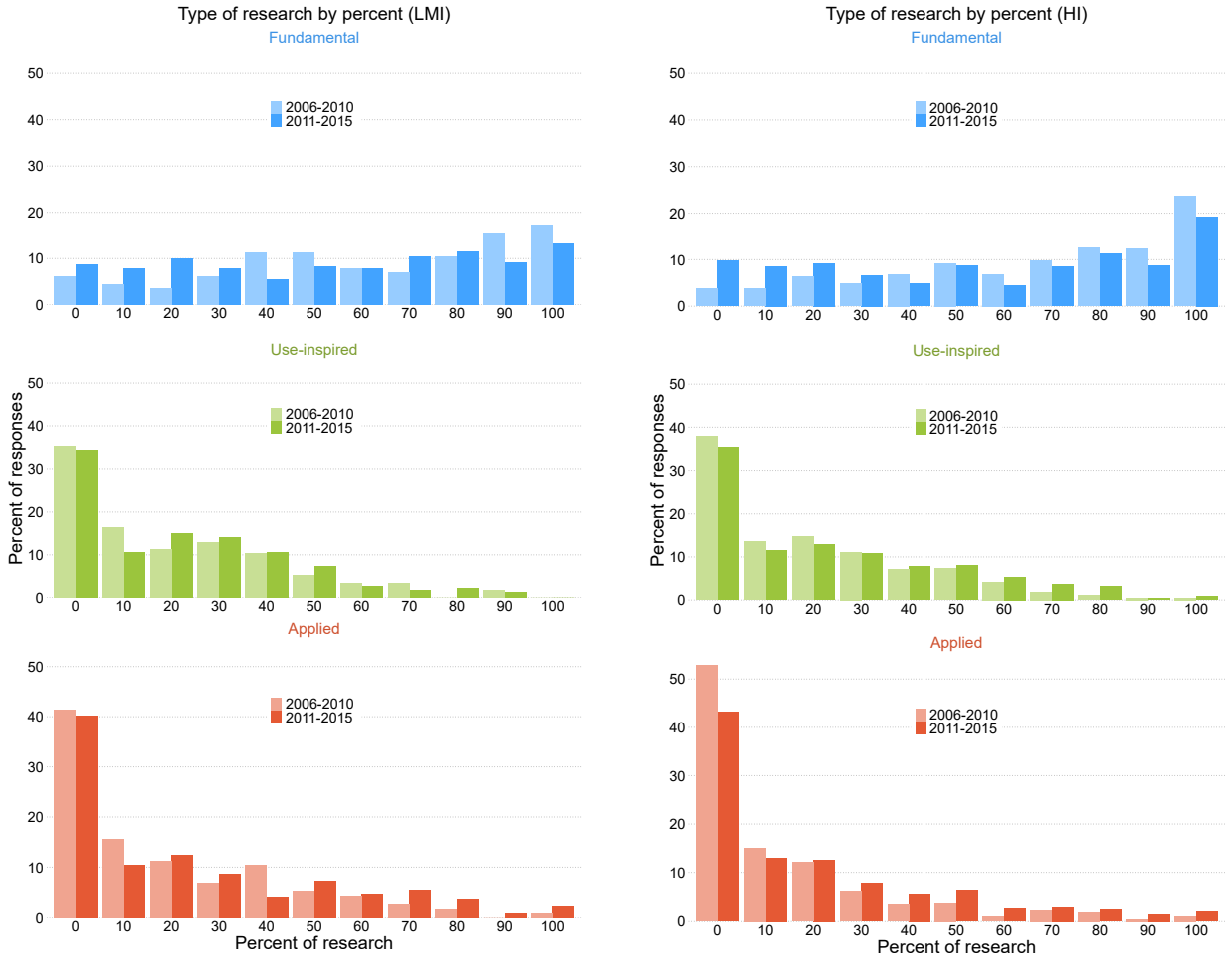

Figure 2.3 A) Percent of survey respondents' research programmes that focused on fundamental, use-inspired, applied research in the period 2006–2010 and in the period 2011–2015 (LMI: n= 116 for 2006-2010, n = 219 for 2011-2015; HI: n = 638 for 2006-2010, n = 1512 for 2011-2015; HI). Vertical bars indicate emphases in research programmes (e.g., for HI countries approximately 350 respondents did not have any applied research (0% of the research programme) in the first time period, but only 300 respondents did not have any applied research component to their research programme in the second period).

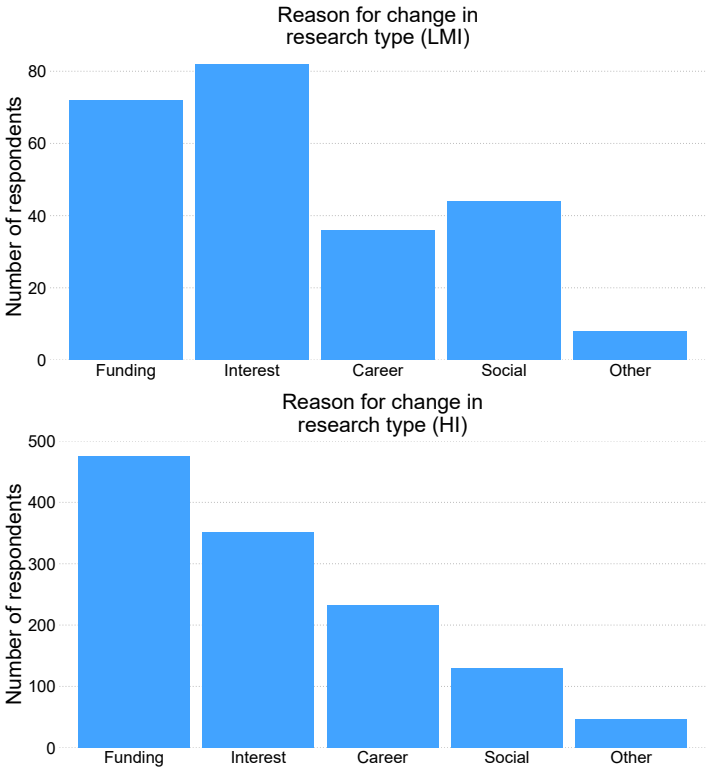

Figure 2.3 B) Researchers' motivations for shifting their research focus.

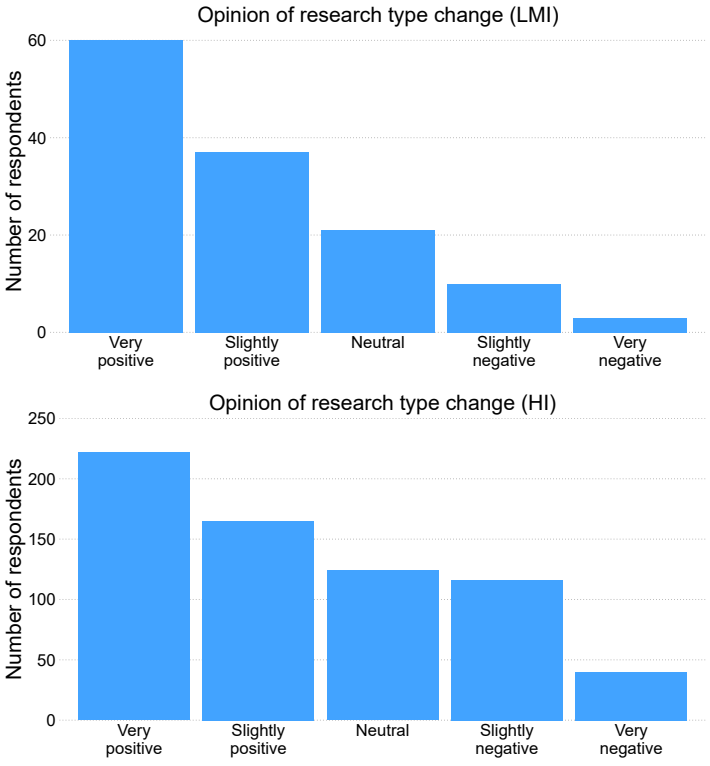

Figure 2.3 C) Attitudes of researchers toward the shift in emphasis in their research programmes.
Note that the number of respondents in **B)** and **C)** is limited by the number of researchers who indicated that their research focus had

shifted (LMI n =131; HI n = 670). (Panel A; left: LMI; right: HI; Panels B and C; top: LMI; bottom: HI; Note the differences in y-axis scales).

2.3 Government priorities: applied research is perceived as a high priority

Sixty percent of the total sample (47% LMI; 63% HI) report that their government considers fundamental research to be either very important (24% total; 19% LMI; 25% HI) or somewhat important (36% total; 28% LMI; 38% HI) (Figure 2.4a). However, 37% report that their government considers fundamental research to be either not very important (29% total; 43% LMI; 27% HI) or not at all important (8% total; 9% LMI; 8% HI) (Figure 2.4A).
At the same time, 82% (87% LMI; 81% HI) of respondents said that applied research has become a higher priority for their government over the past decade, and 37% (27% LMI; 39% HI) believe that use-inspired research had become a higher priority (Figure 2.4B). This high level of priority for applied research may be the source of the perceived disparity in funding among the different research types. Several respondents indicated multiple higher-priority areas for their government.

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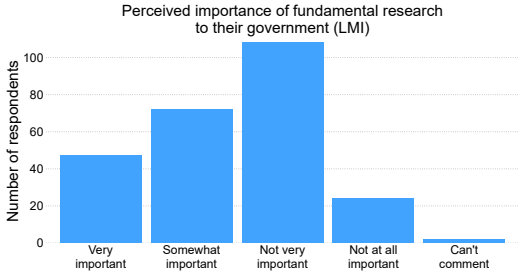

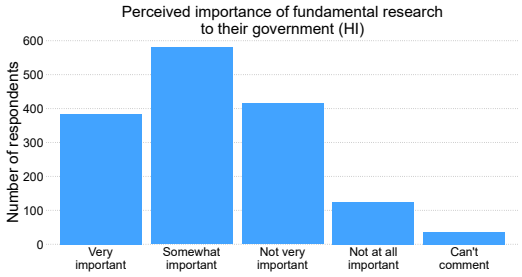

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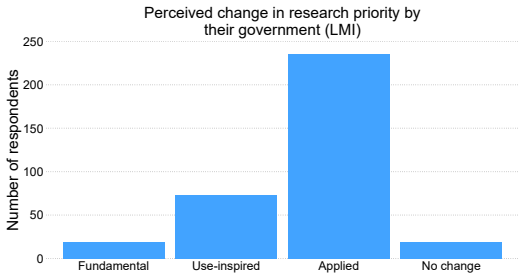

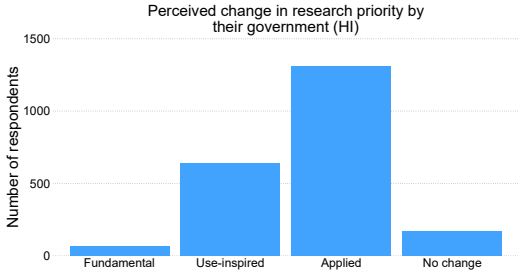

Figure 2.4 A) Researchers' perceptions of the importance their government places on fundamental research. **B)** Types of research perceived to have become a higher research priority to governments over time. The number of respondents (n = 1,892) is lower than the

sum of responses because several respondents indicated multiple areas as priorities for their government. In A and B top: LMI; bottom: HI; Note the differences in y-axis scales.

2.4 Grant success rate: it has become harder to get fundamental research funded

On the one hand, for fundamental research grant applications, 72% (62% LMI; 74% HI) of surveyed researchers report that success rates had declined either slightly (40% total; 42% LMI; 40% HI) or considerably (32% total; 20% LMI; 34% HI) over the decade preceding their participation in the survey (Figure 2.5). On the other hand, for applied research grant applications, 47% (68% LMI; 43% HI) perceived success rates to have increased either slightly (25% total; 32% LMI; 24% HI) or considerably (22% total; 36% LMI; 19% HI), over that same period (Figure 2.5). More researchers report increases in success rates of use-inspired research grant applications (27% total; 38% LMI; 26% HI) than decrea-

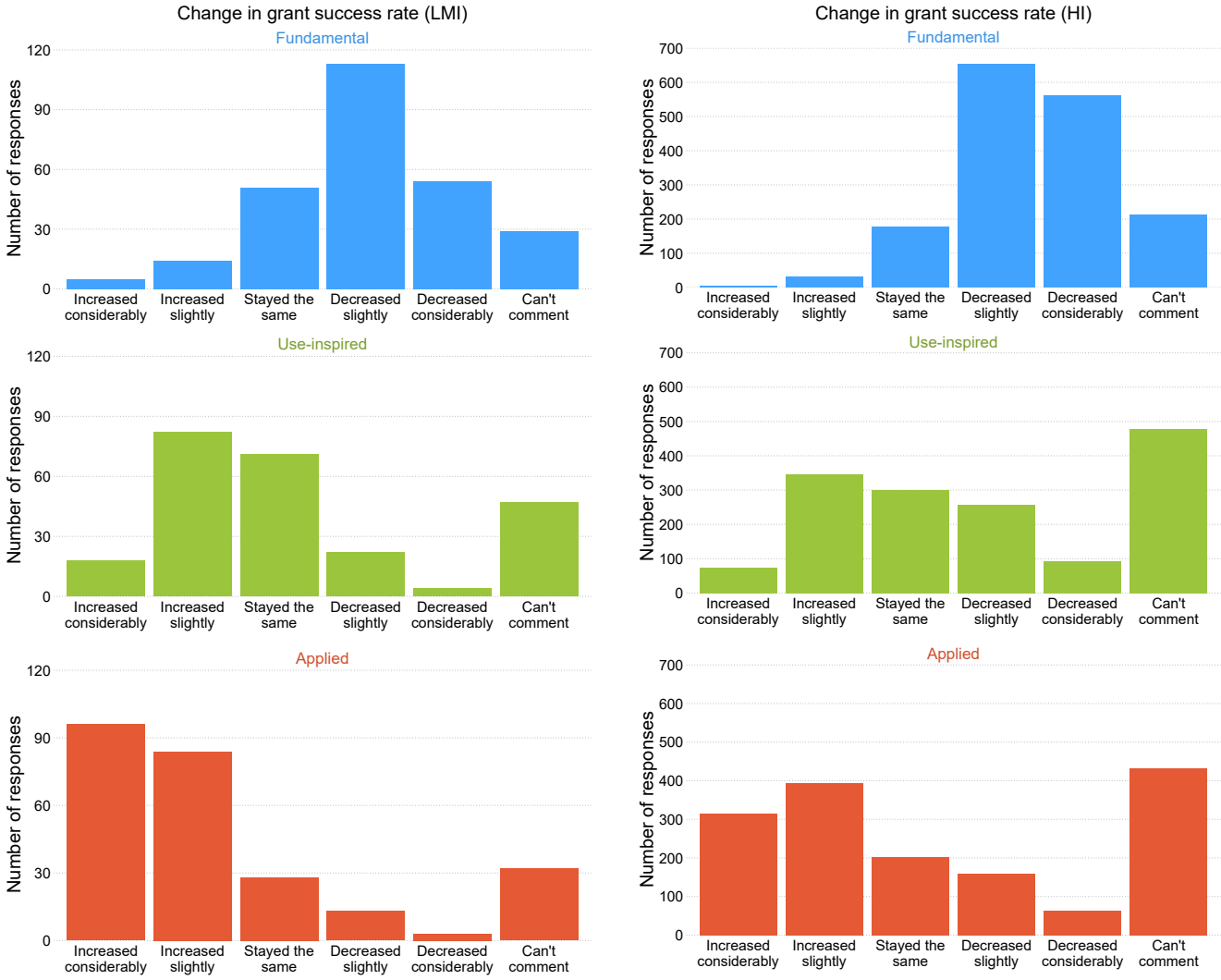

Figure 2.5 Researchers' perceptions of how success rates for fundamental (LMI n = 266; HI n = 1642), use-inspired (LMI n = 244; HI n = 1546) and applied (LMI n = 256; HI n = 1568) research grants have changed in the ten years preceding their participation in the survey (left: LMI; right: HI; Note the differences in y-axis scales).

Different factors could be contributing to the perceived decrease in the availability of funding for fundamental research. Decreased availability of funds, an increased number of applicants, and/or changing application requirements could be contributing to the overall impression held by researchers. Regardless of the relative contribution of factors, the surveyed researchers are sending a clear message that the

have seen a reduction in success for gaining fundamental research funding.
Limited availability of fundamental research funding from governments has serious consequences, considering that researchers rely heavily on this source of funding: 66% (56% LMI; 67% HI) of respondents fund 50% or more of their research programme with money from their government, and 11% (10% LMI; 11% HI) are entirely financed by their government (Figure 2.6). As funding for fundamental research is perceived to have diminished, researchers have diversified their funding sources, as evidenced by the increase in research funding from non-governmental, for-profit (i.e., industry), internal, and other funders between the periods 2006–2010 and 2011–2015 (Figure 2.6). The challenge with this change in funding source, however, is that the goals of the research also change, shifting from fundamental research towards applied research. Industry funding constrains research directions and narrows horizons for discovery.

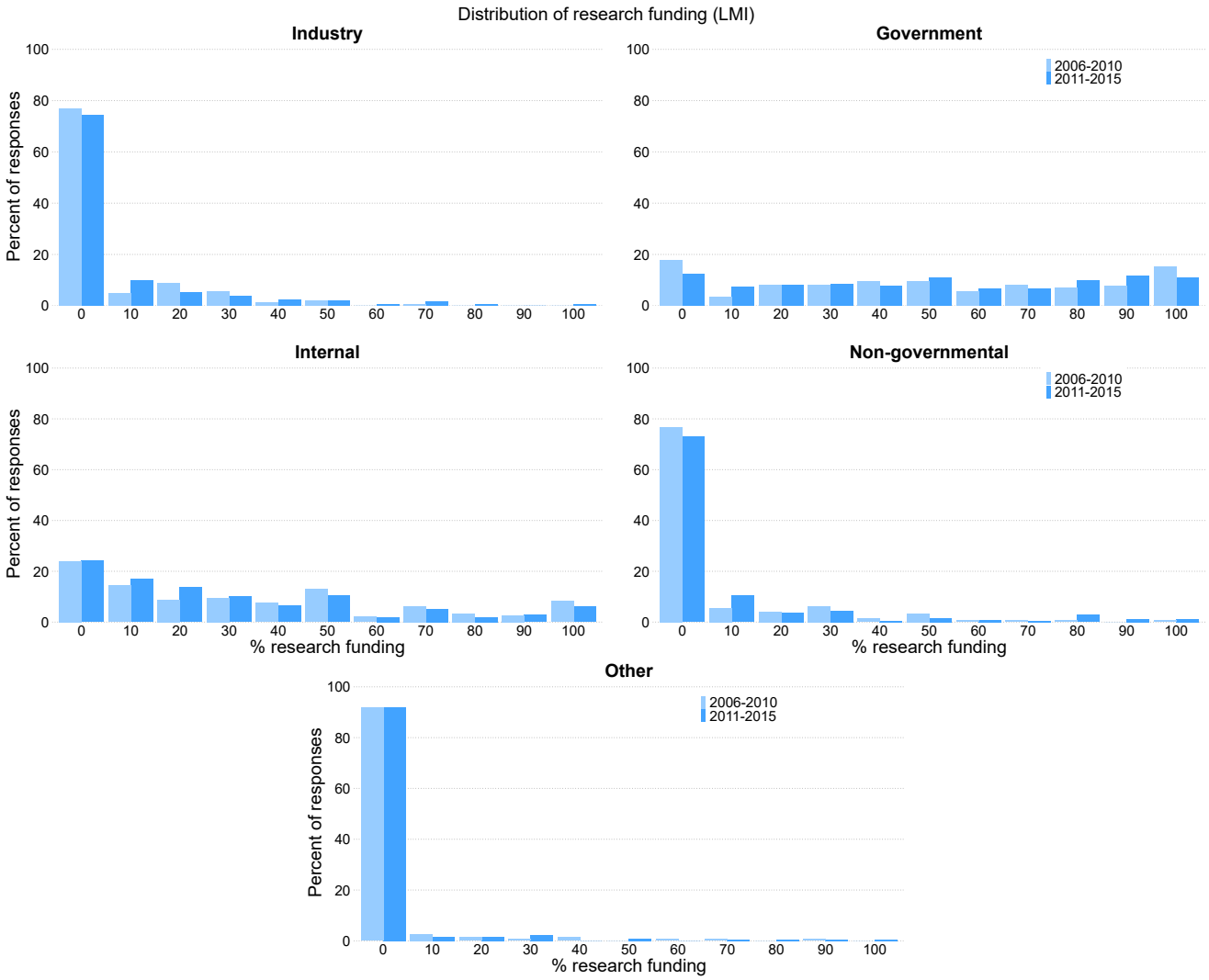

Figure 2.6 The changing distribution of research funding. Researchers quantified the percentage of research funding they received in 2006–2010 and 2011–2015 from government and other sources (top: LMI n = 146 for 2006-2010, n = 248 for 2011-2015; bottom: HI n = 920 for 2006-2010, n = 1,589 for 2011-2015).

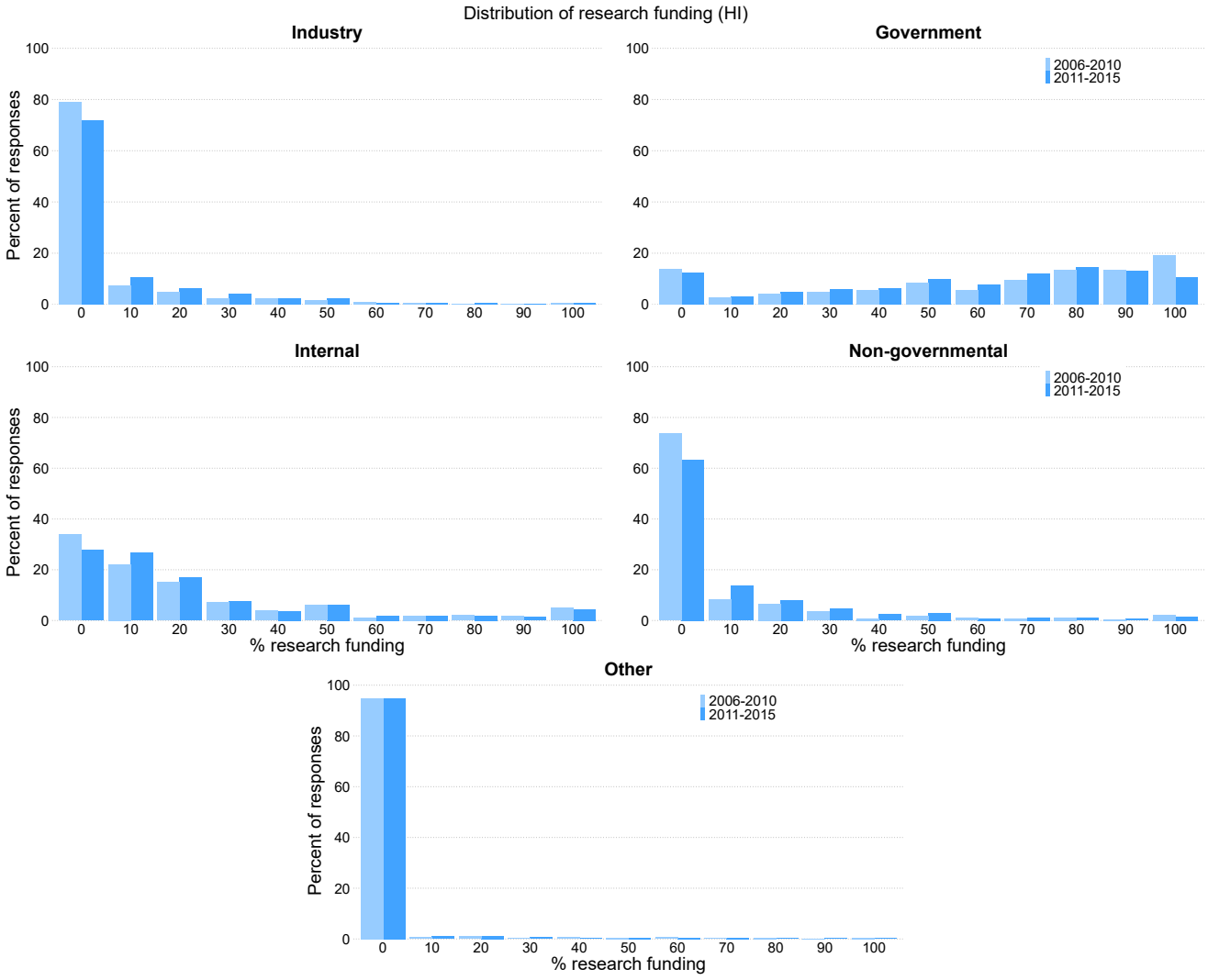

Figure 2.6, continued.

2.5 A greater emphasis on practical applications and external partnerships

Requirements for grant application success, such as listing practical applications or having external partners, can also indicate an emphasis on use-inspired or applied research (although note that not all fields or countries allocate funding through a competitive grant process). For example, external research partners (e.g., in industry or non-governmental sectors) are now required for several types of grants. Nineteen percent (11% LMI; 20% HI) of surveyed researchers report that it is now mandatory to suggest practical applications as an outcome of their research in order to obtain funding, and a further 31% (36% LMI; 31% HI) believe it is very important to do so (Figure 2.7A). In contrast, only 9% (7% LMI; 9% HI) of researchers believe that it is not at all important to suggest practical applications of their research (Figure 2.7A).

These viewpoints have changed considerably over time, with researchers believing that suggesting practical applications of their research is now much more important than it was in the past. For example, in the period 2006-2010, only 6% (4% LMI; 6% HI) and 19% (22% LMI; 19% HI) of researchers believe

practical applications were mandatory or very important, respectively (Figure 2.7A).

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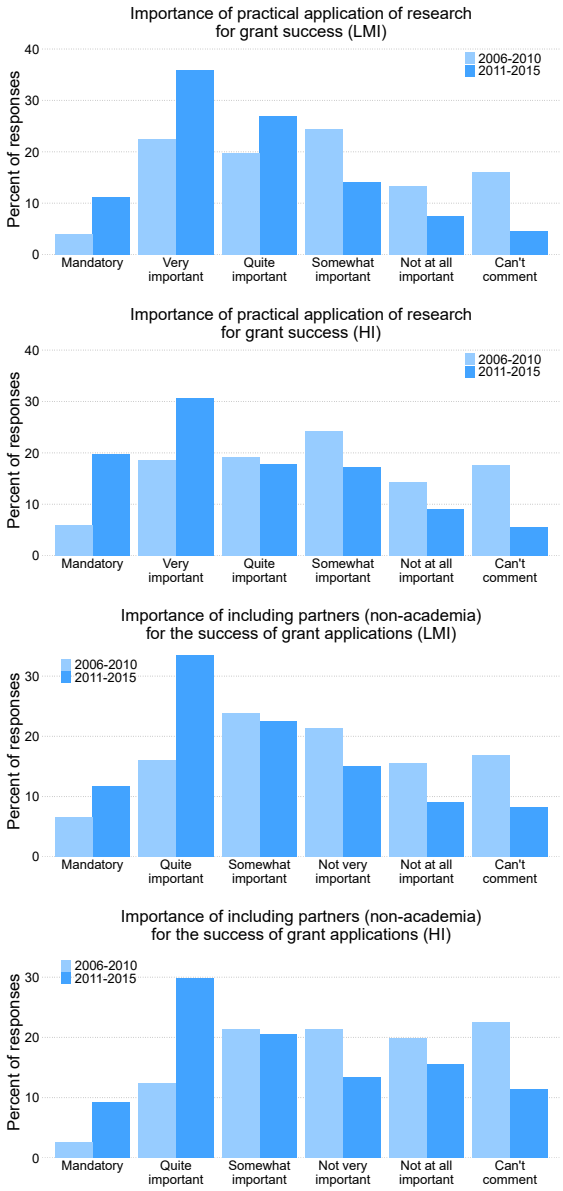

B

Figure 2.7 Researchers' perceptions of: **A)** the importance of suggesting practical applications of their research to successfully obtain funding, in 2006–2010 and in 2011–2015 (Top: LMI n= 249 for 2006-2010, n = 268 for 2011-2015; Bottom: HI n = 1,599 for 2006-2010, n = 1,643 for 2011-2015); and **B)** the importance of including external partners (e.g., from industry or non-governmental sectors) to successfully obtain funding, in 2006–2010 and in 2011–2015 (Top: LMI n= 244 for 2006-2010, n = 266 for 2011-2015; bottom: HI n = 1,582 for 2006-2010, n = 1,643 for 2011-2015).

The importance of having external (outside academia) research partners also seems to have changed over time, with an increase in the percent of respondents who consider it mandatory or quite important (Figure 2.7B). When we look at the inclusion of external partners in research (Figure 2.8a), fifty-nine percent (61% LMI; 58% HI) report that their current research includes external partners to some degree: 41% (50% LMI; 40% HI) report some partnerships and a further 17% (11% LMI; 18% HI) report strong partnerships. In contrast, in the preceding five years, 53% (60% LMI; 52% HI) report

engaging in some level of external research partnership, and only 9% (7% LMI; 9% HI) had strong external partnerships. This increase in partnerships goes with a corresponding decrease in researchers without any external partnerships, from 46% (31% LMI; 47% HI) between 2006 and 2010 to 41% (38% LMI; 42% HI) between 2011 and 2015 (Figure 2.8a). Only 1% (1% LMI; 1% HI) of researchers report conducting their research exclusively with partners outside of academia, and this had not changed noticeably over t

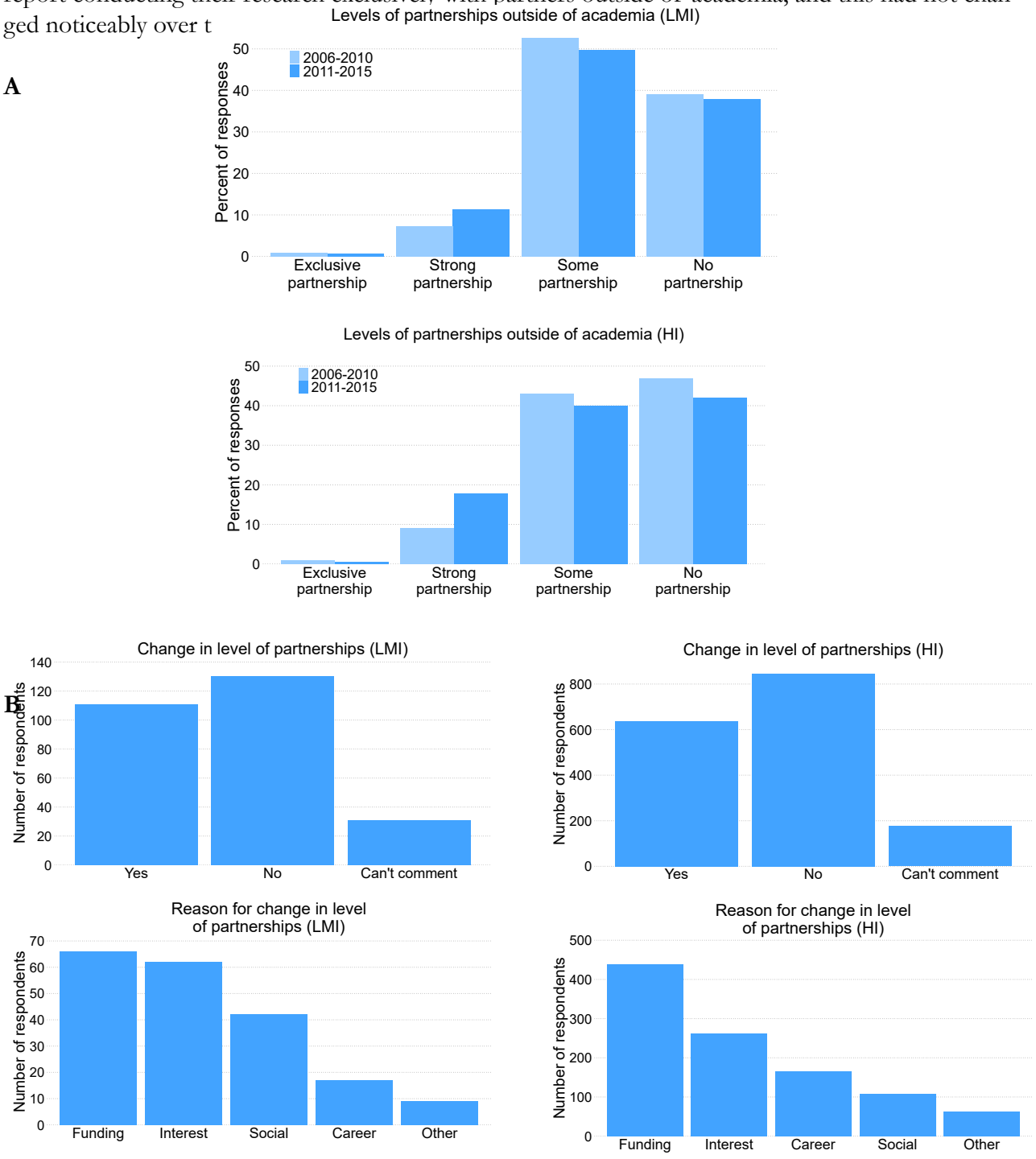

Figure 2.8 A) Levels of partnership outside of academia in 2006–2010, and in 2011–2015 (LMI: n = 110 for 2006-2010, n = 271 for 2011-2015; HI: n = 645 for 2006-2010, n = 1,654 for 2011-2015). **B)** Reasons for changes in the level of external research partnerships over the decade preceding participation in the survey; and **C)** views on these changes. In panels A and C top: LMI; bottom: HI; panel B

left: LMI; right: HI; Note the differer

C

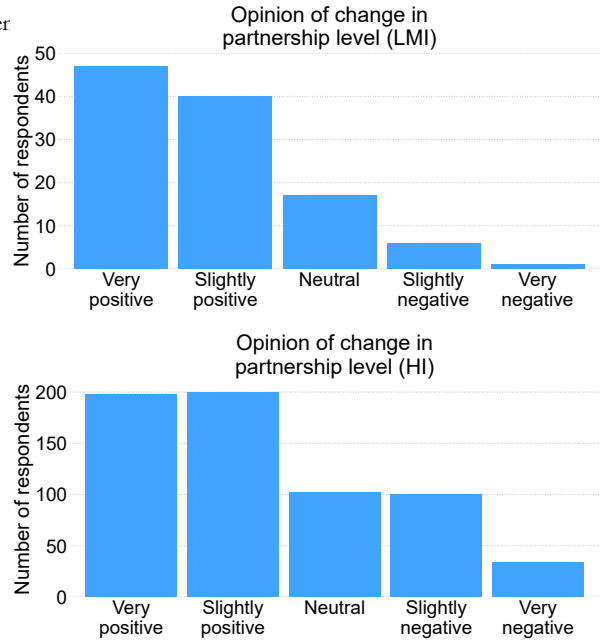

Figure 2.8, continued.

Funding was the main driving force behind the shift towards external partnerships, with 41% (34% LMI; 42% HI) of respondents reporting that they developed external partnerships to qualify or increase success in new funding (Figure 2.8b). The remaining respondents indicated that the motivation for the partnerships was interest-based (26% total; 32% LMI; 25% HI), career-based (15% total; 9% LMI; 16% HI), socially motivated (12% total; 21% LMI; 10% HI), or based on other reasons (6% total; 5% LMI; 6% HI; Figure 2.8B).

Attitudes toward these changes were mixed, with a tendency towards being positive (Figure 2.8c). Sixty-five percent (78% LMI; 63% HI) of respondents viewed the change in external partnerships as slightly or very positive. However, 19% (6% LMI; 21% HI) regarded the change as slightly or very negative, and 16% (15% LMI; 16% HI) were neutral about the change (Figure 2.8C).

Taken together, these results demonstrate the increasing rarity of researchers operating without external partnerships. Funding is the driving factor in forming these partnerships, and researchers' feelings about these changes are mixed, but many have had positive experiences. One potential outcome of these changes is that individual research focus is more strongly influenced by the partnership, and government funding availability, rather than the scientific priorities identified by researchers themselves or pure curiosity.

2.6 Future research funding: looking ahead and thinking about changes and implications for the next generation of researchers

The majority of surveyed researchers believe that funding will either be stable or increase in the five years following their participation in the survey for use-inspired and applied research, but not for fundamental research (Figure 2.9). Despite some optimistic replies, such as 12% (9% LMI; 12% HI) of

respondents predicting that fundamental research funding would increase slightly in the subsequent five years, only 1% (2% LMI; 1% HI) believe that fundamental research funding would increase considerably (Figure 2.9). Moreover, almost sixty percent of respondents (59% total; 53% LMI; 61% HI) believe that support for fundamental research would continue to decrease (Figure 2.9). In contrast, more than half of respondents (53% total; 63% LMI; 51% HI) expect funding for applied research to increase either slightly (33% total; 29% LMI; 33% HI) or considerably (20% total; 34% LMI; 18% HI; Figure 2.9). In the context of funding success expectations, where the ratio of applicants to available funding determines success rates, these evaluations are likely to influence future decisions, pushing scientists away from fundamental research

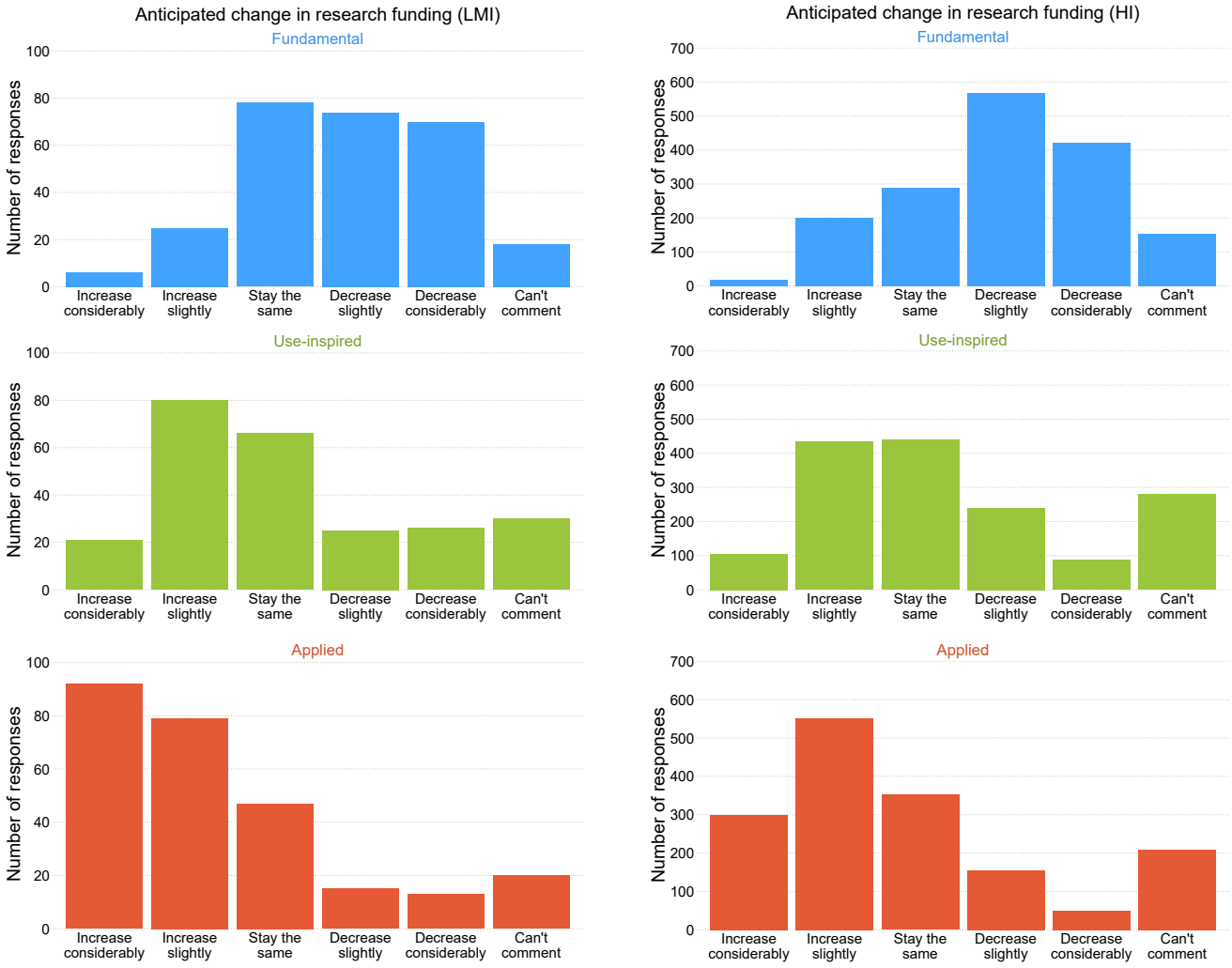

Figure 2.9 Researchers' perceptions of how funding for fundamental, use-inspired, and applied research was likely to change in the five years following their participation in the survey in their respective countries (left: LMI; right: HI; Note the differences in y-axis scales).

More than half of surveyed researchers (57% total; 43% LMI; 59% HI) believe that recent changes in the funding landscape will lead to fewer young citizens choosing to pursue research careers in the future (Figure 2.10). Few researchers (6% total; 13% LMI; 5% HI) believe that recent changes would inspire considerably more young citizens to choose a career in research, while 9% (19% LMI; 7% HI) believe that they might result in a slight increase (Figure 2.10). The capacity or possibility of any country to compete on the world stage as a scientific powerhouse will be greatly diminished if it cannot attract that country's brightest young minds to research careers. Today's researchers, particularly those in HI countries, believe their respective government's recent funding priorities negatively affect their country's future science capacity.

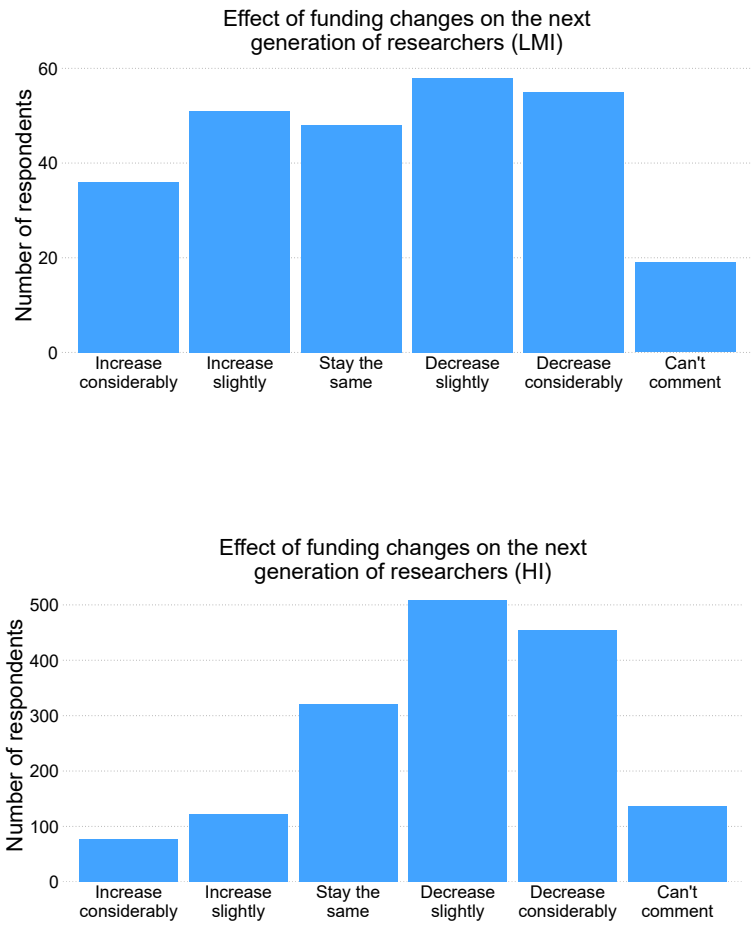

Figure 2.10. Effect of change in research funding on research careers of next-generation scientists around the world. Researchers were asked if they thought that changes in funding availability would influence the likelihood of the next generation pursuing careers in research. Note the differences in y-axis scales.

2.7 The bottom line

The data presented in this report represent the views of a sample of researchers from around the world and from many different fields. Although this heterogeneity can sometimes be a challenge, in this case, it results in a unique insight into the various factors that influence decisions about the type of research we engage in. A caveat for our interpretation is that here we present summary survey data, relying on qualitative interpretations rather than statistical analyses. Even at this level, however, and despite our participants' distinct experiences, backgrounds, and cultural reference points, clear messages come through regarding the emphasis and value of fundamental research.

The recurring theme in our data is that researchers see a change in the balance of priorities, with applied research receiving more funding and being valued more by governments and funders than fundamental research. There is a subsequent shift towards working in more applied research and a clear perception that future research funding will amplify this trend. The consequences of these perceived differences might be far-reaching. The effects range from the loss of intellectual potential in terms of people leaving or not taking on research careers, through to changes in research focus to be only on applied or industry-led problems. The ability to spur innovation and build research capacity in the future rests on funding agencies increasing their financial support for fundamental research, and greater public awareness of the crucial role fundamental science plays in our ability to respond to global challenges.

3. Conclusions and recommendations

The benefits of scientific discoveries are felt throughout our society, ranging from health to security, communication, and quality of life. With our rapidly changing world, society has a considerable vested interest in attracting creative, passionate, and intelligent people into scientific careers. But this career path is becoming less certain: researchers perceive that fundamental science — the pursuit of knowledge and understanding of humanity or the natural world without consideration of an end product — is undervalued, underfunded, and under threat.

This report presents the results of a survey on researchers' perceptions about fundamental science and how it is valued in our societies. Our sample includes researchers from low- and middle-income countries whose voices are rarely heard on this issue. Researchers around the world perceive a decrease in the funding available for fundamental science, in the context of increased support for applied research. This has wide-ranging consequences, including a shift in the direction of research programmes, a change in the emphasis of research, and potential impacts on the recruitment of future generations of researchers.

Our results show that many researchers have shifted from doing primarily fundamental science towards a focus on use-inspired or applied questions. Many had reduced their fundamental science research by more than 25% over the ten-year period addressed in this report. The primary reason given for this change was funding. In contrast, those who report an increase in their fundamental science research by more than 25% over the same period attribute this to interest and career development. Researchers from HI countries report success rates for fundamental science grants have dropped in the context of increases in the success rates for applied science grants, and emphasise that greater importance is placed on nominating practical applications for their research. Finally, our respondents believe future funding would increase for applied research and decrease for fundamental research, which would decrease the attractiveness of a career in fundamental science for future generations.

The respondents perceive that their governments had increased their prioritisation of applied research, and that it had become harder to get fundamental science funding. Support for fundamental research is perceived to be greater in high-income than low- and middle-income countries. To the extent that these researchers' experiences with their national funding structures are representative, our results are consistent with inequities in opportunities depending on where researchers work. Most LMI researchers report that their governments do not place much importance on fundamental research, and that research priorities have changed towards applied research. This is reflected in their perception of changes in success rates for grants over the 10-year period from 2006–2016, and their prediction of what would happen in the next 5 years (i.e., a further reduction in funding for fundamental research in the context of increases in funding for applied research). Overwhelmingly, our respondents believe funding for applied and use-inspired research is increasing at the expense of funding for fundamental research and many are changing their research directions to "follow the money". Their reaction is understandable, but less researchers conducting fundamental research creates a problem for the whole innovation system, because translational outcomes rely on pre-existing knowledge. If we do not replenish this knowledge reservoir, we will rapidly dry up our capacity for applications.

The consequences of pressure on fundamental science funding will be felt in both LMI and HI countries. If researchers are primarily channelled into applied research in LMI countries, then these economies have less potential for innovation and lower likelihoods of ground-breaking discoveries that can

catalyse new industries and applications. Focusing on a single problem results in (potentially) a single solution, specific to that scenario. Focusing on underlying theory or curiosity-driven research questions has the potential to inform a whole host of applied or translational outcomes. As a concrete example, the COVID-19 pandemic response relies on a wide range of research that originally was not designed to address this specific challenge. If research only responds once challenges emerge, we lose valuable time and the opportunity to limit damage. This can turn out to be far more costly than ongoing investment in broad proactive fundamental-science-based research programmes.

One might counter this by ensuring that fundamental research discoveries are open and accessible to all so that HI countries could shoulder the bulk of the investment, and applied research in LMI countries could be based on fundamental research undertaken elsewhere. Certainly, it is increasingly evident that we need solutions that serve a global society. However, training in fundamental research is a crucial part of a nation's capacity for future innovation, and so having fundamental science only conducted by wealthy countries will produce more inequity. Building research and innovation capacity, in turn, is crucial for leaping ahead economically and overcoming dependencies on wealthier and more technologically-advanced countries. Many different initiatives that were originally blue-sky research (such as the examples given in the introduction) have resulted in great financial benefits. This means that investment in fundamental research can be a long-term strategy for maintaining or raising levels of wealth. HI countries with sufficient financial resources for an investment that pays off only in the long term therefore end up with the greatest potential wealth through such investments. Countries under greater financial pressure face a difficult choice between investment in the development of specific solutions (e.g., to supply clean water) or in fundamental research with long-term (and less-specific) benefits. Although many LMI countries are in urgent need of solutions to existing problems, a path that neglects fundamental research will, in the longer term, deprive them of the foundation for such innovation as well as research training and capacity.

Furthermore, while the outlook and support for fundamental research are perceived to be stronger in high-income countries than in low- and middle-income countries, researchers express concerns regarding the stability and trajectory of this support. Our data show concerning changes in the degree to which researchers are confident in careers pursuing fundamental science. The most valuable asset of any country is its people, and the development of their skills provides an essential basis for societal development and advancement.

A new major risk factor to the crucial support is the economic fall-out of the COVID-19 pandemic, which may cause major funding bodies to reconsider their funding priorities with great risk to the future of fundamental research. The importance of commitments to fundamental research across diverse disciplines is emphasised by the vast efforts to mitigate COVID-19, which rely on previous knowledge on vaccination development techniques, drug repurposing, life-support treatments, but also sociological and psychological knowledge to understand societal behaviour, develop pandemic containment strategies, and the consequences of all of these for well-being and behaviour. The urgent need for global action to cope with the changing climate of the planet is also one that requires input from diverse research fields. We need wide-ranging research, from scientific and technological advances through to understanding of societies and human behaviour to respond to the challenges confronting humanity.

Therefore, despite the limitations on resources, a substantial investment in fundamental science should be a key priority, contributing greatly to overcoming current and future problems. One avenue forward would be to develop specific funding programmes to support fundamental research collaborations between researchers from HI and LMI countries with clear ethical guidelines and oversight to ensure all

parties are benefiting from the collaboration, and contributions are clearly recognised.

The International Year of Basic Sciences for Sustainable Development in 2022 provides a unique opportunity for the scientific community to engage with governments around the world on the value of fundamental research and the importance of raising sustainable funding levels. The Global Young Academy and National Young Academies can be key points of contact for policymakers who aim to involve researchers in their decision-making process. Through outreach and educational programmes, the scientific community can also increase the emphasis on the foundational science that has allowed important society-changing applied outcomes to occur. Again, young researchers may be particularly well placed to use social media and the internet to make this message widely accessible.

In conclusion, our findings highlight how researchers are being affected by perceived changes in government priorities, competitiveness for limited resources and fundamental science funding. Research activities and innovation proceed more rapidly in a system that balances fundamental, use-inspired, and applied work. In line with the 2022 International Year of Basic Sciences for Sustainable Development and the quest for transformational changes that will address the 17 UN SDGs, we call for the value and importance of fundamental research to be emphasised and manifested in policy, funding, and education, and for this message to be communicated widely to the general public.

Recommendations

* Develop specific funding programmes to support fundamental research collaborations between researchers from HI and LMI countries. This requires clear ethical guidelines and oversight to ensure all parties are benefiting from the collaboration, and contributions are clearly recognised.

* Ensure science advice to policymakers and governments includes input from early- to mid-career researchers, as they often are the ones most directly experiencing the consequences of the funding environment changes.

* Increase the emphasis on the value of fundamental research for the general public through outreach, education and science communication efforts.

* Reflect the value of fundamental science in policy and funding decisions, recognising the crucial foundational role it plays in advancing our knowledge and promoting it through the education system to establish new generations of fundamental researchers.

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5. Abbreviations

DAC	Development Assistance Committee
GPS	Global Positioning System
GYA	Global Young Academy
HI	high-income
LMI	low- and middle-income
MRI	Magnetic Resonance Imaging
NMR	Nuclear Magnetic Resonance
ODA	Official Development Assistance
OECD	Organisation for Economic Co-operation and Development
SDG	Sustainable Development Goal
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organisation

About the Global Young Academy

The vision of the GYA is science for all; science for the future, and its mission is to give a voice to young scientists and researchers around the world. The GYA, founded in 2010, is an independent science academy of 200 outstanding early- to mid-career researchers from six continents who are selected from across disciplines based on their academic excellence and commitment to engage with society. GYA members serve five-year terms, and the GYA presently counts members and alumni from 100 countries. The GYA administrative Office is publicly funded and hosted at the German National Academy of Sciences Leopoldina. The wide array of GYA activities are supported by a range of international public and private funders.

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