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Article

Impacts for whom? Assessing inequalities in NSF-funded broader impacts using the Inclusion-Immediacy Criterion

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Abstract

Broader impacts (BI) policies generate debate on the purpose of science, measuring the impact of research, and is an important topic for the science policy community. However, BI policies often fail to determine if R&D funding helps marginalized communities. This paper introduces a new framework, the Inclusion-Immediacy Criterion, that assesses who benefits from research impacts as divided into three groups: (1) advantaged groups; (2) the general population; and (3) marginalized groups. The study analyzes National Science Foundation (NSF) project outcome reports and finds that advantaged groups are the most likely to benefit from NSF-funded research. The study also shows that certain areas of NSF research, such as Social, Behavioral, and Economic Sciences, more efficiently generate impacts for marginalized groups compared to other directorates. This paper further argues that persistent inequalities in BIs limit the potential of R&D to increase prosperity and well-being, two of NSF's mandated goals.

Key words: broader impacts; immediacy-inclusion criterion; science policy; National Science Foundation.

1. Introduction

There is a general consensus among scientific research funding organizations that the benefits of research should translate to benefits in society, and public monies spent on research should support national interests (Bush 1945; OECD 2014). To hold scientists accountable to these aims, federal science funding organizations from countries and regions such as Australia, South Africa, and the European Union (EU)[1] have all adopted policies to promote broader impacts (BIs) of scientific research. For example, in South Africa, nanotechnology policy promotes research that can address the key societal needs of energy, water, and health (Department of Science and Technology South Africa 2005). In the USA, politicians regularly publish 'Wastebooks' that detail spending that they deem inefficient, including scientific research (Paul 2019).

Nevertheless, it can be hard to transfer the benefits of research to the general public, and it is even harder to measure the outcomes of research for public good (McLellan 2021). To address this challenge, a variety of frameworks were developed to encourage explicit links between research projects and impacts on society. These included the Broader Impact Criteria (BIC) in the USA and measures of Responsible Research and Innovation in the EU (Langfeldt and Scordato 2015). These frameworks focus on how research is designed and executed (the research process) and how knowledge and outputs are used (research impacts) (Davis and Laas 2014). While both approaches seek to monitor research funding, risk, and benefits, these frameworks often fall short on two dimensions.

First, the frameworks do not adequately assess *who* benefits from research (Bozeman 2020). Will the project mostly help wealthy consumers and businesses or is the impact targeted toward poor and marginalized communities? Second, how does the impact align with the underlying research project? Is the BI aligned with the research objectives, like creating a new vaccine, or is it a side project in addition to the research, like disseminating the research results to secondary school children? These criteria shed light on how science policy for BIs is interpreted by scientists (as an add-on or deliberate goal) and how the larger population experiences research outcomes (as maintaining or challenging status quo inequality). While these dimensions are often overlooked, they are necessary to understand how BI policy affects the research process and its outcomes. In the case of the American National Science Foundation (NSF), the absence of such knowledge could mean funding research and promoting policies that fail to meet the NSF's mission to support science and technology in service of the nation's health, prosperity, and welfare.

This paper uses a new framework, the Inclusion-Immediacy Criterion (IIC), to analyze BIs based on two criteria, inclusion and immediacy. Inclusion evaluates the grant based on the people that will benefit from the research. Immediacy characterizes a research grant based on the alignment of the research and BIs. We apply the IIC to a representative sample of NSF grants from 2014-2017 to understand the impacts of funded research on marginalized communities throughout the USA and the world. Importantly, we argue that addressing inequalities through inclusive BIs is not just beneficial for marginalized groups but supports the entire innovation system because inequality limits the advancement of national health, prosperity, welfare, and security (National Science Foundation 2020a; Intemann 2009). Our findings also answer the question of whether BI requirements 'distract' scientists from their primary research aims. The IIC is a tool to classify and enumerate the distribution of BIs, and, consequently, it can help policy makers better identify and support inclusive research.

This paper has five sections. Section 2 discusses the literature related to BIs research, explains the importance of using R&D to reduce inequality, and describes how the IIC captures a more nuanced picture of BIs. Section 3 is an overview of the research methods for the project, and Section 4 discusses the analysis and main findings. Section 5, the conclusion, discusses the implications of our findings and gives policy recommendations.

2. Literature review

2.1 Why (in)equality matters to BIs

In the USA, the emphasis on science benefiting society can be traced back to science administrator Vannevar Bush's 1945 report entitled, 'Science, the Endless Frontier' (Bush 1945). In the report prepared for the president of the USA at the end of World War II, Bush asserted that science was an 'endless frontier' for uplifting society and that all the innovations developed during WWII should not remain locked away in military bunkers. Rather, the technology should be leveraged to help the world.

After WWII, the Cold War began and sparked a race to develop the best technologies for defense and national pride. Many world leaders believed that if America and the West had better technology and living standards than the Soviet Union, then it proved that capitalism and democracy were better than communism (Neal et al. 2008). R&D spending dramatically rose and new agencies, such as the NSF, were created. The mission of the NSF, established through the National Science Foundation Act of 1950, committed the Foundation 'to promote the progress of science, to advance the national health, prosperity, and welfare; and to secure the national defense' (National Science Foundation 2019). From its inception, the NSF aimed to support science that had an impact on society.

From 1950 to 1997, the NSF had various policies to evaluate the merit of a potential award. In 1997, it made a major shift in its merit review process to require that grants be judged on two criteria, intellectual merit and BIs (National Science Board 2011). The intellectual merit criteria judge the proposal on how it will add to a scientific field, the extent the proposal is new and creative, and whether the proposal is feasible and well organized. The BIC evaluates the proposal on how well it does things such as promoting teaching and learning, broadening STEM participation, increasing scientific infrastructure, and researching topics that benefit society. Often, the BIC is grouped into eight categories (see Table 1), and, over the past decade, researchers have analyzed the distribution of BIs across NSF grants (Kamenetzky 2013; Nadkarni and Stasch 2013; Roberts 2009; Watts et al. 2015).

While the eight NSF BIC describe a variety of impacts, they do not specifically track who benefits from these interventions. Many innovations that are released are costly, and

Table 1. BI coding scheme of Roberts (2009).

Criteria for science	
Infrastructure for science	Creation of new research methodology, tools, or data sources that will be useful to advance science
Broadening participation	Recruiting or including underrepresented groups in research or in outreach efforts. Includes efforts to attract women to science and to keep them in the academic pipeline for all fields but excludes funding female students in biology and social sciences
Training and education	Includes mentoring undergraduates, graduate students, and postdoctoral fellows in the laboratory and teaching classes
Academic collaboration	Research collaborations with other universities in the USA or abroad
K-12 outreach	Outreach to kindergarten to 12th grade students or teachers helps to get kids excited about science and ensure a pipeline of future scientists. Note: In the USA, K-12 education is synonymous with primary and secondary education
Criteria for society	
Potential societal benefits	Direct claims that the research could help to inform policy, be useful for industry, or lead to some solution to a real-world problem. General statements of improved understanding of a natural or technical process (i.e. climate change or ecosystems) were not included
Outreach/broad dissemination	Dissemination of research results for non-academic audiences in any form (web site, seminars, meetings, and newspapers). Does not include K-12 outreach
Partnerships with potential users of research results	Includes partnerships with industry, non-profits, government bodies, and national labs

the benefits tend to concentrate in groups with high purchasing power, compounding inequalities (Bozeman 2020; Hicks 2012). For example, a recent analysis of NSF nanotechnology grants found that the majority of BIs either sustained or increased the status of advantaged groups (Woodson et al. 2021). These data contradict the discourse of an 'endless frontier' of research impacts that implies equal and universal benefits across the population (Bozeman 2020).

Although some critics argue that basic research should not be concerned with social outcomes or that such concerns distract scientists from their primary aims (Tretkoff 2007), other scholars demonstrate the value of equality and inclusion to the NSF's mission (Intemann 2009; National Science Foundation 2014). The NSF goes even further and says that inequality dulls the effects of BIs and curtails the potential to advance national health, prosperity, welfare, and security (National Science Foundation 2020a). Each of those four areas is positively correlated with levels of equality in society; and an increase in one area, such as wealth, is associated with an increase in another, such as health (Chetty et al. 2016; Thorbecke and Charumilind 2002). Equality and diversity are

Table 2. Inclusion-immediacy criterion (author generated).

		Immediacy of BIs		
		Intrinsic	Direct	Extrinsic
Inclusivity of BIs	Universal (everyone)	UI: Developing smart grid technology	UD: Collaborating with public sector utility	UE: Creating new K-12 curriculum
	Advantaged (status quo)	AI: Smart watches/fabrics, infrastructure for science	AD: Training undergraduate research assistants	AE: Developing new graduate course
	Inclusive (marginalized group)	II: Developing new malaria medicines	ID: Training under-represented groups in STEM	IE: Discussing STEM careers at a low-income high school

central goals of science funding agencies, such as the NSF, and, therefore, these factors should be studied to understand the effectiveness of scientific funding.

2.2 Inclusion-Immediacy Criterion

Measuring the distribution of R&D impacts across social groups helps scholars and policy makers understand the effects scientific research has on inequality and allows them to create policies that ensure that the benefits of science accrue to everyone (Fisher and Mahajan 2006; Hall et al. 2014; Rosenbloom and Ginther 2017). The framework used in this paper, the IIC, identifies the beneficiaries of R&D and how BIs are integrated into the research process (Woodson et al. 2021). The IIC includes two dimensions, inclusion and immediacy. Each dimension has three levels.

The inclusion dimension classifies the main beneficiaries of the funded research into three groups: advantaged (such as scientists or wealthy people), universal (everybody), and inclusive (marginalized or underrepresented). An example of research impact that benefits an advantaged group is purchasing equipment for a lab used by academics or advancing high-end technology available only to wealthy institutions, like creating a quantum computer. While the benefits from this research may eventually diffuse to the larger population, the primary benefit will be experienced by advantaged groups and/or maintain the status quo. Research impact that has universal benefits will, in general, be experienced by everyone. Often, universal BIs provide a public good, and people will benefit from the research even if they do not actively participate or purchase the end product. For example, research that improves primary school teaching practices or develops a better municipal water filter would be categorized as universal because everyone, all children and all water drinkers, would benefit from the research. Last, inclusive BIs focus on groups that are typically underserved or marginalized. A common example of an inclusive BI is a program that helps women, people of color, and people with disabilities advance in STEM fields. Immediacy characterizes the centrality of the BI to the research project itself.

The immediacy dimension has three levels: intrinsic, direct, and extrinsic. BIs are classified as intrinsic when the BIs are central to the main objective of the research. For example, if a project is developing carbon capture and sequestration technology, the research and societal benefits of reducing greenhouse gases overlap. It is not possible to separate the BI and the research; the BI is neither an add-on nor an optional component; it is intrinsic to the research. The second level of immediacy is direct. Direct BIs flow from the research but are not the specific goal of the research. Training graduate students is a quintessential direct BI. For most research grants, training a graduate student is not the purpose of the research. Rather, researchers train graduate students in order to complete a research project. The training is directly related to the research, but it is not the point or purpose of the research. Finally, the third level of immediacy is extrinsic. Extrinsic BIs are separate from the main intellectual merit of the research project, and often the project is only tenuously related to the BI. For example, if a cell biologist studying proteins creates a presentation for a local high school about STEM careers, the BI is extrinsic. The outreach to high-school students is a separate endeavor that takes place outside, or is extrinsic to, the research.

Each level of inclusivity intersects with a level of immediacy to create nine categories of BIs shown in Table 2. Based on these categories, we can quantify the distribution of impacts by whom they benefit and by how they are integrated into the research project. We can also identify how these categories interact (i.e. are some target groups more likely to benefit from intrinsic impacts than others?) and the extent to which incorporating BIs shifts the attention of scientists away from the research.

We apply both the BIC and the IIC to a random sample of NSF grants to determine the relative insights of the frameworks. This paper demonstrates the value of the IIC to reveal patterns that are not captured by the BIC. It also helps to identify how these patterns overlap across the two criteria. By considering these relationships, scholars can better gauge the types of research affecting society and the most efficient ways to generate BIs. The next section explains how we arrived at our sample, the limitations of our methods, and robustness checks of the coding process.

3. Data and methods

3.1 Sample

The data for this study were generated from a random sample of Project Outcome Reports (POR) for research that received NSF funding between 2014 and 2017. A POR is a mandatory report required by the NSF that is submitted by Principal Investigators following the completion of the grant. These are publicly available through the NSF website. PORs discuss the intellectual merit and BIs of the project and are written so that the public can understand the research and impact (National Science Foundation 2013).

PORs are useful documents for analyzing BIs because they give retrospective descriptions of grant activity. Grant abstracts, on the other hand, are prospective descriptions of the activity. A previous study found that researchers tend to propose more BI at the beginning of their projects than they report at their project's conclusion (Watts et al. 2015). Scholars also find that abstracts tend to be aspirational and incomplete in their descriptions (Burggren 2009), and scientists suggest BIs in their abstracts without providing plans for implementing them (Mardis et al. 2012). Using PORs allows us to analyze the grant's known and unforeseen impact. This approach reduces the incentive to propose idealized impacts simply due to the force of expectation (Sovacool and Hess 2017) and allows for the explanation of how the research evolved throughout the grant's time horizon. Consequently, PORs give a more accurate record of the grant impacts than abstracts.

It is important to note that no further documentation is required of NSF grantees after the submission of the POR. Given that BI may take time to unfold or even be known, scholars have criticized the short time frame of common impact evaluation practices (Penfield et al. 2014). Nevertheless, until a longer time frame monitoring strategy is implemented, PORs are the only reliable data source on NSF BI that allow examination on a broad scale. We, therefore, make the most of the available data in the current study.

For this analysis, we chose PORs from 2014 to 2017. Grants submitted before 2013 are not directly comparable because the NSF had different BI guidelines prior to 2013. Grants awarded after 2013 are more consistent in their reporting with respect to BIs. We had to limit the analysis to grants up to 2017 because most grants awarded after the 2017 award cycle were not completed at the time of analysis and, therefore, their PORs are not available. Across the 4 years of study, the NSF received 194,292 proposals and awarded 45,312 grants across all directorates (National Science Foundation 2020b). Once we downloaded the corpus of NSF grants from 2014 to 2017, we proceeded to exclude any grants that were still in process and did not have an accompanying POR.

Given the population of 45,312 grants awarded, we determined that a sample of 400 PORs allows us to draw conclusions at the 95 per cent confidence level. In the last stages of preparing the data for analysis, we removed three grants from the sample with ambiguous information. In one case, the grant did not include information about its funding directorate, and, in two cases, the grants had multiple directorates, and it was not possible to determine the lead directorate. Based on these data preparation procedures and accuracy checks, we are confident that our findings are representative of the composition of NSF awards.

3.2 Coding schemes

The PORs were coded using the BIC and the IIC. The BIC identifies common activities or applications of research that are considered BIs (see Table 1). While some of these activities have obvious beneficiaries (e.g. K-12 outreach benefitting elementary and high school students), the BIC does not specifically identify target audiences, nor does it indicate the extent to which the research project and the BIs are integrated. The IIC, on the other hand, provides insights in just these areas (See Table 2). Coding the data with both schemes allows us to capture how common activities (as identified by the BIC) translate to groups and how they are integrated into the research (as identified by the IIC).

3.3 Content analysis: manifest content coding

Content analysis is a method of data categorization by systematically coding text to identify and record the prevalence of themes. Codes are labels that assign meaning to the text (Miles et al. 2014). While content analysis can be used in a variety of ways to better understand textual data, we used this method to summarize the data numerically by calculating the frequency of each code. The coding process was closed, meaning that codes were determined in advance of analyzing the data. One code was created for each designation of the BIC and IIC, resulting in the application of 17 distinct codes to the sample data. We added an additional code to record instances of POR that included no BI.

When applying the codes, we used manifest content coding consistent with other studies of NSF BIs (Watts et al. 2015). Manifest coding is concerned with explicit and observable data; it does not require interpreting a deeper meaning from the text (Kleinheksel et al. 2020). This approach is the most faithful to the text and helps the team avoid bias in the analysis. Indeed, the breadth of NSF-funded research is vast. The NSF has seven directorates, encompassing hundreds of programs, cross-cutting initiatives, and special focus areas. It is impossible for any research team to be conversant in every type of funded project. Therefore, it was necessary to use manifest coding and strictly code the PORs based on what researchers wrote. This approach is the most transparent coding strategy that leads to higher intercoder reliability and easier replication by future scholars.

3.4 Intercoder reliability

Before the full sample was coded, we performed several consistency checks. Both authors trained on the BIC and IIC coding schemes, and each coded 30 PORs to test our reliability. After our first round of reliability testing, the Krippendorff Alpha reliability score was low. The researchers met to discuss differences and reach a consensus on how to code certain types of research projects. The codebook evolved in this process as we discussed how to classify types of activities and target audiences to ensure consistency. For example, we discussed whether attending conferences could be considered academic collaboration or training and education. Our conclusion was that sending graduate students to a conference was training and education, and hosting an academic conference with a partner university was an academic collaboration. If the conference recruited participants from minority groups underrepresented in STEM fields, we coded the BI as inclusive.

After discussing our differences, we did another round of intercoder reliability and got a Krippendorf Alpha score of 0.453. This score indicates that we have a moderate agreement (Hallgren 2012). When we analyzed the coder reliability for individual coding categories, we noticed several trends. First, we found high levels of agreement in fourteen of the sixteen categories of codes. The two categories that had lower agreement were Potential Societal Benefits, from the BIC, and Universal Intrinsic, from the IIC. Out of forty pairs of observations, the two coders only agreed on twenty six out of forty cases for Universal Intrinsic. In comparison, for K-12 outreach and advantaged extrinsic, the coders agreed on thirty nine out of forty cases. The two categories where we had higher levels of disagreement are acknowledged as particularly challenging to code given that expected and actual benefits are not always clearly distinct and that benefits for

Table 3. Descriptive information on the directorate, award, and funds of the data in the sample.

Directorate	Awards	BIC	IIC	Total funds awarded	Median award	SD
BIO	34	61	53	$14,478,405.00	$306,081.50	$315,456.51
CISE	35	59	51	$8,100,957.00	$150,000.00	$212,651.75
EHR	26	52	34	$9,125,311.00	$249,885.00	$293,941.75
ENG	93	171	119	$24,100,058.00	$200,000.00	$261,399.23
GEO	63	115	94	$15,962,529.00	$204,120.00	$193,386.98
MPS	93	162	151	$27,570,328.00	$223,482.00	$269,517.64
SBE	53	57	51	$7,562,766.00	$99,772.00	$144,850.16

Table 4. Correlations between BIs, awards granted, and funds awarded across directorates ($n=7$).

	Total BIC	Total IIC	# of awards granted	Total funds awarded (in dollars)
Total BIC	1.00			
Total IIC	0.96	1.00		
# of awards granted	0.96	0.95	1.00	
Total funds awarded (in dollars)	0.94	0.95	0.88	1.00

society, in general, are often ambiguously described (Von Schomberg 2013; Watts et al. 2015). When we removed the codes with low agreement and recalculated the Krippendorff alpha score, it raised to 0.637. This indicates substantial agreement between the coders (Hallgren 2012).

3.5 Descriptive statistics

Table 3 shows some basic descriptive information about the distribution of grants in the sample by a directorate. Directorates with the most awards are engineering (ENG) and Math and Physical Sciences (MPS). Not surprisingly, these directorates also awarded the largest amount of funding. Award size is highly variable, ranging from doctoral dissertation grants of $15,000 to major research grants over $1 million. The median award size ranges from $99,772 (standard deviation [SD] of $144,850) for SBE to $306,081 (SD $315,456) for BIO.

Table 4 shows high correlation between the number of awards, number of BICs, number of IICs, and total funds awarded listed in Table 3. The high correlation between the variables is not surprising. It is expected that more awards are associated with more funds distributed and more impacts. Furthermore, the IIC and BIC have a high correlation, 0.96. This suggests that the two measures are related even though they focus on different aspects of the impacts.

3.6 Limitations

3.6.1 Magnitude

Each code that was applied to the data was used only once per grant. In other words, if a POR included five different training and education activities, it would only be coded as training and education once. No file received more than one designation per code. This did not preclude multiple unique codes per file, as some PORs included BIs across a spectrum of activities and groups. For example, PORs could be coded K-12, academic collaboration, universal-direct, and universal-intrinsic.

Accordingly, BIs were coded as either present or absent and not adjusted based on the degree or extent of the potential impact. Therefore, training one graduate student is coded the same as training 10 graduate students. This rule was applied consistently across the two criteria. We took this approach to avoid undue inferences about the degree to which an impact was experienced. Neither the authors nor either of the criteria can sufficiently judge the magnitude of an impact. Most PORs do not give specific numbers related to their BIs, and we cannot determine whether one BI is better than another. For example, we could not reliably judge whether training one student in depth or training a group of students in a single workshop had different levels of impact. Indeed, this study does not (and cannot) give a full cost-benefit analysis of the BIs and their downstream effects. Other scholars have grappled with similar questions about impact *quality* and how to assess it over time (Burggren 2009). Accordingly, we focus on whether grantees report BIs, the type of impact they had, and who benefited from the BI activities.

3.6.2 Lack of detail

At times, the BIs in the PORS were vague and difficult to code. Some researchers included an aspirational statement about the potential impacts of their work without explaining the specific interventions intended to bring about those impacts. For example, one project reported, 'Future scientists trained to be environmentally-conscientious will benefit all of society'. We coded the project as including training and education but not for having potential societal benefits due to the tenuous link between the two. When faced with borderline cases, we gave the grant the 'benefit of the doubt' and coded them as having BIs. As a result, we may be overestimating the impact of NSF grants.

4. Findings and analysis

4.1 Comparing the BIC and IIC

The first analysis examined the number of awards per directorate and the distributions of BIs by the number of awards and funds disbursed using both the BIC and IIC. One major finding is that 40 of the grants, or 10 per cent of the sample, contained no clear BIs in their PORs that met either the IIC or BIC. These grants described scientific research processes but did not state how the research could benefit society. This finding supports other studies that find outcome reports may be valued more for form (was the report submitted?) than content (were outcomes achieved?) (Langfeldt and Scordato 2015).

Table 5 shows the cross-tabulation between the BIC and the IIC. These numbers indicate how BIC-identified impacts target different groups (advantaged, universal, and inclusive)

Table 5. Cross-tabulation of IIC and BIC frequencies[a,b].

	AC	BP	IfS	K12	OBD	PSB	PPURR	TEd	Total
AD	33	37	51	30	11	52	26	175	415
AE	1	0	1	1	1	2	0	2	8
AI	42	21	87	16	3	32	23	104	328
ID	12	42	11	14	2	17	6	43	147
IE	0	6	0	5	1	4	2	6	24
II	4	20	3	6	1	4	5	21	64
UD	6	12	9	17	3	36	15	26	124
UE	11	12	8	26	10	11	3	27	108
UI	7	10	10	12	0	29	11	16	95
Total	116	160	180	127	32	187	91	420	

[a]Please note that grants can contain multiple impacts, so the row and column totals can be more than 400.
[b]IIC categories are listed in the first column. BIC categories are listed across the top row. See Appendix 1 for list of acronyms.

Table 6. Relative frequency of BIs by millions of dollars awarded, by directorate.

Directorate	Relative BI/$M
BIO	7.87
CISE	13.58
EHR	9.42
ENG	12.03
GEO	13.09
MPS	11.35
SBE	14.28

Table 7. NSF average, relative frequency of BI/$M, by inclusion type.

Advantaged	Inclusive	Universal
3.27	0.75	1.14

and how they are integrated into the research (direct, extrinsic, and intrinsic). For example, it is evident that Training and Education activities (TEd) are most likely to coincide with advantaged direct (AD). Relative to the other categories, AD is the most common classification that suggests that NSF funding primarily serves advantaged groups.

4.2 Examining BIs by the directorate

To compare BIs between directorates, we standardized the data to control for the varying sizes of the directorates. To adjust for differences in total funds and awards granted, we calculated the relative frequency of BI by millions of dollars awarded for each directorate (see Table 6). These figures gave us an approximate 'cost' of impacts for the respective directorate. Although ENG and MPS have the most money and most impacts in the absolute sense (see Table 3), the relative frequencies show that CISE and SBE achieve BIs more efficiently.

We then normalized the number of IIC and BIC classifications based on the SD of award size (see Appendix 2 for full table). In a normal distribution, statistical theory indicates that 68 per cent of the sample will fall within 1 SD of the mean and 95 per cent of the sample will fall within 2 SDs of the mean. In order to focus large differences between directorates, we plot values greater than the absolute value of |1| SD.[2]

Table 8. Relative frequency of BI/$M by immediacy, NSF mean.

Direct	Intrinsic	Extrinsic
2.65	2.08	0.45

The primary observation from Fig. 1 is that most, 86 out of 117, BIC and IIC classifications across the directorates fall within 1 SD of the mean, and 28 out of 117 classifications fall in between 1 and 2 SDs. As a result, there is little evidence that the majority of BIC and IIC classifications for the directorates are different from each other when accounting for their size. However, SBE has significantly more grants classified as inclusive direct. This is due to more of SBE's grants engaging underrepresented groups. EHR has significantly more grants classified as intrinsic inclusive (II). EHR's strength in II makes empirical sense because the directorate tends to fund more grants that diversify STEM. Finally, GEO has significantly more grants classified as universal extrinsic (UE). UE grants have BI that helps everyone regardless of status and are extrinsic to the research.

4.3 Different directorates target different groups

When we collapse the data into the three main inclusion categories, it becomes clear that BIs for advantaged groups (3.27) are much more frequent than BIs for marginalized groups (0.75) or everyone (1.14) (see Table 7). These results confirm our hypothesis that most of NSF BIs benefit people from advantaged groups.

Figure 2 shows the variations among directorates by target beneficiaries for the BI. The lightest gray columns, representing inclusive impacts, are higher for EHR and SBE, whereas CISE is most likely to target advantaged groups. Although SBE is the leader for inclusive impacts (almost 2 SDs above the mean), it also ranks highly (1 SD above the mean) for advantaged groups. ENG and GEO are more likely than any other to generate impacts that can be enjoyed universally. BIO is below the NSF mean for all target groups.

To determine varying levels of immediacy across directorates, we collapsed inclusion levels to see more clearly how each discipline incorporated impacts in their research. Table 8 shows the relative frequency distribution of BI per million dollars by immediacy level for the NSF. Direct impacts are the most common, 2.65 direct BIs per 1 million awarded, followed by intrinsic. Extrinsic impacts are much less common. These data suggest that the concern that BI activities detract from scientists' primary research aims is relatively unfounded. The minority of research awards fund BI activities extrinsic to the research itself.

Figure 3 shows the normalized values for BI by immediacy level.

From Fig. 3, it is evident that the MPS and CISE are the most likely to achieve direct impacts relative to the NSF mean, followed closely by SBE. Intrinsic impacts are concentrated in the activities of SBE, CISE, and EHR. GEO is the only directorate that is above average for extrinsic BIs, standing almost 2 SDs above the NSF mean. However, GEO's large difference in extrinsic BIs may be somewhat exaggerated by the small number of extrinsic BIs across the sample.

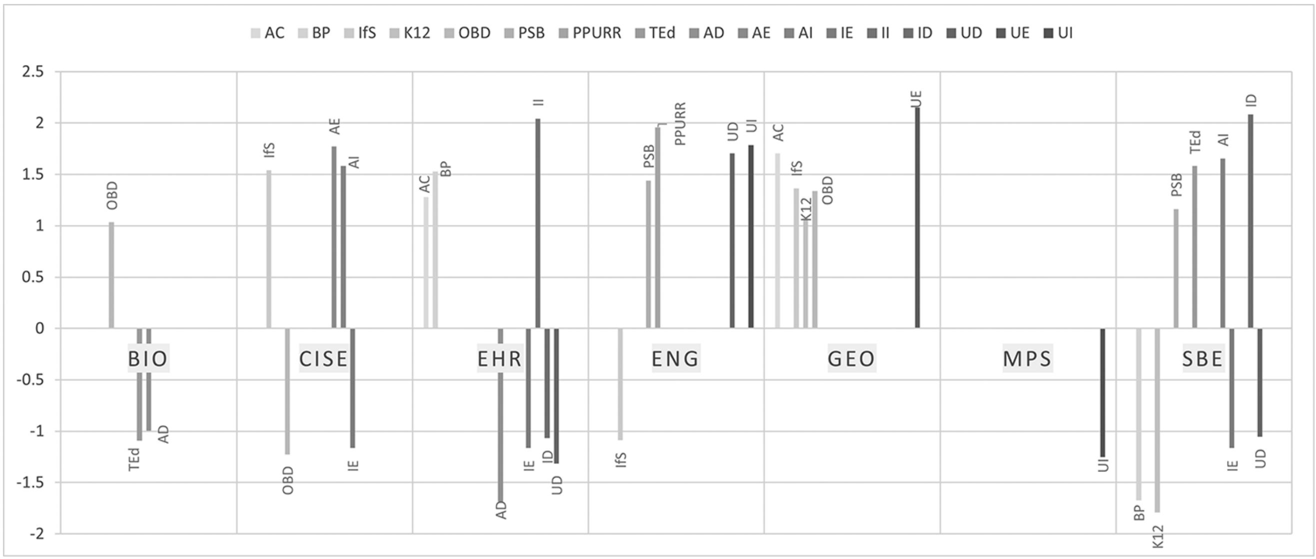

Figure 1. BIs by millions of dollars, normalized values greater than |1| SD unit.

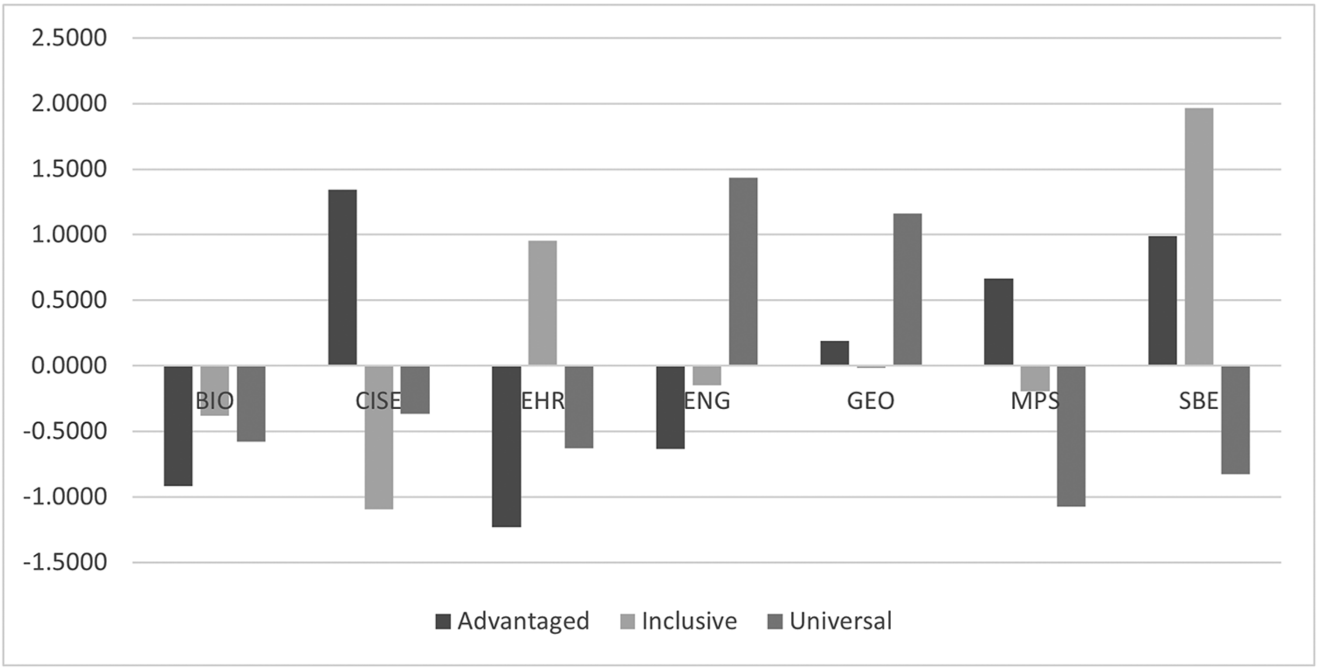

Figure 2. Average BI/Mn$ per directorate by inclusion.

5. Discussion

Using a statistically representative sample of NSF PORs from 2014 to 2017, we examined the distribution of BIs across levels of inclusion and immediacy and how each directorate performs on these measures. We also measured BIs using the NSF's BIC to compare that framework to the IIC. Overall, the analysis shows that the majority of BIs benefit advantaged groups no matter which directorate is funding the research. This finding is consistent with previous findings that inclusive impacts were the least common form of NSF BIs (Watts et al. 2015). When directorates are compared to the NSF mean, some stand out as more effective at reaching marginalized groups. In particular, one of the smaller directorates, SBE, funds the most BIs per dollars awarded, and it is well above the average for funding projects that help marginalized groups. Likewise, EHR, which gives out the fewest awards annually, also funds grants that have BIs that benefit marginalized groups at an above-average rate.

We also find that extrinsic impacts are in the minority, confirming previous findings that BIs do not cause scientists to redirect substantial research energies. Perhaps to be expected, given the concentration of BI for advantaged groups, Training and Education was the most common category of the BIC in the sample. While training and education are not inherently reserved for advantaged groups, we found that two-thirds of training activities (281/420, see Table 5) served advantaged

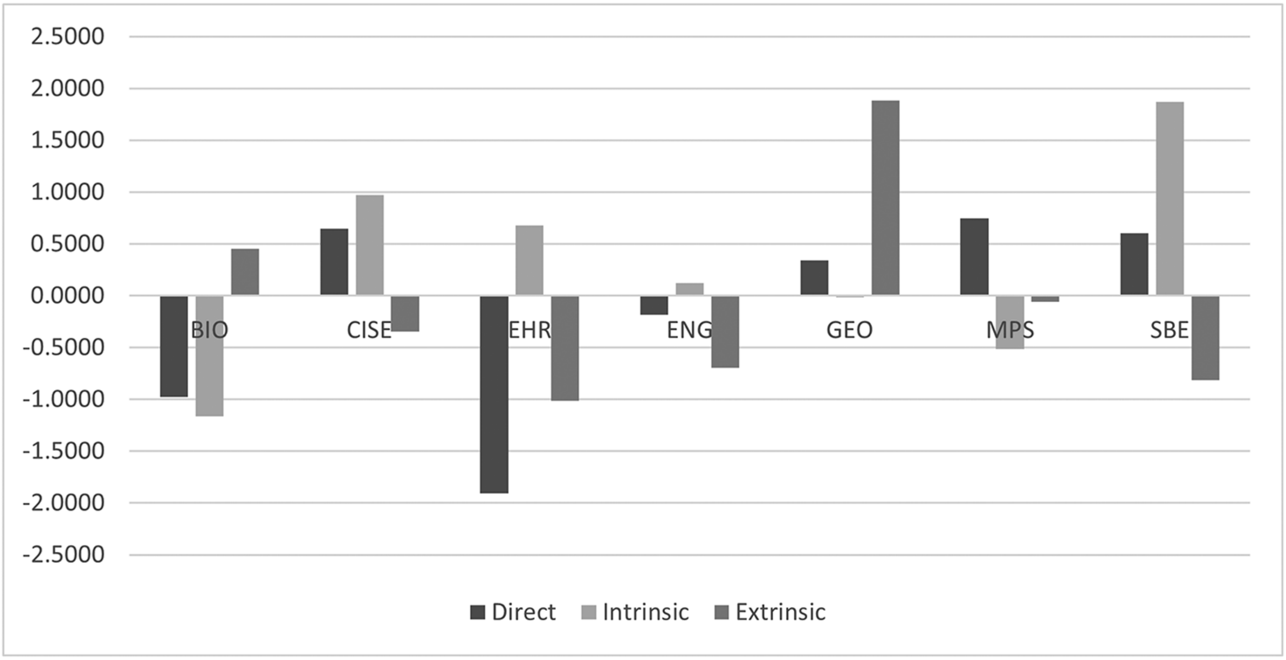

Figure 3. Avg BI/Mn$ by directorate by immediacy, normalized.

groups. This finding shows the value of using the two frameworks working together. Without the insights of the IIC, it would be difficult to determine the extent to which education activities identified by the BIC maintained or challenged the status quo. The current study helps us to recognize these patterns to inform science policy makers. For those who wish to increase the equity of BI, the IIC is a valuable tool for understanding how impacts (whether categorized by the BIC or not) reach wider society.

Despite the valuable insights of combining the frameworks and considering for whom BIs are beneficial, we note that it can be challenging to evaluate whether someone in a particular population group can actually access the benefits from the research. For example, some research, like developing a low-cost water filter system, can be very inclusive. However, there could be a variety of roadblocks, such as patents laws, distribution channels, or geo-politics, preventing a person in need from using the technology. Other researchers have also found it difficult to judge accessibility, and it is often cited as a limitation of evaluating BIs (Mardis et al. 2012; Von Schomberg 2013). To avoid inaccurate extrapolation, we assume that BIs reached the intended audiences even when access was uncertain. More in-depth follow-up monitoring may be required to track impacts from source to consumer.

5.1 Policy implications and recommendations

Science funding institutions have made it a priority to consider equality and diversity in their funding decisions. Diverse groups of scientists are more likely to solve problems for a broader segment of the population. More equality in society leads to higher levels of health (Chetty et al. 2016; Dewan et al. 2019; Walsh and Theodorakakis 2017), wealth (Ehrhart 2009; Neves et al. 2016; OECD 2015; Smeeding 2005), happiness (Oishi et al. 2011; Veenhoven 2012), and security (Hill 2014; Hurrell 1999), each of which serve the larger goals of the NSF mandate. If policy makers want to support more equitable research impacts, legislation is an effective tool to change research portfolios. (Asongu and Nwachukwu 2016; Hall et al. 2014; Rosenbloom and Ginther 2017). Accordingly, we recommend the following approaches to increase the equity of BIs.

R&D funding institutions can make commitments to inclusive research: If R&D funding institutions want to fund research that reduces inequality, they must make it an explicit goal. Others have shown that scientific outcomes often reflect the social context into which they are released (Mirowski and Van Horn 2005). To counter status quo inequalities, we recommend that the science funding institutions make equity a priority in their mission statements, funding criteria, and monitoring approaches.

Incentivize inclusive BIs: As an extension of prioritizing equity, R&D funding institutions should incentivize inclusive research. If institutions give more money and accolades to scientists that conduct inclusive research, then scientists will respond by doing more of this type of work. In the same vein, proposal reviews and evaluations should ensure that scientists fulfill their obligations discussed in proposals. Institutions should disincentivize vague and incomplete attempts at BIs and reward concrete descriptions of *how* BIs are achieved and *for whom.*

Monitor inclusivity of BIs overtime: Policy makers and researchers must monitor and evaluate BIs of science funding organizations and measure how policy changes impact R&D proposals and outcomes. This paper offers a baseline for the equity of BIs by coding a representative sample of NSF grants. If the NSF introduces new incentives for inclusive research, it will be important to reevaluate the distribution of BIs across inclusion to measure the policy's effectiveness over time.

Provide a separate funding line for BIs: Although our data show that achieving BIs does not necessarily distract researchers from the core research project, other scholars note that researchers will try to get the most research out of their grant, thereby potentially reducing their focus on BIs (Bozeman and Boardman 2009). To avoid incentivizing the least expensive BI possible, BI funding could be earmarked separately. This may require adapting reporting approaches to account for activities where there is a high degree of overlap between the research and impact activities. However, requiring a discrete BI budget can help scientists to prioritize BI implementation and make it clear that BIs are not competing with the underlying research.

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Notes

1. See Appendix 1 for all acronyms used throughout the paper.
2. Columns above the central axis have impacts per dollar spent that are above the NSF average and columns below the central axis have impacts per dollar spent that are below the NSF average.

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Appendix 1. Acronyms of key terms

Acronym	Definition
AC	Academic Collaboration (BIC designation)
AD	Advantaged Direct (IIC designation)
AE	Advantaged Extrinsic (IIC designation)
AI	Advantaged Intrinsic (IIC designation)
BI	Broader Impact
BIC	Broader Impact Criteria
BIO	Biological Sciences (NSF Directorate)
BP	Broaden Participation (BIC designation)
CISE	Computer and Information Science and Engineering (NSF Directorate)
EHR	Education and Human Resources (NSF Directorate)
ENG	Engineering (NSF Directorate)
EU	European Union
GEO	Geosciences (NSF Directorate)
ID	Inclusive Direct (IIC designation)
IE	Inclusive Extrinsic (IIC designation)
II	Inclusive Intrinsic (IIC designation)
IIC	Inclusion-Immediacy Criteria
IfS	Infrastructure for Science (BIC designation)
K-12	Kindergarten to Grade 12 (BIC designation)
MPS	Mathematical and Physical Sciences (NSF Directorate)
NSF	National Science Foundation
OBD	Outreach and Broad Dissemination (BIC designation)
PI	Principal Investigator
PURR	Partnerships with Potential Users of Research Results (BIC designation)
POR	Project Outcome Report
PSB	Potential Societal Benefits (BIC designation)
RRI	Responsible Research and Innovation
SBE	Social, Behavioral and Economic Sciences (NSF Directorate)
STEM	Science, Technology, Engineering, Mathematics
TEd	Training and Education (BIC designation)
UD	Universal Direct (IIC designation)
UE	Universal Extrinsic (IIC designation)
UI	Universal Intrinsic (IIC designation)

Appendix 2. Normalized values of BI/millions by directorate. Positive values are highlighted in light gray and negative values are highlighted in dark gray.

	AC	BP	IfS	K12	OBD	PSB	PPUR	TEd	AD	AE	AI	IE	II	ID	UD	UE	UI
BIO	−0.86	−0.05	−0.09	0.22	1.04	−0.89	−0.79	−1.09	−1.00	−0.77	−0.64	1.29	−0.52	−0.20	−0.59	0.31	−0.84
CISE	0.17	−0.88	1.54	−0.76	−1.22	0.45	0.18	0.82	0.86	1.77	1.58	−1.16	−0.74	−0.39	0.26	−0.46	−0.40
EHR	1.28	1.53	−0.78	0.95	−0.33	−0.96	−0.51	−0.57	−1.69	−0.77	−0.47	−1.16	2.04	−1.07	−1.31	−0.58	0.37
ENG	−0.69	−0.05	−1.09	−0.41	−0.55	1.44	1.96	−0.88	−0.52	0.08	−0.68	−0.43	0.18	−0.38	1.70	−0.64	1.79
GEO	1.70	0.38	1.36	1.08	1.34	−0.29	−0.99	0.14	0.37	−0.77	0.01	−0.05	−0.35	0.47	−0.42	2.15	0.37
MPS	−0.27	0.06	0.08	0.02	−0.63	−0.76	−0.60	0.78	0.98	0.72	0.16	0.77	−0.40	0.06	−0.29	−0.42	−1.25
SBE	−0.50	−1.67	−0.23	−1.79	0.94	1.16	−0.03	1.58	0.34	−0.77	1.66	−1.16	0.94	2.08	−1.06	−0.38	−0.33