

Citation Impact of NHLBI R01 Grants Funded Through the American Recovery and Reinvestment Act as Compared to R01 Grants Funded Through a Standard Payline

Narasimhan S. Danthi, Colin O. Wu, Donna M. DiMichele, W. Keith Hoots, Michael S. Lauer

Rationale: The American Recovery and Reinvestment Act (ARRA) allowed National Heart, Lung, and Blood Institute to fund R01 grants that fared less well on peer review than those funded by meeting a payline threshold. It is not clear whether the sudden availability of additional funding enabled research of similar or lesser citation impact than already funded work.

Objective: To compare the citation impact of ARRA-funded de novo National Heart, Lung, and Blood Institute R01 grants with concurrent de novo National Heart, Lung, and Blood Institute R01 grants funded by standard payline mechanisms.

Methods and Results: We identified de novo (type 1) R01 grants funded by National Heart, Lung, and Blood Institute in fiscal year 2009: these included 458 funded by meeting Institute's published payline and 165 funded only because of ARRA funding. Compared with payline grants, ARRA grants received fewer total funds (median values, \$1.03 versus \$1.87 million; $P<0.001$) for a shorter duration (median values including no-cost extensions, 3.0 versus 4.9 years; $P<0.001$). Through May 2014, the payline R01 grants generated 3895 publications, whereas the ARRA R01 grants generated 996. Using the InCites database from Thomson-Reuters, we calculated a normalized citation impact for each grant by weighting each article for the number of citations it received normalizing for subject, article type, and year of publication. The ARRA R01 grants had a similar normalized citation impact per \$1 million spent as the payline grants (median values [interquartile range], 2.15 [0.73–4.68] versus 2.03 [0.75–4.10]; $P=0.61$). The similar impact of the ARRA grants persisted even after accounting for potential confounders.

Conclusions: Despite shorter durations and lower budgets, ARRA R01 grants had comparable citation outcomes per \$million spent to that of contemporaneously funded payline R01 grants. (*Circ Res.* 2015;116:784-788. DOI: 10.1161/CIRCRESAHA.116.305894.)

Key Words: bibliometrics ■ economics

When Congress enacted the American Recovery and Reinvestment Act (ARRA) in 2009, the National Institutes of Health (NIH) was faced with an unprecedented opportunity and challenge of quickly assembling and supporting a portfolio of short-term grants that under normal circumstances would not have been funded. The ARRA came in the midst of a continuous decline in real NIH dollars available for extramural research support; the decline continued after the ARRA program ended.¹ National Heart, Lung, and Blood Institute (NHLBI) chose to spend some of its ARRA (or stimulus) funds on shovel ready R01 grants that had undergone peer review in fiscal year (FY) 2008 and FY 2009 but had not been funded due to failure to meet the Institute's payline.² NHLBI program staff contacted investigators whose grants

were within 10 percentile points of the 2009 payline and asked them to revise the scope and the budget of their projects that were originally proposed for 4 to 5 years to fit into the ARRA 2-year time frame. As noted by others, the sudden ability of NIH institutes to fund grants that missed paylines effectively created a natural experiment of the impact of additional research funding on scientific productivity.³ Because the newly funded grants fared less well on peer review and were subject to budgetary and calendar restrictions, we might surmise that their productivity per dollar would be lower than that seen for payline grants. We therefore decided to compare the citation impact of ARRA-funded de novo NHLBI R01 grants with concurrent de novo NHLBI R01 grants funded by standard payline-based mechanisms.

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Nonstandard Abbreviations and Acronyms	
ARRA	American Recovery and Reinvestment Act
FY	fiscal year
LOWESS	locally weighted scatterplot smoothing
NHLBI	National Heart, Lung, and Blood Institute
NIH	National Institutes of Health

Methods

Study Sample

We included all de novo (type 1) FY 2009 NHLBI-funded R01 research grants along with their subsequent noncompeting (type 5) and competing (type 2) renewals. There were 458 grants funded by meeting Institute’s published payline (payline R01 grants) and 165 funded only because of ARRA funding (ARRA R01 grants).

Data Collection

Using publically accessible NIH Research Online Portfolio Reporting Tools (RePORT, <http://projectreporter.nih.gov>), we recorded data for each grant on project start and end dates (including no-cost extensions), budget start and end dates, total funding, and publications. We supplemented these data with internally available data on use of vertebrate animals, involvement of human research subjects, performance of clinical trials, amount of requested funding and duration, the principal investigators’ prior NIH funding (number of prior funded projects and amount of prior funding), and previous participation in meetings of NIH study sections, special emphasis panels, and advisory councils. We defined early stage investigators as a new investigator who was within 10 years of completing his/her terminal research degree or medical residency (or equivalent).

Outcomes

We used InCites, a database developed by Thomson-Reuters to measure citation impact. For each article, InCites provides a

Table 1. Grant Characteristics According to Mechanism

	R01	R01 (ARRA)	Test Statistic
	n=458	n=165	
Percentile ranking	6/10/14	20/23/25	$F=469, P<0.001$
Project duration, y	4.8/4.9/5.0	2.8/3.0/3.3	$F=300, P<0.001$
Total award, \$M	1.56/1.87/2.29	0.83/1.03/1.63	$F=171, P<0.001$
Requested budget, \$M	1.8/1.9/2.3	1.8/1.9/2.4	$F=0.68, P=0.41$
Clinical trial	7% (33)	7% (11)	$\chi^2=0.05, P=0.82$
Human study	44% (201)	35% (57)	$\chi^2=4.4, P=0.037$
Animal study	64% (293)	67% (110)	$\chi^2=0.39, P=0.54$
Early stage investigator	19% (88)	9% (15)	$\chi^2=9.0, P=0.003$
Prior council meetings	0/0/0	0/0/0	$F=0.0, P=0.95$
Prior study section meetings	0/3/13	0/3/9	$F=0.2, P=0.66$
Prior SEP meetings	1.0/5.5/12.0	2.0/4.0/11.0	$F=1.3, P=0.26$
Prior projects	1/2/5	1/3/4	$F=0.15, P=0.70$
Prior total funding, \$M	0.47/1.89/7.96	0.61/2.66/8.11	$F=0.97, P=0.33$

Continuous variables are presented as *a/b/c* where *a*=25th percentile, *b*=median, and *c*=75th percentile. Categorical variables are presented as percent (number). Note that there were no nonmissing values, except for percentile ranking, for which there were data for 389 R01 grants and 160 R01 (ARRA) grants. Continuous variables were compared with the Wilcoxon test and categorical variables with the Pearson test. ARRA indicates American Recovery and Reinvestment Act; and SEP, special emphasis panel.

Table 2. Bibliometric and Economic Outcomes by Mechanism

	R01	R01 (ARRA)	Test Statistic
	n=458	n=165	
Publications	3/7/11	2/4/8	$F=17, P<0.001$
Normalized citation impact	1.59/3.82/7.58	0.87/2.84/4.91	$F=14, P<0.001$
Top 10% publications	0.0/1.0/2.5	0.0/0.0/2.0	$F=7, P=0.008$
Publications per \$M	1.3/3.3/6.3	1.3/3.6/7.2	$F=0.64, P=0.42$
Normalized citation impact per \$M	0.75/2.03/4.10	0.73/2.15/4.68	$F=0.27, P=0.61$
Top 10% publications per \$M	0.00/0.52/1.29	0.00/0.00/1.26	$F=1.5, P=0.23$

Continuous variables are presented as *a/b/c* where *a*=25th percentile, *b*=median, and *c*=75th percentile. Comparisons were made with the Wilcoxon test.

percentile value, which is a measure of how often the article was cited compared with articles that were published in the same year, were of similar type (review, research, report, book chapter, etc), and focused on the same scientific topic.⁴ Thus, a highly cited article that received more citations than another similar article (by year, type, and topic) has a percentile value close to zero, whereas articles that received no citations have percentile values of 100. By using the formula $[(100 - \text{InCites percentile})/100]$, a normalized citation impact score per publication was obtained, where 1 has the highest citation impact within its group and 0 has the lowest.⁵ We calculated the normalized citation impact per grant by adding the normalized impact scores for each of its publications. Our primary grant-based end point was normalized citation impact per \$million spent. Secondary outcomes included number of publications, normalized citation impact, number of top 10% publications (ie, among the top 10% cited stratified by subject, publication year, and article type), number of publication per \$million spent, and number of top 10% publications per \$million spent.

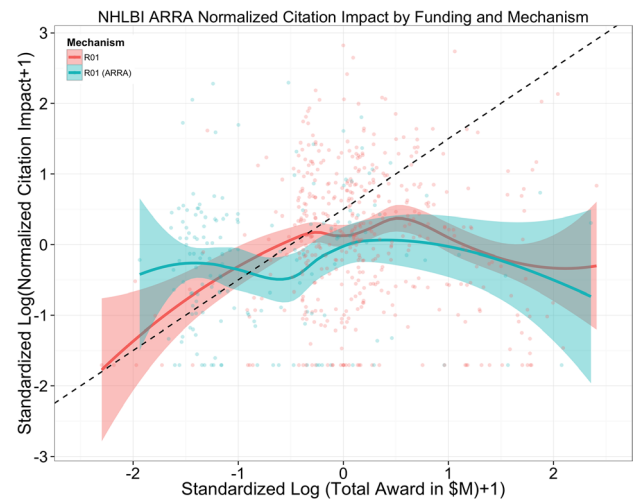


Figure 1. Scatter plots with locally weighted scatterplot smoothing smoothers and confidence ranges of normalized citation impact according to total award dollars and grant funding mechanism. Both the x-axis and y-axis values are logarithmically transformed and standardized (to allow for meaningful comparisons). The dotted line represents a slope of 1, corresponding to a state in which a standardized unit increase of funding would be associated with a standardized unit increase of citation impact. The slopes <1 correspond to expected diminishing marginal returns. ARRA indicates American Recovery and Reinvestment Act; and NHLBI, National Heart, Lung, and Blood Institute.

Statistical Methods

Descriptive statistics for the continuous variables of the project characteristics, such as project duration and total award in million dollars, were presented using quartiles (1st quartile, median, 3rd quartile) and compared using the *F* tests for the payline R01s and the ARRA R01s. For categorical variables, such as clinical trials and human and animal research, descriptive statistics were presented using percent and counts and compared using the χ^2 tests for the 2 types of grants. Multivariable linear regression models were used to describe the associations of normalized citation impact per \$million spent with grant types (payline R01s versus ARRA R01s) after accounting for potential grant-based confounders, including peer-review grant percentile ranking (if available), total award in \$millions, project duration, involvement of vertebrate animals and human research subjects, and performance of a clinical trial, and investigator-based confounders, including early-stage/new-investigator status, prior NIH funding, number of prior NIH grants, and prior service on NIH study sections, special emphasis panels, and advisory councils. To evaluate the potential nonlinear effects of total award (in \$million) on the outcome measures of grant productivity, nonparametric regression method based on locally weighted scatterplot smoothing was used to estimate the mean grant productivity as a smooth function of total award, where natural logarithmic transformations were applied to both the outcome measures of grant productivity and the covariates to reduce skewedness. Scatter plots were used to present the distributions of grant productivity outcome measures and the locally weighted scatterplot smoothing estimates.

Further analysis of the independent associations of grant types, total awards in million dollars, and other covariates with grant

productivity outcome measures was carried out using the machine learning method of Breiman's random forests.^{6,7} This analysis was intended to produce a robust, unbiased, and flexible assessment of the complex associations, which led to the relative importance of the independent predictors. Statistical results were produced using the R statistical packages RMS, Hmisc, GAM, ggplot2, and RandomForestSRC.

Results

Grant and investigator characteristics of 458 payline R01s and 165 ARRA R01s are shown in Table 1. The ARRA R01s were shorter in duration and lower in budget, but were otherwise similar to the payline R01s. The ARRA R01 grant recipients did not have prior knowledge of ARRA funding, and their original proposals were not tailored to any ARRA funding solicitations. Peer-review grant percentile values were obtained for 549 grants; the remaining 74 grants were reviewed by special study sections and therefore were not assigned a percentile value.

The payline R01s yielded 3895 publications and a normalized citation impact of 2586. There were 954 publications (24%) that were top 10% publications, publications that had a citation percentile (stratified by subject, year, and article type) $\leq 10\%$; there were correspondingly 126 (3.2%) top 1%

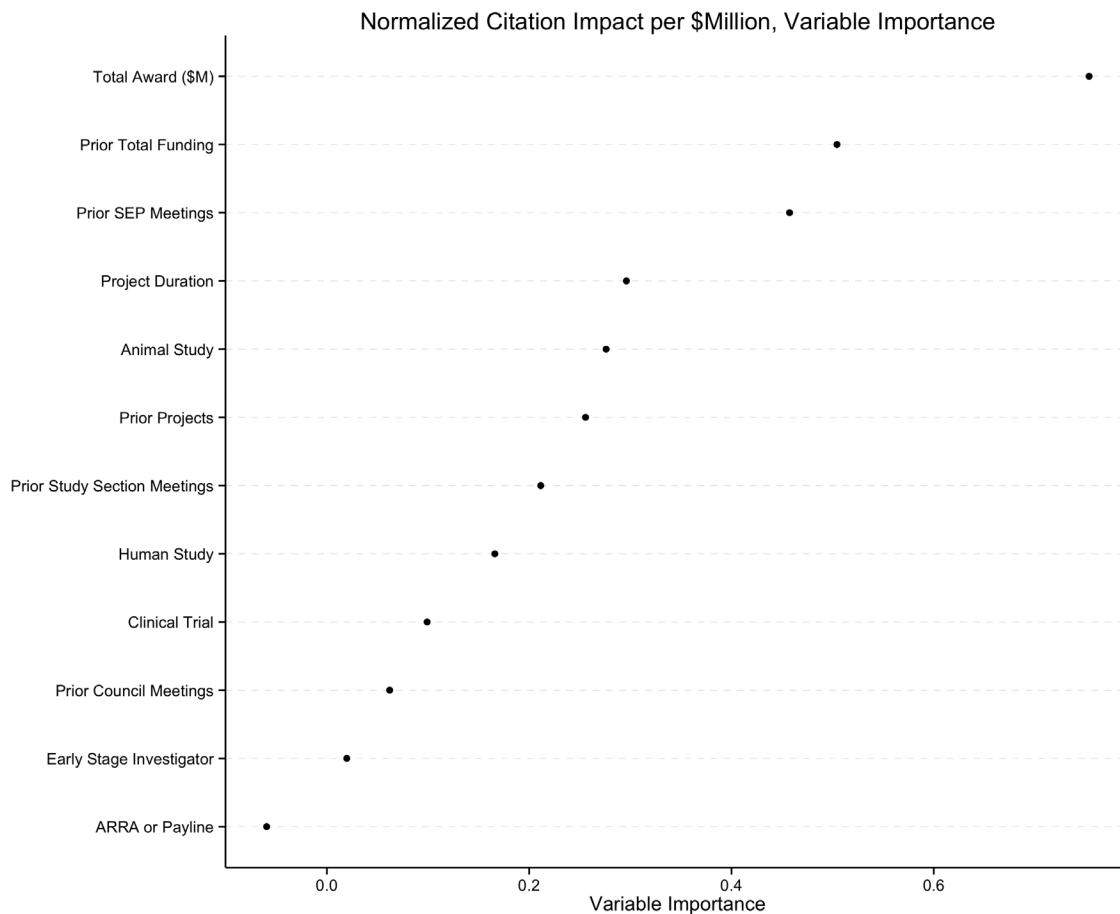


Figure 2. Results of random forest regression showing variable importance values. The most important variable for prediction of normalized citation impact per \$million spent was total award; the second most important was an investigator's prior total funding. The funding mechanism (American Recovery and Reinvestment Act [ARRA] or payline) was the least important predictor. SEP indicates special emphasis panel.

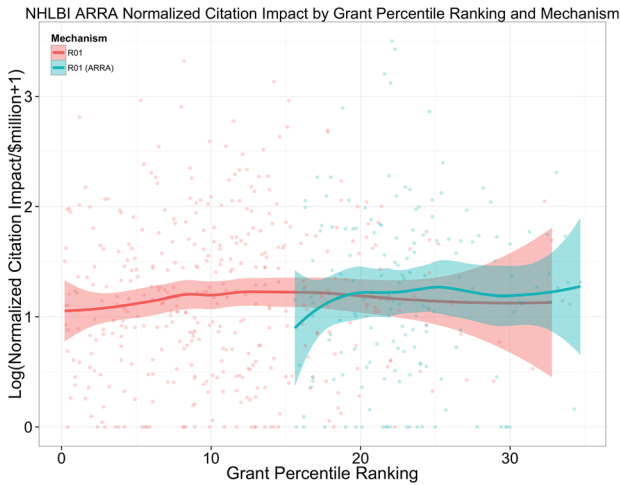


Figure 3. Scatter plots with locally weighted scatterplot smoothing smoothers and confidence ranges of normalized citation impact per \$million spent according to grant percentile ranking and grant funding mechanism. ARRA indicates American Recovery and Reinvestment Act; and NHLBI, National Heart, Lung, and Blood Institute.

publications. The 165 ARRA R01s yielded 996 publications and a normalized citation impact of 651, with 231 (23%) top 10% publications and 24 (2.4%) top 1% publications.

Bibliometric outcomes of payline and ARRA R01 grants are shown in Table 2. The payline R01 grants yielded more articles and had higher normalized citation impacts (Table 2), but the differences between payline and ARRA R01 grants disappeared when accounting for \$million spent (Table 2; Figure 1). In multivariable regression analyses, the mechanism of funding continued to be unrelated to normalized citation impact per \$million ($P=0.82$). By random forest machine learning regression, the grant mechanism (ARRA or payline) was the least important predictor, whereas the total award amount was the most important predictor (Figure 2).

When we confined our analyses to those grants that were assigned a peer-review percentile ranking, we found that neither the grant mechanism nor the grant percentile ranking was associated with normalized citation impact per \$million (Figure 3). By random forest machine learning regression, both of these variables emerged as relatively unimportant predictors (Figure 4).

Discussion

We analyzed the citation impact of NHLBI-funded R01s that received funding in FY 2009, the year that the ARRA was passed and implemented. We found that R01s that met the

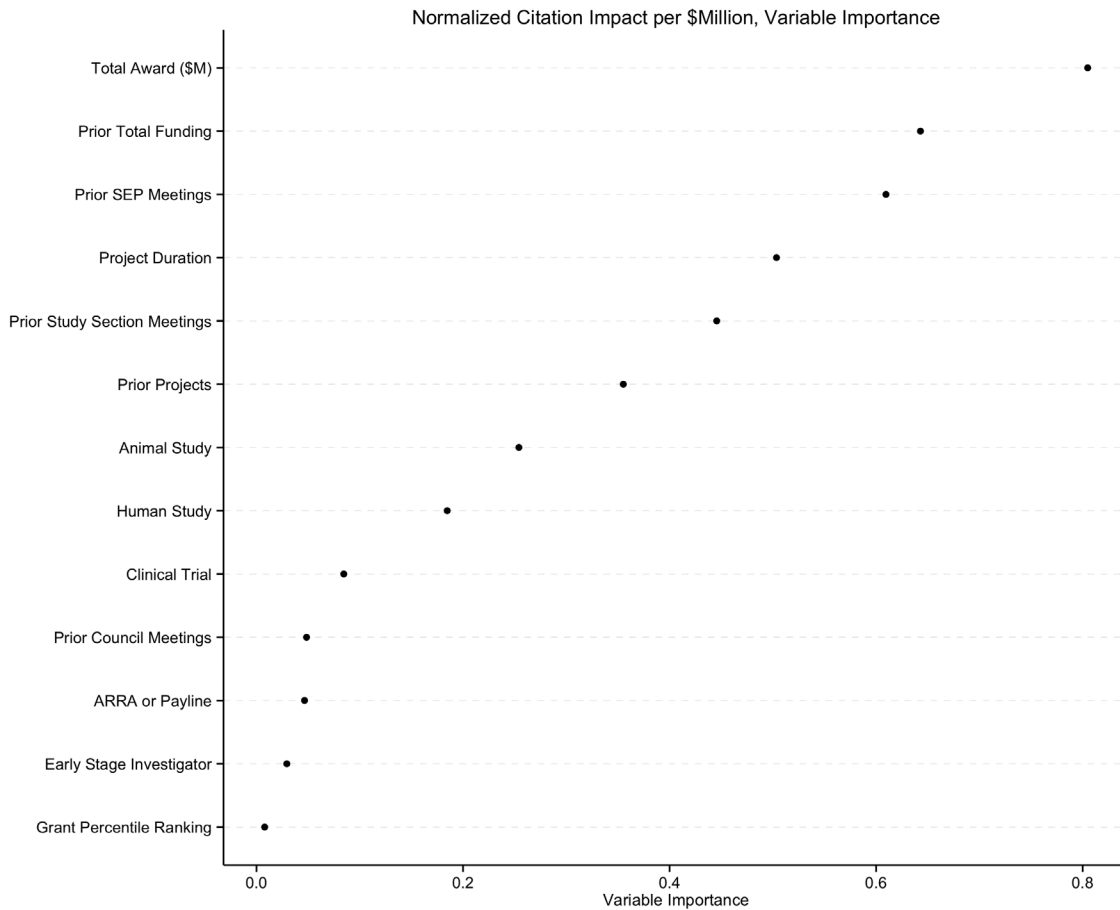


Figure 4. Results of random forest regression showing variable importance values for those grants that received a peer review percentile ranking. The most important variable for prediction of normalized citation impact per \$million spent was total award; the second most important was project duration followed by an investigator’s prior total funding. The funding mechanism (American Recovery and Reinvestment Act [ARRA] or payline) was the least important predictor. SEP indicates special emphasis panel.

funding guidelines for FY 2009 and were funded with funds from regular appropriations yielded more publications and citation impact than those that were funded using ARRA funds. However, after we accounted for the lower budgets allocated to ARRA R01s, we found that both types of grants yielded similar citation impacts per \$million spent. We further found no association between grant percentile ranking and citation impact, confirming our previous findings but on a completely different set of R01 grants.^{5,8}

Park et al³ recently posted a similar analysis comparing outcomes of regular NIH grants with NIH ARRA grants. They found that these 2 mechanisms yielded similar measures of productivity, which they defined as the number of publications per project, and the respective citations along with the journal impact factor of those publications. Although their findings are consistent with ours, there are some important differences. Our analysis focused on R01 grants only, and we used InCites, a tool developed by Thomson-Reuters to derive the publication ranking, which is a measure of how often the articles are cited compared with articles that were published in the same year, similar type (review, research, report, book chapter, etc), and similar scientific area. This approach is arguably more robust than a focus on raw publication and citation counts or impact factors, which have been criticized for their failure to account for different publication/citation behaviors varying across scientific disciplines.⁴ Nonetheless, our findings are consistent with their conclusion that a dollar increase in public research funding from the current scale would produce an equivalent level of scientific knowledge as a current dollar does.³

There are some important limitations in our analyses. We only measured citation impact but did not consider other measures of scientific impact, such as study quality according to other measures, long-term importance of specific discoveries, replication, data sharing, and translation—all measures that deserve attention but were beyond the scope of this study.⁹ As we have acknowledged before, citation measures reflect only one measure of scientific productivity and impact.^{5,8} Traditional citation counts have been viewed as suspect, particularly because of their failure to account for highly variable citation behaviors within disciplines (eg, due to the number of investigators and journals).⁴ Nonetheless, we did use a measure—normalized citation impact—that accounts for discipline-based variations and that has been considered by external authorities as useful and validated.¹⁰ Beyond differences in budget and project duration, we did not consider the specific actions of program staff in postreview reshaping, reshaping that by statute was considerable for the ARRA grants. We also did not consider nontangible inputs into scientific publications.

Despite these limitations, we present evidence that, at least according to the metrics we considered, ARRA enabled NHLBI to support additional R01 grants that were just

as productive—in terms of citation impact per dollar—as payline-supported R01 grants. This finding may have policy implications and is consistent with Augustine's contention that "with a mere 0.2% of Gross Domestic Product currently being devoted to federally funded basic research of all kinds ... it would seem that we are far from any danger of overinvesting."¹¹

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Disclosures

None.

References

1. Moses H III, Dorsey ER. Biomedical research in an age of austerity. *JAMA*. 2012;308:2341–2342.
2. Lauer MS. National Heart, Lung, and Blood Institute and the American Recovery and Reinvestment Act of 2009: 1 year later. *J Am Coll Cardiol*. 2010;56:234–236. doi: 10.1016/j.jacc.2010.03.042.
3. Park H, Lee J, Kim B. Less bang for the buck? A natural experiment in NIH funding [Internet]. 2014. Available at: http://www.econ.gatech.edu/files/papers/NIHARRA_RP.pdf. Accessed December 17, 2014.
4. Borrmann L, Marx W. How good is research really? Measuring the citation impact of publications with percentiles increases correct assessments and fair comparisons. *EMBO Rep*. 2013;14:226–230. doi: 10.1038/embor.2013.9.
5. Kaltman JR, Evans FJ, Danthi NS, Wu CO, DiMichele DM, Lauer MS. Prior publication productivity, grant percentile ranking, and topic-normalized citation impact of NHLBI cardiovascular R01 grants. *Circ Res*. 2014;115:617–624. doi: 10.1161/CIRCRESAHA.115.304766.
6. Ishwaran H, Kogalur UB, Gorodeski EZ, Minn AJ, Lauer MS. High-dimensional variable selection for survival data. *J Am Stat Assoc*. 2010;105:205–217.
7. Gorodeski EZ, Ishwaran H, Kogalur UB, Blackstone EH, Hsieh E, Zhang ZM, Vitolins MZ, Manson JE, Curb JD, Martin LW, Prineas RJ, Lauer MS. Use of hundreds of electrocardiographic biomarkers for prediction of mortality in postmenopausal women: the Women's Health Initiative. *Circ Cardiovasc Qual Outcomes*. 2011;4:521–532. doi: 10.1161/CIRCOUTCOMES.110.959023.
8. Danthi N, Wu CO, Shi P, Lauer M. Percentile ranking and citation impact of a large cohort of National Heart, Lung, and Blood Institute-funded cardiovascular R01 grants. *Circ Res*. 2014;114:600–606. doi: 10.1161/CIRCRESAHA.114.302656.
9. Ioannidis JP, Khoury MJ. Assessing value in biomedical research: the QRST of appraisal and reward. *JAMA*. 2014;312:483–484. doi: 10.1001/jama.2014.6932.
10. Informing Research Choices: Indicators and Judgement. *The Expert Panel on Science Performance and Research Funding*. Ottawa, Canada: Council of Canadian Academies; 2012.
11. Augustine NR. Is biomedical research a good investment? *J Clin Invest*. 2014;124:5087–5089. doi: 10.1172/JCI79617.

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