ORIGINAL RESEARCH

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Factors associated with cumulative research funding of investigators from CIHR – a major health-research funding agency

Abstract

Purpose: Few systematic studies have focused on determinants of cumulative research funding (CRF), a measure of research productivity among career researchers world-wide. Using researchers funded by the Canadian Institutes for Health Research (CIHR), this exploratory study quantifies the association between CIHR-investigator roles and CRF obtained from the CIHR.

Methods: CIHR grants and awards obtained in fiscal years 1999-2006 by non-trainee principal investigators (PI) and by supervisors of CIHR trainee awards were used to determine investigator-level CRF. Log-transformed CRF was regressed on investigator role as CIHR-salary award recipient or supervisor of CIHR-trainee award recipients after adjustment for number of project-years, research area, and PI status. Number of publications in life sciences and biomedical journals from January 2000 to August 2007 was compared among 80 randomly-selected CIHR-investigators who were supervisors (n=40) and non-supervisors (n=40). Reported results were considered significant at P-value < 0.05.

Results: Multiple regression analysis based on 6515 CIHR-investigators indicated that salary award recipients were associated with a 29.5% higher CRF but the magnitude of this positive association was inversely associated with time since first receiving salary award. Supervisors were associated with, on average, a 13.1% decrease in CRF; increasing numbers of trainees supervised was associated with decreasing CRF. Earlier recipients of grants and salary awards were more likely also supervisors. The median number of publications for supervisors was higher than that for non-supervisors (31 *vs.* 11.5).

Conclusions: Demonstrated associations between investigator-level CRF and predictors suggest that CRF should be considered in the context of investigators' multiple roles. The study, without establishing causality, also documents evidence of multi-lateral returns to the enterprise of academic research from salary and trainee awards. The major limitation is that CRF and predictors are derived from a single funding agency. Findings should be viewed as preliminary and should serve to develop hypotheses for future, comprehensive research.

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Few systematic, analytical studies have determined investigator-level factors associated with research productivity. Cumulative research funding (CRF) is often being used as one measure of research productivity [1-6]. Among career researchers, longevity in research was shown to increase CRF obtained by individual investigators [1]. Longevity in academic research is typically accompanied by teaching, mentoring, administrative, and clinical responsibilities [7]. To what extent competing academic roles and responsibilities influence traditional research productivity has not been documented.

The objective of the present, exploratory study was to quantify the associations between investigator roles and CRF obtained from the Canadian Institutes for Health Research (CIHR), the government of Canada's health research funding agency. Although not all-inclusive, data from national research funding agencies have been used previously to describe trends and factors influencing research funding at aggregate levels, and also to define success at research [4,8-11]. Also, CIHR was the most frequent source of peer-reviewed grant funding among a cohort of Canadian researchers [1]. Therefore, an assumption in the present study was that CIHR funding was a reasonably good indicator of trends in research funding obtained by individual investigators.

Materials and Methods

The CIHR Funded Research database is a publicly-available, project-based online database that provides basic information on open-competition, peer-reviewed funding granted by the CIHR from fiscal year 1999-2000 [12]. Project commitments made previously by the Medical Research Council of Canada and duly honoured by the CIHR are also included in the database. The database, which is comprised of text fields such as principal investigator (PI), supervisor and co-investigator, funding program, and research theme, numerical fields such as the funded amount and date fields such as the effective date of funding and the expiry date of funding, was downloaded in April 2006 from the CIHR website. Downloaded data were first accessed as a Microsoft Excel spreadsheet (Excel 2003; Microsoft Corporation, Richmond, WA, USA). Multiple investigator names (separated by semicolons), embedded in single text fields, were split using Excel's 'Text to Columns Wizard'. The data, now containing several additional columns to individually accommodate the names of the first, second, third and fourth investigator and so on, were exported into SAS for Windows (SAS version 9.1; SAS Institute, Inc., Cary, NC, USA) for further handling and analyses.

From the project-based data structure, an investigator-specific database, containing variables limited to information

derived from the funded projects, was recreated in SAS. An investigator was defined as a researcher who received funding in the capacity of a non-trainee PI or as supervisor of a trainee who had received an award. Neither students, fellows and others requiring project supervisors, nor those who were listed on projects as only co-investigators were included as investigators in the study database.

For each investigator, the total number of funded projects; average number of years per funded project; number of times as PI, supervisor and co-investigator; research theme(s); and types of grants received were listed. Based on the effective date of the earliest active grant received by the investigator during the study period, the number of years since first active grant funding was calculated. Similarly, the effective date of investigator's earliest salary award that was funded during the study period was used to determine the number of years since first receiving salary award.

Cumulative amount received by an investigator was calculated as the sum total of amounts received for different projects (grants or awards) in the capacity of a PI or supervisor. That is, amounts funded towards trainee awards were credited to the supervisors of the awards. For projects with two or more PIs (or supervisors) the funded amounts were split evenly among the listed PIs (or supervisors). For example, if a project with two PIs received a funding of \$100,000, then only \$50,000 was assigned to each investigator. If a graduate student award of \$30,000 was awarded and two supervisors were listed, then \$15,000 was assigned to each of the two supervisors. An investigator who served as a co-investigator on additional projects was not assigned any funding on those projects.

Data Quality Control

As far as possible, care was taken to 'clean-up' data every step of the way—variations in the spelling of names were checked and corrected individually; values for newly created variables were double-checked against hand-calculated summaries for 5-10% of the database entries; codes were rewritten and data transformation procedures were carried out separately a second time in order to duplicate the investigator database.

Statistical Analyses

Categorical and ordinal independent variables were coded as dummy variables with the reference category given a value of zero and the category-of-interest given a value of one. Contingency tables were compared using χ^2 analyses or χ^2 test for trend. Continuous variables with skewed distribution (cumulative funding, number of projects funded, number of years

FIGURE 1. A Venn-diagram representing the roles and responsibilities of 6570 investigators holding at least 1 active CIHR grant or award during fiscal years 1999-2006.

funded) were log-transformed for achieving normal distribution. A multiple regression model was built to study the effects of investigator role as supervisor or salary award recipient (independent variables) on investigator CRF (dependent variable), while adjusting for covariates such as number of funded projects and years, PI status, types of grants funded and themes of research [13]. The model was repeated with ordinal variables to identify a dose-response relationship between time since receiving first active grant during study period, time since first receiving salary award, number of times investigator supervised trainee awards and CRF. The format for interpretation while regressing log-transformed dependent variable is that dependent variable changes by $(100 \times \text{regression coefficient})$ percent for a one unit increase in the categorical independent variable, while all other variables in the model are held constant. When continuous independent variables are also log-transformed, then the format for interpretation becomes the percent change in dependent variable when independent variable is increased by one percent. Regression coefficients were considered to be statistically significant at $P\text{-value} < 0.05$. Data were examined for satisfying regression assumptions. Residuals from the fitted model were systematically analyzed through regression diagnostics.

Bibliometric analyses

Forty investigators who supervised CIHR-trainee award recipients were randomly selected. Their publication counts, for the period from January 2000 to August 2007 in the subject category 'Life Sciences and Biomedicine', were determined using the 'Author Finder' feature on The Thompson Corporation Web of Science® ([http://portal.isiknowledge.com/portal](http://portal.isiknowledge.com/portal.cgi?DestApp=WOS&Func=Frame)

FIGURE 2. Proportion of 1529 investigators with CIHR salary awards who supervised CIHR trainee awards, by time since first receiving salary award.

[portal.cgi?DestApp=WOS&Func=Frame](http://portal.isiknowledge.com/portal.cgi?DestApp=WOS&Func=Frame)). Using the Wilcoxon rank sum test for non-parametric data, the publication counts were compared with those of 40 randomly selected investigators who did not supervise CIHR-trainee award recipients. Only publications with Canadian addresses were counted. No attempt was made to distinguish publications by order of authorship, type of publication or type and impact factor of journal. Similar bibliometric analyses were conducted and compared between 40 randomly-selected investigators who served as CIHR co-investigators at least once during the study period and 40 randomly-selected investigators who were not CIHR co-investigators during the study period.

Results

There were 6570 investigators who received funding, one or more times, from the CIHR in the capacity of a PI or a supervisor during the fiscal years 1999- 2006. While most (93.4%) were PIs on at least one project, fewer served as supervisors (35.3%) or were awarded salaries (23.3%). (Figure 1). A breakdown on the types and duration of funding received by the investigators are given in Table 1. The mean (standard deviation) of CRF was CAD\$574,999 (\$1,170,361); the median (minimum, maximum) was \$249,300 (\$133, \$32,147,637). The interquartile range was \$625,111.

Interrelationships between covariates

Investigators with salary awards were more likely to be supervisors of CIHR trainee awards compared with those without salary awards (47% *vs.* 32%; $P\text{-value} < 0.0001$). There was a significant positive association between time since first salary award and supervision of trainee awards ($P\text{-value for trend} <$

TABLE 1. Duration and type of funding received by 6570 CIHR investigators during fiscal years 1999-2006

	Number*	Percent of 6,570 investigators
Time since 1 st active grant received as PI during study period		
< 3 years	1660	25.3
≥ 3 - < 5 years	1365	20.8
≥ 5 - < 7 years	674	10.3
≥ 7 years	2084	31.7
Missing date	351	5.3
Time since 1 st receiving salary award during study period		
< 3 years	345	5.3
≥ 3 - < 5 years	352	5.4
≥ 5 - < 7 years	389	5.9
≥ 7 years	443	6.7
Number of times supervised trainee awards during study period		
1	1330	20.2
2-3	709	10.8
≥ 4	280	4.3
As Co-Investigator		
At least once	3905	59.4
Research theme		
Biomedical at least once	3591	54.7
Biomedical only	1679	25.6
Clinical at least once	1122	17.1
Clinical only	455	6.9
Population-based at least once	1035	15.8
Population-based only	518	7.9
Health services at least once	733	11.2
Health services only	310	4.7
Unspecified at least once	3273	49.8
Unspecified only	986	15.0
More than one theme	2622	39.9
Type of grant		
Randomized Controlled Trial at least once	231	3.5
Randomized Controlled Trial only	112	1.7
Operating at least once	5529	84.2
Operating only	4852	73.9
Equipment at least once	354	5.4
Equipment only	20	0.3
Other grant at least once	455	6.9
Other grant only	151	2.3
More than one grant type	1435	21.8

* Does not add up to 6570

FIGURE 3. Proportion of 6133 investigators with CIHR research grants who received CIHR salary award and supervised CIHR trainee awards, by time since receiving first active grant.

FIGURE 4. Proportion of 6570 investigators who received CIHR salary awards and supervised CIHR trainee awards, by research theme.

0.0001) (Figure 2). The proportion of investigators that received salary awards (P -value for trend < 0.0001) and supervised trainee awards (P -value for trend < 0.0001) also increased positively with time since first receiving a grant (Figure 3) but varied (P -values < 0.0001) in a less predictable fashion across research themes (Figure 4).

After adjustment for number of funded projects, years and PI status, salary award recipients were overall associated with a 29.5% increase in CRF relative to researchers without salary awards (Table 2). Supervisors of trainee awards were associated with, on average, a 13.1% decrease in CRF. Compared with investigators in biomedical research, CRF was lower for investigators in clinical (17.4% lower), population-based (33.7%), health services (51.9%), unspecified research themes (69.6%), and for those receiving funding in multiple themes (15%). Receiving funding for randomized controlled trials increased

TABLE 2. Factors associated with investigators' cumulative funding (CAD\$) received from CIHR: results from a multiple linear regression model*

Independent variable	Reference category of independent variable	Magnitude of association between independent variable and cumulative funding [†]		P-value
		β-coefficient [‡] (95% confidence interval)	Standardized β-coefficient	
Funded projects and years				
Number of projects [†]	NA [§]	+1.097 (+1.051, +1.144)	+0.479	<0.001
Average years per project [†]	NA	+0.958 (+0.932, +0.983)	+0.471	<0.001
Investigator role** (at least once)				
As Principal Investigator (PI)	Never as PI	+0.900 (+0.790, +1.010)	+0.129	<0.001
As Co-Investigator (Co-I)	Never as Co-I	+0.040 (-0.002, +0.083)	+0.011	0.061
Salary award				
Received	Never received	+0.295 (+0.244, +0.345)	+0.072	<0.001
Supervised trainee awards				
At least once	Never supervised	-0.131 (-0.189, -0.073)	-0.036	<0.001
Research theme				
Clinical only	Biomedical only	-0.174 (-0.261, -0.086)	-0.025	<0.001
Population-based only	Biomedical only	-0.337 (-0.417, -0.257)	-0.052	<0.001
Health services only	Biomedical only	-0.519 (-0.617, -0.422)	-0.063	<0.001
Unspecified only	Biomedical only	-0.696 (-0.762, -0.629)	-0.142	<0.001
More than 1	Biomedical only	-0.150 (-0.211, -0.089)	-0.042	<0.001
Type of grant funding				
Randomized Controlled Trial only	Operating only	+0.668 (+0.512, +0.824)	+0.050	<0.001
Equipment only	Operating only	+0.225 (-0.122, +0.571)	+0.007	0.203
Other only	Operating only	-0.489 (-0.625, -0.354)	-0.042	<0.001
More than 1	Operating only	+0.016 (-0.041, +0.073)	+0.004	0.579

*Based on 6515 investigators with non-missing values for all variables in the model. R-sq = 0.795; F-statistic = 1682; P-value < 0.0001

[†]Log-transformed variables.

[‡](β -coefficient*100%) is the percent change in cumulative funding associated with independent variable, compared with reference category, when all other variables are held constant.

[§]NA-Not Applicable.

**Variables grouped under this label are not mutually exclusive; an investigator may be represented by more than one variable.

CRF by 66.8% compared with receiving funding for operating grants. About 80% of the variability in cumulative research funding of the investigator was explained by the chosen model (i.e., $R^2 = 0.795$; P-value < 0.0001).

The model with ordinal variables indicated that the magnitude of positive association of salary awards with CRF was inversely related with time since first receiving salary award (Table 3). An inverse dose-response relationship was observed between supervision of trainees with CIHR awards and CRF. That is, increasing number of trainees supervised was associated with decreasing CRF. No linear relationship was observed between time since receiving first active grant during the study period and the investigator's CRF obtained during the same time period.

Those who supervised one or more trainee award recipients had a higher number of publications (mean=40.2; maximum=167) since the year 2000 than those who never supervised (mean=21.3; maximum=122). The median number of publications among supervisors was significantly higher than the median number of publications among non-supervisors (31 vs. 11.5; P-value = 0.0007). Investigators who also served as CIHR co-investigators during study period had a higher number of publications (mean=30.9; maximum=211) in the years 2000-2007 than those who never served as CIHR co-investigators (mean=10.7; maximum=58). The median number of publications among co-investigators was significantly higher than the median number of publications among those who were not co-investigators (15.5 vs. 8; P-value = 0.006).

TABLE 3. Dose-response relationship between time since receiving first active CIHR grant, time since first receiving CIHR salary award, number of times supervised trainee awards and investigators' cumulative funding (CAD\$) received from CIHR: results from a multiple linear regression model^{*}

Independent variable	Reference category of independent variable	Magnitude of association between independent variable and cumulative funding [†]		P-value
		β-coefficient ^{‡§} (95% confidence interval)	Standardized β-coefficient	
Time since 1 st active grant received as PI during study period				
No active grant during study period	≥ 7 years	-1.040 (-1.167, -0.912)	-0.154	<0.001
< 3 years	≥ 7 years	-0.142 (-0.213, -0.071)	-0.036	<0.001
≥ 3 - < 5 years	≥ 7 years	-0.186 (-0.244, -0.127)	-0.045	<0.001
≥ 5 - < 7 years	≥ 7 years	-0.259 (-0.321, -0.185)	-0.046	<0.001
Time since 1 st receiving salary award during study period				
< 3 years	Never received	+0.260 (+0.159, +0.360)	+0.031	<0.001
≥ 3 - < 5 years	Never received	+0.224 (+0.131, +0.317)	+0.029	<0.001
≥ 5 - < 7 years	Never received	+0.197 (+0.108, +0.287)	+0.027	<0.001
≥ 7 years	Never received	+0.137 (+0.051, +0.223)	+0.020	0.002
Number of times investigator supervised trainee awards during study period				
1	Never supervised	-0.144 (-0.206, -0.082)	-0.034	<0.001
2 – 3	Never supervised	-0.244 (-0.324, -0.164)	-0.045	<0.001
4 +	Never supervised	-0.401 (-0.522, -0.279)	-0.049	<0.001

^{*} Based on 6,163 investigators with non-missing values for all variables included in the model; R-sq = 0.806; F-statistic = 1110; P-value < 0.0001.

[†] Log-transformed variable.

[‡] (β -coefficient*100%) is the percent change in cumulative funding associated with independent variable, compared with reference category, when all other variables are held constant.

[§] After adjustment for number of funded projects and years, co-investigator role, research theme and type of grant funding.

Discussion

Cohorts of single-agency grants have been described previously to highlight trends in research productivity [1-3]. CRF, one measure of research productivity, has been reported to be positively influenced by early beginning of research career, number of years in research and specialty training or training in research [1,4,5]. The results of the present short-term study did not provide evidence for a linear, positive relationship between early receipt of grant funding and CRF. As expected, there was a positive association between increased CRF and receipt of salary awards; however, there was an unexpected negative association between CRF and early receipt of salary awards. The hypothesis had been that salary award recipients would subsequently go on to obtain further funding, thus engaging in a continuous, positive cycle of growth in CRF. Perhaps, a reality more complex than the simple vision of unbridled, linear growth in CRF is in effect here. Alternatively, it may simply be that the data have provided circumstantial evidence that salary awards were prioritized to investigators with increased CRF.

Those who received salary awards and grant funding early in the period under study were most likely to be supervisors of successful trainee award applicants than late recipients (and non-recipients, in the case of salary awards). A cautious approach to interpretation of data is needed here, however, as this association could very well be the result of the synergy between above-average trainee applicants and successfully established investigator-cohorts or investigators with seniority. Given the negative association between supervision of trainee awards and investigator CRF in the multiple regression models, it seems reasonable to caution the use of CRF as a measure of general research productivity. Already there has been some concern that, even in academic environments, increasing emphasis is being placed on the size of external funding received [14].

As an aside, the study also documents the proportion of investigators engaged in CIHR-funded clinical research *vs.* other themes of research. The question of the actual number of investigators engaged in clinical research nation-wide was raised elsewhere amidst concerns that both clinical research and clinical researchers are endangered [15]. The number of clinical researchers funded by CIHR was documented else-

where, but neither the ratio of clinical to basic research capacity was established nor the proportion of all CIHR-funded researchers that clinical researchers represent was documented [16]. Current findings also underline that funding disparities across themes, observed at an aggregate level previously [8], extend to the level of individuals after adjustment for receipt of salary awards and supervision of trainee awards.

Study limitations

Several limitations to the study should be noted. Firstly, the values of the dependent and independent variables were all limited to publicly-available data obtained from a single, albeit major, national funding agency, and covered a relatively short observation period. CIHR is often only one source of research funding, albeit a key source. Inclusion of funding received from other national and international funding agencies would have given a more comprehensive picture. The list of explanatory variables is also admittedly short. Several factors (e.g., professional status, administrative activities, clinical responsibilities, teaching commitments, mentoring activities, supervision of trainees who are not recipients of CIHR trainee awards, demographics including stage of career, alternate funding sources) that are known to be or are suspected of being associated with research productivity have not been accounted for or explored in this study. For example, in this study, it was not possible to identify those investigators who likely supervised students, fellows and other trainees paid directly from CIHR grants or other external grants. Another example is that data from Canada Research Chair (CRC) program were not included although several investigators classified as without a CIHR salary award may have held a Tier 1 or Tier 2 CRC. Secondly, as the investigators under study represented those who were successful at having a grant or award application accepted for funding at a national agency, the study is based on a very select population. Thus, the generalizability of the study results may be limited. Finally, causal relationships were not established or explained adequately by this study design.

Future directions

Future studies on research productivity, in general, and research funding, in particular, must expand on the list of explanatory variables and include funding received from different agencies and sources, including CRC programs. The period of productivity evaluated should also be longer. More comprehensive, multi-level data should be collected through multiple sources by employing more flexible study designs. Other more comprehensive research funding databases are presently made

available even through the CIHR; for example, the Canadian Research Information System database, containing data from major national and provincial funding agencies, can now be accessed through the CIHR, as can data on CIHR grants funded in collaboration with partner funding agencies.

In conclusion, the findings of this exploratory study suggest previously undocumented interrelationships between CRF and each of the following factors: salary awards, supervision of trainee awards and timeline of receipt of active grants and salary awards. In this respect, the present study is valuable in its contribution to a field with little or no literature. While increased CRF may very well be considered a general indicator of high research productivity, the present study also suggests that the opposite need not be true; i.e., decreased CRF does not imply a decrease in overall research productivity. This assertion is additionally supported by the limited bibliometric analysis. Although not unexpected, the study also documents a positive association between co-investigator status and publications and between co-investigator status and CRF. Although demonstrated associations may not show causality, they are suggestive of multi-lateral, long-term returns to the enterprise of academic research from grants and awards. These complex interrelationships among CRF and its predictors could be viewed as preliminary and could serve to develop hypotheses for future, more comprehensive research across different populations.

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