The Research Money Can't Buy:
The Impact of Funding on Scientists' Research Behavior

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Abstract

While corporations increasingly rely on academic science and greater financial resources are directed to academic research, we know little about how external funding affects the research direction and behavior of academic scientists. We explore this question by exploiting the unexpected decline in federal funding for human embryonic stem cell (hESC) research in the United States in 2001. We find little evidence that the policy change had a significant effect on U.S. scientists' hESC output. However, U.S. scientists experienced a relative decrease in their output in other stem cell subfields. They were also more likely to move from academia to industry following the policy change. These results provide novel insights into how scientists strategically respond to funding policies to maintain their focus on research lines perceived more promising by their peers. We discuss how misaligned financial and reputational incentives may have important unintended consequences for those funding academic science.

1. Introduction

Academic science can help firms overcome technological barriers and identify new technological and business opportunities (Gambardella 1995, McMillan et al. 2000, Fleming and Sorenson 2004). Firms that invest in basic science may experience higher R&D productivity and innovation rates by gaining advanced access to new discoveries and developing superior abilities to absorb external knowledge (Cohen and Levinthal 1990, Rosenberg 1990). Moreover, recent research suggests that large corporations increasingly rely on scientists in academia and startups as sources of novel ideas to take advantage of new technological opportunities (Pisano 2010, Arora et al. 2015, Tijssen 2004; Coombs and Georghiou 2002). Following the 1980 Bayh-Dole Act, universities have also become more active in supplying scientific discoveries and inventions to industry (Mowery et al. 2001, Sampat 2006). The development of thicker markets for ideas along with the strengthening of intellectual property rights has potentially contributed to a sharper division of labor between academia and industry, in which academic scientists invest heavily in basic scientific research and large corporations focus more on applied research, technological development, and commercialization.

The benefits of such a division of labor depend on the alignment between the direction of research in academia and the interests of industry and the public (Pisano 2010). However, the highly autonomous and decentralized nature of the "Republic of Science" limits the scope for governments and private organizations to influence the direction of research in academia (Dasgupta and David 1994). Among the few strategic levers available to external actors, the allocation of funds for academic research is probably the most frequently used policy to steer the rate and direction of academic research. In the United States alone, government and industry spent more than $36 billion and $3.6 billion on academic research in 2014 respectively (National Science Board 2016). Yet we know little about how effective funding policies are at shaping the research direction of academic scientists. Prior research has largely focused on the efficacy of funding allocation mechanisms in identifying the higher quality proposals through review system (Azoulay et al. 2011, Boudreau et al. 2016) or the causal impact of receiving funding on the research productivity of recipients (Benavente et al. 2012, Jacob and Lefgren 2011, Whalley and Hicks 2014).

On one hand, a model of scientists as knowledge workers who produce scientific output from human capital, material, and monetary inputs suggests that changing the funding available in a particular research area would directly affect the level of research activity in that domain. The rationale is that changing the availability of funding shifts the relative cost of doing research across related areas because it becomes more difficult to acquire the requisite resources in some domains and easier in others. Assuming scientists' expertise can be applied to proximate scientific domains, shifting money from one area to another would lead to a change in their research direction towards the domain with relatively more abundant resources. In fact, a core reason for government funding of academic research is the concern that reliance on industry funding may shift academic scientists' research efforts towards more applied lines of research with greater apparent commercial value. This may then suppress the freedom of inquiry and basic research that generate new knowledge that is valuable to society (Bush 1945). Following the same logic that academic scientists will simply follow the money, various figures both inside and outside academia have expressed concerns about how private or public institutions may influence the direction of academic research according to political, ethical, or economic agenda (Kennedy 2003, Agres 2003, Wagner and Steinzor 2006, Hedge 2009).

On the other hand, the priority-based reward system of academic research and an incentive structure that is based on impact, reputation, and prestige (Crane 1965, Merton 1968, Dasgupta and David 1994) play a significant role in shaping the choices of scientists to invest in particular research projects. The desire for impact and recognition leads scientists to have a strong preference for working in areas that their peers consider most impactful or important. At the same time, the priority-based reward system reinforces the urgency to be the first to publish in an area with high potential impact in order to receive recognition and credit for a new research output. These two aspects of the reward system in academic science combine to create an institutional environment in which citation distributions and credit allocation among individuals are highly skewed and particularly favors scientists with early accomplishments in areas regarded as promising by the wider scientific community.

Therefore, to the extent that funding policies align with the interest of the scientific community, new financial resources can reinforce scientists' choices to invest in a particular scientific domain. In contrast, transferring financial resources away from an area regarded as promising by the scientific community to one considered less promising may fail to have a similar influence on scientists' research direction. The lower cost of accessing funds in the less promising research area may not offset the perceived loss in credit that scientists could otherwise accrue by investing in the more promising domain. Moreover, misalignment between the funding regime and scientists' preferences may trigger a range of strategic responses by scientists as they seek to find alternative sources of research funds and material. This in turn may reduce scientists' research productivity and have various unintended consequences. In particular, to circumvent resource shortcomings in a promising area, academic scientists may form closer ties with the private sector, collaborate with peers overseas, or move to another country where resources are more abundant. Any of these strategic responses can have important ramifications for the productivity of scientists, future scientific and technological progress, scientific labor mobility, and international knowledge spillovers.

In this study, we explore the consequences of misalignment between the funding regime and scientists' preferences by examining a policy shock to federal science funding in the United States that was initiated by the George W. Bush administration in 2001. The policy placed severe restrictions on federal funding of human embryonic stem cell (hESC) research on ethical grounds, with funds instead reallocated to other subfields of stem cell research. The Bush administration's stem cell policy set off waves of concern in the scientific and regulatory communities (Fletcher 2001, Holden 2004, Holland et al. 2001, Holm 2002, Johnson and Williams 2007, Vogel 2001). Faced with the new policy, U.S. researchers who had already invested, or were planning to invest in, hESC research suddenly found themselves in a new institutional environment with very limited federal funding available for research on new hESC lines compared to their earlier expectations. Instead, the new policy increased the amount of federal funding available to scientists for stem cell research that did not involve human embryos.

Given that federal funding was the primary source of financial resources for embryonic stem cell (ESC) research at the time of the policy change, a passive view of scientists suggests that U.S. researchers would shift their research direction to work on non-human areas of ESC research, or to other non-embryonic subfields of stem cell research. This was both the intended purpose of the policy (Vogel, 2001) and the reason for the serious concerns shared by both politicians and academics in response (Fletcher 2001, Holden 2005, Holland et al. 2001, Holm 2002, Levine 2004, Levine 2006, McCormick et al. 2009). In April 2004, 206 members of Congress released a letter to President Bush urging him to relax the restrictions on hESC research funding (Holden 2005). A key point highlighted by the authors was that "this promising field of research is moving overseas" and that "leadership in this area of research has shifted to the United Kingdom." Furthermore, the letter stated that "it is increasingly difficult to attract new scientists to this area of research because of concerns that funding restrictions will keep this research from being successful." At a subcommittee hearing of the Senate Appropriations Committee in 2005, the then NIH Director, Elias Zerhouni, cited "mounting evidence" showing that numerous problems had been uncovered due to genetic instability in the aging 22 approved hESC lines. In the same session, the chair of the subcommittee, Arlen Specter, released several letters drafted by various NIH institute directors warning that the NIH would fall behind other local and international institutions in the field due to the restrictions on research funding (Holden 2005).

Considering the reward system of academic science, there are several reasons to believe that such a shift in research direction was not in line with U.S. scientists' preferences. Therefore, the policy change may have triggered scientists to use alternative strategies to avoid shifting their research direction as much as possible. At the time, hESCs were considered the most promising research area within stem cell domain with the highest potential to cure severe human diseases (Vogel 1999, Holden 2004). For example, for articles in our sample published in 2001, the average number of citations received by hESC articles is approximately 230 compared to 100 for animal ESC articles, 60 for articles in non-embryonic stem cell subfields, and fewer still for scientists' publications not in a stem cell field. A similar citation pattern continues during the period after the policy, although the gap in citation numbers between hESC articles and other articles declines in relative terms for subsequent papers as the hESC field continues to mature from the earlier nascent phase. While U.S. scientists had the option to work on the approved hESC lines under the Bush policy, these lines had a limited range of genetic diversity and many of them were contaminated with mouse embryonic feeder cultures by 2004 (Holden 2004, 2005). Given the attractiveness of hESC research at the time of policy shock, scientists could potentially circumvent the funding restrictions by seeking resources from other sources. Potential channels for accessing resources included funding from industry collaborators, starting to work directly for the private sector, seeking funding outside the United States through international collaborations, or moving to another country with more permissive funding policies for hESC research.

To test these arguments, we use longitudinal data on the research activity of all the scientists in the Scopus database – the most extensive dataset on scientific publications – who published at least one article in the field of stem cell research before the change in funding regime in 2001. We employ a difference-in-differences methodology to establish the causal impact of the 2001 policy on the research behavior of U.S. scientists. In particular, we compare the U.S. scientists to a similar group of scientists based at institutions in other developed countries with permissive hESC policies both before and after the policy change in the United States. Exploiting the sudden change in funding regime, we examine how U.S. scientists changed their research direction, affiliations with academia and industry, local and international collaboration patterns, and location after the policy shock.

We do not find any significant effect on the subsequent hESC research output of U.S. scientists from the sudden change in funding policy for hESC research in 2001. However, the results suggest that in the face of funding restrictions on new hESC lines and increased costs of conducting research in the cutting-edge hESC domain, U.S scientists decreased their research investment in non-embryonic stem cell research and sought new sources of funding and material in the private sector. The funding crunch appears to have had a long-lasting negative effect on the productivity of U.S. scientists in the broad field of stem cell research. Meanwhile, the relative number of U.S. scientists with a background in stem cell research leaving academia for industry increased by more than 10 percent in the years after the Bush policy change. The findings also suggest that those who moved to industry did indeed manage to produce more hESC publications than their matched counterparts. The results further indicate that U.S. scientists acquired relatively more institutional affiliations following the change in the funding regime. However, the results do not show much support for a change in the level of international collaborations or international mobility triggered by the policy shock.

Our findings shed light on the effectiveness of funding policies in steering the direction of academic research. While we only look at the case of federal funding, the results nonetheless point out to a broader conclusion that a funding regime (be it sourced from industry or public money) can lead to unintended consequences when there is misalignment between the research interests of scientists and the goals of public or private funders. The autonomous nature of academia, the global nature of science, and a reward system based on reputation and credit place important constraints on the extent to which the direction of scientific research can be effectively managed. The findings also highlight the role of funding regimes in the mobility of scientific labor between academia and industry.

2. Institutional Details

Stem cells are undifferentiated biological cells that are capable of dividing and differentiating into specialized cell types such as skin cells, nerve cells, or muscle cells. There are two broad types of stem cells: adult stem cells (which are found in tissues throughout the body) and embryonic stem cells (which can only be derived from the inner cell mass of early-stage embryos). Adult stem cells are already successfully used in treating several severe conditions. However, they have the major limitation of being lineage-restricted, which means that they can only develop into particular forms of cells. A blood stem cell can differentiate into several types of blood cells but cannot develop into nerve or brain cells. In contrast, embryonic stem cells are known to be pluripotent, meaning that they can develop into any type of cell. Furthermore, embryonic stem cells have the useful property of being able to self-propagate indefinitely under certain conditions.

Embryonic stem cells were first derived from mouse embryos in 1981 by two independent research teams. It took another 17 years before James Thomson and his research team at the University of Wisconsin-Madison made the breakthrough of developing a technique to grow and isolate human embryonic stem cells (Thomson et al. 1998). Due to their pluripotency and their derivation from human embryos, hESCs are acknowledged to have the highest potential among all types of stem cells to advance current clinical treatments and generate novel therapies (Vogel 1999). Yet, despite their scientific and economic value, there have been ongoing political debates over hESC research driven by ethical concerns.

In the United States, the first laws prohibiting research on fetuses and embryos date back to 1973. However, these laws have not been rigorously enforced. In 1995, just a short period of time after the Clinton administration approved federal funding for research on leftover embryos created through in vitro fertility treatments, Congress passed the Dickey-Wicker Amendment that prohibited any federal funds for use in research that involved the creation or destruction of a human embryo. It was during this period that Thomson made his breakthrough in isolating human embryonic stem cells in 1998 using private funding. Following Thomson's breakthrough, and recognition of the enormous opportunities it opened up, the Clinton administration began to loosen the policies governing federal funds available for embryonic research in 1999. Just two years later, on August 9, 2001, the newly elected President George W. Bush announced his administration's stem cell policy. Despite the scientific community's hopes for growing federal funds available for hESC research, the announced policy banned any federal funding for research on new hESC lines, while approving federal funding for existing hESC lines and non-human ESC research developed in the United States or outside. On March 9, 2009, President Barack Obama issued an executive order lifting the restrictions on hESC research put in place by the Bush administration. The new policy became effective in July 2009 when NIH published the new guidelines for funding hESC research.

3. Related Literature

3.1. Funding and Scientific Research

Prior studies on the impact of funding regimes on academic research output can be categorized into two broad streams. The larger stream is mainly concerned with estimating the causal impact of receiving funding on the productivity of recipients. For example, using a difference-difference approach, Arora and Gambardella (2005) show that younger economists who received NSF funding between 1985 and 1990 experienced an increase in their productivity subsequently, while their more senior colleagues experience little change after receiving an NSF grant. Similarly, Jacob and Lefgren (2011) compare the outcomes of successful and unsuccessful research proposals to NIH from 1980 to 2000. They find that there is an average 7 percent increase in the research output of successful applicants over a decade after receiving funds compared to the unsuccessful scientists.

The second, relatively smaller, stream of research is largely focused on how effective are funding agencies in selecting the “better” proposals. For example, Johnson (2008) provides some evidence of reviewer bias, which could explain as much as a quarter of funding decisions at NIH, using a Bayesian hierarchical statistical model of about 19,000 applications for NIH funding. Exploring more than 130,000 grants awarded by the NIH between 1980 and 2009, Li and Agha (2015) show that the peer evaluation procedure used by NIH indeed succeeds at distinguishing high impact-potential proposals. Their results suggest that proposals with one-standard-deviation lower peer-review scores garnered 7 percent fewer publications, 15 percent fewer citations, and 14 percent fewer follow-on patents. However, other scholars have challenged the credibility of peer review system due to various reasons, including the usual high degrees of variance in scores for each proposal across reviewers (Graves et al. 2011, Fang et al. 2016) and a discount for novelty driven by reviewers’ bounded rationality in evaluating new ideas (Boudreau et al. 2016).

Although these works contribute significantly to our understanding of the impact of funding on scientific output, they do not provide much insight on how effective funding policies are in shaping the direction of scientific research. Nor do they explore how scientists' mobility and collaboration patterns change in response to changes in funding regimes.

3.2. Past Research on the Bush Policy Effects

The Bush administration's stem cell policy set off waves of concern in the scientific and regulatory communities (Fletcher 2001, Holden 2004, Holland et al. 2001, Holm 2002, Johnson and Williams 2007, Vogel 2001). In the wake of these concerns, several studies have attempted to document the impact of the Bush policy on subsequent hESC research in the United States relative to other countries (Furman et al. 2012, Levine 2004, Owen-Smith and McCormick 2006, Scott et al. 2009, Vakili et al. 2015). Using five less controversial biomedical research areas as the baseline, Levine (2004) reports that the share of hESC publications credited to U.S. scientists dropped considerably in 2003 and remained at this lower level in 2004. Studying the same time period, Owen-Smith and McCormick (2006) also report a decline in the relative share of hESC publications by U.S. scientists compared to scientists elsewhere in the world. While both studies report a decline in the share of U.S. stem cell scientists, it is not clear whether this share is due to a decline in the productivity of U.S. scientists or rather an increase in the number of stem cell scientists in other regions of the world. This is particularly pertinent given the evidence of the growth in stem cell research in emerging markets such as China, South Korea, and Singapore over this time period (Vakili et al. 2015). Furthermore, both studies only examine the short-term impact of the Bush policy in the two years following the policy change due to data constraints. Looking at an extended timespan, Vakili et al. (2015) find that the United States share of hESC publications stopped declining after 2003, increased slightly in 2004, and then remained consistent at about 33 percent of total hESC publications until 2010. Similarly, using a difference-in-differences methodology to analyze the causal impact of the 2001 policy, Furman et al. (2012) also find that the United States' cumulative production of hESC research declined between 2001 and 2003 but rebounded in the subsequent years.

While these studies provide important insight into the impact of the Bush policy on the total share of hESC research carried out by scientists in the United States, they do not report how these policies affected individual scientists' research productivity and behavior. Moreover, these studies provide little explanation of how individual scientists may have responded strategically to the Bush policy intervention. Their findings also do not distinguish between the intensive margin effect of the policy (i.e. the effect on current scientists' research output) and its extensive margin effect (i.e. the effect on new scientists entering the field of hESC research). Both Furman et al. (2012) and Vakili et al. (2015) provide preliminary evidence of an increase in the aggregate level of international collaborations involving U.S. scientists after the policy shock, suggesting that the recovery in hESC research after 2004 may have been related to the increased level of international collaboration. Yet these results are not fine-grained enough to establish a direct link between the quick recovery and increased amount of international collaborations.

4. Empirical Design

4.1. Data

We examine the effects of changes in scientific funding on scientists' research productivity, direction, collaborations, and affiliations using the drastic change in federal funding for human embryonic stem cell research introduced by the Bush administration in the United States in 2001. We start by using the Scopus database to identify all scientists who had at least one publication in a stem cell field and were affiliated only with U.S.-based organizations during the period from 1996 to 2000 inclusive, according to their affiliation information on publications. We use Scopus because it is the most comprehensive database of peer-reviewed publications. To identify stem cell publications, we search for articles that mention "stem cell" or its variants in their titles, abstracts, or keywords. Using this approach, we create a relatively inclusive sample of all the U.S. scientists who had already published at least one article in a stem cell field before 2001 and so were potentially affected by the policy change. Second, we identify all scientists who had a publication in a stem cell field and were affiliated only with organizations in one of several countries that did not have restrictive funding/policy regimes for stem cell research during the 1996-2000 period and which continued to have non-restrictive policies throughout the sample period.[1] The scientists based in the U.S. form our treatment group and the non-U.S. based scientists are used to construct a control group. In our core analysis, we only include the scientists who did not have industry affiliations prior to the policy shock as these scientists would have greater dependence on federal funding for their research. We nonetheless use the sample of scientists with industry affiliations for robustness checks presented in the appendix. In our estimations, we use both the full sample of scientists and a conservatively matched sample described in further detail below.

For each scientist in our sample, we extract the author information, affiliations, abstracts, and citation figures of all papers she authored until 2009, the year in which the restrictions were lifted by the Obama administration. We exclude those scientists whose first publication appeared before 1975 to mitigate the risk that a reduction in publication rates after the 2001 policy change could be driven by older scientists retiring from active research. The above procedure yields 7,818 scientists, more than 250,000

[1] The specific countries are Australia, Belgium, Canada, Denmark, Finland, Greece, Ireland, the Netherlands, New Zealand, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.

unique publications, and approximately 185,000 author-year observations.[2] During the 1996-2009 period – the focus of our empirical analysis – we have approximately 150,000 unique publications and more than 100,000 author-year observations. In the five years from 1996 to 2000 before the Bush policy was introduced, 70 percent of the scientists were exclusively U.S.-based and 30 percent were based exclusively in one of the control countries. We then performed an initial keyword search and created an inclusive set of articles that had any indication that they contained embryonic research. Next, two graduate students in biology at a leading university in the field manually coded articles into subfields within stem cell research: human embryonic (hESC); animal embryonic (animal ESC); and other stem cell fields. Both research assistants had completed at least one year of graduate coursework, including work in cell biology. The research assistants made the same categorization decision on more than 90 percent of articles that were assigned to both. In cases of disagreement, if one of the research assistants read the article as containing hESC or animal ESC research, it was coded as belonging to that category.

4.2. Dependent Variables

Our interest in this paper is to understand how scientists responded to the change in funding policy regime. We investigate scientists' behavior using a range of dependent variables that allow us to analyze changes in scientists' research direction and productivity, collaboration patterns, and institutional affiliations. Our first set of dependent variables measure scientists' research productivity and direction using their citation-weighted number of publications per year. Specifically, we use the natural logarithm of one plus the number of forward citations to scientist *i*'s publications in year *t*. We measure this both for scientist *i*'s total research output and her output in different stem cell subfields. We also create variables for the citation-weighted number of publications by subfield (human embryonic stem cell, animal embryonic stem cell, and other stem cell subfields). These variables represent scientists' quality-weighted research output across related research domains.

Our second set of dependent variables allows us to examine whether scientists respond to the policy change by acquiring new affiliations or initiating new collaborations. We use the author affiliation information from each publication on Scopus to identify the institutional affiliations both of the focal scientist *i* and of each of her coauthors on a given paper. We use this information to identify the country

[2] We excluded 72 scientists who were very large outliers either on their total number of citation-weighted publications or their stem cell citation-weighted publications in the 2001 base year. The exact thresholds were 1,500 citations to papers from 2001 (approximately 4 standard deviations above the mean), which eliminated 66 scientists and 1,000 citations to stem cell papers from 2001 (approximately 6 standard deviations above the mean), which eliminated a further 6 scientists.

in which each coauthors' institutions are located and create dummy variables to indicate whether scientist *i* had international coauthors in year *t* for each stem cell subfield.[3]

The affiliations data also allow us to examine whether a focal scientist acquires a new type of institutional affiliation. We identify whether an institution with which a scientist is affiliated primarily belongs to one of two categories: academic research, hospitals, and other health service provision;[4] or corporate research. We create a dummy variable to indicate whether scientist *i* was affiliated with an institution in each category in year *t*. Where a scientist did not have an identifiable affiliation because we do not observe a publication in a given year, we interpolated her affiliation between observed data points by finding her most proximate observed affiliation.[5]

4.3. Independent Variables

Our core interest is in how scientists who were based at U.S. institutions during the period 1996-2000 responded to the policy change. To analyze this using a difference-in-differences method, we create a time-invariant dummy variable equal to one for all scientists whose primary affiliations were exclusively with U.S.-based institutions during the 1996-2000 period, and equal to zero for all other scientists in our sample. We also create three indicator variables to distinguish each of the following three periods: 1996-2001, 2002-2005, and 2006-2009. The 1996-2001 indicator variable is used as the base and capture the pre-policy shock period. The other two indicators capture post-shock periods. The interaction of these indicators with the indicator for the U.S.-based scientists (during the 1996-2000 period) enables us to capture the short- and long-term effects of the policy on U.S scientists in years after the policy regime changed in 2001. Since we include scientist fixed effects in all analyses, we do not include separate independent variables for scientists' country of affiliation in the 1996-2000 period. Similarly, due to the inclusions of year fixed effects in all specifications, we do not need to include additional indicators for the three time windows in our analysis. We use the variance in the level of scientists' investment in the field of stem cell before the policy shock for robustness checks. We examine whether those whose research was most directed to stem cell domains had the largest responses to the policy change as we would expect to find. We describe our approach in more details in the subsequent sections.

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[3] There are too few scientists with pre-change international collaboration on hESC research papers to reliably capture a pre-change trend for this subfield of stem cell research. For this reason, we measure only international collaboration on stem cell papers rather than hESC only papers.

[4] We group these together because from the affiliation data it is very difficult to determine whether a scientist should be categorized as affiliated with a hospital or university when this distinction is blurred for many institutions.

[5] Where there was an even number of years between observed affiliations, we broke ties by attributing the subsequent affiliation to the scientist. This was done on the grounds that it takes some time to carry out research and publish it after acquiring a new affiliation and therefore it was more likely that a transition occurred before, rather than after, the midpoint of the interval.

4.4. Identification Strategy

To identify scientists' responses to the change in policy regime we employ a difference-in-differences analysis. In simple terms, we compare the change in the U.S scientists' research outcome and behavior after the policy change in 2001 to those of their counterparts in countries with flexible policies towards hESC research. Since the population of U.S.-based scientists may have systematically different characteristics to our control group of scientists, we use Coarsened Exact Matching (CEM) to create a matched sample of U.S. and control scientists. We match on total citations to all publications and citations to stem cell papers for each of the four years prior to the policy regime change in 2001. In generating the matches we also include the year in which a scientist first published and the year of her first stem cell publication and whether they had an (animal or human) embryonic stem cell publication in the 1996-2000 period. Matching on these variables is intended to ensure that scientists of similar research productivity, research history, and investment in stem cell research are being compared in the analysis. This matching procedure results in 3,693 scientists in the CEM sample, with approximately 60 percent of matched scientists based in the U.S. during the 1996-2000 period and 40 percent in the control countries. We weight each set of matched scientists following the guidance in Blackwell et al. (2009). This means that where multiple treatment and/or control authors are assigned to a specific covariate-balanced stratum, we do not lose information from the additional units that would be discarded in one-to-one matching. We report results for both the whole sample and the matched sample.

We are aware that a change in the research output of the U.S. scientists due to a change in the U.S. funding regime can potentially change the stem cell scientific landscape around the globe and hence influence the behavior of matched scientists as well. However, on average, this potential contamination would work against finding significant effects on the research output of U.S. scientists and result in more conservative estimates. For example, if a decline in funding for hESC in the U.S. leads to less U.S. hESC research and consequently less research elsewhere in the world, the true effect of the U.S. funding policy change will be underestimated in our setting.

Our sample provides panel data on scientists' output, institutional affiliations, and co-authoring patterns from 1996 to 2009. We use the following specification for our core analysis:

$$Y_{it} = \beta_0 + \beta_1 . US\_scientist_i . T0205_t + \beta_2 . US\_scientist_i . T0609_t + \tau_t + \delta_i + \varepsilon_{it}$$

Where Y_{it} denotes the dependent variable of interest in each regression for scientist i in year t. $US\_scientist_i$ is a dummy variable equal to one if scientist i was affiliated exclusively with institutions in the United States during the 1996-2000 period (and zero otherwise). $T0205_t$ and $T0609_t$ are dummy variables respectively equal to one for observations during each of the respective time periods after the policy change, namely 2002-2005 and 2006-2009 (and zero otherwise). The main coefficients of interest are β_1 and β_2 which respectively capture the differential effects of the Bush policy on U.S. scientists' during each of the two post-shock periods.[6] Year fixed effects are captured by τ_t and time-invariant individual characteristics are controlled for using scientist fixed effects, δ_i. Therefore our regressions identify the within-scientist change in scientists' output, affiliations, or collaborations following the change in policy regime for U.S. scientists compared to non-U.S. controls. Table 1 summarizes the definitions of the variables used in the analysis.

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5. Results

Table 2 provides summary statistics for both the full and matched samples for the entire sample period from 1996 to 2009 inclusive. An average scientist in our sample has approximately 85 citation-weighted publications per year, of which 18 percent are in a field of stem cell research.[7] An average scientist also has about 3 weighted publications in the animal ESC subfield and half a publication in the hESC subfield per year during the sample period. In our analysis we exclude all scientists with industry affiliations before the policy shock. In the original sample, about 20 percent of scientists had pre-shock industry affiliations. A typical scientist has about 1.3 affiliations in a given year. Furthermore, only 5 percent of scientists engaged in international collaborations in the stem cell area, while about 15 percent had industry collaborators between 1996 and 2009. The statistics for the matched sample are generally similar, although the publication rates are attenuated due to lack of proper matches for scientists with extremely high research outputs.

Table 3 compares the characteristics of U.S. and non-U.S. scientists in the full sample and the matched sample (using matching weights) during the 1996-2000 period, prior to the policy change. The t-test statistics suggest that U.S. scientists in the full sample had their first publication a few months earlier than their non-U.S. counterparts and produced on average more citation-weighted publications in animal embryonic stem cell research between 1996 and 2000. The two groups however produced similar amounts of research in the non-embryonic and hESC subfields. The t-test statistics for the matched sample shows no significant difference between the matched scientists on most key observables before

[6] In regressions for which the dependent variable is citation-weighted hESC publications, we restrict our sample to the 1998-2009 period. This is because the breakthrough research by Thomson et al, which opened up the major new opportunities for further hESC research and hence changed the opportunities and incentives for scientists to work in this field, was published in 1998.

[7] The reason that the average logged number of citation-weighted publications in Table 2 suggests a smaller number of publications is due to the skewed nature of research output.

the shock. The only exception here is the difference in research output in the hESC domain where the U.S. scientists in the matched sample produced fewer hESC publications than their non-U.S. matches. There are very few scientists with hESC publications before 2001. Therefore it is very difficult to find matches for authors according to pre-shock hESC citations with control scientists who are similar in other salient characteristics. However it is important to our analysis to include authors who have hESC publications during the pre-shock period so that our results are not biased by missing changes on the intensive margin of those with pre-shock hESC publications. In our analyses, we report estimations for both the full sample and the matched sample to make sure a selection effect from the matching criteria does not bias our interpretations.

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5.1. Research Productivity and Direction

Table 4 presents our first set of results. This table shows the relative change in the citation-weighted research output of U.S. scientists following the change in policy regime in the United States. Panel A presents the treatment effects for the full sample and Panel B shows the results for the matched sample. The dependent variable is further broken down by stem cell subfields in Models 2 to 5 to capture the change in the research direction of U.S. scientists.

-- INSERT TABLE 4 HERE --

Model 1 of Panel A shows that there is a significant decrease in U.S. scientists' total research productivity in the unmatched sample following the change in policy regime. U.S. scientists produced 11 percent fewer citation-weighted publications compared to scientists in control countries in the four years following the funding policy change. The gap increases over the next four years. However, in the matched sample in Panel B we find that the decline is of a more modest magnitude – between 4 and 6 percent – and not statistically significant at the 10 percent level. The difference between the estimates from the full sample and those from the matched sample may be due to the underrepresentation of highly productive scientists in the matched sample. The impact of policy shock may have been particularly strong on the U.S. scientists who had very high productivity levels before the policy change and were underrepresented in the matched sample due to a lack of appropriate matches with scientists in control countries with otherwise similar covariates. In additional analysis (available from the authors), we find some evidence that the shock had a relatively stronger effect on the total citation-weighted output of scientists with higher levels of productivity. Had the federal funding not been cut by the new administration, the U.S.

scientists with the highest productivity levels would arguably have had the most opportunity to shift their focus into the emerging domain of hESC research. Hence, federal restrictions potentially had the most harmful effect on the research output of the most productive U.S. scientists who faced greater costs of acquiring resources to work on the frontier of research in the hESC domain compared to scientists in other countries with flexible policy regimes.

Focusing only on stem cell research, we find in Model 2 that the relative citation-weighted stem cell publications of U.S. scientists decreased significantly in both the unmatched and matched samples following the funding regime change in 2001. The results in the unmatched sample suggest that U.S. scientists experienced a 12 to 13 percent decline in their citation-weighted stem cell publications over the eight years following the shock. The estimates from the matched sample report a more moderate effect, suggesting a decline of approximately 6 percent in the citation-weighted stem cell publications of the U.S. scientists compared to their matched counterparts in the eight years after the policy shock. Overall, the estimations in Model 2 indicate that the funding regime had a long-lasting negative effect on the U.S. scientists' total productivity within the stem cell domain.

Moving to a more fine-grained level of analysis, Models 3, 4, and 5 report the change in the citation-weighted output of U.S. scientists in non-embryonic, animal embryonic, and human embryonic stem cell domains respectively. Interestingly, the estimates from Model 5 show little evidence of any effect on U.S. scientists' citation-weighted research output in the hESC domain in either the matched or unmatched sample following the change in policy regime. There is also no apparent effect on citation-weighted publications of U.S. scientists in the animal ESC field in the matched sample, shown in Model 4, although the estimates based on the full sample suggest a significant 10 percent decline over the years subsequent to the policy change. Model 3 of the matched sample shows a significant 6 percent decline in U.S. scientists' citation-weighted publications in non-embryonic stem cell subfields in the four years after the policy shock. The effect shrinks to 5 percent over the next four years. Interestingly, in unreported analysis available from the authors, analyzing the effect on a year-by-year basis we find that U.S. scientists in the full sample do have lower citation-weighted output in the hESC domain in 2003 (significant at the 10 percent level) in line with the findings of Furman et al. (2012). However, this is the only year in which there is evidence of such an effect in the full sample and there is no evidence of any effect when U.S. scientists are matched to similar control scientists from flexible policy regime countries.

In Table 5, we further explore the variance in the level of scientists' investment in the field of stem cell research before the policy change as a robustness check for our main results. We expect to find that U.S. scientists who had previously invested a greater share of their research efforts in stem cell fields will be more affected by the funding policy change of 2001.[8] Table 5 repeats estimations in Panel B of Table 4 (the matched sample), but splits the sample into two subsamples: scientists for whom more than half of their citation-weighted publications between 1996 and 2000 were in the area of stem cell research; and scientists for whom less than half of their weighted output was in a stem cell field. The estimates in Table 5 indeed suggest that the effects reported in Table 4 are largely driven the result of the policy having an impact on those with more investment in the stem cell domain prior to the policy change. Table A1 in the appendix presents another set of robustness checks using scientists with industry affiliations before 2001. Given their access to private financial resources, we expect scientists with pre-shock industry affiliations to be less affected by the change in the Bush funding policy in 2001. The results reported in Table A1 confirm our predictions.

-- INSERT TABLE 5 HERE --

Overall, the estimates provide no evidence to indicate that the sudden cut of hESC funding in the U.S. had a significant effect on U.S. scientists' research output in the hESC subfield. However, U.S. scientists experienced a significant decline in their research output in non-embryonic stem cell subfields, despite the fact that the federal funding in those subfields was increased by the new policy. The results suggest that U.S. scientists may have shifted some of their research efforts in non-embryonic subfields towards supporting their research in the more promising and potentially valuable hESC domain.

In the next section, we explore two of the channels through which U.S. scientists could potentially have used in order to acquire non-federal resources for their human ESC research: working with private companies and collaborating with international or industry scientists.

5.2. Institutional Affiliations

We now move to examining how U.S. scientists changed resource acquisition behavior in response to the policy change. In this section, we focus on institutional affiliation changes. Table 6 presents results showing how U.S. scientists' affiliations changed in response to the policy change.

-- INSERT TABLE 6 HERE --

[8] We repeated this analysis excluding scientists in our sample with only one pre-shock publication to ensure these results are not driven by early career researchers with only one publication for whom this may be a less effective measure of research investment than those with larger publication portfolios. The results are qualitatively similar to those reported in the paper. For similar reasons, we performed additional tests to ensure that the results were not sensitive to whether those with 50 percent of publications in a stem cell domain during 1996-2000 are included in the above or below median group. Again, the results were qualitatively similar to those reported in the paper.

The estimates in Models 1 and 4 suggest that there was a significant increase in the share of U.S. scientists acquiring a corporate research affiliation after the policy change compared to the control scientists. The estimates from the matched sample in Model 4 suggest an increase of 1.3 percentage points in the share of U.S. scientists with company affiliations in the four years immediately after the policy shock, compared to the matched scientists. The relative rate of acquiring industry affiliations among U.S. scientists increases to 1.8 percentage points over the subsequent four years. We find similar effects in the full sample, with slightly larger coefficients. The estimates from Models 2 and 5 suggest that there was a decline of approximately the same magnitude in the number of U.S. scientists with university or hospital affiliations after the policy shock relative to the scientists in the control sample. Given that in the base year of 2001 only 12 percent of the U.S. scientists in the overall sample had a company affiliation, these estimates represent an increase of close to 15 percent in the share of U.S. scientists with an industry affiliation.[9]

One concern with these results is that our exclusion of scientists with pre-shock industry affiliations may be mechanically driving our estimates. If scientists in the U.S. are on average more likely to have industry affiliations, those with no industry affiliations pre-2001 would be naturally more likely to so after 2001 than control scientists. Hence, we may be wrongly attributing a higher probability of movement to industry in the U.S. to which-scientist changes due to the policy shock. To address this concern, we repeated our analysis using the full sample that includes the U.S. scientists with industry affiliations before 2001 as well. We do not find any significant change in the rate of acquiring industry affiliation pre-2001 among the U.S. scientists. To further substantiate our findings, we also explored the difference between the U.S. scientists with high and low investments in stem cell research pre-2001. There is no significant difference in the rate of U.S. scientists acquiring industry affiliations relative to those in the control group for either of these two groups of scientists before the funding policy change in 2001. However, after 2001, our estimates suggest a significant increase in the rate of movement to industry (from universities and hospitals) among the U.S. scientists with high levels of pre-shock investment in stem cell research, relative to control scientists with similar high levels of stem cell research investment. Notably, we do not find a similar trend for the U.S. scientists with low levels of pre-shock investment in stem cell research (Table A2 in the appendix). Overall, the estimates suggest an increase in mobility from university and hospitals to industry among the U.S. scientists triggered by the funding policy change in 2001.

[9] This relative increase is even larger if we use the share of U.S. scientists with industry affiliations in the matched sample as the denominator for this calculation. In the matched sample, close to 5 percent of U.S. scientists had an industry affiliation in 2001. Therefore our point estimates indicate that there was an increase in the share of U.S. scientists with an industry affiliation of approximately 30 percent in the years immediately following the policy change relative to matched control scientists.

One explanation that is consistent with these results is that U.S. scientists sought out corporate research affiliations to access resources that were more difficult to acquire in academic research settings after the policy change. However, an alternative interpretation would be that some scientists became disillusioned with academic research when they could not pursue the frontier of stem cell research in academic settings. Consequently, they may have chosen to move to industry to access the relatively greater monetary rewards as their opportunity to realize non-monetary or intrinsic rewards from academic research was diminished by the change in policy regime.

To see what happened to the research output of scientists who acquired industry affiliation, we examined their research output after the switch in their affiliation. The results are reported in Table 7. The variable 'Industry Affiliation' is an indicator variable that is equal to one for scientists from the point at which they acquire a corporate affiliation after 2001 (the indicator is set to zero again if we observe that they had no corporate affiliation in a subsequent year). For the sake of space, Table 6 only reports the estimates for the matched sample. The results for the full sample are very similar. Consistent with the hypothesis that U.S. scientists moved to industry to pursue their interest in the cutting-edge area of hESC research, the estimates in Model 5 suggest that U.S. scientists who acquired industry affiliation after the policy change experienced a relative increase in their hESC citation-weighted research output in the four years immediately following the policy change (2002-2005). Interestingly, there seems to be no significant effect on their output in other areas of stem cell research.

-- INSERT TABLE 7 HERE --

Overall, these results suggest that acquiring a corporate affiliation may be a mechanism that U.S. scientists used to acquire resources necessary to continue their research in the hESC area after the Bush administration limited the availability of federal resources. In unreported analysis (available from authors), we also find that the level of basicness/appliedness of research done by the U.S. scientists who moved to industry does not change significantly after the move.

U.S. scientists could also access new sources of funding and material for their research through acquiring additional institutional affiliations. We test this hypothesis by looking at the average number of affiliations associated with each scientist on their published papers in any given year. The results reported in Models 3 and 6 of Table 6 indicate a significant increase in the number of institutions with which U.S. scientists were affiliated in the eight years after the policy shock relative to the institutional affiliations of the control scientists. This would be equivalent to an additional 3 percent of U.S. scientists acquiring at least one new institutional affiliation relative to the control scientists between 2002 and 2005. The effect increases slightly over the next four years.[10]

5.3. Collaboration

A second way in which U.S. based scientists could access resources for stem cell research following the policy change was to develop new collaborative relationships with scientists in industry or scientists in other countries who had superior access to resources for hESC research. Table 6 shows the change in U.S. scientists' co-authorship patterns relative to control scientists in both the full and matched samples following the policy change in 2001. Models 1 and 3 show the impact of Bush policy on U.S. scientists' likelihood of working with cross-border collaborators within the stem cell area compared to scientists in the full sample and the matched one, respectively. Models 2 and 4 show the policy effect on the likelihood of collaborating with industry partners.

-- INSERT TABLE 8 HERE --

The estimates in Models 1 and 3 show no significant change in the international collaboration patterns of U.S. scientists after the change in funding regime. However, it is important to note that during this period there was an increase in funding available through the European Union's Framework Programmes, of which life sciences was a major area of focus. One aim of this program was to promote more integration of scientific research within Europe. Analyzing the 1998-2003 period, Mattsson et al. (2008) find that intra-European international collaboration on scientific publications increased at a faster rate than collaborations between European and U.S.-based scientists, with one of the most pronounced increases being in the life sciences. Scientists from European countries comprise most of the authors from flexible policy regimes in our sample, so the rate of international collaborations for control scientists will be affected by this external trend. This may partly be responsible for the non-significant results reported in Models 1 and 3. Furthermore, it is possible that the demand for collaboration with U.S. scientists decreased following the Bush policy change due to their diminished access to federal funding for research on new hESC lines. Another limitation of this research design is that our estimates cannot capture the increase in collaborations initiated by U.S. scientists reaching out to scientists in the control sample.

[10] Building on the same rationale that scientists may seek new institutional affiliations to access resources for continuing their research in hESC research, we also examined whether U.S.-based scientists became increasingly likely to change country after the policy regime change. We found no significant difference in the probability that U.S. scientists move country compared to the control authors in either the full or matched sample.

However, focusing on international collaborations with scientists outside the control countries produce similar results.[11]

Overall, we find little support for a change in international collaborations by U.S. scientists in response to Bush policy shock. This result contrasts with previously reported evidence by Furman et al. (2012) and Vakili et al. (2015). One possible explanation for this discrepancy is that the increase in international collaborations reported in Furman et al. (2012) and Vakili et al. (2015) may be driven by new entrants into the hESC area after the policy change rather than the scientists who were already publishing in the stem cell area. Alternatively, international collaborations may have involved scientists who had spent time at research laboratories overseas or those moved to the U.S. in the five years before the policy change, who were excluded from our study by design. Such scientists would likely have had larger international networks before the policy change through which they could access collaborators with resources for hESC research.

Models 2 and 4 in Table 8 report the policy effects on U.S. scientists' collaboration with industry after the policy change. Again, the estimates suggest no significant change in the rate of collaboration with industry among the U.S. scientists after the policy change.

6. Discussion and Conclusion

Academic science plays a central role in advancing technology and fostering economic progress (Romer 1990, Nelson and Romer 1996; Jaffe 1989). Recent research suggests that large corporations increasingly rely on academia to produce new knowledge from basic research (Pisano 2010, Arora et al. 2015, Tijssen 2004, Coombs and Georghiou 2002) and highlights various benefits that firms can gain from better access to academic science (Gambardella 1995, McMillan et al. 2000, Cohen and Levinthal 1990, Rosenberg 1990). However, an efficient division of labor between industry and academia requires alignment between the research direction of academic scientists and the needs of industry and society. Meanwhile, the autonomous and independent nature of academia provides external agents with little leverage to shape the direction of research pursued by academic scientists (Dasgupta and David 1994). Funding policies for academic science remain one of the primary levers that are used to steer academic research. Yet little is known about the effectiveness of funding regimes in shaping the research direction of academic scientists.

[11] While we do not see an increase in international collaborations, our additional analysis (available from the authors) suggests a positive association between having international collaborators and producing highly impactful hESC research. We find that this effect was particularly pronounced for U.S. scientists in the four years following the policy change.

In this paper we attempt to address this gap by examining the effect of a substantial cut in funding for human embryonic stem cell research, introduced by the Bush administration in 2001, on the research direction and behavior of U.S. scientists. The change in the funding regime substantially increased the relative cost of doing research in the hESC area for U.S. scientists, while making it relatively easier to access funding for research in other areas of stem cell research. In particular, we investigate how U.S. scientists responded to the cut in hESC funding by changing not only their research direction and effort, but also their institutional affiliations and collaboration patterns. At the time of the Bush policy change, the hESC subfield was considered the most promising area of the stem cell research. Studying the effect of the Bush policy change provides us an opportunity to understand how scientists respond to funding policies that are not aligned with their research priorities that emerge from the role of priority-based rewards and credit in the community of academic scientists.

Interestingly, our results suggest that the cut in federal funding for hESC research in 2001 did not have a significant effect on the hESC research output of U.S. scientists compared to a matched set of control scientists in countries that maintained more flexible funding regimes. However, the results indicate that there was a significant decline in U.S. scientists' research output in non-embryonic areas of stem cell research. Overall, the findings suggest that the U.S. scientists may have responded strategically to the policy change by allocating some of their effort away from non-hESC areas towards securing the financial and material resources needed to carry out their research in the hESC domain. As a result, the policy appears not only to have failed at steering U.S. scientists away from doing research in the hESC area, but also cast a long-lasting negative effect on their research productivity in other areas of stem cell research.

Our findings enhance our understanding of the ways in which scientists 'pay' to carry out scientific research. Not only do they sometimes forego monetary rewards to participate in the community of open science, as shown by Stern (2004), but we find evidence that scientists may also forego easier access to resources in order to undertake research that is seen as more important and potentially impactful by the wider scientific community. This has significant implications for any actor seeking to affect the division of scientific labor across research domains. We find that adjusting the relative cost of doing research in one subfield relative to another may not lead to more scientific labor and research effort flowing to the lower cost area if these incentives are not aligned with the scientific community's interests. Rather, in order to maintain research intensity in the more costly subfield, scientists may cut effort in the less costly area. This may have the perverse consequence of less research being performed in the relatively less costly subfield and diminish the total productivity of scientists' who must now exert a greater share of their efforts to acquire resources for research in the more costly area. This effect may be especially pronounced for the most able scientists who believe that they could to make valuable contributions to the area that offers greater credit and reputational rewards.

Therefore, our results highlight the importance of considering the role of scientific credit and reputation in shaping the research behavior of academic scientists. A reward system based on recognition, reputation, and academic credit creates a highly skewed incentive structure in which scientists disproportionally lean towards conducting research in novel areas that are considered promising by their peers. Hence, as long as scientists have access to multiple sources of funding and material resources, a single external funder would have limited ability to direct scientists' activity towards research domains that are considered less promising by the scientific community. Given that we find U.S. scientists appear to resist changing their research direction even when faced with substantial federal funding restrictions, corporations may have even less leverage in shifting the research direction of scientists working in academia away from their areas of interest. Resources made available to scientists through a given corporation's funding of a particular area of academic research represent a small share of the total funding sources potentially available to an academic scientist to pursue her research interests. This also means that corporations (or other institutions) that use funding to steer academic scientists towards an area of research that is perceived as less promising by the scientific community may risk attracting lower quality scientists who do not see themselves as being competitive enough in the more promising areas. Similarly, it may be significantly more costly for corporations to provide academic scientists with funding-based incentives that are strong enough to overcome those from the priority-based reward system of science, compared to cases when both types of incentive are aligned. Given the monitoring challenges for funders in tasks as inherently unpredictable as basic research, the misalignment of financial and credit-based incentives may lead to significant risks that some of their financial resources are used by academic scientists to pursue research which offers greater potential for credit and reputational rewards.

Our findings also indicate that the Bush funding policy led to an increase in the mobility of U.S. scientists from academia to industry. Furthermore, we find that the scientists who switched to industry following the change in the federal funding regime had greater research output in the hESC area relative to other scientists, suggesting that this offered scientists a strategy to work around a restrictive public funding regime. The results highlight the important role of public funding in shaping the division of labor between academia and industry and the mobility of academic scientists between the two types of institution. Our results suggest that in the absence of public funding in a research area, corporations with an interest in that area seem to prefer hiring academic scientists away from their academic institutions rather than funding collaborative research with them at their academic home.

Past research suggests that academic scientists with a taste for science are willing to pay a premium to be able to participate in the scientific community and contribute to open science through scientific publications (Stern 2004). By hiring scientists away from academia, firms may be able to exert more control over the research direction of scientists, while potentially paying them less in exchange for giving them the flexibility to publish their findings. In comparison, funding scientists in academia gives them less control over their research choice and direction. The sudden cut of public funding in a promising area thus may provide a unique opportunity for firms to attract qualified scientists away from their academic homes. Given the endogenous selection of scientists in moving to industry in our setting, we cannot make any comparison between the effectiveness of research in academia versus industry. Future research is needed to shed more light on this issue and, more broadly, to explore the role of funding policies in shaping the mobility of scientific labor.

In summary, our results call into question the efficiency with which funding policies can shape scientists' research direction particularly when the funding agenda is not aligned with the interest of the scientific community. The results highlight the potential challenges that firms may face as they rely more on academic research to generate ideas that they can develop and commercialize. The findings indicate that it is important to recognize the significance of the incentives in academic science that emerge from the opportunity to gain scientific credit, in addition to intended incentives designed in a specific funding policy. In particular, we show how scientists' strategic choices in response to the introduced policies can undermine the intended purpose of these policies and lead to further unintended consequences when the types of incentive are misaligned. Future research can shed more light on these issues by studying other contexts and funding policies. Moreover, additional research is needed to understand how funding policies can influence the direction of technology, the performance of firms in related technological domains, and the effectiveness of the division of labor between academia and industry under different circumstances.

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Table 1: Definitions of main variables

Variable	Description
U.S.-based between 1996 and 2000	Indicator variable equal to one if scientist *i* was based exclusively at U.S. institutions from 1996 to 2000 (inclusive)
Total Citation-Weighted Publications	The total number of citations to scientist *i*'s publications in a given year *t*
SC Citation-Weighted Publications	The total number of citations to scientist *i*'s publications in a stem cell field in a given year *t*
Non-Embyonic SC Citation-Weighted Publications	The total number of citations to scientist *i*'s publications in a non-embryonic stem cell field a given year *t*
aESC Citation-Weighted Publications	The total number of citations to scientist *i*'s publications in the aESC domain in a given year *t*
hESC Citation-Weighted Publications	The total number of citations to scientist *i*'s publications in the hESC domain in a given year *t*
Has Industry Affiliation	Indicator variable equal to one if scientist *i* had an industry affiliation in year *t*
Has University/Hospital Affiliation	Indicator variable equal to one if scientist *i* had an university or health service provider affiliation in year *t*
Number of Affiliations	The mean value of the total number of affiliations scientist *i* has on papers in year *t*
Has International Collaborations in Stem Cell	Indicator variable equal to one if scientist *i* collaborated on a publication with a scientist from a foreign country in year *t*
Has Industry Collaborators	Indicator variable equal to one if scientist *i* collaborated on a publication with a scientist from a foreign country in year *t*

To be included in the sample a scientist must have been based exclusively in either the U.S. or one of our control countries. Therefore the zero value of the indicator variable defined in the first row of the table denotes a scientist who was based exclusively at institutions in a control country from 1996 to 2000 (inclusive). Where we do not observe an affiliation or collaboration for scientist *i* from a publication in a given year *t*, we interpolate using the most proximate observation of that variable to fill the missing observations for the final five variables listed in the table.

Table 2: Summary statistics for the full sample and the matched sample (1996-2009)

Panel A: Full Sample

Variable	N	Mean	Std. Dev.	Min	Max
U.S.-based between 1996 and 2000	84,822	0.674	0.469	0	1
Total Citation-Weighted Publications	84,822	85.37	203.2	0	6,092
Ln(Total Citation-Weighted Publications+1)	84,822	2.386	2.3	0	8.715
SC Citation-Weighted Publications	84,822	15.13	75.99	0	5,218
Ln(SC Citation-Weighted Publications+1)	84,822	0.648	1.487	0	8.56
Non-Embryonic SC Citation-Weighted Publications	84,822	11.71	64.65	0	5,041
Ln(Non-Embryonic SC Citation-Weighted Publications+1)	84,822	0.543	1.363	0	8.526
aESC Citation-Weighted Publications	84,822	3.424	38.08	0	2,380
Ln(aESC Citation-Weighted Publications+1)	84,822	0.113	0.701	0	7.775
hESC Citation-Weighted Publications	84,822	0.404	11.03	0	1,234
Ln(hESC Citation-Weighted Publications+1)	84,822	0.015	0.254	0	7.119
Has Industry Affiliation	84,822	0.02	0.142	0	1
Has University/Hospital Affiliation	84,822	0.988	0.106	0	1
Number of Affiliations	84,822	1.265	0.53	1	11
Has International Collaborations in a Stem Cell Area	84,822	0.054	0.225	0	1
Has Industry Collaborators	84,822	0.146	0.353	0	1

Panel B: Matched Sample

Variable	N	Mean	Std. Dev.	Min	Max
U.S.-based between 1996 and 2000	45,363	0.584	0.493	0	1
Total Citation-Weighted Publications	45,363	28.18	74.99	0	2,923
Ln(Total Citation-Weighted Publications+1)	45,363	1.546	1.906	0	7.981
SC Citation-Weighted Publications	45,363	6.225	32.82	0	1,596
Ln(SC Citation-Weighted Publications+1)	45,363	0.452	1.178	0	7.376
Non-Embryonic SC Citation-Weighted Publications	45,363	5.286	29.97	0	1,596
Ln(Non-Embryonic SC Citation-Weighted Publications+1)	45,363	0.402	1.111	0	7.376
aESC Citation-Weighted Publications	45,363	0.842	11.97	0	931
Ln(aESC Citation-Weighted Publications+1)	45,363	0.05	0.437	0	6.837
hESC Citation-Weighted Publications	45,363	0.204	6.956	0	487
Ln(hESC Citation-Weighted Publications+1)	45,363	0.008	0.183	0	6.19
Has Industry Affiliation	45,363	0.019	0.133	0	1
Has University/Hospital Affiliation	45,363	0.989	0.104	0	1
Number of Affiliations	45,363	1.221	0.509	1	11
Has International Collaborations in a Stem Cell Area	45,363	0.048	0.214	0	1
Has Industry Collaborators	45,363	0.111	0.314	0	1

Table 3: Pre-shock statistics (1996-2000)

Panel A: Full Sample

Variable	**U.S. scientists**	**Non-U.S. scientists**	**t-test difference**
Number of Scientist-Year Observations	18,843	9,060	
First Publication Year	1989.875 (6.429)	1990.015 (6.392)	-0.140* (p=0.088)
Ln(Total Citation-Weighted Publications+1)	3.172 (2.318)	2.780 (2.121)	0.392*** (p=0.000)
Ln(SC Citation-Weighted Publications+1)	1.097 (1.848)	0.959 (1.627)	0.138*** (p=0.000)
Ln(Non-Embryonic SC Citation-Weighted Publications+1)	0.848 (1.653)	0.830 (1.520)	0.017 (p=0.393)
Ln(aESC Citation-Weighted Publications+1)	0.266 (1.089)	0.138 (0.768)	0.129*** (p=0.000)
Ln(hESC Citation-Weighted Publications+1)	0.008 (0.192)	0.010 (0.210)	-0.001 (p=0.576)
Has International Collaborations in a Stem Cell Area	0.046 (0.210)	0.068 (0.252)	-0.022*** (p=0.000)

Panel B: Matched Sample

Variable	**U.S. scientists**	**Non-U.S. scientists**	**t-test difference**
Number of Scientist-Year Observations	8,293	5,989	
First Publication Year	1991.970 (5.801)	1991.885 (5.795)	0.085 (p=0.382)
Ln(Total Citation-Weighted Publications+1)	2.032 (1.918)	2.094 (1.581)	-0.062 (p=0.527)
Ln(SC Citation-Weighted Publications+1)	0.863 (1.508)	0.856 (1.465)	0.006 (p=0.796)
Ln(Non-Embryonic SC Citation-Weighted Publications+1)	0.742 (1.413)	0.744 (1.381)	-0.002 (p=0.932)
Ln(aESC Citation-Weighted Publications+1)	0.125 (0.685)	0.116 (0.649)	0.008 (p=0.456)
Ln(hESC Citation-Weighted Publications+1)	0.003 (0.101)	0.008 (0.184)	-0.005** (p=0.028)
Has International Collaborations in a Stem Cell Area	0.046 (0.208)	0.056 (0.229)	-0.010*** (p=0.006)

Note: We use the weighting procedure employed in the regression analysis to compare summary statistics in the matched sample.

Table 4: Impact of Bush hESC policy on U.S. scientists' research direction and productivity

Panel A: Full Sample

	Ln(Total Citation-Weighted Publications+1)	Ln(SC Citation-Weighted Publications+1)	Ln(Non-Embryonic Citation-Weighted Publications+1)	Ln(aESC Citation-Weighted Publications+1)	Ln(hESC Citation-Weighted Publications+1)
	(1)	(2)	(3)	(4)	(5)
US Author * T0205	-0.108***	-0.124***	-0.033	-0.094***	-0.001
	(0.036)	(0.024)	(0.023)	(0.011)	(0.006)
US Author * T0609	-0.198***	-0.122***	-0.017	-0.109***	-0.001
	(0.040)	(0.024)	(0.023)	(0.012)	(0.007)
Year & Scientist FEs	Yes	Yes	Yes	Yes	Yes
Obs.	84,822	84,822	84,822	84,822	74,812
No. of Scientists	6,337	6,337	6,337	6,337	6,337
Within R^2	0.080	0.053	0.037	0.017	0.001

Panel B: Matched Sample

	Ln(Total Citation-Weighted Publications+1)	Ln(SC Citation-Weighted Publications+1)	Ln(Non-Embryonic Citation-Weighted Publications+1)	Ln(aESC Citation-Weighted Publications+1)	Ln(hESC Citation-Weighted Publications+1)
	(1)	(2)	(4)	(3)	(5)
US Author * T0205	-0.036	-0.069**	-0.063**	-0.003	0.004
	(0.050)	(0.027)	(0.026)	(0.014)	(0.006)
US Author * T0609	-0.063	-0.060**	-0.045*	-0.006	0.001
	(0.055)	(0.028)	(0.027)	(0.015)	(0.007)
Year & Scientist FEs	Yes	Yes	Yes	Yes	Yes
Obs.	45,363	45,363	45,363	45,363	40,502
No. of Scientists	3,458	3,458	3,458	3,458	3,458
Within R^2	0.061	0.078	0.064	0.015	0.001

Notes: All estimates are based on panel OLS regression with year and scientist fixed effects. Standard errors (in parentheses) are clustered at the scientist-level to allow for serial correlation and are robust to arbitrary heteroskadasticity. The 1996-2009 period is used for Models 1 to 4. Model 5 limits the window to 1998-2009 for the reasons described in footnote 7. *** p<0.01, ** p<0.05, * p<0.1. SC: stem cell; aESC: animal embryonic stem cell; hESC: human embryonic stem cell.

Table 5: Heterogeneity of Bush policy impact based on prior investment in stem cell research (matched sample results)

	Ln(Total Citation-Weighted Publications+1)		Ln(SC Citation-Weighted Publications+1)		Ln(Non-Embryonic Citation-Weighted Publications+1)		Ln(aESC Citation-Weighted Publications+1)		Ln(hESC Citation-Weighted Publications+1)	
	SC citation share≥0.5 1996-2000	SC citation share<0.5 1996-2000	SC citation share≥0.5 1996-2000	SC citation share<0.5 1996-2000	SC citation share≥0.5 1996-2000	SC citation share<0.5 1996-2000	SC citation share≥0.5 1996-2000	SC citation share<0.5 1996-2000	SC citation share≥0.5 1996-2000	SC citation share<0.5 1996-2000
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
US Author * T0205	-0.041 (0.078)	-0.043 (0.065)	-0.093** (0.045)	-0.030 (0.034)	-0.105** (0.044)	-0.016 (0.033)	0.011 (0.027)	-0.009 (0.015)	0.005 (0.011)	0.002 (0.007)
US Author * T0609	-0.160* (0.087)	-0.003 (0.069)	-0.094** (0.049)	-0.010 (0.034)	-0.086* (0.047)	0.004 (0.032)	0.009 (0.027)	-0.013 (0.016)	-0.001 (0.014)	0.003 (0.006)
Year & Scientist FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	19,361	26,002	19,361	26,002	19,361	26,002	19,361	26,002	17,724	22,778
No. of Scientists	1,546	1,912	1,546	1,912	1,546	1,912	1,546	1,912	1,546	1,912
Within R^2	0.053	0.070	0.144	0.041	0.119	0.035	0.027	0.008	0.001	0.001

Notes: All estimates are based on panel OLS regression with year and scientist fixed effects. Standard errors (in parentheses) are clustered at the scientist-level to allow for serial correlation and are robust to arbitrary heteroskadasticity. The 1996-2009 period is used for Models 1 to 8. Models 9 and 10 limit the window to 1998-2009 for the reasons described in footnote 7. *** p<0.01, ** p<0.05, * p<0.1. SC: stem cell; aESC: animal embryonic stem cell; hESC: human embryonic stem cell.

Table 6: Impact of Bush hESC policy on U.S. scientists' institutional affiliations

	Full Sample			**Matched Sample**		
	Has Industry Affiliation	Has University/Hospital Affiliation	Number of affiliations	Has Industry Affiliation	Has University/Hospital Affiliation	Number of affiliations
	(1)	(2)	(3)	(4)	(5)	(6)
US Author * T0205	0.017***	-0.010***	0.036***	0.013***	-0.010***	0.029**
	(0.003)	(0.002)	(0.010)	(0.005)	(0.003)	(0.014)
US Author * T0609	0.022***	-0.015***	0.041***	0.018***	-0.013***	0.039**
	(0.004)	(0.003)	(0.011)	(0.006)	(0.004)	(0.015)
Year & Scientist FEs	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	84,822	84,822	84,822	45,363	45,363	45,363
No. of Scientists	6,337	6,337	6,337	3,458	3,458	3,458
Within R^2	0.027	0.018	0.002	0.025	0.016	0.002

Notes: All estimates are based on panel OLS regression with year and scientist fixed effects. Standard errors (in parentheses) are clustered at the scientist-level to allow for serial correlation and are robust to arbitrary heteroskadasticity. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Moderating effect of switching to industry on U.S. scientists' research output (matched sample results)

	Ln(Total Citation-Weighted Publications+1)	Ln(SC Citation-Weighted Publications+1)	Ln(Non-Embryonic Citation-Weighted Publications+1)	Ln(aESC Citation-Weighted Publications+1)	Ln(hESC Citation-Weighted Publications+1)
	(1)	(2)	(3)	(4)	(5)
Industry Affiliation	0.104	-0.031	-0.039	0.047	-0.017
	(0.212)	(0.149)	(0.134)	(0.068)	(0.012)
US Author * T0205	-0.047	-0.069**	-0.060**	-0.004	0.001
	(0.050)	(0.027)	(0.026)	(0.014)	(0.006)
US Author * T0205 * Industry Affiliation	**0.347**	**0.051**	**-0.019**	**-0.004**	**0.104***
	(0.252)	**(0.174)**	**(0.152)**	**(0.083)**	**(0.062)**
US Author * T0609	-0.066	-0.061**	-0.048*	-0.007	0.001
	(0.055)	(0.029)	(0.027)	(0.015)	(0.007)
T0609 * Industry Affiliation	-0.240	-0.199	-0.226	-0.078	-0.027
	(0.237)	(0.152)	(0.146)	(0.053)	(0.060)
US Author * T0609 * Industry Affiliation	**0.137**	**0.139**	**0.192***	**0.038**	**0.085**
	(0.241)	**(0.120)**	**(0.101)**	**(0.056)**	**(0.056)**
Year & Scientist Fes	Yes	Yes	Yes	Yes	Yes
Obs.	45,363	45,363	45,363	45,363	40,502
No. of Scientists	3,458	3,458	3,458	3,458	3,458
Within R^2	0.061	0.078	0.065	0.015	0.002

Notes: All estimates are based on panel OLS regression with year and scientist fixed effects. Standard errors (in parentheses) are clustered at the scientist-level to allow for serial correlation and are robust to arbitrary heteroskadasticity.. The 1996-2009 period is used for Models 1 to 4. Model 5 limits the window to 1998-2009 for the reasons described in footnote 7. *** p<0.01, ** p<0.05, * p<0.1. SC: stem cell; aESC: animal embryonic stem cell; hESC: human embryonic stem cell.

Table 8: Impact of Bush hESC policy on U.S. scientists' collaboration patterns

	Full Sample		Matched Sample	
	Has International Collaborations in Stem Cell Area	Has Industry Collaborators	Has International Collaborations in Stem Cell Area	Has Industry Collaborators
	(1)	(2)	(4)	(5)
US Author * T0205	-0.004	-0.006	-0.008	-0.001
	(0.005)	(0.007)	(0.006)	(0.009)
US Author * T0609	-0.003	-0.003	-0.003	0.002
	(0.005)	(0.008)	(0.006)	(0.010)
Year & Scientist FEs	Yes	Yes	Yes	Yes
Obs.	84,822	84,822	45,363	45,363
No. of Scientists	6,337	6,337	3,458	3,458
Within R^2	0.003	0.007	0.002	0.010

Notes: All estimates are based on panel OLS regression with year and scientist fixed effects. Standard errors (in parentheses) are clustered at the scientist-level to allow for serial correlation and are robust to arbitrary heteroskadasticity.. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. SC .

Appendix

Table A1: The impact on scientists with industry affiliation between 1996-2001

	(1)	(2)	(3)	(3)	(5)
	Ln(Total Citation-Weighted Publications+1)	Ln(SC Citation-Weighted Publications+1)	Ln(Non-Embryonic Citation-Weighted Publications+1)	Ln(aESC Citation-Weighted Publications+1)	Ln(hESC Citation-Weighted Publications+1)
US Author * T0205	-0.216	0.033	-0.009	0.057	-0.003
	(0.169)	(0.085)	(0.093)	(0.050)	(0.021)
US Author * T0609	-0.335**	-0.005	-0.055	0.050	-0.019
	(0.169)	(0.088)	(0.092)	(0.054)	(0.031)
Year & Scientist FEs	Yes	Yes	Yes	Yes	Yes
Obs.	3,112	3,112	3,112	3,112	2,770
No. of Scientists	272	272	272	272	272
Within R^2	0.097	0.095	0.085	0.049	0.005

Notes: All estimates are based on panel OLS regression with year and scientist fixed effects. Standard errors (in parentheses) are clustered at the scientist-level to allow for serial correlation and are robust to arbitrary heteroskadasticity.. The 1996-2009 period is used for Models 1 to 4. Model 5 limits the window to 1998-2009 for the reasons described in footnote 7. *** p<0.01, ** p<0.05, * p<0.1. SC: stem cell; aESC: animal embryonic stem cell; hESC: human embryonic stem cell.

Table A2: The Impact of Bush hESC policy on U.S. scientists' institutional affiliations based on prior investment in stem cell research (full sample results)

	Has Industry Affiliation	Has Industry Affiliation	Has Industry Affiliation	Has Uni/Hospital Affiliation	Has Uni/Hospital Affiliation	Has Uni/Hospital Affiliation
	Top Quartile SC citation share 96-00; >0 Pubs	Top Quartile SC citation share 96-00; >1 Pubs	Lower 3 Quartiles SC citation share 96-00; >1 Pub	Top Quartile SC citation share 96-00; >0 Pubs	Top Quartile SC citation share 96-00; >1 Pub	Lower 3 Quartiles SC citation share 96-00; >1 Pub
	(1)	(2)	(3)	(4)	(5)	(6)
US Author * T0205	0.014*	0.018**	0.001	-0.012*	-0.022***	-0.005
	(0.008)	(0.009)	(0.004)	(0.007)	(0.007)	(0.003)
US Author * T0609	0.018**	0.023**	-0.001	-0.012	-0.024***	-0.009*
	(0.009)	(0.01)	(0.005)	(0.008)	(0.008)	(0.005)
Year & Scientist FEs	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	24,715	18,379	80,500	24,715	18,379	80,500
No. of Scientists	1,952	1,373	5,858	1,952	1,373	5,858
Within R^2	0.005	0.005	0.005	0.004	0.004	0.01

Notes: All estimates are based on panel OLS regression with year and scientist fixed effects. In columns (2) and (5) we exclude those scientists who have only one publication up to 2000 and therefore for whom a single publication meant that they were in the top quartile of citation share to SC papers in 1996-2000 for the full sample of scientists. Scientists with only one publication may be less invested in scientific research and publishing (in SC or other research areas) than scientists with multiple papers. Therefore by excluding these scientists, we limit the top quartile of scientists to those scientists we can be more confident have heavily invested in SC research in their careers. The cut-off point for inclusion in the top quartile is to have 68.5 percent of citations to SC papers between 1996 and 2000. Since scientists were required to have at least one SC publication to be included in the study, there are no scientists with only one publication who did not receive 100 percent of citations to a SC paper and hence were not in the top quartile. Standard errors (in parentheses) are clustered at the scientist-level to allow for serial correlation and are robust to arbitrary heteroskadasticity. *** p<0.01, ** p<0.05, * p<0.1.