Freeze! You Are Under a Ban:

The Impact of Funding Moratoriums on Scientific Progress

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Abstract

In August 2001, on the premise of ethical concerns, George W. Bush implemented a policy to restrict federal funding for human embryonic stem cell (hESC) research. But did the ban actually halt progress in that field? That is the question subject to analysis, with the aim of commenting on the regulation of innovation as a whole. To this end, using a difference in differences model, hESC trends pre and post ban were compared to the similarly evolving field of RNAi. I find that the ban did significantly reduce hESC patents in the US, suggesting that innovation in surging sciences can, at the least, be constrained. This effect may have been overestimated however, as the reduction more than halved when accounting for the potentially ban-induced workaround of iPS. Moreover, I find evidence of a global amplification effect, as the reduction in hESC patents worldwide almost doubled the US-isolated drop. Turning next to qualitative measures, findings suggest that innovation in the area occurred with equal novelty and proximity to hESC, and that the public and private sector shared the burden equally. The first stem cell ban-related paper to utilize patents in this manner, it joins an area of inquiry that, in the face of contemporary ethical concerns, is of growing relevance.

Introduction

Innovation, though a cornerstone of progress, is not free from controversy. Currently at the forefront are discussions surrounding artificial intelligence and biotechnology. A.I. has applications to various fields and will continue to improve seemingly every aspect of life. By the same token, AI has been cited as the main culprit in hate speech, privacy violations, autonomous weapon errors, and countless other calamities. Bioengineering has played a vital role in our improved ability to treat and cure diseases and represents a burgeoning field of exciting developments. It has also, however, been beset with ethical disputes. Many scholars have expressed these trepidations both informally and formally. Others take a more hands on approach; for instance, in March of 2023, over one thousand tech luminaries signed a petition to halt the training of A.I. systems more powerful than GPT-4. As they would agree, the necessity to both foster and regulate these advancements are tantamount.

One primary way to guide this progress at the national level is through funding policy. The rationale behind these policies seems rather intuitive, and governments worldwide have long been implementing such measures; increasing (funding) boosts progress and decreasing sees it slackened. In reality, however, this relationship may not always play out how it does on paper. Two articles found dispiriting effectiveness of government funding; million-dollar-plus funding grants leading to a trivial 1-2 additional publications over the next five to ten years, with a loss of grants causing researchers to shift to other funding sources (Popp (2015); Jacob and Lefgren (2011)). Another paper suggests that increased R&D does not lead to increased innovation, evidencing that the majority of government R&D goes towards higher wages, effectively crowding out private inventive activity (Goolsbee 1998). These articles among others show that predicting outcomes is tricky, especially in dynamic fields. Many hold the belief that development and rollout of such technologies is inexorable, and perhaps rightly so. However, substantial opposition is adamant in their stance that we can and should regulate progress in these fields. This begs the question, can we rein in innovation? More specifically, will moratoriums halt the progress of surging sciences?

In order to explore this question, I analyze the impact of one such funding ban on the progress in that field. Specifically, I test whether the federal funding ban on hESC (human embryonic stem cell) research led to a fall in patents relative to a similarly developing field unaffected by a ban.

Human embryonic stem cells were first derived in 1998. The cells' value to regenerative medicine and developmental biology as a whole was immediately recognized, driven by their unique capacities to differentiate into any embryonic cell type (pluripotency) and to self-renew. However, harvesting these cells often requires the destruction of the embryo from which the cells were obtained. The practice thus became fraught with the same ethical debates that surround abortion. With both immense potential benefits and fomenting controversy, political decisions were inevitable.

At the height of controversy in the early 2000's, countries around the world adopted a range of prohibitive measures on hESC research and practices. The U.S. took an assertive stance by restricting funding for hESC research in 2001. In particular, it limited funded research on embryonic stem cells to already derived cell lines. Being a federal ban, private and regional funding were unimpeded. Nonetheless, this created uncertainty for researchers in the field. The decisive policy was implemented by the then newly-elect George W. Bush. The announcement of the funding ban appears to have come as a surprise to stem cell researchers, which suggests that no anticipatory actions could be taken prior to the announcement. Ultimately, after almost a decade of ethical debate, former president Barack Obama lifted the ban in 2009 (Gottweis 2010). In order to examine the impact of the ban on progress in this field, I test whether the number of USPTO-approved patents fell in response to the ban. I believe studying the causal effect of the funding ban on the number of patents is useful for multiple reasons. In addition to the lack of pertinent patent literature, a patent-oriented analysis is applicable due to the connection – which may be more ambiguous for other markers like publications – it has to innovation. Hegde et al. (2023) find that patent publication has a "profound impact on follow-on innovation", supplemented by the Brookings institute findings that STEM industries patent more (Shambaugh et al. 2017). Acemoglu et al. (2011) moreover suggest that patents encourage rapid experimentation and efficient ex post knowledge transfer. The connection is empirically supported. Thus, the tailored question for investigative purposes can be reiterated: How did the 2001 funding ban affect hESC patent output?

Literature Review

As mentioned previously, outcomes of government funding policy can follow the intended course just as well as diverge. In fact, this paradigm holds not only for raised funding but funding in general. Looking at the rate of inventive activity, Corredoira et al. (2018) situate the government as irreplaceable in regard to the rate and direction of inventive activity. Contrarily, a ten-year study of Swiss science funding could establish no significant correlation between money received and bibliometric productivity (Mariethoz, Herman, and Dreiss 2021). These two papers, out of many, highlight the unpredictability which justifies further examination; it would contribute another piece to the complex puzzle.

In order to understand hESC development, it might be useful to first give an overview of stem cell patenting as a whole. In an extensive study, a US based team produced an empirical review of the global stem cell patent landscape. With the goal of understanding main trends in patenting activity, the authors analyzed a data set consisting of over 10,000 patents spanning from 1986 to 2007. The key observations include a possible peak in patents between 2001 and 2003, US patents having been in the decline since 2001, and that, nonetheless, the US produced the lion's share of patents (Bergman and Graff 2007). A later paper conducted a similar investigation. With the goal in mind of highlighting increasing private ownership of stem cell technologies, the group noted upward trends in patent data across the globe (Mathews et al. 2011). Again, the important distinction here is the range of included stem cell types. The two above papers incorporated patents queried for all stem cell types; not just the ban-specific human embryonic stem cells.

A further cluster of papers do follow a guiding question similar to my own, but with different markers for scientific progress. Looking at firm reactions, Huang and Jong (2019) found that in the aftermath of policy shifts which increased uncertainties for stem cell therapy research, R&D project initiation rates decreased and discontinuation rates for existing projects rose. More concerned with public sector response, a series of papers sought to answer a question more closely aligned with my own. Owen-Smith and McCormick observe a significant gulf, apparent after 2002, between US and non-US publication rates; the ban may have debilitated our performance in the international race (2006). Some six years later, a study utilizing a citation-based evaluation found that "US production of hESC research lagged 35 to 40 percent behind anticipated levels". Moreover, this research dip was concentrated in the 2001 to 2003 period, followed by a steady recovery (Furman, Murray, and Stern 2012). Soon after, a group based in Seoul endeavored to further dissect this apparent impact. In hope of developing a more vivid picture of the trends, they categorized hESC publications into three subfields. Compared to other countries, they concluded that the US outperformed in hESC research between 1998 and 2008. However, for the derivation subfield, the policy seemed to have the intended effect (Moon and Cho 2014). Refocusing on the field as a whole, another paper presents a contradictive outcome. The primary finding echoed that of Moon and Cho's, in that other than a short-termed lag at the start of the millennium, the policy had no significant aggregate effect on US hESC journal publications (Vakili et al. 2015). The disparities between findings proves perplexing. Taking adapted angles would thus, at worst, continue the discussion, and at best provide clarity to these inconsistencies.

However, more nuanced inquiries may also offer explanations. The first suggestion comes from international collaboration. Agreement between papers justifies the hypothesis that the funding ban necessitated the cultivation of international relationships. The waning in research from 2001 to 2003, Furman, Murray, and Stern posit, was reinvigorated partly by international collaboration. Subfield cooperation additionally underscored US resilience through international collaboration (Moon and Cho 2014). Further analysis unveils the existence of certain preferences. Two studies cite the US' selective collaboration with less prohibitive countries. US based scientists partnered with tolerant countries at 3.9 times the rate as with constrained countries (Vakili et al. 2015). As for the counterfactual they use (RNAi), trends suggest that US researchers collaborated with countries maintaining similar levels of policy permissiveness (Moon and Cho 2014). That is to say, the hESC ban impelled US researchers into collaboration with countries unrestricted by policy.

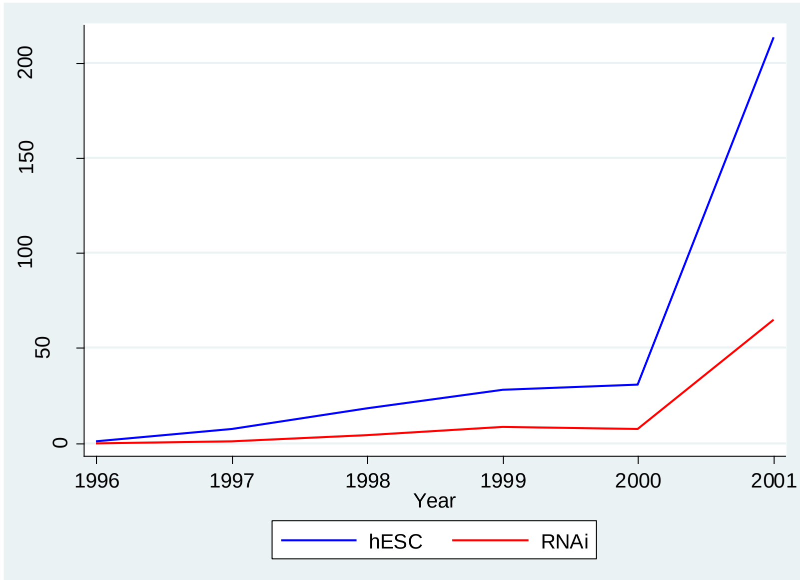
Dulling the analytical shovel even further, we next look towards academic institutions. While still under the strain of policy, research was able to rebound. Year-by-year effects imply that top 25 U.S. research institutions, many of which are universities, led the resurgence of hESC research after 2003 (Furman, Murray, and Stern 2012). A similar paper considers state level funding following the policy; publication concentration shifted to "early funding states". California and Massachusetts, two early funding states, accounted for 42% of domestic publications (Vakili et al. 2015). Under the federal restriction, states and state/privately run institutions took over the reins of research.

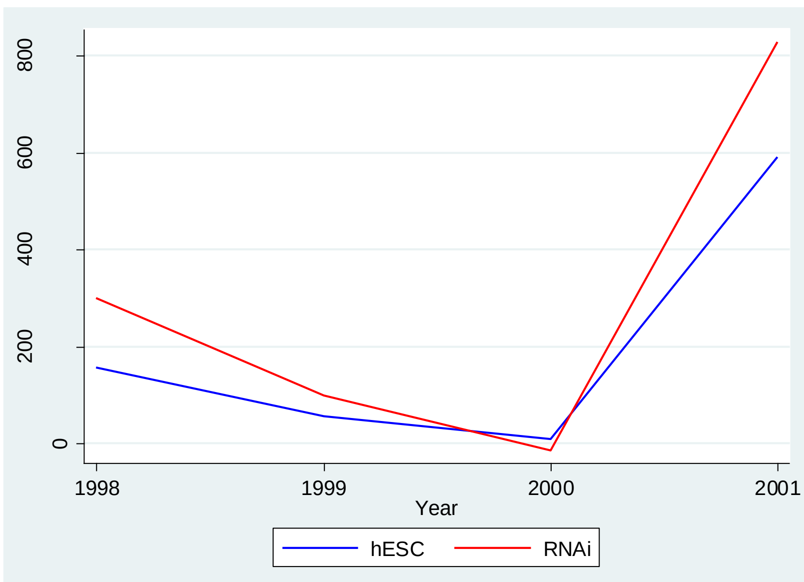
The current study adds to the literature in a number of important ways. Of the three most common indicators for scientific progress (patents, citations, and publications), one has yet to be analyzed. While they all provide a measure for advancement, patent filings are uniquely useful for multiple reasons. They are incentivized by possible commercialization. In that sense, they represent the real-world application of scientific innovation – a gauge that publications and citations might not. Plentiful and accessible patent data, that can be used as an indicator for inventive input and output, provides an often unmatched resource for measuring innovation (Griliches 1990). As our world has become increasingly data-driven, the value of patenting as a comprehensive indicator has risen in tandem (Nagaoka, Motohashi, and Akira Goto 2010). Additionally, substantial connections between patenting and prior scientific inquiry solidify the metric as a reliable illustrative power (Ahmadpoor and Jones 2017). Moreover, no literature has looked past 2011. Extending the time-series dimension could unearth latent implications of the ban, revealed from this new analysis of long term evolution; over the past decade, hESC research may have very well been shifting to the same degree as during the turn-of-the-century thicket of controversy. An empirical analysis of the efficacy of said moratorium would thus act as both novel and supplemental to current literature. Additionally, it would serve to advise legislation in connection with the suppression of controversial scientific progress.

Methodology

The purpose of this inquiry is to determine the impact of the funding moratorium on hESC patent filings. An intuitive approach to study this inquiry would be to compare the number of US hESC patents before and after the ban. Such a strategy, however, might not yield the true impact of the ban due to any changes in other factors affecting the quantity of patent applications. Omitted variable bias could thus contaminate the comparison; an ebb or flow in the whole patent landscape, contemporaneous with the 2001 funding ban, would lead to a misinterpretation of the impact of the ban. Given this issue, the approach taken to determine the true impact of the federal ban on patent applications is to compare the path of hESC patent applications with the path of patent applications for a similar field of research that was not affected by the ban. Following the approaches of (Moon and Cho 2014; Furman et al. 2012; Vakili et al. 2015), I choose RNAi (RNA interference) as my comparison field. Anticipating a likely rebuttal, yes, OSC (other stem cell) research may appear the more intuitive control group, as the policy did not restrict funding for those areas. Ultimately however, the high possibility that the 2001 policy enactment affected this hESC-adjunct area of research, indirect or otherwise, renders the group less suitable. Besides its recurrence in related studies, RNAi serves as a favorable counterfactual for multiple reasons. It represents a breakthrough with primarily US roots (like hESC) that occurred during the same time period, and was of comparable relevance around the time of the ban. The independence of research methods is also notable in this respect; crossover between the two areas is unlikely. Thus, by comparing the path of the number of USPTO-approved patents for hESC with the path for RNAi, using a difference-in-differences model, I will be able to determine the impact of the hESC funding ban on scientific progress.

The validity of a difference in differences model relies heavily on the parallel trends assumption. That is to say, in the absence of the ban, hESC and RNAi patent filings would have followed parallel trends. Obviously this cannot be proven directly. Visual inspection is the oft-invoked alternative. In the two figures below, I plot the number of patents and the percentage growth rates of patents for both hESC and RNAi up to the year of the ban.



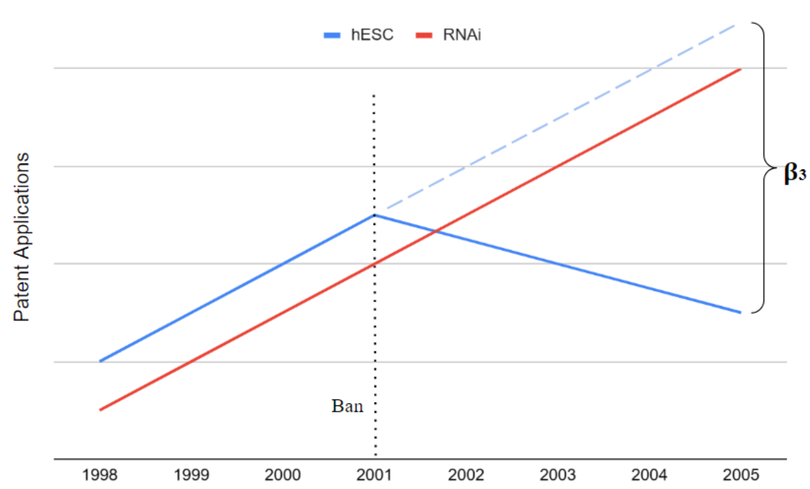


In these two figures, the lines appear to mimic one another closely, with both technologies growing somewhat slowly until 2000 when both saw significant increases in approved patents. Combined with the previously mentioned fact that multiple similar studies utilized RNAi as a difference in differences counterfactual, the assumption can be sufficiently established to hold.

The baseline regressions in which I test the ban effect on hESC patents approved both in the US and worldwide take on the following form:

$$Patents_{g,t} = \beta_0 + \sum \gamma_t + \beta_1 hESC + \beta_2 Post_t + \beta_3 hESCxPost_t + \varepsilon_{g,t}$$

One notices two levels of indices. g indexes the group of research (hESC or RNAi) and t indexes each year. The dependent variable $Patents_{g,t}$ is the number of accepted patent filings, indexed at the group and year levels. $\sum \gamma_t$ represents year fixed effects, which controls for any factors that vary across years but are constant among hESC and RNAi patenting. These could include (but are not limited to) economic fluctuation and changes in patent laws. $hESC$ is a binary variable, with 1 corresponding to hESC patents and 0 corresponding to RNAi patents. $Post_t$ is a binary variable as well, holding a 0 for pre-ban patents and 1 for post-ban patents. Their coefficients (β_1 and β_2) respectively represent the difference in hESC patents relative to RNAi, and the difference in patents before and after the policy. The key coefficient is β_3, which estimates the difference in hESC and RNAi patent output prior to and following the 2001 funding ban. Based on conflicting literature, a confident prediction of β_3 as positive or negative could not be made. Here, a hypothetical graph may accommodate a more vivid understanding of the coefficient.



The graph shows the hypothesized divergence – correlating with a negative β_3 – in patent applications following the policy year that a difference in differences would estimate. Anyhow, the effect of the policy now becomes isolated from external factors. The methodology should be considered, in this sense, specified and thus reliable.

Data

All data was pulled from the USPTO. Data was first extracted at the individual patent level. Using key word queries, this was done for hESC, RNAi, and hESC + iPS. Utilized search queries are as follows:

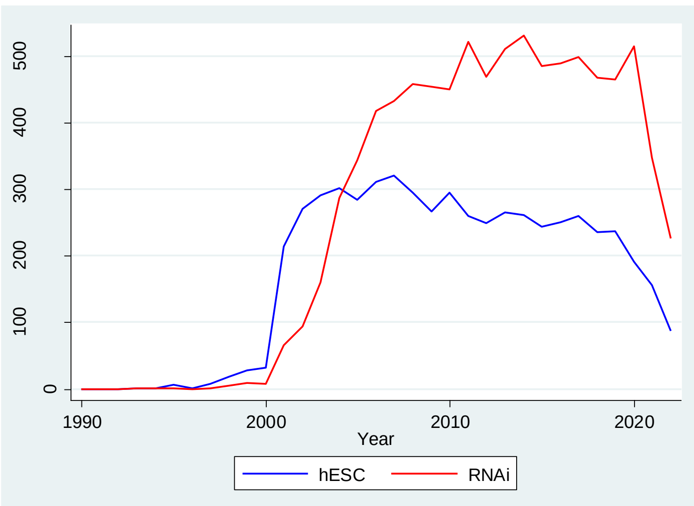
hESC: *"human AND (embryo OR embryonic) and (stem ADJ cell) NOT (ips OR ipsc OR hipsc OR plant OR vegetable OR fruit OR agriculture OR non-human)"*

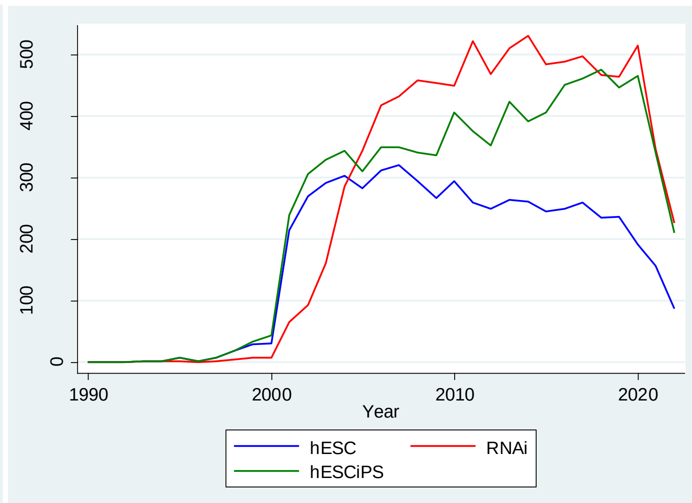
RNAi: *"(sirna OR rnai OR (allele?specific ADJ oligonucleotide)) AND (human OR disease OR disorder) NOT (plant OR vegetable OR fruit OR agriculture OR non-human)"*

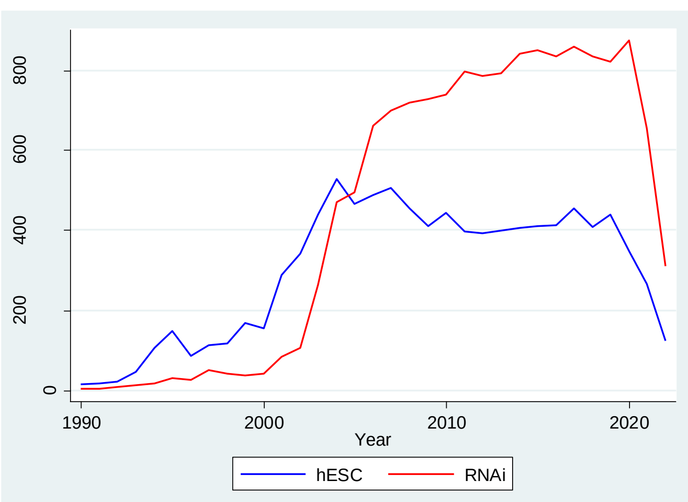
hESC + iPS: *"((human AND (embryo OR embryonic) AND (stem ADJ cell)) OR (induced ADJ pluripotent OR ipsc OR hipsc)) NOT (plant OR vegetable OR fruit OR agriculture OR non-human)"*

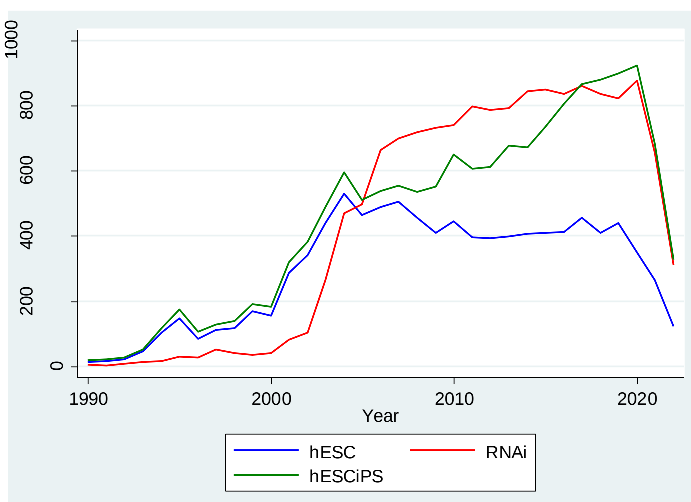
For hESC, all keywords prior to the *NOT* were borrowed directly from Moon and Cho's paper (2014). The *NOT* "groups" were included to respectively ensure no iPS related patents and no non-human related stem cell patents could confound the data. For RNAi, a similar strategy could not be employed. Instead, the query was constructed through the expert judgment of Holy Cross biology professor Geoff Findlay. Given his extensive knowledge on the biological process (RNAi), the query can be considered representative. *NOT*s were utilized to again ensure the omission of any non-human related patents. hESC + iPS is simply a combination of the hESC query and iPS relevant keywords. The iPS keywords may appear too limited in range compared to its counterparts. However, iPS, as will be further explained, was created as an alternative to hESC and is consequently more confined in scope. While quality control was deployed, there may well be extraneous patents in the data that the keywords were unable to account for. To filter by country the searchable alias index twolettercountrycode.INCO. was included in the search query, where INCO stands for inventor country. For each patent, Assignee, Applicant Name, Pages, and

Relevancy were additionally pulled from the USPTO. Patents totaled 19556 for hESC, 29540 for RNAi, and 30140 for hESC + iPS. Given this patent data, I then performed a count operation by group and year to determine the overall path of the respective patent approvals. This made up the working data set, which can be further described using summary statistics and visual aids.









hESC

Variable	Obs	Mean	Std. Dev.	Min	Max
Year	33	2006	9.66954	1990	2022
World	33	297.1515	168.5097	14	528
US	33	170.7273	124.5214	0	321

RNAi

Variable	Obs	Mean	Std. Dev.	Min	Max
Year	33	2006	9.66954	1990	2022
World	33	439.2121	359.4431	3	876
US	33	263.697	219.902	0	531

hESC + iPS

Variable	Obs	Mean	Std. Dev.	Min	Max
Year	33	2006	9.66954	1990	2022
World	33	453.5455	289.0927	20	923
US	33	249.1515	180.8815	0	475

Did the Ban Affect the Quantity of hESC Patents in the US?

As mentioned earlier, the overarching question in this paper concerns whether the federal ban on hESC research stymied the progress of hESC. In order to be made more suitable for testing, the specific question I ask is whether the ban in August of 2001 affected the quantity of hESC patents (relative to RNAi) submitted by US inventors? To answer this question, the following regressions were used.

$$USPatents_{g,t} = \beta_0 + \sum \gamma_t + \beta_1 hESC + \beta_2 Post1_t + \beta_3 hESCxPost1_t + \varepsilon_{g,t}$$

$$USPatents_{g,t} = \beta_0 + \sum \gamma_t + \beta_1 hESC + \beta_2 Post2_t + \beta_3 hESCxPost2_t + \varepsilon_{g,t}$$

Here, patents are restricted to only those involving a US inventor. More specifically, an inventor whose residence is listed on the patent as being in the US. $hESC$and $Post_t$ maintain the same description as before. The only difference is the utilization of two different $Post_t$ variables. $Post1_t$ represents the expected cutoff, taking on a 0 for patents filed in and before 2001, while taking on a 1 otherwise. $Post2_t$ is designed to account for the potentially lagged effect of the ban. It takes on a 0 for patents filed in and before 2002, while taking on a 1 otherwise. I.e., it assumes a one year lag in ban impact. The tandem regressions yielded the results below.

VARIABLES	(1) Ban Effect (US)	(2) Lagged Ban Effect (US)
hESC	18.25	30.46
	(30.88)	(25.46)
Post1	243.4***	
	(78.08)	
hESCxPost1	-174.8***	
	(38.71)	
Post2		257.8***
		(66.94)
hESCxPost2		-203.7***
		(32.70)
Constant	-9.125	-15.23
	(55.67)	(47.63)
Observations	66	66
R-squared	0.919	0.940

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The variables of interest (highlighted in red) are the interaction variables. They are both statistically significant at the 1% level. For the first regression, the suggestion is that the ban caused a decrease in hESC patents of ~175 relative to RNAi patents. When assuming a lagged impact, the effect becomes even more pronounced, reflecting an additional 29 patent decrease. Recall that US patents peaked for hESC at just above 300 and for RNAi at around 550. Taking these values as a yardstick, the ban did appear to significantly lower the quantity of hESC patents in the US. It is possible that the US federal funding ban on hESC decreased the number of patents applied for and approved by US inventors, while also not slowing overall progress in the field as research migrated to other countries. If this was the case, then my above results suggesting the ban to have stymied progress could be overestimating the impact of the ban. I test for this possibility in the next question.

Did the Ban Affect the Quantity of hESC Patents Worldwide?

In this section, I test whether the ban in August of 2001 affected the quantity of hESC patents (relative to RNAi) globally.

$$WorldPatents_{g,t} = \beta_0 + \sum \gamma_t + \beta_1 hESC + \beta_2 Post1_t + \beta_3 hESCxPost1_t + \varepsilon_{g,t}$$

$$WorldPatents_{g,t} = \beta_0 + \sum \gamma_t + \beta_1 hESC + \beta_2 Post2_t + \beta_3 hESCxPost2_t + \varepsilon_{g,t}$$

The sole modification from the previous two regressions comes in the makeup of the dependent variable. The US specification is dropped, and I analyze all patents irrespective of inventor country.

VARIABLES	(1) Ban Effect (World)	(2) Lagged Ban Effect (World)
hESC	77	89.23**
	(50.40)	(41.75)
Post1	379.6***	
	(127.4)	
hESCxPost1	-344.2***	
	(63.18)	
Post2		398.3***
		(109.8)
hESCxPost2		-381.6***
		(53.63)
Constant	-29.50	-35.62
	(90.86)	(78.11)
Observations	66	66
R-squared	0.912	0.935

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The hypothesized ban effect would be a decrease in patents, but of weaker degree relative to the US-specific effect. Being a federal ban, it did not directly influence hESC patenting in any country other than the US. However, it may have indirectly influenced patent output in a multitude of ways, most saliently through disrupting international collaborations. One would accordingly expect coefficients of interest to be less than or equal to their US correlatives. That is not the case. In fact, the magnitudes virtually double, with the non-lagged coefficient being -344, and the lagged one being -382. These results suggest that the ban significantly lowered the quantity of hESC patents, both in the US and worldwide. More curiously though, they suggest the effect to be almost doubly pronounced compared to the US-only analysis.

Was the breakthrough of iPS a confounding factor?

The 2001 ban was by and large a response to ethical concerns surrounding the usage of embryonic stem cells. However, in 2006, Shinya Yamanaka and his team discovered induced pluripotent stem cells (iPS). iPS are essentially adult stem cells reprogrammed to have capabilities and applications similar to embryonic stem cells. In this way, iPS offered an alternative avenue for researching stem cells, while sidestepping the ethical concerns. This suggests that the impact of the ban (found above) might once again be over-estimated, with researchers turning to iPS instead of hESC as a way of skirting the ban while continuing the same or similar line of research. Failure to account for this would cause any effect of iPS patenting to be a potentially confounding factor in the face of my overarching inquiry. I would thus be remiss to not include iPS in the analysis in some capacity. Two strategies were developed to this end. The first was to repeat the original US patent regressions but with year cutoffs. The intent was to isolate the ban for hESC patents, prior to certain time periods when iPS might become a confounder. The cutoffs are – up to but not including – 2006, 2009, and 2015 (previously the "cutoff" was 2022). The regressions are identical in form to the original model, with the only differences being the time periods analyzed.

VARIABLES	(1) 2006 Cutoff	(2) 2009 Cutoff	(3) 2015 Cutoff	(4) 2006 Cutoff	(5) 2009 Cutoff	(6) 2015 Cutoff
hESC	18.25	18.25	18.25	30.46	30.46	30.46
	(17.99)	(24.25)	(31.19)	(18.34)	(21.22)	(25.94)
Post1	289.1***	393.9***	461.1***			
	(47.59)	(62.68)	(79.39)			
hESCxPost1	47.75	-34.82	-130.3***			
	(35.98)	(39.96)	(43.25)			
Post2				313.7***	416.1***	479.3***
				(51.32)	(57.31)	(68.73)
hESCxPost2				-1.462	-79.29*	-166.5***
				(42.35)	(37.77)	(37.44)
Constant	-9.125	-9.125	-9.125	-15.23	-15.23	-15.23
	(32.43)	(43.72)	(56.22)	(34.30)	(39.70)	(48.53)
Observations	32	38	50	32	38	50
R-squared	0.937	0.933	0.919	0.929	0.945	0.939

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For both non-lagged and lagged Post variables, 2015 cutoff coefficients are negative and statistically significant. 2009 and 2006 cutoffs are not, apart from the lagged 2009 cutoff coefficient at the 10% level. This suggests that it was not until the turn of the decade that a noticeable relationship between the ban and hESC patents developed. This is arguably the result of a sizable lag between when research progress is made and when patents are approved under USPTO. Whether the funding ban is situated in 2001 or lagged in 2002, my results suggest that the ban did not reduce the number of patents approved by the USPTO for more than a decade.

The second strategy stands on the construction of the hESC + iPS data set, while maintaining RNAi as the counterfactual. For the regressions, hESC is simply replaced with hESC + iPS, denoted by $hESCiPS$. To construct this variable, I queried the USPTO using the terms found in the **Data** section. With this variable, I again ran the count operator to determine the number of patents by year. Finally, I ran the following regressions to tests whether the ban affected the quantity of hESC + iPS patents (relative to RNAi) submitted by US inventors:

$$USPatents_{g,t} = \beta_0 + \sum \gamma_g + \beta_1 hESCiPS + \beta_2 Post1_t + \beta_3 hESCiPSxPost1_t + \varepsilon_{g,t}$$

$$USPatents_{g,t} = \beta_0 + \sum \gamma_g + \beta_1 hESCiPS + \beta_2 Post2_t + \beta_3 hESCiPSxPost2_t + \varepsilon_{g,t}$$

The following results were produced.

VARIABLES	(1) Ban Effect (US)	(2) Lagged Ban Effect (US)
hESCiPS	22	36.69*
	(22.81)	(20.07)
Post1	247.2***	
	(57.67)	
hESCiPSxPost1	-57.43*	
	(28.59)	
Post2		260.8***
		(52.78)
hESCiPSxPost2		-84.54***
		(25.78)
Constant	-11	-18.35
	(41.12)	(37.55)
Observations	66	66
R-squared	0.963	0.969

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For the non-lagged regression, the coefficient of interest is -57.43, and is significant at only the 10% level. The lagged coefficient, significant down to the 1% level, is -84.54. Combined, these results maintain that the ban did curtail the desired sphere of research. However, when factoring in the breakthrough workaround that is iPS, the ban effect is much less pronounced than my earlier results suggested.

My above empirical work showed that the federal funding ban reduced the quantity of patents approved by the USPTO both for American inventors and inventors worldwide. Nonetheless, this effect took a decade to emerge and might be overstated due to the access researchers gained to a related technology that was not affected by the ban. Still, the funding ban might affect more than just the quantity of patents approved; the ban could well have affected the "quality" and "boldness" of patents, as well as the type of inventor applying for a patent. In the next section, I test the possibility of these additional consequences of the ban.

Did the ban affect the quality/boldness of hESC patents?

This question is tested only at the US level. While being supplemental to the main inquiry, it serves importantly to estimate some of the nuances that the ban may have induced. The ban restricted the creation of new embryonic stem cell lines but permitted the usage of pre-existing lines. From this, the logical hypothesis is that research, and subsequently patenting, would exhibit less novelty. To test this hypothesis, page length and relevancy are invoked as proxy variables. Page length can be associated with the level of complexity and innovation of a patent. Relevance, based on a USPTO algorithm, measures how frequently search terms appear in the patent. As the ban took its firm grasp on hESC, perhaps scientists shifted their work to areas on the periphery or tangentially related to hESC. Patents produced here would likely involve hESC related terms, just at a reduced frequency. And so the appropriate regressions become:

$$USPages_{i,g,t} = \beta_0 + \sum \gamma_t + \beta_1 hESC + \beta_2 Post_t + \beta_3 hESCxPost_t + \varepsilon_{i,g,t}$$

$$USRelevancy_{i,g,t} = \beta_0 + \sum \gamma_t + \beta_1 hESC + \beta_2 Post_t + \beta_3 hESCxPost_t + \varepsilon_{i,g,t}$$

These regressions run at the individual patent level, represented by the inclusion of the index i and reflected in the number of observations. Additionally, two regressions really represent four here – $Post_t$ signifies both post variations.

VARIABLES	(1) Pages	(2) Lagged Pages	(3) Relevancy	(4) Lagged Relevancy
hESC	1.369	-5.277	5.605***	5.695***
	(6.280)	(4.418)	(1.464)	(1.030)
post1	39.74		-8.798	
	(37.02)		(8.627)	
hESCxPost1	-8.909		-0.365	
	(6.346)		(1.479)	
post2		36.39		-8.749
		(36.95)		(8.611)
hESCxPost2		-2.169		-0.467
		(4.514)		(1.052)
Constant	25.32	28.64	39.18***	39.13***
	(36.70)	(36.63)	(8.552)	(8.536)
Observations	14,449	14,449	14,449	14,449
R-squared	0.035	0.035	0.078	0.078

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The page count coefficients are both insignificant. This suggests that the ban had no effect on the average number of pages for approved patents. The relevancy coefficients are also both insignificant. This suggests that the ban had no effect on key word frequency. Combined, it may be interpreted that the ban had no effect on the novelty of hESC patents or how closely focused on hESC the patents were. It must be said withal, that these variables are imperfect indicators of the proposed phenomenon, and therefore results should be viewed with a higher degree of reservation.

Did the Ban Affect Who Was Submitting Patents?

More specifically, did the ban cause a larger decrease in patent production among public institutions like colleges and universities than in the private sector? With the ban freezing public funding, the deduction may be self-evident. Indeed, that is the hypothesis subscribed to here. To test this hypothesis, applicant and assignee names were first pulled for all patents. They hold essentially the same information – namely, what entity is sponsoring or otherwise facilitating the production of the patent. When there are entries for both, they are largely the same entity. More often than not however, due to a USPTO procedural change in 2010, one or the other is blank. Thus, they are combined under the intention of comprehensive data for the desired metric. A university dummy variable was then created, taking on a 1 if the assignee or applicant name includes "Univ*" or "Coll*", and a 0 if not. This becomes the dependent variable for the regressions, which take the following form.

$$UniUS_{i,g,t} = \beta_0 + \sum \gamma_g + \beta_1 hESC + \beta_2 Post_t + \beta_3 hESCxPost_t + \varepsilon_{i,g,t}$$

$$UniWorld_{i,g,t} = \beta_0 + \sum \gamma_g + \beta_1 hESC + \beta_2 Post_t + \beta_3 hESCxPost_t + \varepsilon_{i,g,t}$$

Again, they include the i index as well as the placeholder $Post_t$ for both post variations.

	(1)	(2)	(3)	(4)
VARIABLES	Applicant Type (US)	Lagged Applicant Type (US)	Applicant Type (World)	Lagged Applicant Type (World)
hESC	0.0504	0.0821	-0.0350	-0.0278
	(0.111)	(0.0753)	(0.0343)	(0.0318)
Post1	0.0170		0.0174	
	(0.0982)		(0.0303)	
hESCxPost1	-0.0177		0.00619	
	(0.111)		(0.0350)	
Post2		0.115*		0.0383
		(0.0650)		(0.0281)
hESCxPost2		-0.0477		0.000850
		(0.0759)		(0.0326)
Constant	0.333***	0.236***	0.367***	0.347***
	(0.0981)	(0.0648)	(0.0300)	(0.0278)
Observations	11,351	11,351	19,800	19,800
R-squared	0.001	0.002	0.001	0.001

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

None of the coefficients of interest are statistically significant. This suggests that neither the public nor private sector bore the bulk of the ban effect. Moreover, with respect to the previously established causal effect of the ban, it suggests that patent reductions were derived (more or less) equally from both sectors.

Conclusion and Discussion

This study was designed to evaluate the impact of the ban on hESC patents. In doing so, the goal was to make empirically supported statements about the efficacy of funding policies in general. The main findings are threefold. First, the ban did appear to have the intended effect of curbing progress in the field of hESC. Moreover, the ban worked both in the US and globally, suggesting the ban to have had a more potent effect than one might initially expect. Lastly, the discovery of iPS allowed researchers, in sizable extent, to circumvent the ban. Novelty, relevancy (to hESC) of research, and inventor sector were also analyzed and found to not have been affected by the ban. However, the novelty and relevancy indicators were perhaps not strongly associated with the phenomenon of which they were employed to comment on. In this, qualitative effects of the hESC funding ban on scientific progress remain a relevant consideration for more rigorous investigation.

Combining these results, what can be concluded is that the impact of funding bans on innovation is indeed complex and highly nuanced. Additionally, the impact cannot be measured perfectly for many reasons, including unpredictable global ripple effects, potential incentives to create a workaround, and significant lags between research and patenting. These represent shortcomings for policy measures, and while the extrapolation (from this study to funding policy as a whole) would be that bans are effective in their main aim, such shortcomings nevertheless support the notion that research into the efficacy of funding policies remain useful endeavors. In understanding the potential effects of a funding ban, we improve both the efficiency of such policies and our ability to predict their outcomes. There is little doubt that A.I., biotechnology, and other pioneering technologies will shape our future. How it is to be shaped rests gravely on us. Luckily, inaction is not conclusively bad; nor is action. What is, however, is a lack of conversation and deliberation before the die is cast. These efforts should absolutely include research into every dimension of funding bans and funding policy as a whole.

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