KAUFFMAN
The Foundation of Entrepreneurship

KAUFFMAN DISSERTATION EXECUTIVE SUMMARY

Part of the Ewing Marion Kauffman Foundation's Emerging Scholars initiative, the Kauffman Dissertation Fellowship Program recognizes exceptional doctoral students and their universities. The annual program awards up to fifteen Dissertation Fellowship grants of $20,000 each to Ph.D., D.B.A., or other doctoral students at accredited U.S. universities to support dissertations in the area of entrepreneurship.

Since its establishment in 2002, this program has helped to launch world-class scholars into the exciting and emerging field of entrepreneurship research, thus laying a foundation for future scientific advancement. The findings generated by this effort will be translated into knowledge with immediate application for policymakers, educators, service providers, and entrepreneurs as well as high-quality academic research.

Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP Kauffman Dissertation Fellowship Program KDFP

www.kauffman.org/kdfp

NORTHWESTERN UNIVERSITY

Essays on Estimating Policy Effects in Science-Based Industries

A DISSERTATION

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

for the degree

DOCTOR OF PHILOSOPHY

Field of Economics

By

Jason M. O'Connor

EVANSTON, ILLINOIS

December 2010

Abstract

This dissertation investigates the effect of policy shocks on entrepreneurial innovative activity and develops a new estimation method tailored for this environment. I investigate the effect of Genetically Modified Organism labeling regulations on GMO innovation. Using R&D and patent data, I estimate a drop of 50% in innovation activity in organisms most affected by labeling. A counterfactual analysis finds that the economic value of lost innovation approaches 10 % of total market value. However, activity by entrepreneurial firms remains constant, which may be due to differences in funding sources. Finally, I extend the Change-in-Changes estimator proposed by Athey-Imbens (2006) to estimate differential policy impacts based on unobservable characteristics.

Category: Economics : Applied Microeconomics : Innovation
Keywords: Innovation, Entrepreneurship, Policy Analysis, Agricultural Biotechnology, Treatment Effects

Executive Summary

My dissertation focuses on improving our understanding of how policy can affect the incentives of entrepreneurial and incumbent firms to innovate in high technology industries. As a considerable number of radical innovations come from entrepreneurial firms, improving our ability to understand how policy or how funding experimentation affects their performance could measurably improve the institutions that support entrepreneurial innovative output. My first essay targets this problem: I extend a recently developed econometric technique to improve estimation of policy (and, more broadly, treatment) effects in science-based industries, where firm performance is measured by patenting or other discrete variable. In the next two essays, I investigate an instance of a policy affecting innovation: the implementation of Genetically Modified Organism labeling laws in the European Union. I find that these laws triggered a 50-70% decrease in innovative activities in the GMOs most affected by the law. A simple counterfactual exercise shows that the costs of lost innovation to innovators and farmers approaches 10% of market value. However, I find that the law's impact was significantly greater for large incumbents than for entrepreneurs. I present a model that explores how differences in funding sources and commercialization routes could cause the observed outcomes. In sum, my dissertation quantifies the economic costs of policy shocks in innovative markets, distinguishes the effect of these policies on entrepreneurs and incumbents, and proposes a new estimation technique that improves our ability to perform such analyses. As economic growth relies more on science-based entrepreneurship and knowledge production, the need to answer these kinds of policy questions will grow significantly.

The intangible nature of knowledge creation hampers our attempts to empirically estimate policy effects in certain high-technology industries. The problem becomes acute when evaluating the performance of entrepreneurial firms produce that have no products or sales, as they lack the complementary assets required for full commercialization of that knowledge.

Work over the past decade (the ``citation revolution'') has improved our understanding of how certain types of codified knowledge (e.g. patents and scientific citations) operate in different institutional settings. In particular, citations are useful for determining the quality of a given patent or scientific article. More importantly, they allow us to identify the propensity of current knowledge to generate further innovations and discoveries. While these data are far from ideal, they remain our best option for investigating the science-based economy.

Entrepreneurs are especially important in developing the radical innovations that underpin continued economic growth. In these industries the time from firm founding to realization of economic returns through standard measures of performance like sales or profits, etc can be long and even successes that are acquired by larger firms may never actually produce a product for sale. In these cases, again, patents and scientific citations may be our best measures of performance. The methods described in this section are useful for evaluating the effects of exogenous policy shocks (or well designed experiments). I first briefly discuss the justification for a difference-in-differences approach, as it is the subject of my first essay and is the primary estimation technique that I use in the last two essays.

To estimate the effect of some policy event or experimental intervention, the researcher needs data from two groups and (at least) two time periods: a group that is affected by the intervention and a similar group that is not affected by the intervention. The first group is called the “treatment group” and the second group is called the “control group” (or in the medical parlance, the placebo group). Without having a well-chosen control group for comparison, the researcher cannot attribute changes in the outcomes of the affected group to the treatment event, as the change may be the result of some other factor. However, if the only difference between the two groups is their exposure to the treatment, then we can safely infer the causal effect of the treatment, to the exclusion of other possible factors.

The current standard practice estimates the average effect of the treatment or intervention on everyone. While this is a useful summary statistic, it may obscure outcome tradeoffs

that might crucially identify optimal policy. In particular, we may be interested in the distribution of effects: we can ask if the outcomes of firms with better performance before the intervention change more than those with worse outcomes pre-performance. Did the treatment help firms with worse outcomes by the treatment and hurt those with better performance? In such a case it may appear that the average effect was zero, but this statistic fails to convey important information for successful policy analysis.

Athey and Imbens (2006) propose a new, flexible estimator for estimating treatment effects that they call the "Changes-in-Changes" estimator. The CIC estimator provides a key technical advantage: there is no straightforward way to estimate quantile effects with a count dependent variable using standard techniques. Treating data as continuous (that is, assuming that it can take non-positive integer values) can cause estimates to be severely biased. My study builds on their work by accounting for the effects of age in a particular way. I extend the CIC estimator to include paper (or patent) age covariates with the goal of applying it to citation count data. I present two different techniques to handle the age covariates before applying the CIC estimator to estimate treatment effects. I test the performance of the proposed estimators in a simulated data environment that varies the underlying quality of the treatment group observations, the outcome production functions, and the functional form of the age contribution to the outcome. Finally, I compare my extensions to the estimates of standard techniques using OLS and quantile regression.

My data simulations found that in cases where the assumptions of standard techniques are (relatively) true, the CIC estimator does not offer much of an advantage. However, when these assumptions are violated, the CIC estimators proposed in this paper, in contrast to the standard techniques, are able to recover the true estimates. One particular example is when the unobservable characteristics of the treatment group are considerably different than the control. This might often be the case if incumbents are treated as the control and entrepreneurs are the treatment group. Similarly, if the treatment affects outcomes according to a "superstar" effect or winner-take-all outcome, where only the highest quality firms see any effect, the CIC will provides substantially better outcomes. Overall, this CIC estimator extension presents a useful tool for estimating treatment effects in the presence

of confounding covariate effects and unclear differences in unobservables across the treatment and control groups.

The focus of the second essay is to measure how a policy-driven market size shock shapes the R&D investment decisions of innovating firms. Although innovative activity will likely respond to policy changes in some way, the magnitude of their reaction is an empirical question. For example, a highly concentrated market structure with weak competitive pressures may insulate firms from the effects of policy shocks. Furthermore, it is unclear that firms will respond to current policy if future policy amendments are likely. Finally, from a welfare standpoint, the economic impact of even a large response may be insignificant.

I use events in the European Union (EU) related to consumer opinion and regulation of genetically modified organisms (GMOs) to estimate the effects of a substantial negative policy-driven market size shock on innovation in the agricultural biotechnology industry. The EU is an important agricultural market with a population of 450 million relatively wealthy consumers. Over the period 1997 to 2002, there was a clear increase in EU consumer resistance to genetically modified foods. However, the nature of agricultural production creates an information problem -- consumers cannot accurately identify GMOs without verified labels. Therefore, an additional policy element was needed to create the market size shock: mandatory labeling. Although some supermarket chains pledged GMO-free private label products in 1999, the establishment of clear GMO labeling requirements in 2000 ensured that the information problem would be solved for all observant consumers.

My research question in the context of my data is: How did the complementary changes to EU GMO labeling regulation and demand for GMOs impact the direction of innovative activity in agricultural biotechnology?

While the moratorium applied to all GMOs, I exploit the practical differences in labeling requirements based on crop use to analyze the impact of the labeling requirements on

innovation. My baseline econometric specification defines the treatment group as organisms whose primary use would require GMO labeling to sell to consumers in the EU. My control group comprises all other organisms that have at least one field trial in the data -- this includes organisms like golf course grasses and cotton that are not intended for consumption. Essentially, the sorting criterion is whether or not the final consumer of these products is human. For example, tomatoes, whether processed or sold fresh, are primarily consumed by humans; field corn is overwhelmingly used for animal feed. Genetically modified based animal feed must conform with EU labeling standards so that farmers are aware of its content, but obviously the final consumer is not human and the products from animals fed with GMO feed do not have to indicate this fact.

Using these two use-defined groups as treatment and control, I use a standard Difference-in-Differences method (in a count model) to estimate the impact of labeling on field trial permit application activity[1]. My baseline regressions find a 70% decrease in firm field trial activity in the labeled treatment group. This result holds qualitatively across both a number of alternative specifications and even after the EU's 2004 removal of certain additional restrictions on GMO commercialization.

As stated above, a decrease in R&D activity might not translate into a significant economic effect. To evaluate this possibility, I estimate counterfactual field trial and commercialization activity (at the organism level) under the assumption of the pre-2000 regulatory environment (e.g. no labeling and traceability requirements). Using published and governmental estimates of field trial costs, commercialization costs, pesticide use, and GMO adoption rates, I estimate the welfare effects of the reduction in field trial activity in a medium sized agricultural market ($1.1 billion in 2000) -- sugarbeets. Under conservative assumptions, I find that the costs of lost innovation due to regulation and consumer rejection range from $100 to $200 million over a 7 year period. Farmers could improve

[1] Firms run field trials to test the performance of their candidate GMO seeds in controlled settings that mimic typical growing conditions. Firms must receive permission from the USDA to conduct a field trial, which provides the data on field trials to the public. Firms also use this data to support their application for unrestricted release of the seed in order to sell it to farmers.

their operating margins by almost 20%, and seed companies would see a two-fold return on their investments. My welfare counter-factual, which only estimates innovation costs, provides a useful benchmark for the level of consumer benefit from labeling needed to make the new regulation a net social improvement. Where previous analyses have emphasized the static welfare costs of labeling, my results show that the previously ignored costs of reducing innovation are equally important.

The final essay again uses the GMO regulatory context to estimate how a policy-driven market size shock shapes the patenting output of innovating firms. Patent data provides both a check on the previous results and a fuller picture of both large incumbent firms and entrepreneurs[2]. Obviously, the differential impact of the policy based on firm type has important welfare implications: the critical role of entrepreneurial firms in driving productivity growth implies that the costs of technology market entry and the strategic response of established firms to entrepreneurial entry impacts innovation incentives and, ultimately, long term economic growth. In the context of this policy event, entrepreneurs generally have fewer resources to survive negative demand shocks, which may make acquisition by a large incumbent a more attractive option and may discount the expected payoff of acquisition to entrepreneurs so much that potential entrepreneurs prefer not to enter the market. Overall, the reduced profitability expectation makes entry costs prohibitive for more potential entrepreneurs (but not necessarily all of them), which is likely to have an anti-competitive and anti-innovation effect in markets. In particular, if shocks to market size expectation may affect firms differently based on their ability to raise capital and absorb the losses of delays, smaller firms are likely to either abandon projects entirely or be forced to exit the market.

Commercialization strategies for entrepreneurial firms in science-based industries are strongly related to founder characteristics, appropriability conditions, and incumbents'

[2] The consolidation of Agricultural Biotechnology in the 1990s essentially eliminated field trial stage research by entrant firms. This did not, however, completely remove entrepreneurship from the industry, as discussed below. Entrepreneurs can use licensing arrangements with the incumbents to commercialize their discoveries, similar to how biotech firms rely on large pharmaceutical firms to navigate clinical trials.

market positions. A large body of research has focused on the role of the latter two factors in agricultural biotechnology; these papers find that entrepreneurial firms fall squarely in the role of outsourced R&D labs whose successful innovations are either acquired directly or licensed by the incumbents. The industry's entrepreneur-incumbent symbiosis trend fully developed through a wave in of licensing and M&A activity in the mid- to late-1990s. The 5 largest Ag Bio firms, while making considerable R&D investments, spent more on M&A investments by the late 1990s. Firms sought to vertically integrate GMO seed production; biotech startups were a critical part of their acquisitions. The firms that survived the industry shakeout have very diverse portfolios of patents, but these have come through acquisition of many different players. The entrenched position of the incumbents makes it highly unlikely that the firm that makes a genetic breakthrough will commercialize the innovation. This argument is supported by the statistics on R&D licensing agreements further highlight the value of entrepreneurial innovation. Kalaitzandonakes et al. (1997) find that of 475 licensing agreements between agricultural biotechnology firms from 1980 to 1996; around 90% of them were between large incumbents and startup firms. While entrepreneurial startups obtain only a small share of the patents awarded in agricultural biotechnology, this work makes clear that they are crucial drivers of innovation in the industry

I capture these phenomena in a simple model that investigates incumbent and entrepreneurial incentives to innovate based on the expected size of the product market. Under the assumption that entrepreneurs are either funded by government grants or university sponsorship, there is a continual supply of entrepreneurial ideas in spite of changes to expected market size. Incumbents face a make or buy type decision, where they can attempt to develop a new technology on their own, or license if from the entrepreneur. My model shows that, under a few standard assumptions, when the expected market size drops below a certain threshold, incumbents will cease in-house development and rely on licensing external breakthroughs to develop future products.

This paper addresses two empirical questions:

- Did EU GMO organism labeling regulations affect patenting activity in the same way as it did to GMO field trial activity? (i.e. a significant decrease in labeled organism activity relative to non-labeled activity as a control group).
- Did the response of entrant firms in these markets differ from the response of incumbent firms? That is, did the EU regulations have a different impact on smaller firms than larger firms?

I find that overall firm patenting activity does mirror the results from field trial activity, verifying the conclusions of the previous essay. While the magnitude of the drop was smaller (approximately 50%), the robustness of the result remains. Evidence on the second question finds that entrepreneurial activity is significantly higher (relative to incumbent activity) in the labeled organism categories from 2002-2005. Stated another way, changes in incumbent activity drive the estimated effect. Entrepreneurs, defined as firms with no Ag Bio patents in the previous two years, show no significant change in patenting in labeled organisms in the post-2001 period. A more detailed regression shows that entrepreneurial activity decreased in the non-labeled organisms (likely as a result of the late 1990s consolidation wave) but remained steady in labeled organisms. One possible explanation for this result, as suggested by the model, is that the funding sources of these firms or academic provenance of their IP claims leaves them largely unaffected by long term commercialization profit considerations. Returning to the question of policy analysis, the potential ``dynamic'' costs of regulation may not be as great since entrepreneurs in a heavily mixed public-private innovation system like Ag Bio still produce knowledge at approximately the same rate prior to regulation.

My dissertation provides insights into how firms respond to policies that reduce incentives to generate new products, and how to best estimate these effects when firms (and entrepreneurs especially) tend to license their breakthroughs instead of developing them. My proposed extension of the CIC estimator shows considerable improvements over conventional methods under certain typical empirical scenarios. Turning to my empirical

contributions, while the case of GMOs is still playing out in various jurisdictions, it provides a useful example when considering future regulations on disruptive innovations that pose uncertain risks to consumers. For example, the safety of using carbon nanotubes to improve building materials has been questioned. As in the case of GMOs, there is little scientific evidence that typical levels of exposure are harmful, but this certainly does not exclude the possibility of future regulations restricting its use. As my second essay shows, policy makers need to consider the dynamic innovation costs of these policies when evaluating the tradeoffs involved with potential benefits of additional regulations. Furthermore, the effects of these policies differ by the type of firm. While entrepreneurs that are academically oriented or otherwise grant funded may be able to weather the storm of uncertainty better than incumbents, it is likely that entrepreneurs will still rely on partnerships with incumbents to commercialize products. Indeed, my study does not measure the impact of regulations on this activity. Correspondingly, I hesitate to draw strong conclusions from this finding. Overall, while entrepreneurs in a particular funding environment may discovery activity despite reduced profit incentives, the full impact of such events on the entrepreneur-incumbent commercialization relationship warrants further research.