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The direction of innovation

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Abstract

How do innovation policies affect the direction of research? Is market-based innovation too radical or too incremental? We construct a novel and tractable model of the direction of innovation. Firms pursue inefficient research directions because they race to discover easy yet less valuable projects and because they work on difficult inventions where they can appropriate a larger portion of the social value. Fixing these inefficiencies requires policy to condition on properties of inventions that could have been discovered but were not. Policies which do not do so, like patents and prizes, may fail to encourage firms to research in the efficient direction, even if they obtain the optimal quantity of R&D.

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0. Introduction

It has long been known that laissez faire markets may underproduce innovation due to indivisibilities, where the fixed cost of R&D is only fully paid by the initial inventor, and underappropriability, where research generates spillovers on subsequent inventions (e.g., Arrow, 1962). For this reason, existing theoretical work on innovation policy is largely focused on evaluating how and when mechanisms like patents or research subsidies affect the quantity of R&D. However, firms do not simply choose how much research to perform, but also how to allocate their scientists across different research projects. For example, early nuclear researchers at General Electric or Westinghouse could have researched power plants using either water or deuterium as a moderator, or could have focused on military applications like nuclear-powered ships, or could have been assigned to entirely different energy technology like solar or hydroelectric. These research targets differ in how hard they are to invent, in how valuable they are, and, most critically, in which future research opportunities they make possible for the inventing firm and all others.[2] A natural question therefore arises: how do policies intended to optimize the *quantity* of research affect the *direction* of that research?

To understand when and what kind of directional inefficiencies arise, we construct a novel, flexible, and analytically tractable model of the direction of innovation. Firms are endowed with a set of researchers who can be allocated across a finite set of research projects. After an invention by any firm, a new set of potential research targets appears for all firms. We permit successful invention to affect the properties of future research targets, making future inventions easier (technological complementarities), harder (e.g., the invention reveals information about the difficulty of a research line), more valuable (market complements), or less valuable (market substitutes). Researchers are fixed in number and can be costlessly deployed. By fixing the number of researchers, we both isolate attention on a novel distortion caused by the existence of multiple research paths, and ensure that results hold *even if* the aggregate quantity of research is optimal.

Our model provides three main insights. First, two distinct classes of distortions simultaneously affect inventive direction in equilibrium: a "racing" and an "underappropriation" distortion. Second, policies designed to achieve the efficient rate of innovation, such as patents or subsidies, do not generally achieve the efficient direction of innovation, and can make directional distortions strictly worse. Third, directional inefficiency is generically a property of every innovation policy which both rewards inventors and does not condition on the characteristics of inventions which are not invented in equilibrium. That is, the possibility of directional inefficiency places fundamental limits on the efficacy of decentralized innovation policy.

Intuition for these results can be seen in two highly stylized examples which each isolate a particular directional distortion. In Fig. 1, there are two potential inventions, A and B. Two firms have one indivisible unit of research that can be allocated at no cost to either invention. Assume that inventors appropriate the full undiscounted social value of their invention, and that once either invention is discovered, the marginal value of the other invention immediately falls to zero.[3] We make the latter assumption solely to provide stark intuition; as noted, the main model permits arbitrary links between inventions today and the value or difficulty of inventions available thereafter. Let A be relatively easy, such that if one firm researches A while the other

[2] See Cowan (1990) on the breadth of nuclear plant possibilities available to researchers, and Allen (1977) on which paths were pursued by various firms, and why.

[3] For instance, let A and B be network goods.