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Research Spillovers
What They Are and Why They Matter for Policy

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The Issue

Spillovers confound the measurement of research impacts. Research produces knowledge, which is at the heart of the innovation process, which in turn, is a key driver of productivity improvement, economic growth, and global competitiveness. Unlike most other goods produced, knowledge can be used repeatedly without exhaustion and is often very difficult to exclude others from using it. Knowledge often "spills over" to benefit those who do not pay for the research. While these spillovers make research a potentially powerful engine of growth, it makes research inherently difficult to manage in an economy.

This policy brief describes the primary issues surrounding research spillovers. It begins with a more complete definition of spillovers and then rhetorically asks how spillovers affect the incentives for research, the measurement of commercialization, and the crowding effects of public research. The brief then draws on statistical analysis from Gray, Malla, and Tran (2006) to quantify the magnitude of research spillovers in the canola research sector in Canada. Policy implications are also discussed.

Results and Policy Implications

Despite widespread enforcement of property rights and the prevalence of private research in the canola sector, empirical analysis suggests evidence of many forms and sources of research spillovers.

Knowledge undoubtedly spills over between firms. External research expenditures, germplasm, and basic research, will each enhance a firm's research productivity. This suggests that the knowledge generated from these activities flows beyond (spills over) their source to increase the research productivity of other firms in the industry.

Publicly funded basic research increased the research productivity of applied firms and increased private research revenues. This supports the widely held belief that basic research provides a foundation for private research.

A surprising result shows that public applied research does not "crowd out" private research, but rather causes a crowding effect. Public applied research not only increases the productivity of applied research, it also increases a private firm's research revenue, suggesting that the competitive effect of private research output is more than offset by the benefits of research spillovers.

These large research spillovers suggest that the returns to research and the extent of commercialization are underestimated. The large positive spillovers generated from basic public research affirm the notion that science is an important driver of applied research. The presence of applied research spillovers between private firms suggests that these firms do not fully protect their intellectual property and that research is likely to be more effective if clustered. The positive effect of public applied research on private firm revenue suggests that public applied research has not crowded out private research, but rather has had the opposite affect. This could mean that a reduction in public applied research might have hampered development of the private canola research sector. Finally, these results suggest that many of estimates of the return to public applied research may have been underestimated due to the ubiquitous presence of research spillovers.

Background and Literature Review

Research spillovers are externalities that arise from the public good aspects of knowledge (non-rival, non-excludable)[1] and are central to the economics of research. A knowledge spillover is the involuntary and uncompensated transfer of ideas or techniques.[2] Spillovers are an important determinant of economic productivity (e.g., Griliches, 1992; Jaffe, 1986; Adams, 1990). The non-rival nature of research output has assumed a central role in endogenous growth theory, both in terms of physical capital (e.g., Romer, 1986, 1990; Aghion & Howitt, 1992) and human capital (e.g., Lucas, 1988). A number of studies have also recognized that knowledge is embodied in human capital and that spillovers occur through the education of workers (e.g., Shultz, 1975; Lucas, 1993), learning from others (Foster & Rosenzweig, 1995; Thorton & Thompson, 2001), and worker mobility (Glaeser, Kallal, Sheinkman, & Scheifer,1992).

Spillovers also have important implications for firm behaviour (e.g., Cohen & Levinthal, 1989; Just & Hueth, 1993; Moschini & Lapan, 1997; Adams, 2000) and industrial organization and structure (e.g., Spence, 1984; Dasgupta & Stiglitz, 1980; Fulton, 1997). Acs, Audretsch, and Feldman (1994) examined research spillover from the prospective of a recipient firm, and concluded that "small firms are the recipients of R&D spillovers from knowledge generated in the R&D spillovers centers of their large counterparts and in universities" (p. 336).

Research has shown that the average growth rate, which is an increasing function of the size of the innovation, may be less or more than the socially optimum level (e.g., Romer, 1990; Grossman & Helpman, 1991, 1994; Aghion & Howitt, 1998). According to Aghion and Howitt (1992), the appropriability and intertemporal "spillover effects" generate a less- than-optimal growth rate, while the "business-stealing" effect tends to generate more than optimal growth if innovation is exogenous, but makes growth slower than optimal if the size of innovation is endogenous.

Malla and Gray (2003) have shown theoretically that private firms invest less in R&D than the socially optimal amount even with fully appropriable intellectual property rights (IPRs) because they cannot fully appropriate all the research benefits generated from their investment (i.e., because of the research spillovers). Each firm faces a downward-sloping demand for its products. When the demand for an improved product shifts as a result of variety-improving research, some benefits spill over to farmers. Given that the research firm making the investment in research cannot capture the increase in surplus going to the buyers of their product (i.e., farmers), their private marginal benefit from research is less than the socially marginal benefit. Research firms are only concerned with their private benefits from an R&D investment, not the spillover effects that their action may have on others. Therefore, they will underinvest in R&D relative to the social optimum.

Basic research spillovers are also quite substantial. The seminal work of Evenson and Kislev (1976) introduced the notion of basic research spillover and showed that the outputs of basic research (i.e., scientific knowledge) can improve the productivity of applied research. The work of Evenson and Kislev (1976) has been verified by a number of later studies (e.g., Lee, 1982; Lee, 1985; Kortum, 1997; Malla & Gray, 2003). Few studies (e.g., Diamond, 1999; Robson, 1993; Malla & Gray, 2003) have empirically examined the crowding effects of basic research.

A significant body of economic research has addressed the spillovers from public research by examining the crowding effects of public research investment on private research investment (i.e., whether public research tends to crowd in or crowd out private research) (e.g., Roberts, 1984; Bergstrom, Blume, & Varian, 1986; Khanna, Posnett, & Sandler, 1995; Khanna & Sandler, 1996; David & Hall 2000; Malla & Gray, 2003). Several economists have developed theoretical models that demonstrate that publicly funded research competes for scarce resources, and therefore could crowd out privately funded research. Other economists, considering charitable donations, have shown that public expenditure could have the opposite effect and cause a crowding in of private research expenditure. Empirical studies (e.g., Robson, 1993; Diamond, 1999; David, Hall, & Toole, 1999) have revealed mixed results with respect to private research, but are more or less in agreement that public basic research tends to stimulate or cause a crowding in of private research.[3]

Malla and Gray (2005) distinguished between basic and applied research and have shown theoretically that public basic research causes a crowding in of private applied research, and that public applied research can crowd out private applied research through the yield enhancement of a publicly produced generic variety. Their empirical results verify the analytical results of the study and underline a need to distinguish between basic and applied research when examining crowding effects of public expenditure.

The effects of spillovers on agricultural productivity have also attracted significant attention in the literature (e.g., Griliches, 1979, 1980; Evenson ,1989; Johnson & Evenson, 1999; Huffman & Evenson, 1993; White, He, & Fletcher, 2003), while a number of studies examined the cross-state spillovers from agricultural research (e.g., Alston & Pardey, 1996; Evenson, 1989; Yee & Huffman, 2001). Finally, Pardey, Alston, Christian and Fan (1996) examined the genetic research spillovers through pedigree attribution among different breeding programs, which applies when crop pedigrees are known (Heisey & Morris, 2002).

Alston (2002) provided a recent survey of research spillovers. He concluded that spillovers: are very important; have implications for the distribution of research benefits; the estimates of returns to research; and could lead to underinvestment. Specifically, "First, intranational and international spillovers of public agricultural R&D results are very important. In the small proportion of studies that have taken them into account, spillovers were responsible for a sizeable share—in many cases, more than half—of total measured agricultural productivity growth and the corresponding research benefits. Second, spillovers can have profound implications for the distribution of research benefits between consumers and producers and thus among countries, depending on their trade status and capacity to adopt the technology. Third, it is not easy to measure these impacts, and the results can be sensitive to the specifics of the approach taken, but studies that ignore interstate and international spillovers are likely to obtain seriously distorted estimates of the returns to agricultural research. Finally, because spillovers are so important, research resources have been misallocated both within and among nations. In particular, international spillovers contribute to a global underinvestment in agricultural R&D that the existing policies have only partly succeeded in correcting. The stakes are large as the benefits from agricultural technology spillovers are worth many times more than the investments that give rise to them" (pp. 316-317).

Alston (2002) also stated that "agricultural R&D spillovers are important and interesting but not well understood, and that they are a worthy subject for further study. More work is needed both to develop better methods of measurement and better measures, and to develop better institutions and policies" (p. 339).

Analysis and Results

Gray, Malla, and Tran (2006) empirically examined research spillovers and crowding effects in a modern biotech crop research industry. Specifically, they used firm-specific and public data in the Canadian canola industry to examine the nature and magnitude of inter-firm and public-private spillovers. The potential sources of (non-pecuniary) spillovers examined included basic research (as measured through expenditures), human capital and knowledge (as measured through other-firm applied research expenditures), and genetic spillovers (as measured through variety yields of other-firms). Separate models were used to estimate the non-pecuniary spillovers and the crowding effects of a rival's research.[4] They used two different models for the empirical analysis of research spillovers.

Model 1

The firms' own-lagged applied research expenditure has a positive effect on yield. The coefficient of 2.12 for private firms (0.601 for public firms) implies that a $1 million expenditure increases the yield index by 2.12 (0.601).

The empirical results reveal that lagged basic research expenditure positively affects the annual weighted yield index of private firms, while negatively affecting the weighted yield index of public firms. Public basic research expenditure with a lag of nine periods has a coefficient of .304 in the first model, implying that, *ceteris paribus*, a $1 million increase in the annual public basic research in one year increases the private yield index by .304 index points after nine years. This positive spillover is consistent with the notion that basic research increases the productivity of private applied research. In contrast to this result, a $1 million increase in annual public basic research expenditure in one year reduces the public yield index by .2 index points after nine years. This interesting result suggests that an increase in basic research, which is located within public institutions, uses common resources within the research institution, thereby reducing the resources available for applied public research.

Other- firms' lagged research expenditures have a spillover effect on each firm's yield index. The synergistic effect was strongest within groups (i.e., between public firms (.35) and private firms (.32)). A somewhat smaller synergistic affect was evident between groups in the spillover of public expenditure on applied yields (.158). These positive effects are consistent with human capital and knowledge spillovers. A negative spillover effect (.163) occurred between private firm expenditures and public firm yields. This latter between-group effect may have been generated from private firms bidding highly qualified personnel away from the public sector. During the growth phase of the industry, migration tended to occur from the public sector to the private.

A positive spillover was evident for yields within group, while the spillover was negative between groups. A one-point increase in other- private (public) firms' yield index resulted in a .9 point (.036) increase in the firm's own-yield index. In contrast, the public yield index had a negative .448 point impact on private yield. The reverse between-group impact was also negative, but insignificant.

To sum up, Model 1 reveals strong evidence of positive spillovers within the public and private sectors. Publicly funded basic research and applied research created a positive spillover for private yields. Other-public/private spillovers were negative in sign.

Model 2

Model 2, which examines the determinants of firm revenue, revealed that one dollar of own-firm lagged applied research increased private (public) revenue by $.480 ($.962). This model also showed important spillover effects. In this case, the spillovers include pecuniary effects in the output market and therefore illuminate crowding effects. An additional dollar in lagged basic research expenditure changed private (public) revenue by $.346 (–$.187), indicating that public basic research provides monetary benefits to private industry while drawing resources away for public-firm applied research.

The inter-firm spillover effects of lagged applied research were negative within groups. A $1 increase in other-private (public) firm applied research expenditure reduced firm revenue by $.341 ($2.412). Given that there were positive spillovers in production, these negative impacts show a strong degree of competition within groups, which is not surprising because the firms are competing for the same customers.

In contrast to the within-group competition, a $1 increase in public (private) expenditure increased private revenue by $.311 ($.278), indicating positive spillovers between groups. This indicates that non-pecuniary spillovers dominate the pecuniary spillovers such that public applied research activity has crowded in private research, rather than crowded it out.

The spillover of other-firms' yields tends to have a negative impact on firm revenue. This negative relationship exists among private firms, from both private to public firms and public to private firms. The exception is the public-to-public interaction, where there is a synergistic impact, perhaps due to a different ethos among public breeders.

The variables for proportion of the total area seeded to hybrids and for plant breeders' rights had a positive impact on private revenues, but had a negative impact on public revenue. A complete shift to hybrids would increase (reduce) private (public) revenue by $3.466 million ($3.996 million) per year. PBR increased (reduced) private (public) revenue by $5.592 million ($8.14 million). The TUA fees had a positive affect on total revenue (.94 in the case of private firms), suggesting a slight reduction in the non-TUA revenue. For public firms, however, $1 in TUA revenue tended to increase total revenue by $7.738, indicating a dramatic increase in pricing.

To sum up, Model 2, which examines firm revenue, shows evidence of the pecuniary impacts of competition between firms, particularly within groups. Applied expenditure within-group reduces other-firm revenue, while between-group spillovers are positive. A higher lagged yield for competing firms has a negative impact on revenue, with the exception of public-to-public impacts, for which it is positive. Property rights and hybrid technologies have a positive effect on private sales revenue and a negative impact on public revenue.

Policy Implications

The most apparent implication is that public and private research firms are integrally linked through numerous types of research spillovers. Both publicly funded basic and applied research had positive effects on private research productivity and profitability. The negative impact of basic research on public firm output and revenue suggests that these basic research activities are underreported and tend to use resources earmarked for applied research. Given the importance of basic research to private industry output, this diversion of resources could be optimal. The ability of public institutions to do applied research while crowding in private applied research suggests that public policies, such as the matching investment initiative, have been successful in mitigating normal crowding effects. The positive impact of IPRs on private revenue suggests that these changes have been effective in providing incentives for private research.

The prevalence of non-pecuniary inter-firm research spillovers suggests a strong research clustering effect—an effect that is particularly evident in Saskatoon, Saskatchewan, where there is a significant concentration of public and private firms involved in canola research. The existence of a clustering effect suggests a need for a mechanism to co-ordinate private and public location choices so as to maximize spillover opportunities. The significant public-to-private spillovers emphasize the importance of the public institutions in these clusters.

Overall Results

A large number of mainly theoretically studies have shown that research spillovers are very important and have significant implications for market structure, industrial organization, distribution of research benefits, estimates of returns to research, and agriculture/economic productivity and growth, and could lead to underinvestment.

Empirical evidence of a variety of research spillovers in the Canadian canola research industry quantifies the magnitude of many types/sources of research spillovers. The empirical analysis presented in this paper shows that inter-firm and public-private research spillovers in this modern crop research industry are both prevalent and large. Besides, while private firms tend to crowd each other in the industry, public basic and applied research tends to increase firm revenue consistent with a crowding in effect. The importance of research to economic growth suggests a need to fully understand these complex non-market relationships. The existence of the large spillovers suggests that private incentives and social outcomes may diverge, signaling a need to understand these relationships from a public policy perspective and to manage research policy with these spillovers in mind.

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Endnotes

1 The non-rival nature of research output means that one can use the technology created from R&D over and over again. Non-excludable means that the inventor did not have the ability to exclude others from using, reproducing, or selling the new technology or product created from R&D investment.

2 Research or technological spillovers are most often defined as externalities from which firms are unable to fully appropriate all the benefits of their own R&D investments or activities. Grossman and Helpman (1992) defined spillovers as: "(1) firms can acquire information created by others without paying for that information in a market transaction, and (2) the creators (or current owners) of the information have no effective recourse, under prevailing laws, if other firms utilize information so acquired" (p.16).

Griliches (1992) makes a distinction between two notions of research spillovers: embodied and disembodied spillovers. Embodied spillovers are related to the purchase of goods and services (e.g., product improvements that are the result of R&D investment are not fully absorbed by a concurring price increase). Disembodied spillovers are "ideas borrowed by research teams of industry k from the research results of industry j. It is not clear that this kind of borrowing is particularly related to input purchase flows" (p. S36).

3 David, Hall, and Toole (1999) provided a recent survey of the available empirical evidence and found that the results were inconclusive in terms of direction and magnitude of the relationship between public and

private research expenditure.

[4] Non-pecuniary spillovers are the non-market impacts of a firm's actions on other firms. Pecuniary spillovers are the firm-to-firm interactions that occur through the market. The combined effects of pecuniary and non-pecuniary spillover measure the net effect of a firm's actions on its rivals, or the crowding effect.