The Economic Impact of the IR-4 Project and Programs

Technical Report · November 2017

DOI: 10.13140/RG.2.2.28952.70409

Steven R Miller
Michigan State University
94 PUBLICATIONS **100** CITATIONS

John Mann
Michigan State University
31 PUBLICATIONS **43** CITATIONS

MICHIGAN STATE UNIVERSITY | Product Center Food • Ag • Bio

The Economic Impact of the IR-4 Project and Programs

November 2017

Steven R. Miller

&

John T. Mann

Michigan State University
Product Center Food-Ag-Bio
Center for Economic Analysis

Supported by: Michigan State University AgBioResearch | MICHIGAN STATE UNIVERSITY Extension | Department of Agricultural, Food and Resource Economics

Table of Contents

Introduction and Background

Pesticides fall into many categories and are applicable to crop protection both pre- and post-harvest. Herbicide is the most commonly used pesticide and is used to control weeds that compete for water, nutrients and sunlight with commercial crops. Insecticides are used to manage harmful insects that feed on or are otherwise harmful to the health of commercial plants. Miticides and nematicides are similar to insecticides, but mites and nematodes are not technically defined as insects. Disease-fighting fungicides provide protection against fungal infestations, like molds, mildew and rust, while biocides kill microorganisms. Other pesticide categories exist, including rodenticides, repellents, pheromones and others. All share a commonality that they are considered pesticides by the EPA and, hence, fall under its regulation.

Under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), the EPA is responsible for the registration of and authorization of pesticide products for sale under mandates of intended use. Uses of such products outside of their labels may be deemed unlawful and subject the user to both civil and criminal penalties. EPA approval for pesticide use is preceded by significant investment in research for efficacy, environmental outcomes, and threat to human health, at the expense of the registrant. Each intended commodity the pesticide producer targets may require separate trials to generate data on that use, including data on effectiveness and residues left on the crop after harvest. As such, each additional intended use will incur additional research costs to gain EPA approval for that use. The producer, or registrant, is expected to provide the relevant research data for EPA approval and, therefore, is responsible for the research costs. As such, registrants must weigh the expected market returns for each targeted use against the costs of gaining EPA approval for that use.

Pesticides play an increasingly important role in the global agri-food value chain. Advances in pesticides have reduced or eliminated such catastrophic famine events like the Irish potato famine of 1845-1847 that was caused by late blight [1]. The value growers place on access to pesticides largely depends on the value of crop losses they avert. Crop losses to pests may be quantitative or qualitative [2]. Quantitative losses are expressed in reductions in actual yield counts from potential yields, while qualitative losses are found with crop output that does not meet desired levels of quality. Crop losses are generally stated in percent loss from potential or expected yields and result in varying degrees of lost revenues for the grower. As such, the return to investing in pest control is dependent on the value of the commodity being produced. Growers may opt to reduce pest management efforts if the expected returns to crop yields are low. Similarly, crops commanding higher prices tend to command greater investment in crop protection. Many specialty crops fall into this higher-value crop category, positing a higher risk of loss to growers who do not effectively manage pests. Hence, specialty crop growers are particularly reliant on access to pest management options.

Specialty crops make up about 40% ($83.1 billion) of the total value of all crop production ($212.4 billion) in the U.S. [3, 4]. Of the value of specialty crops, a subcategory called ornamental crops, make up about 36 percent of that value [5]. Ornamental crops include floral plants, household plants, turf grass, and non-fruit bearing shrubs and trees. While specialty crops are grown throughout the United States, its share of the value of state crop production varies from 90 percent in California to approximately zero in the Dakotas and Nebraska. Table 1 shows the value of specialty crop production relative to field crops of the top ten producing states. Specialty crop output for all 50 states is provided in Appendix B of this report.

State	Field Crops ($000s)	Specialty Crops ($000s)	Total Crop ($000s)	Specialty Crops Percent (%)
California	$3,125,206	$29,574,534	$32,699,740	90%
Connecticut	$47,845	$295,225	$343,070	86%
New Jersey	$113,918	$630,713	$744,631	85%
Rhode Island	$4,775	$24,142	$28,917	83%
Massachusetts	$49,200	$215,645	$264,845	81%
Florida	$1,208,790	$4,716,626	$5,925,416	80%
Hawaii	$52,252	$203,262	$255,514	80%
New Hampshire	$26,066	$60,873	$86,939	70%
Arizona	$782,693	$1,548,739	$2,331,432	66%
Washington	$2,420,286	$4,595,505	$7,015,791	66%
Oregon	$1,134,724	$1,855,178	$2,989,902	62%

Table 1: 10 Top Specialty Crop-Producing States

Source: USDA Crop Values 2016 Summary, 2012 Census of Agriculture: Horticulture and author's calculations

Specialty crop uses of pesticides are called "minor uses" of pesticides because of the relatively small acreage potential in each of these specialty crop markets. Despite the smaller number of acres each specialty crop occupies, the per-acre contributions of pesticide use on specialty crops is often greater than for major crops (corn, soybean, cotton, grains). This is because specialty crops command higher economic values per-acre than most row crops. However, the limited number of acres devoted to each specialty crop reduces the economic returns to pesticide registrants for that use, thereby reducing the likelihood that a registrant will pursue the research costs necessary to register the pesticide for those uses. That is, despite this heightened demand for pesticide options, specialty crop growers are at a disadvantage relative to major crop farms in having access to a wide spectrum of options. However, to be profitable for the registrant, the price pesticide producers receive must cover both the average unit cost of registering the pesticide for that use and the production costs. The average unit cost of registering the pesticide declines as more of it is sold. Therefore, registrants seek uses that promise high volume of sales. One may conjecture that registrants should charge higher prices for minor uses to cover the costs of registering for that use. However, pesticide producers cannot charge different prices for different uses. Hence, incurring the costs of registering a pesticide for a minor uses will increase the average costs for all uses and may induce the registrant to increase the price for all uses to cover these additional registration costs. If pursuing a minor use registration risks increasing the costs and thereby the product's competitiveness in other markets, registrants will be reluctant to pursue those minor use registrations. In summary, because specialty crops tend to command fewer acres, the market size may not be sufficient to cover the fixed costs of obtaining EPA registration for that use, where the registrant has little control over the market price across uses (For a more analytic description of this, see Appendix A of this document).

According to Jerry Barron at the IR-4 Project Headquarters at Rutgers University [6], minor uses are not limited to specialty crops. He indicates that increasingly, representatives of major crops have approached the IR-4 Project to address pesticide uses for which producers have indicated an unwillingness to register because of the limited market potential that use poses. That is, the delineation between minor and non-minor uses of pesticides is not well defined, but rather depends on the existence of a pesticide solution in which pesticide producers do not intend to register their products. The IR-4 Project encourages the registration of pesticides for uses that producers are reluctant to support. As pursuing minor use registrations for major food crops remains the exception, there are risks that registrants may opt to focus product registrations to key sectors.

There are many risks associated with registering a pesticide for specialty crop uses, and the registrant must project expected sales potential with uncertainty. Hence, they generally will seek the safest bets that are found in large numbers. Even strong markets for their products can be subject to devastating market and political swings. For instance, U.S. crops are exported to many countries – each with their own regulatory agencies that may scrutinize commodities produced with certain chemicals or MRLs. Domestic buyers may also have policies that eclipse one pesticide regimen for another. That is, the longevity of a particular registration is uncertain, potentially reducing the time horizon for recovering registration costs. Registrants must also contend with possible litigation due to non-performance, or due to industry or trade standards. In short, the market risk-reward tradeoff often favors those commodities making up the larger share of crop production. This is the crux of what has been called the "minor use problem," in that, while the demand and the product for effective pest management may exist, the market risk-reward incentives constrains minor uses of pesticides in light of regulations.

From a policy perspective, it is relevant to ask should public investment and/or policy intervene, or are market efficiencies generating optimal outcomes that require no intervention? If specialty crop growers feel the current offerings of pesticides and prices are not optimal, is this the normal musings of industry participants, or are there market failures that should be corrected? As will be described, we perceive that FIFRA introduces a market failure in the supply of pesticides for minor uses, in that without FIFRA, minor use growers would have more options and access to effective pest management options. This is not to say that FIFRA is not efficient, as it is in place to serve a public purpose in assuring safe access to food, but rather that policy should be put in place to offset the market disruption this has on availability of pesticides for minor uses.

One can view FIFRA as an obstacle to free market outcomes and that without FIFRA, the marketplace would have sufficient resources for combating pests across all commodities. This may be true from a strictly market perspective, but one also should recognize the market contributions FIFRA has provided. Because pesticide use is regulated, consumers have confidence that growers' pesticide use will not harm them when consuming the products they purchase. As the quality and safety of food products are not easily realized until after consumption, FIFRA facilitates markets for food and encourages consumer experimentation across brands and products. FIFRA also enhances producer confidence in the chemicals they purchase and facilitates safe usage of such with minimal risks to health and environment. In that, FIFRA assures clear expectations of results if applied according to the label instructions. However, FIFRA does create a barrier to entry for products that otherwise may be beneficial to growers. The costs of registering pesticides becomes an obstacle to young firms and provides a buffer for larger firms, protecting their market share with existing products. The restriction of new entrants may slow the introduction of new products. It also hinders small-market availability for the reasons described above. This can have far-reaching effects in the marketplace.

Restricting pesticide options for specialty crop growers may result in lower yields and reduced net revenues for growers, thereby increasing the consumer prices of specialty crop foods. This has implications on health and environmental effects. From a consumer health perspective, a varied diet is important for maintaining health. Many researchers attribute Americans' poor health outcomes on the low-cost availability of grains and oilseed crops that make up the largest components of U.S. agricultural crop output [7]. Restricting diets to a small subset of food types may result in higher health care expenditures [8], lower workforce productivity [9], and may adversely impact learning in youth [10]. From an environmental perspective, having fewer inter-crop options promotes monocultural farming and associated environmental impacts of such systems [11]. In this, specialty crops can be introduced to crop rotations as a means of controlling pest risk, while reducing pesticide use [12]. This is also associated with reduced soil degradation associated with monocultural farming. Healthy soils are more productive and less prone to wind and water erosion. Further, access to a wide variety of pesticide options is an important component of managing pest resistance to pesticides. Managing resistance is a primary objective of agricultural pest management professionals [13]. Pest resistance grows with each application of a pesticide, in that, the number of species that survive pass their traits on to the next generation [14]. Controlling the proportion of pests that propagate resistance requires either applying the pesticide in greater concentration, which has health and environment implications, or exposing them to different pesticides by which resistance is less common. By rotating across multiple active ingredients, growers and pest management specialists are able to mitigate the need to increase doses over time. However, the minor use problem limits the number of alternative active ingredients available for effectively managing pests. Outcomes from the minor use problem are suggestive of market failures brought about from the passage of FIFRA. As market failures cannot be corrected in the workings of the market, some policy intervention is prescribed. Public funding of the IR-4 Project is representative of such a policy intervention.

The "Minor Use Problem" and the IR-4 Project

The IR-4 Project is a multi-agency-funded program for facilitating the registration of existing pesticides for use on specialty crops. Established in 1963 as a collaborative effort of the Agricultural Research Service (ARS) agency of the USDA, National Institute of Food and Agriculture (NIFA – formally called the Cooperative State Research, Education, and Extension Service) and state Agricultural Experiment Stations (SAES) at Land Grant universities in coordination with the Environmental Protection Agency (EPA), the IR-4 Project assists in the collection of residue and efficacy data in support of the registration of minor uses of pesticides [15]. It is headquartered at Rutgers University and is geographically diversified through six regional centers housed in Land Grant universities across the U.S. The IR-4 Project released a detailed summary of this program in 2016 that highlights motivations for the development of the IR-4 Project and its program areas [5].

The primary function of the IR-4 Project is to coordinate research and field trials at Land Grant experiment stations across the country for developing data necessary for registering minor uses of existing pesticides [16]. As such, the IR-4 Project fills the gap in minor use pesticide options, where registrants do not have sufficient market incentives to pursue registration, and where specialty crop growers have insufficient access to effective pest management resources. As the pesticide producer is ultimately responsible for registering their pesticides with the EPA, the IR-4 Project acts more as a liaison among agricultural producers, pesticide producers and regulators. Growers and grower organizations establish priorities, while the IR-4 Project works with pesticide producers to identify potential solutions. It then sets out to assemble existing data and develop the data required by the EPA for registering existing pesticides for minor uses. Research and technical guidance is coordinated with Land Grant Experiment Stations, and this data is then combined with existing producer data to meet EPA needs for registering the pesticides for minor uses.

The IR-4 Project gains research efficiencies by extrapolating generated data across multiple crop groups when seeking registration for reduced-risk pesticides. In this, the IR-4 Project works with U.S. and international governing agencies to establish crop groupings of shared characteristics. Data is then generated for the crop group rather than individual crops such that one study may be sufficient to support five to ten commodity registrations [5].

Most of the registrations pursued are pesticides with lower toxicity [17]. While supporting specialty crop growers' access to pesticides, the IR-4 Project has been instrumental in facilitating the development and market for reduced-risk pesticides. These pesticides are more apt to uniquely target specific pests and exhibit lower levels of toxicity to humans, wildlife and other non-target organisms. Since 2000, 70-80% of IR-4's research effort has entailed reduced-risk pesticides. This effort has encouraged other countries to adopt U.S. standards for pesticide residue limits – harmonizing international standards for the trade of agricultural commodities [5].

Pesticide tolerances often differ across countries, and these differences often pose an obstacle to international trade. The U.S. Farm Bureau identified countries' sanitary and phytosanitary standards as a key obstacle to trade [18], and pesticide MRLs tend to disproportionately harm U.S. agricultural producers, given that the U.S. is a net exporter of agricultural crops [19]. The IR-4 Project and the Canadian Pest Management Centre (PMC) worked together to undertake joint residue trials and to harmonize pesticide residue standards for registration with the EPA and Health Canada's Pest Management Regulatory Agency (PMRA). This effort continues to develop with the formation of the Regulatory Cooperation Council (RCC) to further harmonize pesticide regulations, in corroborating testing methods, and in jointly registering pesticides for use on both sides of the boarder. The IR-4 Project leadership and the U.S.-Canada partnership has been instrumental in developing similar programs around the world and in addressing regulatory barriers to international trade through partnerships and through the Global Minor Use Summits. The IR-4 Project also works with the USDA Foreign Agriculture Service (FAS) in assisting other countries to build capacity for regulating food safety and developing standard operating procedures to assure safe agricultural output for local consumption and for export. Such efforts as these facilitate regional specialization and trade that promote global agricultural production efficiency and advance economic growth.

Hence, congruent with promoting specialty crop production and consumer access to specialty crops, including food and ornamental crops, the IR-4 Project undertakes many roles beyond generating data for EPA registrations of pesticides for minor use. They have categorized these efforts into four overlapping program areas:[1]

- Food Crops
- Ornamental Horticulture
- Biopesticides and Organic Support
- International Activities

The three crop programs center on stakeholder input and all programs share a common goal of generating efficiencies through combined efforts across programs and through building collaborative relationships across growers, pesticide producers, research institutions and regulators. Workshops are untaken to establish priorities and discuss developing issues and threats. Such threats and priorities are driven by

---

[1] A fifth area around public health is under review.

grower needs, but solutions are weighted toward those with existing products available to address those needs. As resources are limited, the IR-4 Project, by necessity, leaves gaps in pest management options.

The Food Crops Program is the IR-4 Project's initial and most active program area [5]. This program's activities center on establishing data for EPA registrations of existing pesticides for minor use, but also entail other associated activities to generate research and regulatory efficiencies in generating MRLs and associated data. As of February 2016, the IR-4 Project has submitted over 3,500 tolerance petitions for over 16,000 uses of pesticides on specialty food crops [5]. This program also provides support for Section 18 Emergency Exemption requests when a serious pest issue arises for food crops for which no currently registered pesticide exist. In addition to enhancing the availability of pesticide options for minor use, the program has improved industry responsiveness to policy changes that have brought about substantial disruption in the agricultural chemical industry. An early example is the USDA push to cancel all "No-Residue/Zero Residue" registrations in 1966. The IR-4 Project was able to voice industry concerns and coordinate efforts to extend impacted registrations on 38 pesticides for use on 129 crops [5]. The Food Crops Program was critical in the response to the Federal Food, Drug and Cosmetic Act (FQPA) of 1996. This act posited significant changes to the FIFRA, imposing new standards for maintaining existing registrations and higher standards for registering pesticides moving forward. The EPA also ruled out future registrations of broad-spectrum pesticides like Methyl Bromide. Following this, the IR-4 Project initiated a number of collaborations with the EPA and other pesticide regulatory agencies to streamline and standardize petition submissions and rigorously pursued critical use exemptions, through their Methyl Bromide Alternative Programs, for continued use of Methyl Bromide until viable alternatives could be registered [20]. The IR-4 Project also redirected their efforts from supporting the registration of broad-spectrum pesticides to that of targeted pesticides that limits potentially adverse ecological impacts.

The Ornamental Horticulture Program was developed in response to the 1972 amendments to FIFRA to address the gap in pesticide tools in nursery and floral crops, forest seedlings, turf grass and Christmas trees. Horticulture acres are often more limited than specialty food crops and pose their own challenges to registrants. Therefore, there can be substantial pest management voids largely unaddressed by industry. In addition, greenhouse growers have unique pest pressures. In that, despite the intuition that suggests enclosed space would make it easier to manage pest pressures, disease can be a significant source of greenhouse crop damage. Additionally, the application of pesticides in greenhouse environments can heighten worker health risks of pest management. These considerations add complexity to pest management in horticulture, making the need to address pesticide options more vital. The Ornament Horticulture Program set out to add new ornamental species and/or pests to existing product labels, and up to February 2016, it has delivered more than 16,000 crop uses with over 100 registrations [5].

Organics have received great attention over the last 20 years and the number of acres allocated to organic crops has skyrocketed. According to USDA Economic Research Service (ERS) data, acres in certified organics increased from 638,500 in 1995 to 3,084,000 in 2011 [21]. More recently, the USDA estimates that in 2016 the acres in certified organics totaled 4,082,000 [22]. The implied rate of growth is 10.3 percent per year, and there is no sign this growth will slow, as consumer interest in eating healthy foods continues to gain traction. The IR-4 Project was already positioned to respond to organic grower needs with the formation of the Biorational Program in 1982, later renamed the Biopesticide and Organic Support Program. Consistent with its efforts to increase use of less toxic agricultural pesticides, the IR-4 Project sought to be an early proponent of biopesticide development. These pesticides are drawn from naturally occurring pest repellents and organisms. When growers' interest in organic farming gained momentum, the Biopesticide and Organic Support Program already had a stream of successful pesticide options available. Unlike the other two crop programs, the Ornamental Horticulture Program serves both specialty crop and row crop commodities. It is our conjecture that the IR-4 Project, through facilitating biopesticide availability, contributed to the growth of this sector and that in many cases, pesticide options would not be available to organic growers in the absence of the Biopesticide and Organic Support Program.

In the quest to advance specialty crop production, the IR-4 Project has taken an active role in harmonizing international MLR standards and increasingly leveraging global research efforts and standards for generating data for domestic and international registration of pesticides. Through these efforts, growers, both domestic and abroad, have greater access to pest management options, and pesticide producers have access to larger markets that improve the market incentives to pursue registration. Because the U.S. is a net exporter of agricultural products, harmonizing MLRs across boarders disproportionately benefits U.S. growers. International differences in standards for pesticide residues have long been a barrier to trade in agricultural products. Harmonizing international MLRs assures greater fluidity of the global marketplace. Through international collaboration, the IR-4 Project has advanced joint and shared residue trials with the Canadian Horticultural Council for pesticide registrations with Health Canada's PMRA and the EPA. This was mostly in response to Canadian growers' concern that U.S. specialty crop growers have greater access to pesticide options than Canadian specialty crop growers [23] – a divergence likely resulting from years of IR-4 Project efforts.

In addition to these efforts, the IR-Project engages in a number of other crosscutting efforts. These include efforts and resources for managing invasive species, such as participating on the USDA Interagency Task Force for Q-Biotype Whitefly. Effective management of invasive species can mitigate future pesticide use if invasive species management requires additional pesticide sprays, as is the case with the spotted wing Drosophila. In addition, the IR-4 Project regularly contributes to education and integrated pest management (IPM) support. IPM has been shown to reduce pesticide use through scouting for pests and delaying spraying until economically viable thresholds of pest pressure is reached in the fields [24]. That is, rather than spraying based on a pre-determined schedule, those that effectively adopt IPM are able manage pests as effectively as those applying scheduled sprays but with lower rates of pesticide use.

Sources of IR-4 Funding

The IR-4 Project draws funding from multiple sources. Congressional appropriations through USDA NIFA are the primary source and authorization for the IR-4 Project. Further Congressional appropriations arise through the USDA ARS for assigning research objectives at state experiment stations. Finally, each state agricultural experiment station contributes directly toward those research objectives with direct funding. In total, core funding was $15.56 million in 2016. In addition to this core base of funding, another $2.35 million is generated through ancillary research and industry programming areas around minor uses of pesticides. These sources are less codified and include competitive grants awarded to the IR-4 Project, but consistent year to year.

The IR-4 Project recognizes significant in-kind contributions from various stakeholders, including the use of facilities, equipment and labor provided by partner and non-partner research institutions, EPA waivers of registration fees for registration packets, and similar collaborative contributions from Canadian agencies and research facilities. In addition, the crop protection industry provides significant in-kind contributions, including data, information and services in excess of their direct contributions. The IR-4 Project estimates that these industry in-kind contributions total about $24.1 million.

Core Programs

Amount	Source
$11,913,000	Special Research Grant (NIFA)
$481,182	State Agricultural Experiment Stations
$3,170,000	Agriculture Research Service (USDA)
$15,564,182	**Total**

Enhanced Missions

Amount	Source
$225,000	Public Health
$650,000	USDA-Foreign Agriculture Service
$225,000	USDA-Animal and Plant Health Inspection Srv.
$1,250,000	Industry Support
$2,350,000	**Total**
$17,914,182	**Grand Total**

Table 2: Total 2016 Annual Budget and Sources of Funding

Source: 2016 Annual Report of the IR-4 Project

Conceptual Sources of IR-4 Project Impacts

Contribution to total output of agricultural production is the most direct measure of economic impact of the IR-4 Project. Pesticide availability and use contribute to land productivity [25]. Estimates of pesticide productivity often rely on partial budget assessments that ask how would yields and the costs of production change with changes in pesticide use, where pesticides are properly matched to the targeted pest pressure. The resulting estimates may overstate the true expected social costs in that partial budget analysis does not take into account grower and consumer adaptation behaviors. In the absence of viable pesticide options, growers may opt to change to other commodities with less pest pressures, adapt mechanical means of mitigating pest pressures, or alter management practices that reduce the threat of pests. Consumers can also adjust in response to price signals by substituting from relatively high-priced crop products to relatively low cost products.

Using productivity estimates also overlooks significant secondary sources of economic impacts not readily measurable. By affording growers a wide array of pest management options, and by educating growers of these options, the IR-4 Project enhances yield productivity across all growers. This results in lower consumer prices that encourage consumers to purchase a wider spectrum of food goods. This source of impact is often overlooked in agricultural impact estimates, as estimating price impacts often entails significant assumptions be brought to the analysis.

Should productivity enhancements of specialty food crop production result in lower consumer prices, consumers will increase purchases of these goods in quantities large enough that actual total expenditures for specialty crop foods will increase [26, 27].[2] Lower prices will often induce consumers to increase purchases such that more would be spent than if prices remained at their higher prices. This, in itself, does not suggest a direct increase in economic outcomes that give rise to measurable economic impacts, as the

---

[2] That is, consumer demand is elastic to relative price changes across substitutes.

increased expenditures on specialty crops is most likely driven by a decrease in expenditures of other food crops. That is, it posits a one-to-one substitution from one purchase to another. However, what it does suggest is that consumers have greater access to a varied diet.

A varied diet with fruits and vegetables is associated with positive health outcomes. The USDA MyPlate sets recommended dietary intakes for Americans [28]. In this, balanced intake across multiple food categories, within moderation, is the key to a healthy diet. By reducing the consumer price of vegetables, pulses, tree nuts, fruits and berries, the IR-4 potentially enhances Americans' health outcomes, with far reaching implications. Of developed countries, the U.S. has the highest share of GDP going to healthcare expenditures [29] but a declining measure of health outcomes [30]. Researchers suggest that improving Americans' diets would reduce overall healthcare expenditures and increase health [31]. A healthier workforce has fewer missed work days and greater labor productivity [32]. Such measures of impacts are difficult to generalize, let along to measure, but small sample analysis shows direct links to economic outcomes [32].

By increasing grower productivity, U.S. specialty crop growers are better able to compete in the global marketplace. Productivity is the measure of the value of output given a level of input [33]. As new and more effective chemical technologies are developed and adopted by growers, productivity increases lower the producer costs and selling prices while increasing total output. Even access to a varied toolset of chemical options can help improve grower efficiency by better matching the tool to the pesticide need. Through such productivity gains, U.S. prices become more competitive internationally giving rise to greater exports and reducing dependence on imports. This price competitiveness can also impact the trade balance of other agricultural commodities. As noted above, domestic consumption of fruit and vegetables substitute for major crops, freeing more of the latter to be exported. From an economic perspective, trade is how national wealth is created. By selling in international markets, wealth (money and foreign exchange) is imported into the domestic economy. Hence, increasing exports creates a measurable economic impact. However, many factors contribute to the level of crop exports including other USDA programs under the Foreign Agricultural Service (FAS), Agricultural Marketing Service (AMS), the IR-4 International Activities program, as well as other state and local government agencies like the Department of Commerce and the Department of State, to name a few. Other market forces can impact the exports of specialty crops, including foreign exchange markets that can change the international price of U.S. commodities, and the health of importing country economies. In summary, though it is conceptually possible to measure the economic impact of productivity enhancements through exports, the many contributing factors make this estimate tenuous at best.

Pesticide availability for specialty crops has multiple channels for improving environmental outcomes. First, having access to a more complete toolbox of pest management options encourages growers to add specialty crops to their existing crop rotation. This enhances diversity in production, where careful selection of crop rotations improve non-chemical control of pests [34]. Effective rotations can also improve soil productivity or reduce the need for soil nutrient amendments [35]. Second, a broad range of pesticide options improves growers' ability to manage pest resistance [36]. Continual reliance on one or two pesticides tends to encourage pest adaptation to that pesticide. Resistance to a pesticide's active ingredients necessitates that that pesticide be applied in greater doses to be effective. However, growers with access to multiple pesticide options can alternate pesticide use – minimizing pesticide resistance and reducing overall doses [36]. Finally, innovations in pesticide development have favored targeted pesticides over broad-spectrum pesticides of the past. The IR-4 Project, by principle, pursues lower spectrum pesticide registrations over more environmentally toxic broad-spectrum pesticides. Broad-spectrum pesticides have a tendency to kill or negatively impact all organisms it comes into contact with, including beneficials. Targeted pesticides pose less of a hazard to non-targeted organisms and are consistent with integrated pest management (IPM) operational principles. As the EPA registrations of older broad-spectrum pesticides expire, the minor use problem reduces availability of newer, targeted pesticides. Because targeted pesticides have more specialized applications, this further reduces the market potential for minor uses of targeted pesticides, creating further adverse market incentives for registering pesticides for minor uses.

The manufacture of chemical pesticides gives rise to economic impacts. Agrochemical firms engage in economic commerce by purchasing equipment and chemicals, employing workers, and taking entrepreneurial endeavors to sell a final product that meets growers' expectations. If used properly, this final product will contribute to grower profits. The EPA restricts what products can be brought to market, while the IR-4 Project seeks to expand the markets for these products. Both agencies are justified in their roles. The EPA restrictions assure that only agrochemical products that have been shown to be safe to health and the environment are allowed to market. The IR-4 Project pursues the goal of expanding the resources available to crop growers, thereby expanding minor uses of pesticides and increasing associated economic activity tied to the agro-chemical industry.

The IR-4 Project has facilitated significant changes in regulation processes for minor use and collaborated with multiple state and national regulatory agencies to generate cost savings. The IR-4 Project collaborates with the PMC to leverage data and build efficiencies in registering pesticides with the EPA and PRMA. Through such cooperative efforts with regulators, the IR-4 Project has initiated efficiencies in the way crops are categorized that allow extrapolation of residue data across crops within a category. These innovations have not only reduced IR-4 Project costs, but also reduced the time to registration and created efficiencies for the EPA and PRMA in granting registrations. This jointly beneficial relationship has introduced electronic data submissions and commodity crop groupings that facilitate shared data across multiple crops for low-risk pesticides. For example, registrations jointly pursued in the U.S. and Canada spread the costs of field trials between the IR-4 Project and PMC and avoids duplication of effort. Because a typical field trial costs around $6,000, and each registration requires multiple field trials, this savings can be significant [6]. For example, the IR-4 Project negotiated with the EPA to allow reduced risk chemistries like azoxystrobin and spinosad data trials be conducted on a crop grouping basis rather than for each specific crop, saving about $1,000,000 in data-generating research for over 160 minor uses of spinosad and 120 uses of azoxystrobin [37]. The success of these has led to continued use of crop groupings, rather than crop specific field trials for registering reduced risk pesticides. Additionally, California has some of the most stringent pesticide use restrictions in the nation, to the extent it operates its own pesticide registration program (The California Department of Pesticide Regulation: CDPR). The CDPR generally awaits EPA decisions before conducting their own review, which has the potential to double the time it takes new registrations to be available in California. The IR-4 Project facilitated joint reviews between the EPA and the CDPR where each agency shares in the work of the other, quickening the pace of pesticide introduction for California growers. These are ongoing impacts through system-wide efficiencies spearheaded by the IR-4 Project and merit consideration in the final estimates.

Market innovation is the key to economic growth, and the IR-4 Project advances science and innovation in two broad ways. First, through its relationships with SAES and other research institutions, the IR-4 Project helps to fund the education and research of new scientists. In most SAES labs, undergraduate and graduate students work with research and teaching faculty in field trials and lab analyses. Advancing new scientists is vitally important in promoting future economic growth. Student labor provides both experience and funding for post-graduate research and degrees, where students go on to have careers in academic research, governmental agencies and in private industry. It is difficult to attach a value to student funding and experience gained by working on IR-4 Project funded research, but the Bureau of Labor Statistics reports that median incomes of workers with bachelor's degrees earn 65 percent more income than those with only a high school education, and that those with advanced degrees earn 25 percent more than those with only a bachelor's degree [38]. If earnings reflect contributions to society as most economist attest, then recognition should be made of the IR-4 Project's contribution to promoting students' educational pursuits. Second, and as is highlighted in their annual reports, the IR-4 Project sponsors research publications and presentations, where over the past three years (2014-2016), some 55 publications and presentations around pest management were made, excluding newsletter articles [39]. These represent a key resource toward disseminating information amongst scientists and to producers and industry, who take up research outcomes and put them in practice.

Finally, the IR-4 Project disseminates, and through its network of universities, researchers, and experiment stations, leverages federal funding for research, data generation, grower education, and for devising sound domestic and trade policies. Each of these, in their own, constitutes potential sources of market and economic impacts. More directly, the dissemination of research and outreach expenditures provides local communities economic impacts that aggregate up to national impacts. However, such expenditures imply that other public expenditures on research or other public functions are not undertaken. That is, a true economic impact assessment would account for public expenditures foregone. This report does not account for alternative uses of public investment in the IR-4 Project. Rather, the report focuses on economic contributions of direct and in-kind expenditures that relate to gross contribution of all moneys spent along with associated commodity and industry effects. The omission of recognizing public expenditures foregone is likely to have marginal effects on impact estimates, as direct expenditures make up a small share of the contributions to impacts relative to the dispersed impacts arising from adoption and use of IR-4 Project-sponsored minor uses.

Methods

The methods used to estimate the economic impacts in this report follow well-established economic modeling practices. The bases for impacts fall into two broad categories. The first and smallest component is the value of economic activity taken up by the IR-4 Project and its associated partnering universities, businesses and institutions. These activities include direct expenditures for land, labor and inputs necessary to undertake field trials, for compiling registration packets sent to the EPA and for all other efforts directed toward meeting IR-4 Project goals. The second is the value crop growers extract from productivity enhancements associated with the use of pesticides made available by IR-4 Project sponsored registrations. These productivity-induced sources of impacts are limited to farm-level direct effects in terms of added output and revenues attributed to pesticide access.[3] Because this report limits research to private transactions, and hence returns to expenditures, it does not purport to measure the true social costs of pesticide usages that include public health and environmental quality aspects [40], nor the extent of spillover pest management benefits on non-targeted fields. In addition, the report does not purport to

---

[3] As noted below, the modeling framework explicitly assumes no price effect of added or restricted industry output.

measure the true cost of allocated public and private funds to IR-4 Project activities in terms of the value of foregone uses of such funding.

Impact estimates follow tradition expanded input-output (I-O) modeling approaches that trace transactions across industries, households and institutions,[4] accounting for the recirculation of expenditures resulting from a direct infusion of economic activity. The I-O approach of impact assessment has a compelling history in economic modeling since the 1930s and is the subject of extensive economic research. We provide a cursory description of the I-O approaches and limitations. A more comprehensive introduction to I-O modeling can be found in Harry Richardson's comprehensive text, *Input-Output and Regional Economics* [41]. Most succinctly, this framework tracks transactions across all sectors of the economy via linear mathematical equations. Therefore, an increase in economic activity in one sector will result in changes in economic activities of all associated industries and institutions in fixed proportions.

I-O models build on a standard social accounting matrix (SAM), which represents a double-entry accounting system that tracks the transactions of industries and institutions within the study region. Industries represent productive activities defined along commodity types, institutions represent non-producing sectors such as households and governments within and outside of the region, while the region of analysis entails the entirety of the nation. Transactions include the purchases of goods and services across industries as intermediate inputs[5] to production and the purchases of goods and services for final use by institutions. The SAM also records trade transactions with other regions as imports and exports. The SAM is a true representative model of the national economy reflecting the exchange of funds across all industry sectors and institutions. However, because the SAM is representative based on annual aggregates, and because commodity categories are aggregates of many specialty commodities, the SAM transactions are best-estimated abstractions of the true transaction chains underlying an economy. Because the SAM must balance, such that industry revenues must equate with expenditures, and sectors must sum up to total value of national output, the estimates are consistent with total expected value of transactions. The SAM used in this analysis is adopted from estimated Benchmark Input-Output Accounts reported by the Department of Commerce, Bureau of Economic Analysis [42] as adapted by IMPLAN [43].

The I-O framework applies several simplifying assumptions that may influence impact estimates in this application. First, I-O models are strictly linear in that inputs are additive and transactions rise in proportion to changes in output. This assumption implicitly assumes no externalities, constant returns to scale, and no capacity constraints. Externalities are both benefits and costs accrued to third parties. Proportionality of purchases excludes the possibility of economies of scale that may occur for some inputs, like labor, that become more productive with the size of operation. It seems plausible that scale economies should exist in shared resources across IR-4 Project research and programs, but the loss of precision in estimates due to this assumption is likely to be minor. The last potentially restrictive assumption maintains that land, labor, capital, and intermediate inputs are not constrained by availability that would otherwise result in price changes. For relatively small impacts, this assumption is generally not an issue, but as the source of impact increases relative to the size of the market, accessibility to inputs may be a constraint to further expansion. Other restrictive assumptions of this framework exist but do not necessarily pertain to the analysis at hand. For an introductory treatment of the assumptions of I-O

---

[4] Institutions include corporations, foreign entities and government.

[5] Purchases by businesses from businesses for the production of goods and services

modeled impacts, see Coughlin and Mandelbaum [44]. A more complete treatment can be found in Richardson [45].

Expanded I-O models generate three types of economic impacts. These impact estimates are additive in forming total estimated impacts. First direct effects in dollar value of transactions comprise the most basic level of impact. Other direct effects are measured in terms of employment, labor income and contributions to gross domestic product. These direct effects are estimated as fixed ratios of employment, labor income and gross domestic product to dollar value of sales (output), by commodity. These direct effects set off a chain of secondary transactions including indirect and induced effects. Indirect effects are all the transactions necessary to supply the inputs to accommodate the new direct sales. Induced effects are new expenditures from income. These include consumer spending associated with increased wages and government expenditures from added tax revenues. The induced effects also lead to purchases that give rise to additional indirect effects, as households and government increase the demand for final goods and services sets off a second chain of transactions. These secondary effects are also reported in employment and labor income terms, as well as in contributions to gross domestic product. The total effects are simply the sum of the direct, indirect and induced effects.

The IMPLAN Pro Version 3.0 (IMPLAN) software environment is used to generate impact estimates based on direct effect estimates described below. IMPLAN uses economic and demographic measures from a host of government statistical reporting agencies including the Bureau of Economic Analysis, Bureau of Labor Statistics, and the U.S. Census Bureau [46]. The structure of the model relies on the social accounting matrix that is a modified restatement of the Annual Industry Accounts provided by the Bureau of Economic Analysis [42]. This social accounting matrix is specified in terms of output, which is the sum of all goods and services provided within the economy. The IMPLAN model provides the conversions from output to gross domestic product, employment and wages internally.

Direct Effects

Impact estimates start with estimates of direct effects. Direct effects are broken out into four distinct categories to isolate the impacts of IR-4 Project expenditures and the Food, Ornamental Horticulture, and Biopesticides & Organic Support Programs. In addition to direct expenditures of the IR-4 Project, each program contributes to industry impacts through reductions in crop loses to pests, and increases in product value. These industry direct effects are estimated for each program and detailed below. The next sections discuss estimates of direct expenditure impacts, or effect, and then discuss direct industry impacts. These direct effects are then used to calculate economy-wide impacts using the IMPLAN economic impact model.

IR-4 Project Expenditure Direct Effects

Direct effects of the IR-4 Project entail the sum of expenditures from the annual budget and from partnering state experiment stations in pursuit of EPA data. Other non-monetary contributions are also included, including in-kind contributions by state experiment stations, industry and government agencies. Finally, other revenues pursuing IR-4 Project objectives are included but do not make up the core of the annual budget. These include competitive grants awarded to the IR-4 Project, grants awarded from industry and other non-governmental organizations and other awards by government agencies. The operating budget of the IR-4 Project, including grant awards, has remained mostly constant since 2010 at around $18 million. This means that once accounting for inflation, the IR-4 Project continues to operate with effectively lower spending power. Between 2010 and 2016, the price index of educational and research institutions increased by 6 percent [47], implying a six percent overall decrease in spending power.

According to the IR-4 Project 2016 Annual Report [16], core program funding totaled $15.56 million in 2016. In addition to this, the IR-4 Project generated an additional $2.35 million through grants and industry support, labeled "Enhanced Programs." Hence, for 2016, the IR-4 Project's total expenditures were just under $18 million. For the purpose of this impact estimate, we removed the $225,000 Public Health award, as this is not expected to be an ongoing funding source.

Core Programs	
Amount	**Source**
$11,913,000	Special Research Grant (NIFA)
$481,182	State Agricultural Experiment Stations
$3,170,000	Agriculture Research Service (USDA)
$15,564,182	**Total**
Enhanced Programs	
Amount	**Source**
$650,000	USDA-Foreign Agriculture Service
$225,000	USDA-Animal and Plant Health Inspection Srv.
$1,250,000	Industry Support
$2,125,000	**Total**
$17,689,182	**Core and Enhanced Program Total**

Table 3: 2016 IR-4 Project Budget

Source: 2016 Annual Report of the IR-4 Project

In addition to budget lines, the IR-4 Project receives in-kind contributions from multiple stakeholders. Partnering state experiment stations subsidize field trials, personnel time and lab resources totaling about $6.0 million. Through extensive collaboration, the EPA recognizes the public service attributes of the IR-4 Project, as well as its contributions to efficiency in issuing clearances for pesticide use by waiving PRI fees, totaling about $5.40 million. Similarly, through collaboration with the Canadian PMC and the PMRA, the IR-4 Project is able to defer some data generation and is afforded support that is estimated to be valued at $750,000. Finally, the crop protection industry also makes in-kind contributions, supplying products, sharing data and lab outcomes, and providing technical support on pesticides the IR-4 Project is petitioning for EPA clearance. Through efforts to standardize crop categories and create efficiencies, the IR-4 Project is able to increase the potential for such industry-sponsored in-kind contributions. The IR-4 Project estimates these contributions leverage one-to-one IR-4 Project expenditures specific to generating data for EPA submission and save some $11,929,000 in research expenditures that would otherwise have to be expended out of the operating budget.

In-Kind Contributions	
Amount	**Source**
$6,000,000	State Agricultural Experiment Stations
$5,398,561	EPA PRI fee waivers
$11,929,000	Crop protection industry
$750,000	Canada PMRA/PMC
$24,077,561	**Total**

Table 4: 2016 In-Kind Contributions

Source: 2016 Annual Report of the IR-4 Project

Taken together (Tables 3 and 4), the 2016 budget and in-kind contributions total about $41.77 million dollars working toward registering pesticides for minor uses. This is the direct effect estimate of the IR-4 Project's expenditures for research and administration used to model economy-wide impacts.

Food Crops Program Direct Effects

Industry productivity direct effects measure the contribution that pesticide availability, facilitated by the IR-4 Project, has on grower productivity. In this, the conjecture is that without the 54 years of IR-4 Project efforts to bridge the specialty crop, pest management gaps, growers would have limited options for managing pests. Researchers have long studied the contributions of pesticide and other agro-chemical use on farm productivity, providing a rich set of estimates of the contributions of pesticide use to grower yields and net revenues. As highlighted in the literature, measuring these benefits to productivity is complicated by the heterogeneous options for pest control, inconsistent growing environments across the U.S., variations of pest pressure, and the ability to assign proportional yield loss to various stresses. Such heterogeneity creates varying degrees of impact estimates across the spectrum of applications [48, 49]. Since no recent comprehensive assessment of the productivity impacts of pesticides have been completed since the 1970s, a meta-approach is employed that utilizes estimates across commodities and across researchers to provide an average, or expected impact of pesticide availability on production with no accounting for the type of crop, geography, pesticide, method of application, or combined pesticide/crop interaction.

To keep the analysis manageable, direct effects are measured in terms of production changes only, thereby avoiding the enumeration of price impacts. Shifting prices have the potential to transfer the impacts of greater productivity to various economic sectors including pesticide manufacturers, landowners, farmers, wholesalers, and consumers to name a few. Generally, such distributional effects only establish the allocation of the aggregate impact, not the aggregate impact itself.[6] Similarly, the assessment assumes no spillover effects to neighboring fields. As noted above, one field's attempt to control for pests often impacts other fields both positively and negatively.

For the purpose of this assessment, the IR-4 Project contributes to the availability of newer, less toxic, pesticide products for minor use that affords producers effective ways of mitigating economic losses from pests and for managing pest resistance. There is a clear consensus in the literature that pesticides play a significant role in securing the U.S. supply of food, fiber and energy, and enhances agricultural productivity by reducing crop damage to the extent that the U.S. National Research Council advocates that pesticides are irreplaceable in agricultural production [50]. In quantifying productivity growth of U.S. agriculture, Jorgenson and Gollop [51] noted significant declines in productivity growth following the recall of DDT. Knutson *et al.*, [52] estimated that a total ban on pesticide use in the U.S., including on row crops, would likely result in a cost of $41 billion per year in higher food costs and lower quality crops and livestock. Fernandez-Cornejo *et al.* [25] provided the most comprehensive review of existing studies, showing a wide range of economic impact estimates associated with pesticide use.

Variation in impact estimates arise from many sources. There exist no consensus on the optimal statistical technique for estimating impacts, where different approaches employed in estimation can result in variations in estimated impacts [48, 53]. The effort to generalize the impacts of pesticides becomes more

---

[6] Some distributional impacts may result in slight distortions of aggregate impacts. However, within the I-O modeling framework, where prices are explicitly assumed constant, such distortionary effects are precluded from taking place.

difficult in light of the heterogeneous production responses of plant/pesticide combinations, differences in active ingredients and approaches to measuring active ingredients and varying pesticide practices across regions, crops and environmental factors. A meta-analysis abstracts from such estimation issues by combining the empirics across a wide spectrum of research that, on average, is the best estimate of the potential impact of availability of a wide range of pesticide applications for specialty crops [54]. Zilberman *et al.* estimated that every dollar increase in pesticide expenditure raises gross agricultural output by three to six dollars [55]. Pimentel *et al.* estimates that aggregate crop losses without pesticides would total about 37% of output [34].

In their survey, Fernandez-Cornejo *et al.* found that the return per dollar spent on pesticide applications ranged from \$0.11 to \$11.90 with a mean and median of \$3.66 and \$2.50, respectively. We opt to use the more conservative measure of the median return of \$2.50 because where data is skewed, the median is the preferred measure of the expected impact. Medians are more robust than means to unusually large outliers. Therefore, we estimate that every dollar of pesticide expenditure on specialty crops returns \$2.50 in crop damage mitigation or improved agricultural productivity.

Estimating the direct effects then requires estimating the total value of minor use pesticides purchased for agriculture and attributed to the IR-4 Project in producing specialty crops. Because neither the EPA nor the USDA tracks pesticide usage or expenditures for minor uses, estimates must be derived indirectly. This requires several conjectures. First, while minor uses span both specialty crops and major crops, specialty crop uptake of minor uses dominate. Hence, we proxy minor uses of pesticides by specialty crop production. Additionally, since the literature provides estimates of productivity effects based on pesticide costs, the bases of pesticide uses must be stated in terms of grower expenditures. Using specialty crops as a proxy for minor uses, we can estimate the value of pesticide purchases by isolating agricultural pesticide purchases targeting specialty crops. We turn to the U.S. social accounting matrix (SAM) to determine total purchases. IMPLAN's adaptation of the U.S. SAM [43] was used to estimate pesticide sales for specialty crops for 2016.

Hence, the USDA Crop Values Summary for 2016 [4] indicates that specialty crop sales totaled \$55.53 billion in 2016, compared to \$136.10 billion for major field crops. Food crop-based specialty crops make up just over \$41.7 billion. IMPLAN's SAM indicates that pesticide purchases make up about nine percent of the total value of specialty crop sales, or about \$3.8 billion. This compares with 2012 USDA estimates that suggest pesticide expenditures make up, on average, five percent of total farm expenditures [3, 56]. To be sure, USDA estimates include all agricultural expenditures for both crop and livestock production. Because pesticide usage is generally more intense in specialty crops and because USDA estimates entail all farm expenditures, we anticipate that actual pesticide expenditures for minor uses exceeds the five percent USDA estimate and is closer to the nine percent estimated with the SAM.

Hence, we estimate that minor uses of pesticide make up about \$3.8 billion in annual pesticide sales. However, only a portion of these sales should be attributed to the IR-4 Project. In this, only pesticide impacts made available through the efforts of the IR-4 Project should be recognized. While a bit dated, the EPA indicated that in 2001, the IR-4 Project advanced 50 percent of the registrations for minor uses [57, 58]. With the advances of efficiencies brought about through collaborations, push for minor use registrations of pesticides for non-specialty crops, this percentage is likely higher. Regardless, we estimate that \$1.9 billion in pesticide sales are attributed to the IR-4 Project. Combining this with the expected productivity effect of $2.5 for every one dollar spent, we estimate that the direct effect of the Food Program on crop productivity is to contribute $4.78 billion to annual sales.

Ornamental Horticulture Program Direct Effects

The ornamental crop industry makes up an important component of specialty crop agriculture and like specialty food crops, occupy an important segment of minor uses of existing pesticides. Ornamental crops exclude plants intended for commercial food production. They include floriculture and nursery crops, where floriculture crops include bedding and garden plants, cut flowers, potted flowering plants, indoor foliage plants, and cuttings and other prefinished plants generally sold to other growers to raise for final sale. According to USDA statistics, horticulture sales make up about 7 percent of the total value of agricultural crop production and about 25 percent of the total value of specialty crop production [3, 4, 59]. Accordingly, horticulture output totals about $13.8 billion per year. As an indication to the total value of ornamental crops, Jarardo [60] estimates that sales per U.S. Households are about $147 at the wholesale level. A broader estimate of the size of ornamental horticulture is provided in Hodges, et al. who casts a measure of the economic value of all associated green industry activities, omitting conventional agriculture [61]. In their estimates, the authors tracked economic contributions along the full value chain that also include consumer and capital equipment like lawn and garden equipment, and all associated downstream impacts, including transportation, wholesale and retail activities, to reach a value of $136.44 billion in total output for 2013. While this estimate is based on an expansive definition of ornamental horticulture, it is a relevant reminder of the importance of agricultural production of non-food crops to the U.S. economy.

Similar to the estimates of direct effects for food crops, IR-4 Project-sponsored registrations are expected to generate productivity impacts on horticultural growers. These productivity impacts are the direct sources of economy-wide impacts. However, estimating such direct effects requires estimating the value of pesticide sales for ornamental horticulture production made available from IR-4 Project efforts. The IMPLAN social accounting matrix is once again used to determine pesticide purchases. Accordingly, the share of input purchases attributed to pesticides is much lower than that for food crops at about 2.3 percent. Hence, the estimated pesticide expenditures for ornamental horticulture are about $313 million. As applied for food crops, 50 percent of the pesticides applied are attributed to IR-4 Project efforts.[7] Hence, we attribute about $392.2 million in sales of pesticides to IR-4 Project-sponsored registrations. Applying the $2.5 productivity impact for every one dollar in pesticide expenditures provides a direct effect of an increase in ornamental horticulture output of $391.3 million.

Biopesticides & Organic Support Program Direct Effects

Biopesticides is the fastest growing segment of the pesticide industry and has reached $3.3 billion globally [60], and is expected to reach $4.1 billion by 2018 [63]. There are about 170 to 200 biopesticide companies in Western economies [64], and articles covering firm mergers and acquisitions with major agrichemical firms is increasingly common in popular news sources. The U.S. market makes up about $975 million of the global market for biopesticides [63], where fruit and vegetable crops make up about 80 percent of this use [64]. Much of the remaining share is taken up by row crops, where significant growth is projected [65]. However, biopesticides are also found in forestry and nursery applications [6, 66].

---

[7] According to the IR-4 Project staff, attributing 50 percent of ornamental uses to the IR-4 Project may be conservative 62. Novack, S., *Personal Communications*. 2017..

Biopesticides are derived from natural sources and fall into two categories – microbial and biochemical. Microbial biopesticides are living organisms that compete or repel targeted pests, while biochemical biopesticides are naturally occurring and non-toxic compounds that repel or kill targeted pests. Biopesticide use is generally associated with organic crops, but it is also a viable option for conventional crops. Unlike chemical pesticides, biopesticides do not provide immediate relief from pest pressures. However, they provide a niche in being effective with targeted pests while exhibiting lower toxins that reduce the risks to overspray and residue. That is, biopesticides can also provide added flexibility to conventional agrochemical uses.

Estimating biopesticides' contributions to crop productivity is challenging in that, there does not exist a robust body of studies researching the cost effectiveness of biopesticides for crafting generalizations. In some cases, biopesticides may be considered less effective compared to synthetic chemicals, but in regards to the heightened value of organic produce, marginal improvements in productivity can give rise to large impacts. That is, there is no reason to assume that biopesticides are less or more effective than synthetic chemicals, and because crop values tend to be higher for organic crops, the actual economic productivity impacts may be larger than those for synthetic crops. Rather than conjecture the expected productivity effects, in this study, those used in the Food Crop and Ornamental Horticulture Programs are applied.

The USDA estimates that organic crop sales, including food and non-food crops, totaled $4.2 billion in 2016 [67]. This provides a basis for consideration. However, as noted, biopesticides are not limited to organic crop production. As opposed to the IR-4 Project's Food Crop and Ornamental Horticulture Programs, where pesticide sales for specialty crops are not available, biopesticide sales exist. While U.S. biopesticide purchases total $975 million, we recognize that 50 percent of those sales are attributable to IR-4 Project efforts [62]. A generalizable estimate of the return to biopesticide investment does not exist in the current literature. There is reason to believe the return should be both higher and lower than that provided by conventional pesticides. For organics, often biopesticides are the only option to averting pest damage. However, because biopesticides require greater planning and have lower toxicity, the crop protection afforded may be lower than that of conventional pesticides. Hence, our best estimate of the economic productivity of biopesticides may be the existing rate of return used for food crops and ornamental/horticulture estimates of $2.50 per dollar. Applying this to one-half the U.S. purchases of biopesticides suggest a $1.2 billion return to growers through productivity and crop damage avoidance.

Total Effects

Total effects are modeled based on the direct expenditure or productivity effects detailed in the prior sections. The modeling approach entails standard economic impact modeling, in that direct changes in expenditures and industry output give rise to secondary transactions as described above. This section details the macroeconomic effects of the IR-4 Project, entailing all direct and secondary transactions projected given the estimated direct effects.

The estimates of total effects presented here include direct, indirect and induced effects of employment, labor income and contributions to gross domestic product. These estimates are derived from fixed ratios to direct sales. That is, if an industry creates a million dollars in sales and employs ten persons, then every one million dollar increase in industry sales will increase its employment by 10 jobs. This is a generalization based on average rates of employment, labor income and contributions to gross domestic product, and conveys a best estimate of such impacts to a change in total output or sales.

Productivity effects are estimated based on the expected productivity impacts associated with pesticide access and use. These productivity-based impacts implicitly assume that expenditures for all inputs rise in proportion with the value of production. This can result in over-estimates of impacts, in that productivity gains imply a larger increase in output relative to inputs. Use of some inputs would be expected to increase in proportion to output, including packaging, harvest labor, and transportation. However, usage of other inputs, while largely increasing with increases in productivity, may increase by less than the proportional increase. For example, seeds or rootstocks (for orchards) may increase as growers recognize greater profitability in planting cover crops, but proportional increases are not necessary for generating those increases in output.

IR-4 Project Expenditure Total Effects

The IR-4 Project expenditures support research and associated administrative expenditures for developing data necessary for EPA registration. These expenditures support researcher salaries, the purchases of laboratory and agricultural equipment and the purchases of agricultural and administrative inputs, including seeds, agro-chemicals, land rents and others. Such transactions spawn a continuum of secondary transactions that give rise to macroeconomic-level of impacts that exceed the initial investment in administrative and research expenditures.

The estimated contributions of the IR-4 Project's expenditures are presented in Table 5. In this, the $41.77 million in direct and in-kind expenditures gives rise to about 171 jobs and about $21.3 million in gross domestic product before accounting for secondary effects. Secondary effect, comprising of both indirect and induced effects contribute another 412 jobs and $40.5 million to annual gross domestic product. In total, the expenditures and in-kind contributions to the IR-4 Project generates about 583 jobs with total labor income of $40.4 million, and contributes about $61.8 million to annual gross domestic product, before accounting for its contribution to producer productivity.

Impact Type	Employment	Labor Income	Gross Domestic Product
Direct Effect	171	$16,822,000	$21,290,000
Indirect Effect	170	$10,957,000	$18,356,000
Induced Effect	242	$12,607,000	$22,188,000
Total Effect	583	$40,386,000	$61,834,000

Table 5: Estimated Economic Contribution of IR-4 Project Direct Expenditures

We should be careful to note that the impacts estimated in Table 5, include in-kind contributions to the IR-4 Project. In-kind contributions are estimated based on IR-Project knowledge of the value of stakeholders' and contributors' efforts and non-budgeted annual contributions to completing registrations for minor use. It also entails the value of fee waivers provided by the EPA and PMRA totaling no more than $6.148 million. This amount is considered part of the basis for estimating the economic impacts because these are funds that would not have been available for research should the fee waivers not exist. In addition, the crop protection industry contributes to data for minor use registration, supplying data that often was collected in the initial registration of the product. The IR-4 Project estimates that the value of crop protection industry contributions saves about $11.93 million. In the case that these in-kind contributions arise through sharing existing data, this savings represents new expenditures the IR-4 Project are able to make rather than replicating existing studies and data.

Food Crops Program Total Effects

The Food Crops Program estimated economic impacts measure the direct change in the productivity and all associated secondary impacts. To be sure, impacts are estimated based on the value of specialty food crop production and on pesticide use made available by the IR-4 Project, where specialty food crops is used as a proxy of the value of minor use crop production.

Table 6 shows the expected economic contributions of productivity enhancements of specialty food crop production brought about by the IR-4 Project. Accordingly, specialty crop productivity enhancements afforded by IR-4 Project registrations of $4.78 billion is expected to support 35,028 agricultural jobs and contribute to about $4.0 billion to annual gross domestic product. Once accounting for secondary transactions, food crop productivity enhancements created 70,868 domestic jobs with $4.2 billion annual contributions to labor income and $7.1 billion contributions to gross domestic product.

Impact Type	Employment	Labor Income	Gross Domestic Product
Direct Effect	35,028	$2,424,568,000	$4,041,289,000
Indirect Effect	10,583	$504,715,000	$796,421,000
Induced Effect	25,258	$1,314,806,000	$2,311,203,000
Total Effect	70,868	$4,244,090,000	$7,148,912,000

Table 6: Estimated Economic Contribution of IR-4 Project Registrations: Food Crops

Ornamental Horticulture Program Total Effects

Similar to food crops, the estimated economic impacts of the Ornamental Horticulture Program represents expected productivity effects of this program on industry productivity and associated macroeconomic impacts through indirect and induced effects. Given the relatively small size of this segment, a priori expectations suggest the impacts will be smaller than for food crops.

Table 7 shows the impact estimates in terms of employment, labor income and contributions to gross domestic product. Accordingly, about 3,053 individuals are employed in ornamental and horticulture industries because of the productivity effects afforded by the Ornamental Horticulture Program. These generate about $200.6 million in labor income and contribute about $289.1 million to annual gross domestic product. Once accounting for indirect and induced effects, the Ornamental Horticulture Program generates about 6,470 jobs, with labor income totaling $385.6 million. It also expands annual gross domestic product by just about $597.2 million.

Impact Type	Employment	Labor Income	Gross Domestic Product
Direct Effect	3,053	$200,578,000	$284,129,000
Indirect Effect	1,118	$65,413,000	$102,693,000
Induced Effect	2,298	$119,658,000	$210,392,000
Total Effect	6,470	$385,649,000	$597,213,000

Table 7: Estimated Economic Contribution of IR-4 Project Registrations: Ornamental Horticulture

Biopesticides & Organic Support Program Total Effects

Outside of agricultural practices like rotations and tillage, biopesticides may be the only viable pest control option for organic growers, but also provide alternative pesticide management options for conventional growers. In this, biopesticides can be applied to organic and non-organic specialty and conventional crops. Accordingly, biopesticides make up a small but growing segment of the agro-pest management market.

We estimated that crop productivity impacts of IR-4 Project supported biopesticides generates about $1.2 billion in added crop sales. This supports about 5,306 agricultural jobs with total annual income of $343.5 million. Once accounting for all secondary transactions, the expected macroeconomic effects add 17,340 jobs with labor income of $962.8 million and annual contributions of $1,627.9 million to gross domestic product.

Impact Type	Employment	Labor Income	Gross Domestic Product
Direct Effect	5,306	$343,539,000	$535,439,000
Indirect Effect	6,294	$320,366,000	$566,793,000
Induced Effect	5,741	$298,930,000	$525,648,000
Total Effect	17,340	$962,836,000	$1,627,880,000

Table 8: Estimated Economic Contribution of IR-4 Project Registrations: Biopesticides & Organic

Aggregate Estimated Total Effects of the IR-4 Project

The total effect calculations of all three programs and the IR-4 Project expenditure effects can be added together to form an overall estimated economic impact of the IR-4 Project. Doing so assumes there is no overlap in the form of shared efficiencies across programs, or resource negation. While there may be cases where the benefits accrued to foods crops, for example, may spillover to other crops, it is not likely that benefits are extracted from other crop categories.

Table 9 shows the aggregate economic impacts that sum all the above sources of impacts. In this, the IR-4 Project is estimated to contribute to 95,261 jobs with total labor income of $5.6 billion and contributes about $9.4 billion to annual gross domestic product which stood at $18.62 trillion in 2016 [68]. As discussed above, these estimates leave out some notable sources of economic gains but are representative of the core mission and contributions to the national economy.

Impact Type	Employment	Labor Income	Gross Domestic Product
Direct Effect	43,559	$2,985,507,000	$4,882,147,000
Indirect Effect	18,165	$901,452,000	$1,484,263,000
Induced Effect	33,538	$1,746,000,000	$3,069,430,000
Total Effect	95,261	$5,632,960,000	$9,435,840,000

Table 9: Estimated Economic Contribution of IR-4 Project

Summary

The IR-4 Project's Food Crop Program is by far the largest source of impact and is the cornerstone of the IR-4 Project. However, their other programs are increasingly important to agricultural producers. In the absence of the IR-4 Project, horticulture producers would have few resources by which to control pest pressures. Additionally, consumer interests in organic foods have given rise to increasing number of acres in organic agriculture. As this remains a small share of total acres in crop production, it is easy to understate the significance of this sector's growth. The Biopesticides and Organic Support Program is an essential resource among many participants building up this pest management sector.

Not all relevant sources of impacts were measured in this assessment. Some key sources of impacts not included in this assessment include consumer access to lower cost and more diverse sources of food. Such increases what economists call consumer surplus, and measures the difference between the value of consumer benefits and the amount paid. In addition, greater access to a diverse diet has implications on consumer health that has further implications on labor productivity. Additionally, the IR-4 Project funds and undertakes producer education to optimize safe pesticide use and management, contributing toward optimal use of pesticides. Finally, the IR-4 Project, along with partnering institutions have made great strides toward harmonizing international MRL and food safety testing, facilitating international trade. This potential source of impact may be significant for U.S. growers as the U.S. is a net exporter of agricultural goods. As countries establish their own standards for MRLs, they constitute significant non-tariff barriers to trade. Harmonization reduces these barriers. Other potential sources of impacts apply and are discussed in this report.

In collaboration with pesticide regulation agencies, the IR-4 Project has streamlined processes for registering pesticides, creating efficiencies in its own submissions as well as benefits to private registrants. By petitioning the use of commodity categories, data on low toxicity pesticides used for one use can be applied to other uses – thus significantly reducing the field and laboratory costs of registering for each intended use and expanding the uses under a single set of data submissions. In addition, by partnering with pesticide companies, the IR-4 Project is able to use existing data for new uses rather than reproduce existing data housed by individual pesticide producers. Furthermore, the IR-4 Project is able to reduce overhead by partnering with SAES labs and research facilities for field trials and laboratory research. However, incentives at SAES facilities have slowly evolved over time and enlisting such labs to undertake data generation for registration is becoming increasingly difficult [6].

According to USDA statistics, annual crop production sales, excluding horticulture, averaged $194.2 billion over the past three years [69]. In this report, the IR-4 Project is estimated to contribute $6.3 billion to this production through the direct effects of the Food Crops, Ornamental Horticulture and Biopesticides & Organic Support Programs. This implies a hefty contribution to overall crop production accounting for just over three percent of total value of crop output. Given that specialty crops make up about 40 percent of the value of crop output, this estimate is not implausible.[8] However, while specialty crops are most associated with the minor use problem, the IR-4 Project's impacts span beyond specialty crop agriculture.

Based on standard I-O modeling, the estimated total effects of the IR-4 Project includes an estimated 95,261 jobs with total labor income of $5.6 billion and annual contributions to gross domestic product totaling about $9.4 billion. These impacts represent best estimates of ongoing contributions to the U.S. economy, largely through crop agricultural productivity and damage mitigation via pest management. Relative to core federal funding of $15.6 million dollars, this represents a high return to public investment. Much of this benefit is attributed to a long history of IR-4 Project-sponsored registration that has made up about 50 percent of EPA registrations for minor uses. That is, we attribute the pesticide availability to the IR-4 Project. While it may be possible that such registrations would have been pursued through other

---

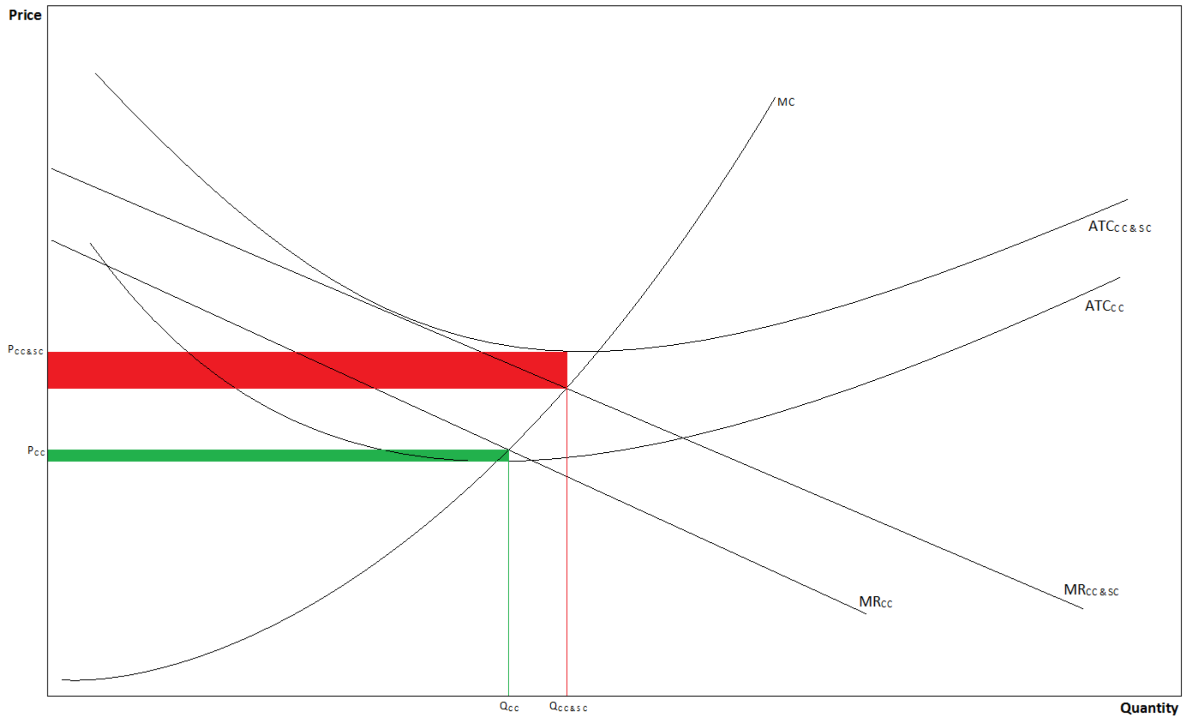
[8] If we limit the basis to the total value of specialty crop production, this asserts that productivity created by IR-4 Project constitutes 8 percent of output. This seems high, but once one considers the expanse of pesticides made available through the 50 plus years of the program's existence, the estimates appear more reasonable. Nonetheless, because many of the registrations impact non-specialty crop production, this 8 percent contribution to specialty crop output overstates the actual impactfulness of the IR-4 Project.

means in the absence of the IR-4 Project, thereby reducing the actual impact estimates, there are many sources of economic impacts that are discussed in this paper that do not underlie the final impact estimates.

Appendix A

From an economic perspective, the chemical producer's choice to register for a specialty use can be depicted in the accompanying graph. Price is the market-determined selling price, while Quantity is the quantity sold. Under the standard production decision rule, a producer will sell as long as the marginal cost (MC curve) of selling an additional unit is less than or equal to the price they receive. Consumers are willing to buy more at lower prices, as exhibited by the downward sloping marginal revenue curves (MR), derived from downward sloping demand curves. The per-unit profit earned by the producer is determined by the difference between the per-unit costs of production (average total cost (ATC)) and the price received.

Starting with a producer that sells to major crop growers, its decision to register its product for a specialty crop use depends on whether that will enhance total profits. Consider the firm facing marginal revenue curve from major crop producers, MR_{CC}. This curve meets the upward-sloping marginal cost curve above the average total cost curve providing a profit equal to the shaded green area. Sales can be increased if the registration was expanded for use on a specialty crop. The combined major crop and specialty crop marginal revenue curve is depicted by the line $MR_{CC\ \&\ SC}$. However, because of the limited number of acres allocated to this crop, the potential change in sales is not significant. Should they choose to pursue this use, the firm will have to undertake field and laboratory tests necessary to meet EPA requirements in determining the health and environmental risks and to assess the pesticide efficacy for the targeted pest. This cost shifts the average total costs up to $ATC_{CC\ \&\ SC}$. Also, increasing production to meet this additional demand, should the registration be granted will increase the marginal cost of each additional unit along the MC curve. The firm would still produce up to the point that marginal cost is equal to price, indicating a level of output equal to $Q_{CC\ \&\ SC}$. However, at this point, the average total cost per unit exceeds the selling price buyers are willing to pay, and the firm will incur losses. The outcome is that the firm will not pursue the specialty crop registration.



Appendix B

State	Field Crops ($000s)	Specialty Crops ($000s)	Total Crop ($000s)	Percent Specialty Crops (%)
United States	**$136,092,279**	**$55,526,378**	**$191,618,657**	**29%**
Alaska	$0	$16,832	$16,832	100%
California	$3,125,206	$29,574,534	$32,699,740	90%
Connecticut	$47,845	$295,225	$343,070	86%
New Jersey	$113,918	$630,713	$744,631	85%
Rhode Island	$4,775	$24,142	$28,917	83%
Massachusetts	$49,200	$215,645	$264,845	81%
Florida	$1,208,790	$4,716,626	$5,925,416	80%
Hawaii	$52,252	$203,262	$255,514	80%
New Hampshire	$26,066	$60,873	$86,939	70%
Arizona	$782,693	$1,548,739	$2,331,432	66%
Washington	$2,420,286	$4,595,505	$7,015,791	66%
Oregon	$1,134,724	$1,855,178	$2,989,902	62%
New Mexico	$348,626	$362,541	$711,167	51%
New York	$1,023,591	$997,442	$2,021,033	49%
South Carolina	$443,798	$308,424	$752,222	41%
Maine	$229,098	$139,232	$368,330	38%
Georgia	$2,065,245	$1,129,738	$3,194,983	35%
Vermont	$91,320	$42,175	$133,495	32%
Virginia	$1,055,689	$436,373	$1,492,062	29%
Michigan	$3,275,413	$1,345,728	$4,621,141	29%
Nevada	$191,102	$78,463	$269,565	29%
Maryland	$640,823	$236,571	$877,394	27%
North Carolina	$2,534,940	$864,569	$3,399,509	25%
Alabama	$960,551	$294,492	$1,255,043	23%
Delaware	$225,846	$66,622	$292,468	23%
Pennsylvania	$2,151,906	$570,390	$2,722,296	21%
Utah	$447,503	$117,251	$564,754	21%
West Virginia	$167,087	$40,609	$207,696	20%
Wisconsin	$3,283,809	$612,318	$3,896,127	16%
Texas	$5,495,650	$924,508	$6,420,158	14%
Tennessee	$2,055,468	$334,385	$2,389,853	14%
Colorado	$2,040,484	$304,513	$2,344,997	13%
Ohio	$4,644,055	$574,561	$5,218,616	11%
Oklahoma	$1,522,664	$177,841	$1,700,505	10%
Louisiana	$1,743,336	$90,256	$1,833,592	5%
Idaho	$3,053,691	$149,929	$3,203,620	5%
Indiana	$6,056,273	$228,289	$6,284,562	4%
Minnesota	$9,866,268	$364,635	$10,230,903	4%
Missouri	$4,368,614	$113,744	$4,482,358	3%
Mississippi	$2,060,325	$51,970	$2,112,295	2%
Illinois	$12,850,078	$315,263	$13,165,341	2%
Kentucky	$2,869,909	$50,130	$2,920,039	2%
Arkansas	$3,557,901	$54,914	$3,612,815	2%
Montana	$2,120,348	$21,497	$2,141,845	1%
Kansas	$6,450,858	$48,554	$6,499,412	1%
Iowa	$14,193,333	$104,586	$14,297,919	1%
Wyoming	$428,217	$2,726	$430,943	1%
Nebraska	$9,744,516	$48,470	$9,792,986	0%
South Dakota	$6,096,084	$14,716	$6,110,800	0%
North Dakota	$6,756,818	$5,533	$6,762,351	0%

Source: [4, 59]

Bibliography

1. Popp, J., K. Pető, and J. Nagy, *Pesticide productivity and food security. A review.* Agronomy for Sustainable Development, 2013. **33**(1): p. 243-255.
2. Oerke, E.-C., *Crop losses to pests.* The Journal of Agricultural Science, 2006. **144**(1): p. 31-43.
3. USDA, N.A.S.S., *2012 Agricultural Census*. 2012, USDA, National Agricultural Statistics Services: Washington, DC.
4. USDA, N.A.S.S., *Crop Values: 2016 Summary*. 2017, USDA: Washington, DC.
5. Baron, J., et al., *The IR-4 Project Over 50 Years of Sustained Success.* Outlooks on Pest Management, 2016. **27**(1): p. 10-25.
6. Baron, J., *Personal Communications*. 2017.
7. Franck, C., S.M. Grandi, and M.J. Eisenberg, *Agricultural Subsidies and the American Obesity Epidemic.* American Journal of Preventive Medicine, 2013. **45**(3): p. 327-333.
8. Arterburn, D.E., M.L. Maciejewski, and J. Tsevat, *Impact of morbid obesity on medical expenditures in adults.* International journal of obesity, 2005. **29**(3): p. 334.
9. Bloom, D.E., D. Canning, and J. Sevilla, *The Effect of Health on Economic Growth: A Production Function Approach.* World Development, 2004. **32**(1): p. 1-13.
10. Dietz, W.H., *Health Consequences of Obesity in Youth: Childhood Predictors of Adult Disease.* Pediatrics, 1998. **101**(Supplement 2): p. 518.
11. Tilman, D., *The ecological consequences of changes in biodiversity: a search for general principles.* Ecology, 1999. **80**(5): p. 1455-1474.
12. Pimentel, D., et al., *Benefits and Costs of Pesticide Use in U.S. Food Production.* BioScience, 1978. **28**(12): p. 772-784.
13. Miller, S.R., *MSU IPM Programming Evaluation: Focus Group Discussions with Technical Consultants and Survey of Growers*. 2016, Michigan State University: East Lansing, MI.
14. Dennehy, T.J. and J. Dunley. *Managing Pesticide Resistance*. 2017 August 22, 2017]; Available from: http://jenny.tfrec.wsu.edu/opm/displayspecies.php?pn=-70.
15. Miller, S. and A. Leschewski, *Economic impacts of the IR-4 project and IR-4 project programs.* East Lansing: Center for Economic Analysis, Michigan State University, 2012.
16. The IR-4 Project, *Annual Report 2016*. 2017, Rutgers University: New Brunswick, NJ.
17. U.S. Environmental Protection Agency, *Report on Minor Uses of Pesticides*. n.d., Environmental Protection Agency: Washington, DC.
18. Farm Bureau, *Do Trade Programs Affecting Specialty Crops Need to be Altered?*, in *Farm Bureau 2018 Farm Bill*. 2016, Farm Bureau: Washington, DC.
19. USDA, E.R.S. *U.S. Agricultural trade Data Update*. 2017 September 7, 2017 September 19, 2017]; Available from: https://www.ers.usda.gov/data-products/foreign-agricultural-trade-of-the-united-states-fatus/us-agricultural-trade-data-update/.
20. Norton, J.A., *A Review of Methyl Bromide Alternatives Evaluated By IR-4*, in *International Conference on Methyl Bromide Alternatives and Emission Reductions*. 2005: San Diego, CA.
21. USDA, E.R.S. *Organic Production*. 2013 September 20, 2017]; Available from: https://www.ers.usda.gov/data-products/organic-production/.
22. USDA, N.A.S.S., *2014 and 2015 Organic Certifier Data*. 2016, National Agricultural Statistics Service: Washington, DC.
23. Miller, S.R. and A. Leschewski, *The Economic Impact of the Minor Use Pesticide Program: Pest Management Centre, Agriculture and Food Canada*. 2011, Michigan State University: Center for Economic Analysis: East Lansing.

24. Miller, S. and A. Leschewski, *An Econometric Evaluation of the North Central IPM Center Funded NRCS & IPM Working Group on the EQIP 595 Practice Adoption*. 2012, Michigan State University: East Lansing.
25. Fernandez-Cornejo, J., S. Jans, and M. Smith, *Issues in the economics of pesticide use in agriculture: a review of the empirical evidence.* Review of agricultural economics, 1998. **20**(2): p. 462-488.
26. Yen, S.T., et al. *Demand for differentiated vegetables*. in *Selected Paper Prepared for Presentation at the American Agricultural Economics Association Annual Meeting, Denver, Colorado. August*. 2004.
27. You, Z., J.E. Epperson, and C.L. Huang, *A composite system demand analysis for fresh fruits and vegetables in the United States.* Journal of Food Distribution Research, 1996. **27**: p. 11-22.
28. USDA. *MyPlate*. 2017 October 18, 2017]; Available from: https://www.fns.usda.gov/tn/myplate.
29. Retzlaff-Roberts, D., C.F. Chang, and R.M. Rubin, *Technical efficiency in the use of health care resources: a comparison of OECD countries.* Health Policy, 2004. **69**(1): p. 55-72.
30. Anderson, G. and P.S. Hussey, *Comparing health system performance in OECD countries.* Health Affairs, 2001. **20**(3): p. 219-232.
31. Gundgaard, J., et al., *Increased intake of fruit and vegetables: estimation of impact in terms of life expectancy and healthcare costs.* Public health nutrition, 2003. **6**(1): p. 25-30.
32. Boles, M., B. Pelletier, and W. Lynch, *The Relationship Between Health Risks and Work Productivity.* Journal of Occupational and Environmental Medicine, 2004. **46**(7): p. 737-745.
33. USDA, E.R.S. *Agricultural Research and Productivity*. 2017 October 18, 2017]; Available from: https://www.ers.usda.gov/topics/farm-economy/agricultural-research-and-productivity/.
34. Pimentel, D., et al., *Environmental and economic effects of reducing pesticide use.* BioScience, 1991. **41**(6): p. 402-409.
35. Doran, J.W., *Soil health and global sustainability: translating science into practice.* Agriculture, Ecosystems & Environment, 2002. **88**(2): p. 119-127.
36. Tabashnik, B.E., *Managing resistance with multiple pesticide tactics: theory, evidence, and recommendations.* Journal of Economic Entomology, 1989. **82**(5): p. 1263-1269.
37. Holm, R.E., *The IR-4 Program: Meeting the U.S. minor crop pest control challenge.* Phytoparasitica, 2003. **31**(3): p. 213-216.
38. Bureau of Labor Statistics. *Median weekly earnings by educational attainment in 2014*. TED: The Economics Daily 2015 October 10, 2017]; Available from: https://www.bls.gov/opub/ted/2015/median-weekly-earnings-by-education-gender-race-and-ethnicity-in-2014.htm.
39. IR-4 Project, *Annual Report*. various, Rutgers University: New Brunswick, NJ.
40. Headley, J.C., *The Economics of Pest Management*, in *Introduction to Insect PestManagement*, R.L. Metcalf, Editor. 1975, John Wiley & Sons: New York, NY. p. 75-99.
41. Richardson, H.W., *Input-Output and Regional Economics*. 1972, New York: Halsted Press.
42. Bureau of Economic Analysis. *Input-Output Accounts Data*. 2017 October 3, 2017]; Available from: https://www.bea.gov/industry/io_annual.htm.
43. IMPLAN Group LLC. *Introducing the Social Accounting Matrix (SAM)*. 2015 October 3, 2017]; Available from: http://support.implan.com/index.php?option=com_content&view=article&id=290:290&catid=228:228.
44. Coughlin, C.C. and T.B. Mandelbaum, *A consumer's guide to regional economic multipliers.* Federal Reserve Bank of St. Louis Review, 1991. **73**(January/February 1991).
45. Richardson, H.W., *Input-Output and Economic Base Multipliers: Looking Backward and Forward.* Journal of Regional science, 1985. **25**(4): p. 607-661.

46. Minnesota IMPLAN Group, I., *User's Guide: IMPLAN Pro. Version 2.0*. 2004, Stillwater, MN: Minnesota IMPLAN Group, Inc.
47. Bureau of Labor Statistics. *Consumer Price Index*. 2017 October 3, 2017]; Available from: http://www.bls.gov/cpi/.
48. Carpentier, A. and R.D. Weaver, *Intertemporal and interfirm heterogeneity: implications for pesticide productivity.* Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie, 1996. **44**(3): p. 219-236.
49. Norwood, F.B. and M.C. Marra, *Pesticide productivity: Of bugs and biases.* Journal of Agricultural and Resource Economics, 2003: p. 596-610.
50. Council, N.R., *The future role of pesticides in US agriculture*. 2000, Washington, DC: National Academies Press.
51. Jorgenson, D.W. and F.M. Gollop, *Productivity growth in US agriculture: a postwar perspective.* American Journal of Agricultural Economics, 1992. **74**(3): p. 745-750.
52. Knutson, R.D., et al., *Economic Impacts of Reduced Pesticide Use.* Choices, 1990. **5**(4): p. 25-31.
53. Saha, A., C.R. Shumway, and A. Havenner, *The economics and econometrics of damage control.* American Journal of Agricultural Economics, 1997. **79**(3): p. 773-785.
54. Alston, J.M., et al., *A meta-analysis of rates of return to agricultural R&D: Ex pede Herculem?* Vol. 113. 2000: International Food Policy Research Institute.
55. Zilberman, D., et al., *The economics of pesticide use and regulation.* Science(Washington), 1991. **253**(5019): p. 518-522.
56. Atwood, D. and C. Paisley-Jones, *Pesticides Industry Sales and Usage: 2008-2012 Market Estimates*, in *US EPA* 2017: Washington, DC.
57. U.S. Environmental Protection Agency. *New Approaches to Minor Uses*. 2001; Available from: http://www.epa.gov/opp00001/minoruse/index.htm.
58. Miller, S.R., *National Economic Impact of the IR-4 Project*. 2007, Michigan State University, Center for Economic Analysis: East Lansing, MI.
59. USDA, N.A.S.S., *2014 Census of Horticultural Specialties*. 2014, USDA: Washington, DC.
60. Jerardo, A., *Floriculture and Nursery Crops Yearbook: 2005*. 2006, USDA: Economic Research Service: Washington, DC.
61. Hodges, A.W., et al., *Economic contributions of the green industry in the United States in 2013.* HortTechnology, 2015. **25**(6): p. 805-814.
62. Novack, S., *Personal Communications*. 2017.
63. Damico, T., *Biopesticides are in High Demand in Today's Pest Management Programs*. 2017, Certis: Columbia, MD.
64. Alexander, L., *Biopesticides by the Numbers*, in *Biopesticides Primed for Growth*, Certis USA, Editor. 2014, Certis: Columbia, MD.
65. Pucci, J., *Biopesticides Move into Row Crop Territory: Suppliers see Big Opportunities Beyond the Specialty Crop Markets*, in *Biopesticides Primed for Growth*, Certis USA, Editor. 2014, Certis: Columbia, MD.
66. Hodges, A.W., et al., *Production and marketing practices and trade flows in the United States green industry in 2013.* Journal of Environmental Horticulture, 2015. **33**(3): p. 125-136.
67. USDA, N.A.S.S., *Certified Organic Survey: 2016 Summary*. 2017, USDA: Washington, DC.
68. BEA, U.S.D.o.C. *National Economic Accounts*. 2017 October 11, 2017]; Available from: https://bea.gov/national/index.htm#gdp.
69. USDA, N.A.S.S. *Quickstats*. 2017 October 11, 2017]; Available from: URL=http://quickstats.nass.usda.gov/results/7360D55A-4222-367D-B010-8CA3F4471C79.