The Economic Impact of the

NextGen Precision Health Initiative

A Report submitted to the University of Missouri System by

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Executive Summary

In this report, we quantify the economic impact that the NextGen Precision Health Initiative will have on the State of Missouri economy. The NextGen initiative is the University of Missouri's plan to coordinate basic research on diagnostics and new treatments in radiopharmaceuticals, cancer, cardiovascular and neurogenerative diseases. In order to coordinate research activities, the NextGen initiative will involve resources across the four campuses, utilizing existing expertise, building a facility and adding additional researchers. With investments in physical capital, human capital and the average effects of R&D spending, our charge is to quantitatively assess the economic impact on the State of Missouri.

Throughout our analysis, we make conservative assumptions regarding the implementation of the NextGen Precision Health Initiative. For instance, we assume a limited five-year horizon for expenditures on additional researchers and on their conduct of basic R&D. With the building expenditure, our assumptions amount to an investment of roughly $400 million between 2020 and 2027.

Because we study the economic impacts over time, our results are stated in terms of the projected economic impacts on *additional* real GDP, employment, and state general fund collections between 2020 and 2045. Our finding are summarized as follows:

- The building, additional researchers, and effects of R&D spending is projected to result in the discounted sum of additional real GDP equal to $5,637.7 million for the State of Missouri between now at 2045.

- The State of Missouri economic growth rate will increase by slightly less than one basis point over the next 25 years as the NextGen initiative adds to the stock of accumulated R&D over the next five years.

- With these investments and R&D, we project that an additional 1,000 workers will be added to the Missouri economy in 2022. By 2045, the additional growth associated with the R&D means that nearly 7,000 additional workers will be employed in Missouri compared to economy in which the NextGen initiative is not implemented.

- As the State of Missouri's tax base expands because of the NextGen initiative, General Fund collections will also increase. Our projections indicate that the discounted sum of additional revenue collections is $227 million between now and 2045.

- Our projections are based on the average impact that investments and R&D spending have on the state economy. If NextGen succeeds in the sense of generating above-average returns, there will be spillovers to the State of Missouri economy; in particular, research findings attract additional research funding and entrepreneurs who seek to draw on the expertise of both researchers and other innovators.

- One cannot plan on such above-average outcomes, but programs like the NextGen initiative provide the intellectual infrastructure that can yield spillovers.

Overall, the NextGen Precision Health Initiative is a R&D project that utilizes the University of Missouri System's current expertise and leverages, along with some critical investments in people, machines and buildings, that into an economic engine that adds to State of Missouri economy in a quantitatively significant way.

1. Introduction

In this report, we quantify the economic impact that the NextGen Precision Health Initiative will have on the State of Missouri's economy. The NextGen initiative is the University of Missouri's plan to coordinate basic research on diagnostics and new treatments in radiopharmaceuticals, cancer, cardiovascular, and neurogenerative diseases. The coordination activities involve expertise already present in the University of Missouri System's four campuses combined with additional faculty/Principal Investigators. The centerpiece will be the NextGen Precision Health Institute, a $220.8 million building located on the Columbia campus. Our charge is to quantitatively assess the impact of additional spending in physical capital, human capital, and research and development (R&D) on the Missouri economy.

In this report, we are looking at how the NextGen initiative will impact the State of Missouri over time. Our starting point is the idea that the investments and the R&D change the economic landscape and therefore the economic impacts last. Buildings last. Through the discoveries made by R&D, this new knowledge lasts. People and their work change over time. Correspondingly, our view is that economic impacts are images comprising a movie. Any static picture of the economic impacts must be an incomplete story. Though one can compute a cumulative multiplier from our analysis, our framework is not one that uses the typical demand-driven static multiplier approach. In other words, we do not rely on the belief that an increase in income is multiplied through spending on additional goods. Rather, we are looking at the underlying production possibilities generated by the NextGen initiative; specifically, how those possibilities move through time. To measure these movements, we must carefully calibrate the effects to match the average effects observed and reported in other studies. The bottom line is that our framework allows us keep track of the productive capacity of the Missouri economy as it moves through time. All of the additional expenditures are properly matched with the increased amount of productive capacity that occurs because the economy is growing, on average, and because these the productive capacity is less constrained owing to NextGen's investments.

The analysis makes conservative assessments of the NextGen Precision Health Initiative and yet generates sizable quantitative economic impacts. In addition to the building investment, we conservatively assume the investments in people will occur over a five-year period. It is more likely that the investments will be for a longer period, but even with this conservative approach, a roughly $400 million expenditure between 2020 and 2027 (including the time to build) will result in an additional $5,637.7 million to the State of Missouri's real GDP between now at 2045. This amount is the discounted sum of increases to real GDP and therefore represents what the additional flow of state output is in 2019 dollars. Initially, our projections are consistent with an additional 1,000 workers in Missouri, By 2045, however, the return to the NextGen initiative is projected to add over 7,000 additional workers to the

Missouri economy. With an expanding economy, there will be additional general fund revenues for the State of Missouri. Our projections are that Missouri's General Fund collections will be $227 million greater with the NextGen Health Initiative implemented compared with an economy in which NextGen is not implemented.

In sum, we carefully and conservatively project the economic impact associated with the NextGen Precision Health Initiative. Our findings indicate that the State of Missouri's economy will grow slightly faster because of R&D spending. There are no heroic assumptions; the NextGen initiative yields normal returns to investments in buildings and people. If the R&D conducted at NextGen Precision Health Institute develops above-average successes in the form of new discoveries and new treatments, the spillovers to the State of Missouri economy will mean even greater real-GDP increases are realized. [1]

2. Health Status, or Why is NextGen so Valuable?

In the United States, health is a big consumer item. Figure 1 plots average spending on healthcare services through time.[2] Healthcare spending has increased at a 3.4 percent average annual rate, much faster than Missouri's average annual real GDP growth, which has increased at a paltry 1.015 percent (a detailed description will be presented in Figure 4 below). The Bureau of Labor Statistics reports that American spent over $640 billion on healthcare in 2017. The lowest income quintile—that is, the 20 percent of U.S. households with the lowest income—spent just 10.1 percent of the $640 billion while the highest income quintile accounted for 31.8 percent of the total healthcare spending.

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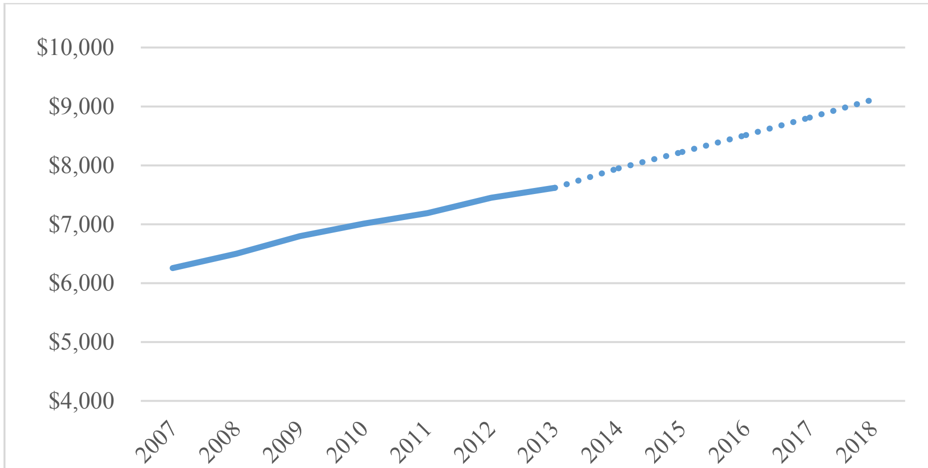
[1] The idea of spillovers is difficult. We provide an appendix in the back of the report that defines and presents examples of spillovers in local economies.

[2] See https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/NationalHealthExpendData/NationalHealthAccountsStateHealthAccountsResidence.html . The latest data available is 2014, all years after 2014 are projected using the average annual growth rate of health care expenditures per person.

Figure 1

Average Healthcare Expenditure per Person, 2007-2018

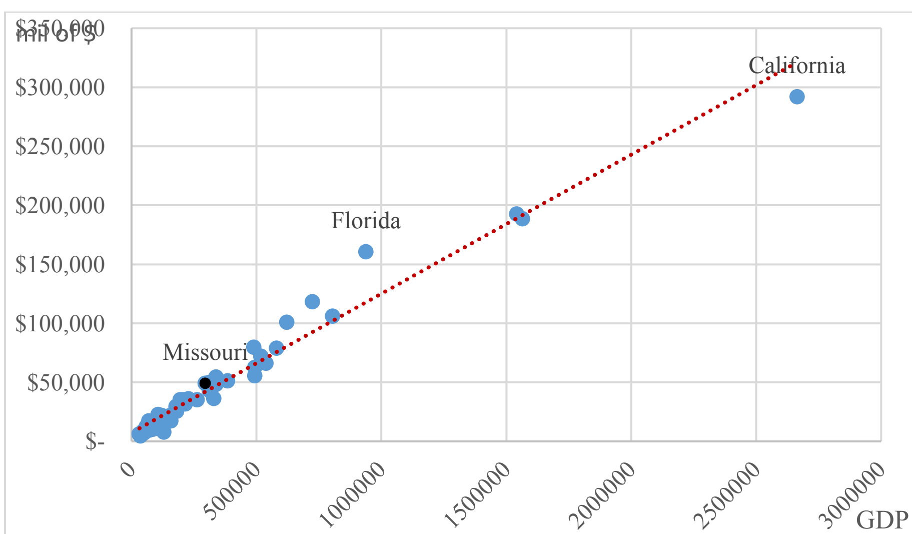


Source: Centers for Medicare and Medicaid Services

Aggregate spending for each state is reported in Figure 2. The horizontal axis is the size of the economy measured by nominal GDP. The positive relationship is not surprising, people living in states with higher incomes will spend more on healthcare than people living in states with lower incomes. We included a trend line to show the average spending per GDP across states. Figure 2 shows that Missouri is

Figure 2

Aggregate HealthCare Expenditure by State, 2014



Source: Centers for Medicare and Medicaid Services slightly above the trend line, indicating Missourians spend a little more on healthcare per dollar of GDP than people do in the typical state. We also highlight Florida and California. In the Florida, the combination of aggregate healthcare spending and GDP is further above the trend line indicating Floridians spend, on average, more on healthcare than predicted for their income. In contrast, California lies below the state level trend, indicating that, on average, Californians spend less on healthcare than would be predicted by their income. Such observations provide some insight into the health status, for a given level of income, in each state.

There are many other ways to break down the expenditure. Table 1 reports share of healthcare expenditures by age group and by region of the country as reported by the Bureau of Labor Statistics. By age group, Table 1 reports that people 65 years and older account for nearly one-third of healthcare expenditures in the United States. When we add those people who are 55 years and older, we see that more than 50 percent of total healthcare spending is attributed to this age group. Broken down, people 65 and older spend more on health insurance, drugs and medical supplies than people in the 55-64 age group, but spending on medical services is about the same for those in the 55-64 age group and those in the 65 and older group.

Table 1

Expenditure Shares by Age and Region of the Country, 2017

	Under 25 years	25-34 years	35-44 years	45-54 years	55-64 years	65 years and older
Share of Healthcare Expenditure by age	1.8	10.5	14.3	18.3	22.3	32.8

	Northeast	Midwest	South	West		
Share of population	17.9	21.6	38.3	22.1		
Share of Healthcare Expenditure by region	18.7	23	36.3	22		

There is no significant difference in healthcare expenditures across the country. In the four geographic regions, the share spent on healthcare is very close to the fraction of the region's population. The South spends about two percentage points less on healthcare than its fraction of the nation's population (38.3 population share versus 36.3 expenditure share) while those in the Northeast (17.9 population share versus 18.7 expenditure share) and Midwest (21.6 population share versus 23 expenditure share) regions spend a little more on healthcare compared with their population share.[3]

According to the Bureau of Labor Statistics, we have observations on the size of the market for healthcare. Healthcare spending is big. With aggregate consumer expenditures in the U.S. over $7.8 trillion in 2017 according to the Bureau of Labor Statistics, healthcare expenditures accounted for over 8.2 percent of total consumer spending. Healthcare spending is huge, not surprisingly, and increasing more rapidly than income. NextGen Precision Health Initiative is important because it seeks to develop new and better treatments, resulting in healthier people.

3. Existing Health Initiative Programs

In 2016, the Academy of Medical Sciences (United Kingdom) released a report on team science. This 2016 report had a very specific mission. The question is whether there are significant benefits to medical researchers working in a coordinated manner that heretofore had been scaled too low compared with the team science approach being advocated.[4] The report makes a compelling case that two or more research teams that previously worked independently could achieve greater productivity through a more coordinated operation. Hence, the scale and breadth of operations could result in an increase in research productivity and grant acquisition. Coordinated activities amongst researchers concentrated in a few, well-defined areas is one of the key features of the NextGen Precision Health Initiative at MU; consequently, it is worth reviewing the report and the implementation in the U.K.

There are two comparable precision health initiative programs that have been created. After releasing the report, the U.K. implemented a team health initiative. In the U.S., the best example of implementing the concepts suggested by the Academy of Medical Sciences report is found in Indiana. The Precision Health Initiative is a $120 million program involving the Indiana University School of Medicine, Indiana University-Bloomington and Indiana University Purdue University at Indianapolis. As part of the Grand Challenges Program, these partners will bring 39 new faculty positions to grow research

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[3] Northeast consists of ME, VT, NH, MA, RI, CT, NY, PA, and NJ. Midwest consists of OH, IN, MI, IL, WI, MN, IA, KS, MO, ND, SD, and NE. The South consists of DE, DC, FL, GA, MD, NC, SC, VA, WV, AL, KY, MS, TN, AR, TX, LA, and OK. The West consists of AZ, ID, CO, MT, NE, NM, UT, WY, AL, NI, CA, WA, and OR.
[4] See "Improving recognition of team science contributions in biomedical research careers," The Academy of Medical Science, March 2016 at https://acmedsci.ac.uk/file-download/6924621.

capability and create new educational opportunities. More specifically, the initiative creates a Precision Health Data Commons that set goals to cure at least one type of cancer (Multiple Myeloma/Triple Negative Breast Cancer and Pediatric Sarcoma are focal points) and pioneer preventative treatment for one chronic illness (Type II diabetes) and one neurogenerative disease (Alzheimer's). There are six research areas (scientific pillars) that operationally will be coordinated in order to achieve these goals: Genome Medicine, Cell, Gene and Immune Therapy, Regenerative Medicine and Engineering, Psychosocial, Behavioral and Ethics, Data and Informatics, and Chemical, Biology and Biotherapeutics. The Initiative stared in June 2016.

As of September 2019, the Indiana Precision Health Initiative reports that they have hired 43 new faculty positions in the Indiana University School of Medicine. New faculty have garnered more than $19 million in grant funding. There have been 96 peer-reviewed papers have been published by members of the Precision Health Team. New companies have been attracted to the area, most notably Thermalin Diabetes, Inc. And, the first CAR-T cell therapies have been successfully administered to adult cancer patients in Indiana and were administered in an Indiana University Health facility.[5]

The sample of coordinated health initiatives is small. Conequently, the returns to the coordinated health programs is not completely settled yet. However, there are older models that offer similar approaches to the implementation of medical treatments. For example, the Mayo clinics offer coordinated treatment approaches and have been tremendously successful. NextGen Precision Health Initiative is implementing a similar approach to coordinating researching efforts.

3. NextGen and Coordinated R&D

Basic R&D has changed as other technologies evolve. In particular, interdisciplinary approaches are far more common today compared with the past. Rather than toil in a lab with a few technicians, a post-doc or two, and a handful of graduate students, most researchers utilize computing power and mathematical simulations. Bench researchers in the sciences are increasingly interacting with computer scientists and engineers to uncover deeper truths.[6]

How will the NextGen Precision Health Initiative promote basic research? One could simply say that the Initiative will proceed to discover treatments for a particular disease. If it were that simple, someone would have done it already. In terms of treatments, the University of Missouri has a nuclear

[5] See https://precisionhealth.iu.edu/progress/index.html .

[6] To illustrate the interdisciplinary nature and its evolution, University of Missouri must look no further than Prof. George Smith, The 2018 Nobel Laureate in Chemistry was a member of the Biological Sciences faculty. The takeaway is that sharp delineations between the physical sciences have been breaking down for years.

reactor on campus, positioning it well to participate in radiopharmaceuticals. NextGen will focus part of its efforts on developing new drugs, as well as three other areas: cancer treatments, cardiovascular treatments, and neurological diseases. Cancer treatments are one of the three focal points, especially those based on immunotherapies, RNA-based therapeutics and methods to detect circulating tumor cells. Cardiovascular treatments are another area in which NextGen will emphasize basic research efforts, including metabolic diseases, cardiac function and utilizing one of the leasing researchers studying the lymphatic system. Lastly, neurological diseases will be a focal point, including research on ALS, Alzheimer's, and the existing research at the Thompson Center for Autism and Neurodevelopment Disorders.

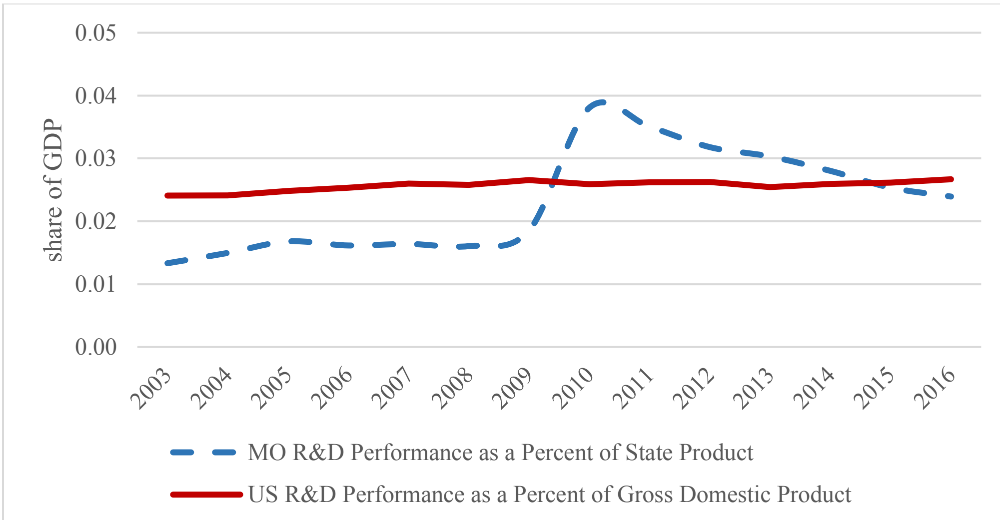
The University of Missouri and NextGen is well suited to provide meaningful contributions and advancements in healthcare initiatives. The University of Missouri has a nuclear reactor on campus, positioning it well to participate in radiopharmaceuticals. Existing scholars at the University of Missouri will be combined with approximately 60 additional Principal Investigators in a new state-of-the-art facility to facilitate R&D success. To our knowledge, to date, no other facility like this exists in the United States. The emerging picture is that NextGen Precision Health Initiative is not start-from-scratch call for basic research. The $220.8 million building provides a space for integrated, interdisciplinary researchers to be located in a single building so that coordinated activities will be made easier. More concretely, biochemists will not have to send their results and questions to a computer scientist across campus; communication will more direct as the team members will be just down the hall from each other.

As we proceed with our quantitative analysis, the fact that NextGen is a research-focus initiative will be important. Figure 3 plots the share of business research and development spending by businesses for the years 2003 through 2016. The U.S. share of GDP spent on R&D is remarkably stable over the period 2003-2016. The share of GDP spent on business R&D fluctuates within the narrow band of 2.4 to 2.7 percent over these 14 observations. During the same period, Missouri's share of GDP spent on business R&D fluctuates between 1.3 percent and 3.8 percent. There was a big increase in business R&D spending reported for the State of Missouri in 2010. Since 2010, the State of Missouri has seen its share of R&D spending decline so that it slightly below the national average share in 2016.

What makes NextGen Precision Health Initiative so useful is that it is a massive research project. Our analysis proceeds as follows: using data on output, capital, and productivity in Missouri, we estimate a baseline economy answering the question "what would be the output of the State of Missouri's economy without NextGen Health Initiative?" We then examine the impact of NextGen in stages; (1) How much does the building and equipment (an increase in physical capital) contribute to Missouri's productive possibilities? (2) What is the impact of the additional human capital on output for the State of Missouri? and (3) How does NextGen contribute to total productivity through time?

Figure 3

Business R&D Spending as a Share of GDP, 2003-16



4. Treatment Effects

A company adds value to the aggregate economy in a region. In order to produce goods and services, a company needs to make payments to workers and expenditures on buildings and machines that workers use. In order to quantify the economic impact that the NextGen Precision Health Initiative will have on the Missouri economy we project what the Missouri economy will look like without the Initiative. In other words, we construct a control, or baseline, path for the Missouri economy and then "treat" it with the NextGen Precision Health Initiative as an exogenous treatment.[7]

[7] Note that our use of the term projection is not equivalent to a forecast. In the absence of controlled economic experiment, we are using the projections to present what the Missouri economy would be like, holding everything else constant, if it increased at the same rate as its historical average. Rather than a forecast of the Missouri economy, our approach is based on some reference point. So, we are looking at the Missouri economy after treatment *relative to* this baseline projection. Because the Missouri economy is subject to lots of forces, it would be foolish to say that the Missouri economy is forecasted to produce $370 billion of final goods and services in 2045. The forecast error would be huge. However, as a reference point, the $370 billion value in 2045 stands as a valuable baseline measure to which we can control one other change; namely, the NextGen Precision Health Initiative.

The baseline part of the analysis is actually very straightforward. We answer the following question: What is a reasonable projection of the Missouri economy over the next generation? For our purposes, we assume that the Missouri economy will continue to grow at the same rate as it has, on average, over the past generation. The average growth rate is obtained by computing the average annual growth rate for Missouri's real GDP. Since 1997. We plot the actual data for Missouri for the period 1997 through 2018 in Figure 4. In 1997, Missouri reported the real value of goods and services within the state's boundaries as \$228.3 billion. By 2018, that value increased to \$282.2 billion.[8] Based on 1997-2018 real GDP values, the average annual growth rate for the Missouri economy was 1.015 percent.

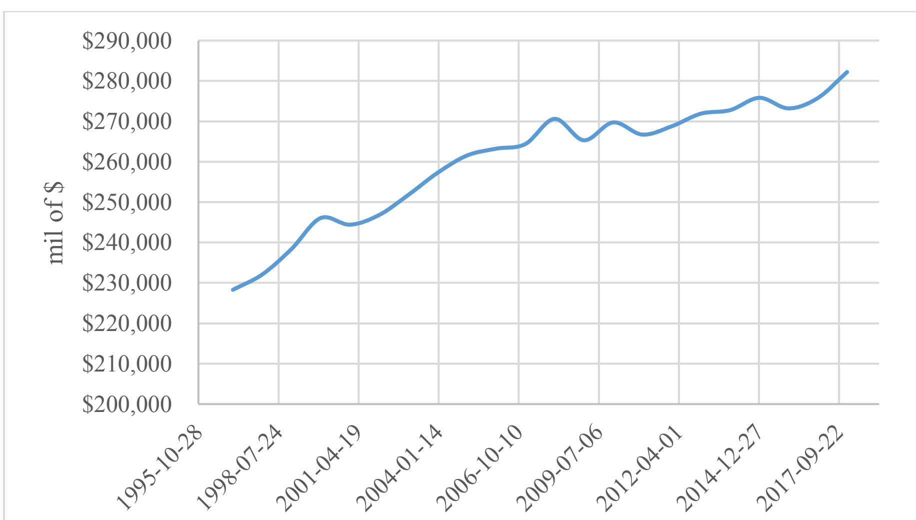
To project the baseline values for the State of Missouri, we need two values: an initial value of real GDP and the average annual growth rate. With real GDP equal to \$282.2 billion in 2018, we project forward by the following equation:

$$GDP_{MO,t} = \left(1 + g_i\right)^{t-2018} \times GDP_{MO,2018} \quad . \qquad (1)$$

where $g_i = 0.0105$, $GDP_{MO,2018} = \$282.2$ and $t = 2019, 2020, \ldots, 2045$. Thus, we can plot a value of the Missouri economy projected from 2019 through 2044 based on the assumption that the

Figure 4

Missouri real GDP, 1997-2018



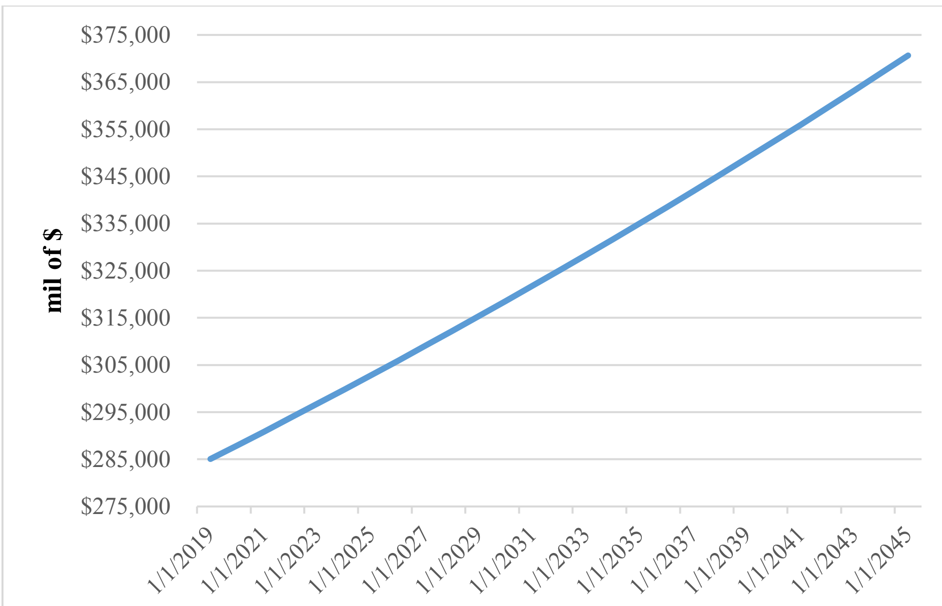
Source: Bureau of Economic Analysis

[1] The real GDP data are produced by the Bureau of Economic Analysis. We downloaded the data from the Federal Reserve Bank of St. Louis FRED database. The data are adjusted for changes in the price level and are officially Missouri real GDP in Chained 2012 dollars.

baseline-version of the economy continues to grow at a 1.015 percent annual rate for the next 25 years. Figure 5 plots the baseline path for the Missouri economy for the 2019-2045 period. By 2045, the Missouri economy would be projected to produce $370.6 billion worth of goods and services. Remember that this baseline path controls for changes in the price level such that this is interpreted as the path for real GDP in Missouri.

Figure 5

State of Missouri Projected Real GDP 2019-2045



Source: authors' calculations

Now that we have a baseline path for the Missouri economy, the economic impact is measured as the difference between the treatment path and the baseline path. In the following section, we demonstrate how we compute the treatment path.

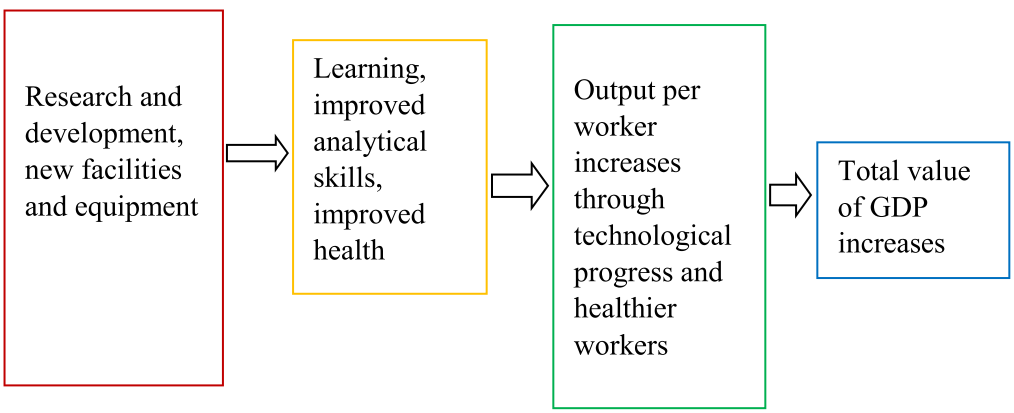
4.1 Computing the Treatment Effect

In order to construct the treatment effect, we need a model of the Missouri economy that is internally consistent. People behave rationally in this model economy, choosing how much to consume and how much to invest to maximize lifetime utility. Production is accomplished by combining machines, people, and other inputs to produce the goods and services sold to consumers and businesses for their final use. Figure 6 provides an overview of the process that takes inputs and turns them into final products. With respect to the NextGen Precision Health Initiative, Figure 6 focuses on the role that additional investment in buildings, machines, and research and development play in terms of the production of final goods and services.

To put Figure 6 into operation, we need a few equations to express how changes in the stock of buildings, machines and new technologies can affect output. Therefore, we estimate the impact of NextGen by quantifying the value of assets that is under the company's direct control. Specifically, what

Figure 6

Flowchart of the relationship between
NextGen Key Components and Economic Outcomes



is the value added to the production of final goods and services—or, Gross Domestic Product (GDP)—that corresponds to this particular Initiative? It is the answer to this question pertaining to NextGen Precision Health Initiative that we measure in this part of the report.[9]

Because economies on average grow over time, we use the "Ak" model of economic growth. The equation is very intuitive in the sense that the model combines physical and human capital—the "k" in the

[9] Sometimes economic impacts studies will refer to the direct impact, which is our focus, and the indirect impact. As the NextGen Precision Health Initiative begins operations, the indirect impact would measure things like the pay increase as the demand for workers increase across the local economy. Unfortunately, the indirect measurements confuse what happens over time and across all the markets. If one company stops operating, for example, income drops by the amount of payments to those workers. In formal language, the production possibilities of the economy shrinks as new operating entity starts production. Over time, productivity and other factors contribute to the production possibilities increasing so that the simultaneous consideration of income increasing because of one new operation and economic growth in the other sectors means that the indirect effects are already incorporated into a measure of total income over time.

model's title—with a technology parameter—the "A" in the model's title—to generate a value of GDP. In other words, technology combined with machines, buildings, and people are brought together to produce final goods and services. The equation is elegant in the sense that we can consider directly how changes in buildings and people affect the quantity of human and physical capital. In addition, we can quantify how research and development (hereafter R&D) affect the technology parameter, denoted by A.

The formal expression of the production of goods and services in Missouri is captured by equation (2). Let real GDP in Missouri be represented by

$$GDP_t = A\left(RD_t\right)K_t\,. \tag{2}$$

Equation (2) says that real GDP in a year is equal to the product of the technology variable, denoted $A\left(RD_t\right)$, and the sum of physical and human capital, denoted K_t. In other words, the market value of final goods and services is comprised of the state of technology that exists and inputs combined with that technology. Note further that $A\left(RD_t\right)$ is the notation we use to characterize the relationship between the stock of accumulated knowledge captured by accumulated R&D spending and the current technology.[10]

Technology is a difficult thing to pin down and to make concrete. It captures production processes, improvements to machines (for example, a 2019 tractor is more advanced than a 1945 tractor), and mnay other little things. For the NextGen Precision Health Initiative, we could include the improvements in people's health, allowing for fewer days off work that occur as medical treatments improve.

The bottom line is that Equation (2) is the means by which we quantify the economic treatments associated with the NextGen Precision Health Initiative. These economic treatments come in two principal forms. First, there are the additions to physical and human capital; that is, the buildings, machines, and people that will contribute to the production of goods and services in the Missouri economy. Second, there are the gains to technology that occur because R&D spending is positively related to way in which we combine physical and human capital to transform these inputs into final goods and services. We evaluate the impact of each of these in turn below.

4.2 Describing changes to physical and human capital

[10] Just because we write $A\left(RD_t\right)$ we are not assuming that the state of technology depends only on the accumulated quantity of R&D spending. Technology depends on a host of other factors, we are using this notation to characterize the functional relationship between additional R&D spending and the level of technology.

For our analysis, the changes to physical and human capital are divided into three main categories: (1) the building will provide space in which the researchers will perform basic R&D, (2) researchers will need specific scientific equipment to conduct experiments, resulting in a financial outlay to acquire physical capital, and (3) various desks, computers, and numerous other pieces of equipment associated with building a research lab. The building, with an expected cost of $220.8 million, will house research space, a vivarium, and offices. Researchers will need scientific equipment to conduct their experiments. A Magnetic Resonance Imaging (MRI) device and a Positron–emission Tomography (PET) device are two of the larger pieces of equipment. The budget calls for $30 million to be allocated for equipment purchases. For the teams that will be housed in the new building, another $30 million is being allocated for startup costs including computers, desks, and numerous other pieces of lab equipment needed to build a lab. Overall, there is a $250.8 million expenditure invested in physical capital.

In addition to the increase in buildings and equipment, the NextGen Precision Health Initiative will also add to the stock of human capital in Missouri. The proposed initiative calls for 60 Principal Investigators who will coordinate their research activities. Of this group, 30 Principal Investigators will added to the existing research community. Funding for the Principal Investigators and their research teams will come from external sources such as the National Science Foundation and National Institutes of Health. The projected aggregate costs of additional researchers is $30 million a year. In terms of equation (2), these costs represent additions to the human capital stock included in K_t.

4.3 Describing changes to technology

Economic research recognizes the role that R&D spending has on the level of technology.[11] According to the NextGen Precision Health Initiative, its R&D spending will add $30 million a year to the quantity of R&D spending in Missouri. How much will this additional R&D spending affect the level of technology in Missouri? To quantify this, we need to construct a baseline measure of $A\left(RD_t\right)$ that is consistent with economic activity in Missouri. We can solve for the equilibrium level of technology implied by the growth rate of the Missouri economy. Formally,

$$g = \left\{\beta\left[\left(1-\tau\right)A+1-\delta\right]\right\}^{1/\sigma} . \tag{3}$$

Equation (3) says that the equilibrium growth rate $\left(g\right)$ is related to the time rate of preference $\left(\beta\right)$ the after-tax level of technology (where τ is the sum of the average marginal federal income tax rate and the

[11] For the interested reader, an introductory presentation can be found in Jones, Charles I. (2002). *Introduction to Economic Growth, 2nd edition,* New York: W.W. Norton Company. See Section 5.3

average marginal income tax rate), the rate at which capital depreciates (δ) and the constant elasticity of intertemporal substitution (σ). If we know the values of each of these five terms, then we can compute the level of A that is consistent with the economic growth rate in Missouri. The economic growth rate is the average annual rate at which Missouri's real GDP increases between 1997 and 2018. The value of the time rate of preference is taken from the economics literature and is consistent with an average annual real return of four percent. The date on the average marginal income tax rate are obtained from two

Table 2

Parameter Values of State of Missouri

Parameter	Values
Growth Rate (g)	1.01015
Beta (β)	0.96
Average Marginal Tax Rate (τ)	0.25742
Delta (δ)	0.1
Sigma (σ)	1.5

sources. The National Bureau of Economic Research maintains a database on the federal average marginal income tax rate. For Missouri, the Economic and Policy Analysis Research Center has constructed an average marginal income tax rate for Missouri filers. The depreciation rate is take from the economic literature as is the constant elasticity of intertemporal substitution. Substituting these parameter values into Equation (3) and solving yields $A = 0.21218$. Thus, this will be our baseline value of the technology parameter for our quantitative analysis.

The most challenging part is quantifying the impact that R&D has on technology. Hall, Mairesse and Hohnen (2009) provide an excellent literature review of the effect that R&D has on technology and output.[12] In general, there is a stock of R&D that corresponds to the body of knowledge accumulated by people. Over time, this stock can depreciate and investments made to accumulate new knowledge. In a more recent paper, Blanco, Gu and Prieger (2016), we find estimates the changes in the stock of R&D on output and separate estimates on the effect of R&D on the technology measure.[13] In Table 2, Blanco, et al. report that a one percentage point increase in the stock of R&D will result in total factor productivity—

[12] See Hall, Bronwyn H., Jacques Mairesse and Pierre Mohnen, (2009). "Measuring the returns to R&D," *NBER Working Paper 15622*, Cambridge, MA: National Bureau of Economic Research.
[13] See Blanco, Luisa R., Ji Gu, and James E. Prieger, (2016). "The Impact of research and development on economic growth and productivity in the U.S. states," *Southern Economic Journal*, 82(3), 914-34.

the A in Equation (2)—will increase by 0.143 percentage points. Moreover, this relationship is statistically significant.

In order to translate the changes in A to a change in Real GDP for the State of Missouri, we must construct a measure of the stock of R&D for Missouri. We follow the perpetual inventory method described throughout the literature. We obtain the stock initial value by following the methods described in Blanco, et al. Specifically, we first obtain the flow measure of business R&D spending as reported by the National Science Foundation. The perpetual inventory needs an initial stock value, which is calculated as the average value of R&D spending for three consecutive years divided by the sum of the average annual growth rate and the depreciation rate. Each successive year is then the sum of undepreciated R&D stock plus the new R&D spending. Formally, the two equations are represented as

$$RD_{2022} = \frac{\sum_{t=1}^{3} X_t}{3} \div (g + d) \tag{4}$$

$$RD_t = RD_{t-1} - (d \times RD_{t-1}) + X_t \tag{5}$$

where X is the flow of R&D expenditures in Missouri in a year, g is the average annual growth rate, and d is the rate of depreciation in the R&D stock. We have consistent measures of the flow of R&D spending by businesses going back to 2003. Here, $g = 14.8$ percent and $d = 5$ percent.

Table 3 reports the value of R&D spending in Missouri and the stock of R&D from 2003 to 2016. The starting value uses the observations for $t = 2003, 2004, 2005$. Using equation (5), the stock is recalculated in each year. For 2016, the relevant year for our NextGen estimates, the stock of business R&D in Missouri is equal to $55.068 billion.

To compute the effect NextGen Precision Health Initiative will have on total factor productivity, we need to follow the following steps. First, compute the percentage change in the stock of R&D. Second, compute the percentage change in total factor productivity, A. Third, compute the new level of total factor productivity. Formally, the first step is the change in R&D spending divided by the stock of R&D. Over time, we assume the stock of (undepreciated) R&D increases at the average annual growth rate, computed as 15.8 percent. Even though the R&D stock is from 2016, we use the initial value of the stock at its 2016 level. Thus, $RD_{2022} = \$55.068$ billion.

Table 3

Stock of R&D in Missouri

Year	*Business R&D flow (in millions of $)*	*Business R&D Stock (in mil of $*
2003	1,742	
2004	2,151	**Starting Value:**
2005	2,602	10922.32
2006	2,675	13051.21
2007	2,736	15134.64
2008	2,875	17252.91
2009	3,136	19526.27
2010	8,106	26655.95
2011	7,544	32867.16
2012	6,982	38205.80
2013	7,174	43469.51
2014	6,720	48016.03
2015	6,078	51693.23
2016	5,958	55066.57

Source: authors' calculations

The flow of additional R&D associated with NextGen is \$38 million to R&D per year. Thus, we can write

$$\%\Delta RD_{2020} = \frac{38}{RD_{2020}} = \frac{38}{55,068} \ . \tag{6}$$

NextGen is expected to increase the R&D stock by 0.06% per year for the life of the project. If we assume that the R&D expenditure will last for ten years, then

$$\%\Delta RD_t = \frac{38}{RD_{t-1} * (1.158)} \quad t = 2022, 2023, \ldots 2027 \ . \tag{7}$$

That is, the percentage change of R&D at date t is equivalent to the contribution made by NextGen in date t-1, divided by the R&D stock in date t-1, adjusted by the growth rate of R&D. We will project values of treatment real GDP for dates through 2045. For dates t=2029, 2032, …, 2045, we set $\%\Delta RD = 0$.

The second step involves taking estimates of the elasticity of total factor productivity with respect to the stock of R&D. Blanco, et al. report the weighted average across states is 0.1453. Thus, we take the sequence of projected percentage changes in the stock of R&D for dates *t = 2022, 2023, …, 2045*, and multiply each by 0.1453 to obtain the sequence of the percentage change in *A* for each of those dates. Formally,

$$\%\Delta A_t = \left(0.1453 * \%\Delta RD_t\right), \quad t = 2022, 2023, ..., 2045 \ . \tag{8}$$

Equation (8) tells us the impact that the additional R&D spending has on the percentage change of total factor productivity.

Lastly, we compute the sequence of total factor productivity under the NextGen treatment. The law of motion for total factor productivity is the previous period's level plus the product of the percentage change in total factor productivity and the previous level. The percent change in total factor productivity is found from equation (8). In equation form,

$$A_t = A_{t-1}\left(1 + \%\Delta A_t\right), \quad t = 2022, 2023, ..., 2045 \ . \tag{9}$$

To summarize, we use the treatment to R&D spending associated with NextGen in Equation (7) to compute the percentage change in R&D stock for each year. Next, plug the value from Equation (7) into Equation (8) to compute the percentage change in total factor productivity that occurs because of the treatment. Then, we use the treatment value of the percentage change in total factor productivity from Equation (8) and plug that into Equation (9) to compute the treatment level of Missouri's total factor productivity. From here, the treatment effect of R&D on Missouri's real GDP is to apply the Ak model. Recall Equation (2), which says that $GDP_t = A\left(RD_t\right)K_t$. We apply the treatment values of A_t computed from Equation (9) and the capital stock K to generate predicted state level output with the NextGen initiative. We report the results of the projections and the calculations of the economic impacts in the next section.

5. Treatment Projections and Economic Impacts

There are numerous channels outside the direct quantifiable impacts estimated below through which something like the NextGen Precision Health Initiative could affect aggregate economic outcomes. While we are explicitly calculating changes in physical capital, human capital and technological changes affecting total factor productivity, it is worthwhile considering the non-pecuniary impacts of this project on the economy. Because NextGen is designed to conduct R&D that will lead to improved healthcare treatments, it is natural to ask the impact of improved health on the economy. In one way, we can interpret the results of the projections as taking improved health into account. More specifically, new and better treatments developed at NextGen can lead to less severe (or even non-existent) symptoms for major medical conditions. Insofar as better health leads to fewer sick days and more productive workers, we can interpret the economic projections as encoding better health through the increase in total factor productivity. Hence, the R&D-induced treatments uncovered through NextGen is projected to have benefits from improved health on economic outcomes.

If able, we would prefer to directly assess the quantity of R&D spending in terms of its impact on fewer patient sick days. Research has not offered much insight into these R&D-to-health outcomes results. For example, a preferred approach would be to use data to measure the marginal (additional) effect that a change in a specific R&D type of spending has on patient health. This measurement of "improved health" can then be used to calculate the decrease in sick days and increase in productive effort of the labor force. Without such careful estimates existing in the literature, however, we would need to try to construct them ourselves. Such original work is outside the scope of this report.

While equally large, the individual welfare impact of improved health is difficult to quantify. How does one measure the relationship between better health and a happier life? In economics, we would attempt to measure the welfare gain associated with such new treatments. To illustrate, a researcher would specify an economic model in which a particular distribution of health outcomes would characterize the current state of the world. Then, the projected distribution of health outcomes would be determined by treatments expected to be produced through the R&D conducted by the NextGen Precision Health Initiative. With the current distribution of health outcomes and the projected "treatment" distribution of health outcomes, an economist would ask what a representative person would be willing to pay to achieve the expected welfare conditioned on the treatment distribution. This compensation is a dollar measure of the expected welfare gain that comes with the new treatments. The challenge with constructing such a gain in expected welfare is chiefly the characterization of the state that is the distribution of health outcomes. Without such a literature existing, the welfare calculation is outside the scope of this report.

To evaluate the economic impact of NextGen on the output in the State of Missouri, we begin by dividing the impact of NextGen into a set of separate treatments. The building, the additional human capital, and the R&D expenditure is considered separately since each has a different impact on the productive possibilities for the State of Missouri. For example, the first "marginal" treatment is the impact that an additional $220.8 million building will have on the Missouri economy. We begin with a very conservative estimate, assuming that the financing for the new building comes from resources saved by people living in Missouri. In this case, the building is not representing new resources acquired by Missouri, but rather a redirection of resources the state already has. This dampens the potential impact of the building – when the funding comes from abroad, the economic impact is greater than when the funding comes from within.[14] The experiment amounts to people saving these funds and acquiring the building as opposed to consuming these goods.

Turning our attention to the quantifiable impact on the Missouri economy, Table 4 reports the impact measured in terms of the discounted sum of the State of Missouri's real GDP. Formally, the impact is represented by the following equation:

$$\sum_{t=2019}^{2045} \beta^{t-2019}\left(GDP_t^T - GDP_t^P\right) \tag{10}$$

where $\beta = 1/1.04$ is the discount factor using the average annual gross real return on securities equal to 4 percent, GDP_t^T is the treatment path for the State of Missouri's real GDP, and GDP_t^P is the projected (untreated) path for the State of Missouri's real GDP. Equation (10) is the measure, therefore, of the impact that the treatment has on Missouri's economy over the next twenty-five years.[15]

Table 4 reports the impact of three different experiments. First, we consider a very conservative estimate of the impact that the building will have on the Missouri economy. Conservative because the $220.8 million for the project is assumed to be taken from the existing set of resources produced in Missouri. In other words, we assume the building is funded by diverting Missouri's real GDP from consumption goods into new physical capital. Since the funding is redirected from Missouri's real GDP, it would be double counting to add the $220.8 million to the economic impact. The row labelled "Building" shows that between 2022 and 2045, the discounted sum of additional real GDP will be $714.6 million greater because of the NextGen Precision Health Initiative facility. That is, spending on this building will increase Real GDP in Missouri by 2.4 times the original investment. The key assumption is that the return to the additional capital is equal to the average return to physical and human capital over the past several decades.

Next, we consider the impact of adding human capital associated with the NextGen Precision Health Initiative. We conservatively assume that an additional $30 million is added to the amount of

[14] If funding comes from other sources, we consider the initial value of the building when evaluating the impact to treatment. When funding comes from within Missouri, the initial value of the building is simply a redirection of already existing resources away from consumption and to capital. Counting both the value of the building and viewing the resources as being redirected from other sources leads to double counting.

[15] The NextGet Precision Health Initiative begins in 2022 with the expected opening of the building. Everything is converted back to the time that this report is being written.

human capital producing in the State of Missouri. We are being conservative in this estimate since we assume that the human capital investment is only guaranteed through 2027.[16]

Table 4

Marginal Economic Impacts of the Treatments

Associated with Next Precisions Health Initiative

Treatment	Immediate Effect on Economy	Discounted Sum 2019-2045
Building	$\Delta K = \$220.8$ million	\$714.6 million
Human capital	$\Delta K = \$30$ million	\$535.5 million
R&D	$\Delta A = 0.0002$	\$2,277.8 million

Source: authors' calculations

Obviously, this project can take a much longer term and contribute even more to the GDP of the state. Beginning in 2028, the human capital treatment stops. Thus, the total amount of additional human capital is \$150 million over this five-year period. The row labelled "Human capital" shows that the discounted sum of additional real GDP in the State of Missouri between 2019 and 2045 is \$535.5 million owing to the human capital investment. Here, the key assumption is that the additional human capital investment is just as productive as the average productivity of Missouri's human capital over the past several decades.

In the final row of Table 4, we report the impact that a change in R&D spending has on the State of Missouri economy. With an increase in R&D spending, we are isolating the impact on total factor productivity and consequently on economic growth. Our calculations project that the State of Missouri economy would grow slightly less than one basis point faster with the implementation of the NextGen Precision Health Initiative. Because of the compounding effect, the discounted sum of additional real GDP is \$2.277 billion in the State of Missouri between 2022 and 2045.

Using the estimates above, we can now discuss the total economic impact of NextGen on the state of Missouri. Changes in physical capital, human capital, and the productivity term affect the productive capacity of the economy differently. Because the impact is the product of changes in physical and human capital and the total factor productivity term, we cannot simply sum across the marginal impacts reported in Table 4. With all three economic effects associated with the NextGen Precision Health Initiative

[16] The assumption regarding the life of the NextGen initiative is an attempt to deal with the uncertainty of future funding. The building, in contrast, has an expected productive life of 25 years, reflecting the ability to move other productive, higher-education activities into it.

accounted for, we project that the discounted sum of additional real GDP is $5,924.3 million for the State of Missouri between 2022 and 2045.

The baseline and treatment projections are plotted in Figure 7. The red line is the projected path of the economy with the NextGen "Treatment"; the blue line is the projected path of the economy without NextGen, that is, the "Baseline." With the lines so close together, the implication is that the projected impact in any given year is fairly small. Indeed, the projected (undiscounted) difference between baseline real GDP and treatment real GDP in 2022 is $87.3 million out of an economy with economic activity of more than $300 *billion*. However, this does not mean that NextGen is quantitatively insignificant. Because of the R&D capacity of NextGen, the economy will enjoy substantial compounding of the research carried out in the facility. Slightly faster economic growth and capital investments will result in a sizeable dollar increase in economic activity. By 2045, the additional economic growth combined with investments in physical and human capital yields an additional $801.8 million out of a $370 billion Missouri economy in that year. In summary, investments are significant contributing factors to economic outcomes. Perhaps most importantly, our results demonstrate that small increases in an economy's growth rate can translate into quantitatively large gains for the economy over the period of a single generation. Thus, implementing the NextGen Precision Health Initiative provides the kind of economic stimulus that is valuable to the State of Missouri economy.

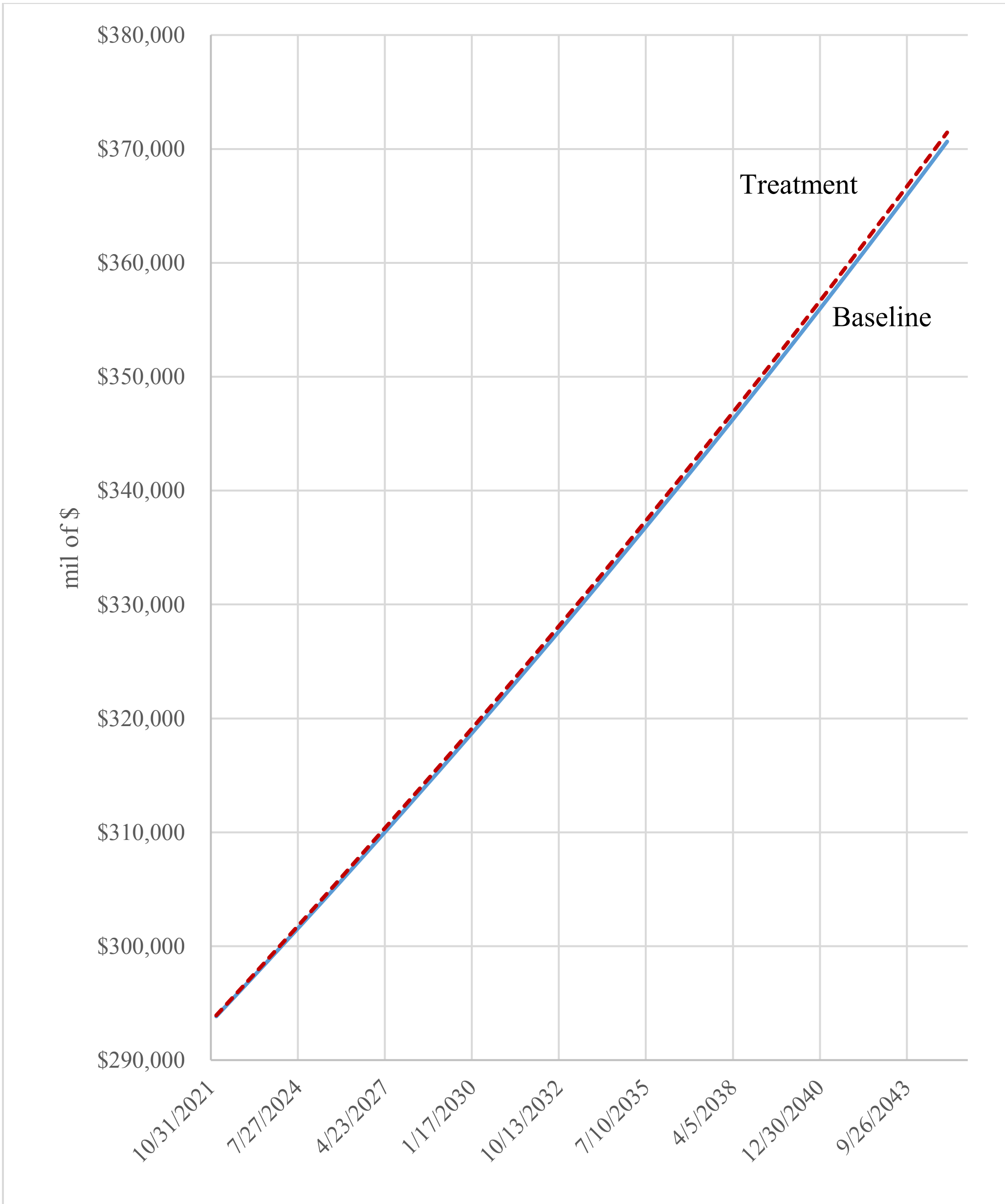
Overall, the gross investment of nearly $400 million in human and physical capital—that is, new investment and replacement for equipment depreciation—combined with the expected effects that R&D have on total factor productivity will have quantitatively large quantitative impacts on the State of Missouri economy. Our projections indicate the impact over the next 25 years is more than $5.6 billion. Of course, the gains in real GDP mean the State of Missouri economy is larger and also mean that the state's tax base expands. In the next section, we project the impact on State of Missouri tax revenues.

Often, people want to convey how many additional jobs are associated with the projected increase in real GDP. That is, how many additional workers could the increase to GDP "hire". To get at this, we use the Bureau of Labor Statistics reports on total compensation. In the fourth quarter of 2018, U.S. workers were compensated, on average, $36.32 per hour. We multiply that value by 40 hours per week and 50 weeks per year to obtain the average annual compensation per worker. We can compute the projected number of additional employees that could be compensated from the projected increase in Missouri's real GDP. Figure 8 plots the projected number of additional workers in Missouri for each year between 2022 and 2045. Over time, we assume that compensation increases at the same average annual

Figure 7

Project paths for Baseline and

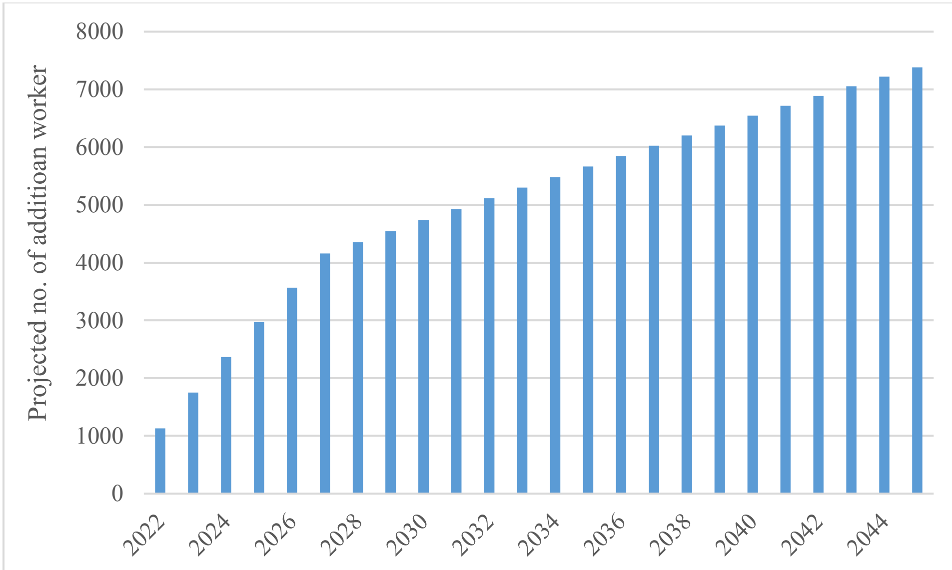
NextGen-Treated Missouri Economies



Source: authors' calculations

Figure 8

Projected Number of Additional Missouri Workers, 2022-2045



Source: authors' calculations

rate as real GDP. In the first year of the NextGen initiative, the projected number of additional workers is just above 1,000. By 2045, the projection indicates that nearly 7,000 additional workers could be paid for by the additional real GDP generated by NextGen Precision Health Initiative.

6. Projected revenue impacts for State of Missouri

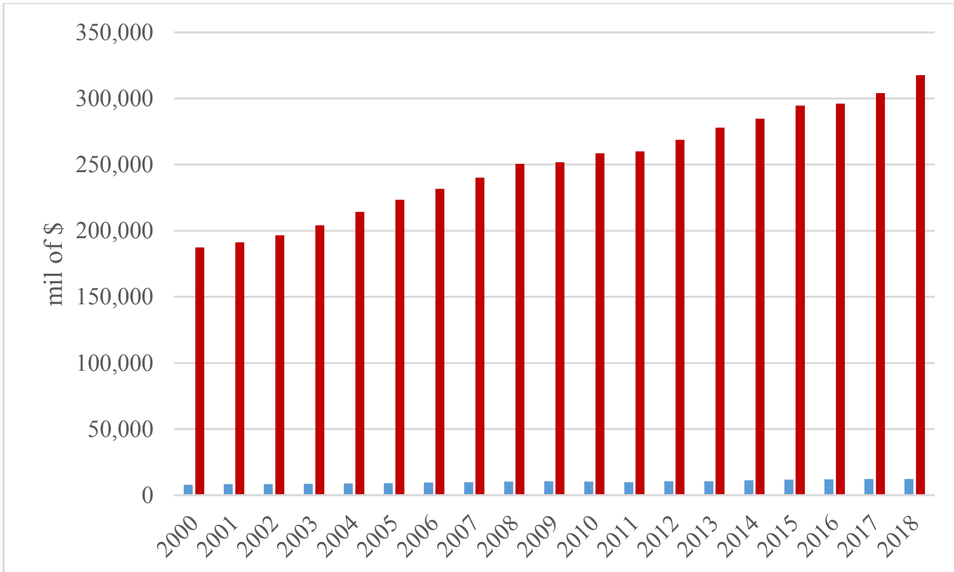
Here, we narrow our focus, projecting how the expanded tax base will affect the general revenues collected by the State of Missouri. Our goal is to represent the increase in economic productivity as a quantifiable increase in the revenue collection for the state of Missouri. That is, since NextGen increases nominal GDP, the State of Missouri can expect to see an increase in the general revenue collections. For revenues, we use the calendar-year series for Missouri's Total General Fund (hereafter General Revenue Funds).[17] In addition, we use nominal GDP for the State of Missouri reported by the Bureau of Economic Analysis. Using data from 2000 through 2018, the State of Missouri collects taxes and fees into its General Revenue Fund equal to 4.04 percent of nominal GDP, on average, per calendar year. In Figure 9, we plot the calendar-year collections into Missouri's Total General Fund and Missouri's nominal GDP for the years 2000 through 2018. The short blue bars are the total general fund collections in a calendar

[17] See https://eparc.missouri.edu/publications/hist_tax/sec02/orp11_2018.pdf for the reported series.

Figure 9

State of Missouri: Total General

Fund Collections Nominal GDP, 2000-2018



Source: Economic and Policy Analysis Research Center, Bureau of Economic Analysis

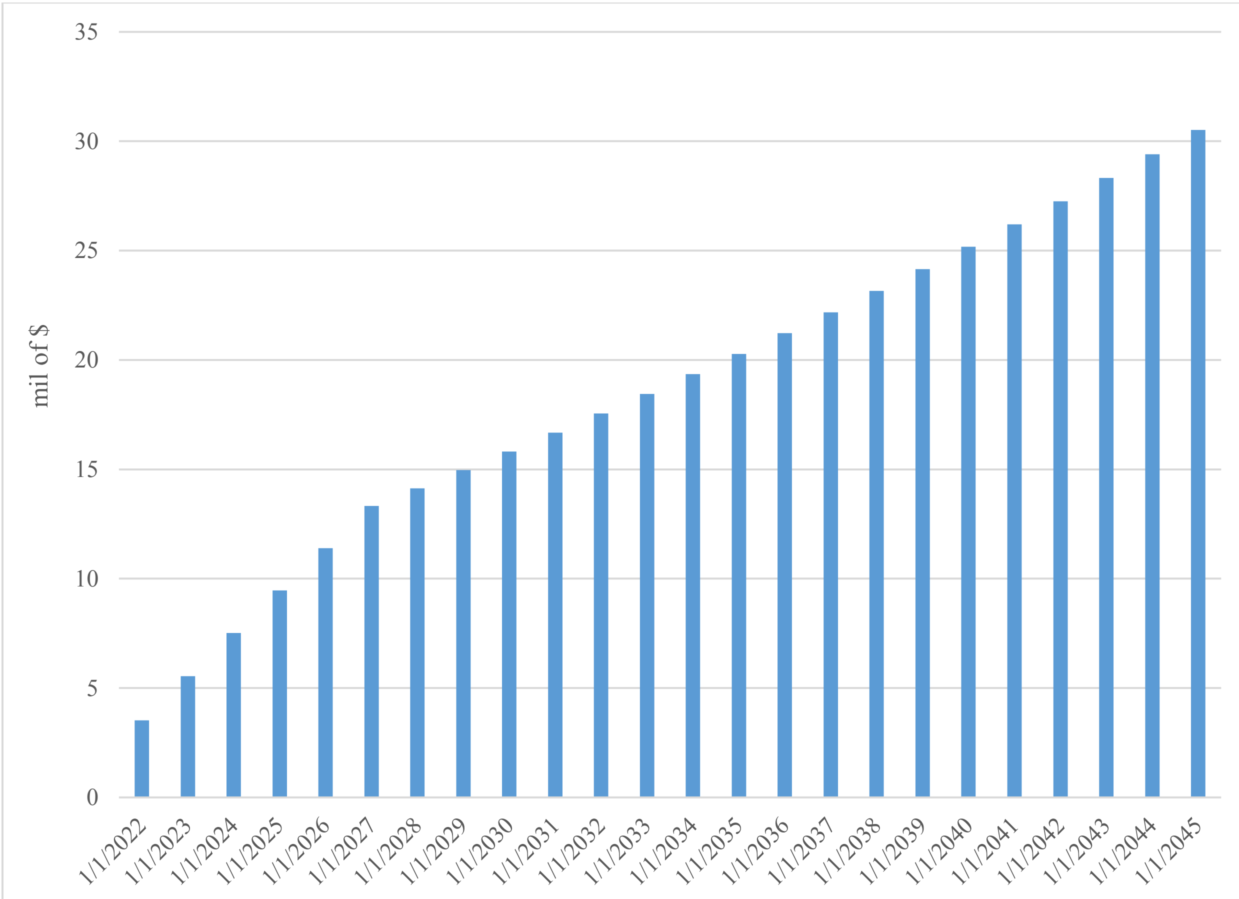
year and the red bars are nominal GDP in a year. Total General Revenue Fund collections by the State of Missouri is small relative to the States nominal value of goods and services.

Based on the data from General Revenue Funds collections and nominal GDP, we project the State of Missouri's additional revenues owing to the implementation of the NextGen Precision Health Initiative. We assume the State of Missouri collects 4.04 cents per dollar of GDP. Figure 10 plots the additional General Fund Revenues collected by the State of Missouri for the years 2022 through 2045. In 2022, for example, the projected increase in General Revenue Funds is $3.5 million. By 2045, the State of Missouri is projected to collect an additional (undiscounted) $30.5 million in its General Revenue. Overall, the State of Missouri is projected to collect the discounted sum of $227.8 million if the NextGen Precision Health Initiative is implemented.

Figure 10

Projected Annual Increases to General

Fund Collections by State of Missouri, 2022-2045



Source: authors' calculations

The economic impact of the NextGen Precision Health Initiative is quantitatively large. With a discounted projected economic impact of over $5.6 billion, and with a discounted projected General Revenue Fund collections equal to $227 million over the next 25 years, there are clear advantages to a program that costs about $400 million over the next five years.

7. Summary and conclusions

The State of Missouri has recorded one of the lowest economic growth rates across the fifty states since 1997. The NextGen Precision Health Initiative is a medical-based research initiative that is projected to have a quantitatively important impact on the Missouri economy. By itself, it will not turn the

State of Missouri into one of the fastest-growing states. However, directed research programs, such as NextGen, potentially generate a cultural change in the economy that could yield even greater benefits. Our findings are centered on the impact of three key quantifiable features of the NextGen initiative.

First, the proposed building is an addition to the stock of physical capital in Missouri that will house productive activities. In this particular case, the building is central to the coordination of research activities across disciplines. In treating diseases, NextGen seeks to use existing faculty and to add new faculty specializing in medicine and other related fields. The building will be structured to foster coordination between medical professionals, engineers, nuclear physicists, computer scientists, veterinarians, and others. In other words, building design is critical to NextGen's mission. Estimates are that the new building will cost $220.8 million.

Second, there is investment in additional human capital. As just mentioned, at least 30 new faculty positions will be added with this new initiative. Just as the building increases productive capacity, so too will additional personnel. It is expected that $30 million a year will be spent on attracting new Principal Investigators and their research teams. Moreover, it is expected that funding will come from external funding sources, such as National Science Foundation, National Institute of Health, and other sponsored-research foundations. The additional funding will contribute to Missouri's economy in meaningful ways over the life of the project.

Third, the expenditures are directed to basic R&D. The impact that R&D expenditures on aggregate economic outcomes contribute the most to Missouri GDP growth. We rely on the economics literature that explains why and documents the relationship between R&D investments, total factor productivity, and ultimately to faster economic growth. Because we look at the economic effects over time, compounding becomes an important factor in characterizing the increase in GDP associated with the NextGen initiative.

Our findings can be summarized as follows. We project that the NextGen Precision Health Initiative will add an additional $5,637.7 million to the State of Missouri's real GDP over the next 25 years. Based on projected compensation for a worker, the additional real GDP would pay for an additional 1,000 workers in 2022. Because of the increase in the economy's growth rate, we project that gains in Missouri's real GDP could pay for an additional 7,000 workers in 2045. With the expanded economy, we project that the State of Missouri's General Revenue Fund collections will increase by more than $227 million over the next generation. The bottom line is that the NextGen Precision Health Initiative is quantitatively important for the State of Missouri in terms of adding to the value of products produced within the state, in terms of additional employment and in terms increasing general fund revenues.

Perhaps one of the exciting factors that is left out of our analysis is a "what-if" scenario. In particular, our analyses are constructed on the basis that the NextGen Precision Health Initiative generates an average return to R&D. In our view, this is the appropriate assumption. However, we can wonder "what if the returns are better than average?" In such cases, there are potentially huge spillovers that accompany significant basic research findings. For one thing, agglomeration effects can arise; agglomeration effects can be described as the generation of researchers and marketable ideas congregating in a geographic area *because* of expertise developed in that area. More concretely, if researchers participating in the NextGen initiative discover important enough findings and the body of researchers is large enough, others will locate near these researchers to develop additional ideas, put the new findings into a function business model, and exchange ideas that lead to even more findings. Well known examples of such spillovers are Silicon Valley and other evidence presented by Carlino, Carr, Hunt and Smith (2011).[18] Based on the evidence from Indiana's Precision Health Initiative, we believe that agglomeration is likely should NextGen produce significant findings. Projects like the NextGen Precision Health Initiative put into place research institutes that potentially lead to these kinds of economic spillovers. We are not forecasting that the Missouri economy will look like our projected values. But the relative amounts are a careful quantitative assessment of the impact that the NextGen Precision Health Initiative has on the Missouri economy, holding everything else constant. Our analyses is built on evidence and observation that support a long-held maxim that success breeds success.

[18] See, for example, Carlino, Gerald A., Jake K. Carr, Robert M. Hunt, and Tony E. Smith, 2011. "The agglomeration of R&D labs," Working Papers 11-42, Federal Reserve Bank of Philadelphia. IN addition, there are case studies presented in Porter, Michael E., 1996. "Competitive Advantage, Agglomeration Economies, and Regional Policy," *International Regional Science Review*, 19, 85-94.

Appendix: The economics of spillovers

In economics, the term spillover is comfortable language that covers a highly technical feature present in economic growth. In this appendix, we provide a definition and several examples that characterize a spillover effect. So the reader will know a spillover effect when he or she sees it (or, at least, be able to make an argument for or against the claim that a spillover effect has been observed).

A spillover effect corresponds to a case in which economic activity is increasing at an increasing rate. These events are rare enough need to be distinguished from the phenomenon of rapid economic growth that occurs when poor countries begin to catch up to countries in which living standards are high. A spillover occurs when the return to locating near an existing operation is greater than locating at some random location. The activities of the original company spillovers to other companies. You will note that the notion of spillover is associated with a spatial feature, which explains why the term agglomeration or clustering is also used as to characterize the consequence of an economic spillover. In other words, agglomeration and clustering are the results when spillovers are operating.

While agglomeration and clustering are within your vocabulary, it is worth it take a minute and use these terms in an economic context. We start with an illustration. Have you ever wondered how Detroit became the center of American auto manufacturing? What reason would car makers have to locate in this particular region of the United States? The story usually builds on low-transportation costs from the iron mines in Minnesota, and includes a references to the assembly line solutions that made automobiles affordable. It was just a spillover enjoyed by car makers that located in and around Detroit; technical expertise was available and assembly line workers with experience could be enticed to join new firms without relocating in the early 1900s. Hence, we observe automobile manufacturing clustering in Southeast Michigan.

In the following section, we present findings from a series of case studies. In each study, the authors will present evidence consistent with agglomeration effects. In doing so, we provide the reader with concrete examples that the spillovers are documented.

A.1 Case Studies Discussing Agglomeration Effects

International Evidence

- "University spillovers and new business location in high-technology sectors: Spanish evidence"[19]

[19] See Acosta, M., Coronado, D., & Flores, E. (2011). University spillovers and new business location in high-technology sectors: Spanish evidence. *Small Business Economics, 36(3), 365-376.*

- The authors examine the relationship between knowledge spillovers from 63 Universities and 604 new business locations for high-tech industries by geographical area

- Key findings of the project:

  "*Knowledge produced in universities diffuses to nearby firms through a variety of mechanisms involving tacit and codified channels, generating positive externalities (spillovers) that can potentially be of use for external agents who do not pay a price for it… We consider university spillovers produced by three main university outputs: knowledge-based graduates, who provide a specialized labor force to firms; research activities, which may be used by companies to create or improve inventions and innovations; and technological knowledge, which can potentially be transferred to firms… We find that university spillovers are relevant in explaining the location of new businesses in high-technology sectors in Spain. Further, our analysis draws attention to the relevance of graduates as the main source of spillovers, while research activities and university technology do not have significant effects*"

- The authors also include a review of related literature (see pg 368 of the article). A summary of the most notable projects is below:

Project – location	Important Finding
Harhoff (1999) – Germany	Regional knowledge infrastructures (universities and research laboratories) is positively correlated with formation of technology-oriented firms.
Audretsch (2004) – Germany	High technology firms have a high propensity to locate close to universities. Location matters more in natural sciences than in other fields.
Ambramovsky (2007) – UK	Co-location of business R&D to relevant university research departments, particularly in pharmaceutical, chemical, machinery, and communications equipment sectors.

Evidence from the United States

- "Clusters and Innovation Districts: Lessons from the United States Experience"[20]
  - The authors detail evidence of co-location between firms and relevant universities from 7 knowledge centers, including UT Austin and Research Park Triangle.

  - Key findings of the project:

    "*Clusters and innovation districts are key sources of productivity growth in an economy. Productivity, the most important determinant of the growth in living standards in the long run, has experienced a significant slowdown globally in recent years. Clusters and districts have the potential to combat this slowdown. They are loci of innovation rapid economic growth and can lead to increased collaboration between firms and universities.*"

  - By comparing 7 successful and several failed efforts, the authors isolate eight key factors that underlie the success of a project. The authors comment that not all factors are present in every project, but caution that "*enough must be present to allow the positive dynamics of a successful cluster to develop.*"
    1. **Core Competency.** "*There must be an economic rationale for the clusters—[a skill] that [the cluster] is good at so that it can develop competitive strength*"

    2. **People.** "*There are three elements to the people requirements for a successful cluster – strong leadership, highly qualified researchers, and a skilled workforce*"

    3. **Culture.** "*There are two elements to the culture needed to develop a cluster. First a business and research culture that supports the sharing of ideas. And second, a lifestyle that attracts talented people to the cluster.*"

    4. **Business Capabilities.** "*Successful start-up tech companies in a cluster must not only have good, innovative ideas, they must also acquire the business skills needed to develop the companies.*"

    5. **Sophisticated Demand.** "*Innovative products and services must find a market. Ideally this market should come from within the cluster (a hospital center that provides demand for medical and biotech products, for example). Otherwise, the companies in the cluster must find a way to access such a market nationally or globally.*"

    6. **Access to Funding.** "*Start-up companies require financial support. Funding is also needed for the infrastructure of the clusters, offices, labs, and so on.*"

    7. **Infrastructure Provision.** "*Physical assets and public amenities such as airports, highways, housing, and building stock are the foundation of a cluster.*

[20] Baily, M. N., & Montalbano, N. (2018). Clusters and innovation districts: Lessons from the United States experience. *Economic Studies at Brookings Institutions*.

Zoning rules must allow or encourage the development of start-up companies and labs."

8. **Regulatory Environment.** "*Cumbersome permitting processes can slow or stop the development of a cluster.*"

- Two notable case studies are discussed in this project:
    1. Austin, TX (UT Austin):

       "*The Austin cluster emerged from a base of technical know-how in electronics as the result of deliberate efforts by the University of Texas and the state and local governments, funding from the federal government, a definitive culture, a business friendly regulatory environment, and help from the presence of established tech companies dating from the 1960s."*

    2. Research Triangle Park:

       "*The Research Triangle Park's success was due in large part to many of the same factors that led to success in Pittsburgh: world-class research universities, high levels of federal and state funding, positions in fast-growing sectors, forward-thinking and strong leadership, low costs of living, and a high quality of life."*

- Building an innovation hub: A case study of the transformation of university roles in regional technological and economic development[21]
    - The authors examine the role of Georgia Tech in creating a "knowledge hub" around the university

    - Key finding:

      "*We note that university R&D, startups, and other knowledge-transfer programs are important, but by themselves may not be enough to turn around an innovation system. The importance of complementary assets (Teece,1986)[22] such as the need for venture capital and a good educational system suggest that there are limits to a university-based strategy."*

- University Research and Local Economic Development[23]
    - The author examines factors relating to agglomeration of firms and start-ups around universities with significant research programs in an attempt to quantify the success of ASU's P^3 program. Specifically, the author writes

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[21] Youtie, J., & Shapira, P. (2008). Building an innovation hub: A case study of the transformation of university roles in regional technological and economic development. *Research policy,* 37(8), 1188-1204.
[22] Teece, D., 1986. Profiting from technological innovation: implications for integration, collaboration, licensing, and public policy. *Research Policy* 15, 285–305.
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"*Evidence of local economic impacts from university research comes from a variety of sources: case studies of local industries born from the ideas of university scientists, university records of income earned and new businesses formed from university research findings, and econometric evidence identifying a statistical association between the level of economic activity in an area and the presence of a research university. The evidence shows conclusively that university research programs have local economic impacts. But these impacts are highly skewed across universities and, on average, are modest in size."*

- Page 27 includes a specific discussion of agglomeration effects. The author finds that agglomeration is important for the production of knowledge for three reasons:
  1. "*Spatial concentration of research activity promotes the development of markets for specialized suppliers*."

  2. "*Agglomeration facilities that matching of jobs and workers in specialized labor markets for scientists and engineers*." Firms often hire graduates of the university in these specialized markets.

  3. "*Concentration of workers promotes informal channels of knowledge transfer*"