Urban First: USDA Research Impacts on Regional Total Factor Productivity

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Introduction

Government funds research in the interest of the public good. Voters and policy makers may tend to focus on the immediate problems to be solved by the research, and this may be appropriate, but the research may also have unintended positive (and negative) outcomes that affect places and sectors to which the research is not directed. It is important to understand the magnitude, direction, and location of the impacts of research in formulating policies around national investments. Innovation does not take place in a vacuum; there are institutional and regional contexts for the work and the structures in place to foster technical progress that may need to be updated or changed based on objective assessment.

The impact of a technical change cannot be expected to be pan-territorial, and may even vary in sign, so policies may need to be adjusted to take into account conditions in lagging regions. At the same time, an understanding and documentation of the beneficiaries of policies can be helpful in obtaining necessary support for a policy. For example, the literature indicates current innovation systems have been inadequate in facilitating the necessary changes to improve rural firm innovation rates (Artz, Kim, and Orazem 2016; Goetz, et al. 2010; Knickel et al., 2009; Renski and Wallace, 2012; Stephens and Partridge 2011). Exogenous innovations are of great importance for regional-level economic growth and performance, and are especially relevant to small and medium sized firms (Audretsch and Keilbacha, 2008; Howells, 2005). This last point is relevant for rural area as the vast majority of rural firms are small and medium sized firms (Brown, Lambert, and Florax, 2013; Low, 2014). Therefore, regional innovation systems need to evolve in such a way that is relevant for rural regions (Goetz, et al. 2010; Kenney and Mowery, 2014; Knickel et al., 2009; Renski and Wallace, 2012). At the same time our understanding of the impacts of investments may be imperfect.

In this article, we develop a better understanding of the location, magnitude and timing of the impacts of research investments by USDA and non-USDA agencies. Since the USDA is highly focused on agricultural and other rural activities, we assess its research expenditure impacts on both rural and urban total factor productivity (TFP) of the United States. Using an econometric approach, we empirically determine the timing and magnitude of effects through a lag structure controlling for non-USDA research funding. We find that USDA research expenditures impact both rural and urban areas, but in urban areas, there are mixed short run effects as well as positive long run effects similar to those present in rural areas. We also find that the non-USDA research has no effect on rural TFP. We use our model to project and map estimates of the positive benefits to personal income in both urban and rural areas by state, and show some state-level variation in benefits in both rural and urban areas. We conclude that policymakers may be underestimating the positive benefits to urban personal income when allocating funding to the USDA. While not the main objective of the research, the model results also imply that marginal changes in labor would contribute relatively more to personal income in urban areas while marginal changes in capital would contribute relatively more in rural areas.

Background

The USDA has many branches and a wide mandate. One of its functions is to improve the performance of the agricultural sector through research investments aimed at increasing the performance of farms through yield improvement or mechanization. Many of these resulting innovations have provided important cost savings benefits to producers operating in Rural America (Barkley, 1995; Dimitri, Effland, and Conklin, 2005; Mowery, Nelson and Martin, 2010). Some USDA research expenditure takes place via investments in its own labs, but it also partners with research universities and the private sector, funding some of their work. Past scholars assessed USDA research expenditures by focusing on agriculture production efficiency measured as TFP, where TFP is often used as a measure of the “technological change” on the economy over time (Alston, et al., 2010; Alston et al., 2011; Anderson and Song, 2013; Antle and Capalbo, 2010; Fuglie and Heisey 2007; Hulten, 2001; Mowery, Nelson and Martin, 2010). Fuglie and Heisey (2007) summarized studies conducted from 1958 to 2006, which use different methodologies to identify annual and life-time returns on investment (ROI) from agriculture R&D expenditures. Estimates range from roughly 20% to 60%. More recently, Alston et al. (2011) provided a conservative estimate of about 9.9%, arguing that the full impact from agriculture-related R&D takes longer than previous studies have allowed, about 17-24 years.

Since the mid-twentieth century, innovations in agriculture—drivers of TPF growth—have allowed producers to generate more food with fewer resources. The USDA’s research expenditures have been credited with significant improvements to the TFP, and thus, provide benefits to producers operating in Rural America (Alston, et al., 2010; Alston, et al., 2011; Fuglie and Heisey, 2007; Mowery, Nelson and Martin, 2010). One impact of the TFP, which is evident from the USDA data product, “Agricultural Productivity in the US” (2016), is the substantial growth in agriculture-related output over the past 60 years while inputs have declined or remained steady.[1] For agriculture production in the US, this has been the primary impact from innovation investment and development.

During this same period, however, the efficiency gains meant that contribution of the agriculture sector to US GDP was reduced to about one-third of what it was (BEA, 2016). These

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[1] It is also important to point out that there has been some debate regarding the accuracy of the USDA TFP estimations (for examples regarding potential bias in TFP measures see Alston et al., 2011; Fuglie and Heisey 2007; Gollop and Swinand 1998; and Hulten, 2001).

changes in the agriculture sector have had the greatest impact on the economies of Rural America, and in states with the highest economic dependence on agriculture (BEA, 2016; Dimitri, Effland, and Conklin, 2005). Agriculture's declining contribution to rural economies has translated into higher opportunity costs for young people to remain in rural communities, which has been observed as the so-called brain drain in rural areas (Carr and Kefalas, 2009; White, 2012). In contrast, innovations in many urban settings led to attractive opportunities for new firm formation or firm growth, which also led to major population gains in urban areas (Barkley, 1995; Black and Henderson, 2003; Dimitri, Effland, and Conklin, 2005). Thus, from technical change a quandary has emerged and one result is the growing economic challenges rural areas face (Gotsch 1972; Lichter and Brown 2011; Taylor and Martin, 2001).

In the context of R&D investment policy and impacts on rural areas, one questions to consider is how benefits are distributed between rural and urban areas. For example, USDA R&D expenditures have been primarily directed towards innovations that resulted in dramatic TFP improvements and there are clear benefits to agricultural producers and rural economies (Alston, et al., 2010; Alston, et al., 2011; Fuglie and Heisey, 2007; Mowery, Nelson and Martin, 2010). At the same time, other innovations, many of which may have emerged from other federal agency R&D expenditures (such as DOD, DOE, NIH, or NSF) have clearly benefited urban areas (Dooley, 2008; Howells 2005; Kim, Kim, and Yang 2012; Mowery, Nelson and Martin, 2010; Simonen and McCann 2008). On the other hand, what are the impacts of USDA R&D expenditures on urban areas? What about the impacts of other federal agency R&D expenditures on rural areas?

As highlighted above, one indirect effect of USDA R&D on urban areas has been the opportunity to focus on things other than agricultural production, thus, fewer resources (including human capital) are needed. More recently, concerns about food safety and security have fueled new R&D efforts by the USDA (and other agencies) and one can argue that many of these benefits may directly and positively impact urban areas (Carr, 2016; Ehrlich and Harte, 2015; Patel, 2011). However, the impact of non-USDA R&D on rural areas is less clear (Goetz, et al. 2010; Renski and Wallace 2012).

Methods and Data

For the analysis, we use a lagged variables modeling approach via the Bayesian Information Criterion (BIC) to parse out the rural and urban effects of research investments on personal income through time. As mentioned previously, the effect of technological change on personal income is often modeled using the concept of TFP. Consider the following, Cobb-Douglas production function:

$$Y_{itu} = A_u L_{itu}^{\beta_{Lu}} K_{itu}^{\beta_{Ku}} \text{ for } u = 0, 1, \tag{1}$$

where Y_{itu} is real personal income for state i in year t with urban/rural indicator u, L_{itu} is the labor stock, K_{itu} is the real capital stock, and A_u, β_{Lu}, and β_{Ku} are parameters to be estimated. For the econometric model, we reduce this equation to a linear form by applying the natural logarithm and then first-differencing the data. Hence, $y_{itu} = \Delta \ln Y_{itu}$, $l_{itu} = \Delta \ln L_{itu}$, and $k_{itu} = \Delta \ln K_{itu}$. This transforms Eq. (1) into the following:

$$y_{itu} = \alpha_u + \beta_{Lu} l_{itu} + \beta_{Ku} k_{itu} + y_{itu}^{o} \text{ for } u = 0, 1, \tag{2}$$

where $\alpha_u = \ln A_u$ and y_{itu}^{o} is a stochastic error. In practice, the capital stock variable is unknown, and hence we replace k_{itu} with the natural logarithm of the interest income which is approximately proportional to the change in capital. The expression y_{itu}^{o} is commonly referred to as the TFP described in the background section. The data for the model, personal income, labor force, and interest income, can all be downloaded from the Bureau of Economic Analysis at the state-level, and split into metropolitan and nonmetropolitan portions (BEA, 2016). The dollar values were transformed to real terms using the CPI downloaded from the St. Louis Federal Reserve Economic Database.

From Eq. (2), we model the TFP linearly using USDA federal research funding and non-USDA federal research funding:

$$y_{itu}^{o} = \sum_{r=1}^{r_{1\mathrm{u}}} \beta_{1,r,u} z_{i,t-\mathrm{lag}_{1,r,u}}^{*} + \sum_{r=1}^{r_{2u}} \beta_{2,r,u} \mathrm{z}_{i,t-\mathrm{lag}_{2,r,u}} + \epsilon_{itu} \text{ for } u \; = \; 0, 1, \tag{3}$$

for state i in year t with urban/rural indicator u, where:

- $z_{i,t}^{*}$ and $\mathrm{z}_{i,t}$ are respectively the total federal R&D funding not including the USDA funding and the USDA funding,
- $r_{1\mathrm{u}}$ and r_{2u} are the maximum number of lags for non-USDA funding and USDA funding,
- $\mathrm{lag}_{1,r,u}$ and $\mathrm{lag}_{2,r,u}$ are the lag years for non-USDA funding and USDA funding associated with the rth lag,
- $\beta_{1,r,u}$ and $\beta_{2,r,u}$ are coefficients to be estimated, and
- ϵ_{itu} is a stochastic error.

In this framework, $r_{1\mathrm{u}}$, $r_{2\mathrm{u}}$, $\mathrm{lag}_{1,r,u}$, and $\mathrm{lag}_{2,r,u}$ all have to be estimated. The USDA and non-USDA funding data are available on the NSF WebCASPAR database as federal R&D funding at the state-level. Combining Eq. (2) and Eq. (3) yields the following reduced-form equation used below:

$$y_{itu} = \alpha_u + \beta_{Lu} l_{itu} + \beta_{Ku} k_{itu} + \sum_{r=1}^{r_{1\mathrm{u}}} \beta_{1,r,u} z_{i,t-\mathrm{lag}_{1,r,u}}^{*} + \sum_{r=1}^{r_{2\mathrm{u}}} \beta_{2,r,u} \mathrm{z}_{i,t-\mathrm{lag}_{2,r,u}} + \epsilon_{itu}, \tag{4}$$

for $u \; = \; 0$ or 1. Eq. (4) is used in the econometric models below.

To avoid long run structural problems, we restrict the model to the last 20 years of data (1995-2014). Lagged data is allowed to pull from before 1995 which means that 20 years of personal income data is always used. To identify the correct set of lags for each of the urban and rural models, we used the BIC to test every possible combination of up to four lags in Eq. (4) with 20 potential lag years (in-line with the implications of Alston, et al., 2011) from which to select. The BIC is a penalization of the log likelihood of the model and is used for consistently estimating the best model from a wide selection of potential alternatives, such as in a data mining scenario (Ghosh, Delampady, and Samanta 2007). The BIC for a model can be written as:

$$\text{BIC} = -2 \cdot \ln \mathcal{L} + r_{\text{all}} \cdot \ln(nT) \tag{5}$$

where $\ln \mathcal{L}$ is the log likelihood, r_{all} is the total number of parameters in the model, n is the number of states (50 + D.C.) and T is the number of years (20) in the sample. The maximum likelihood is hence found at the minimum BIC, so we are minimizing the BIC function. This estimator has the benefit of being the optimal Bayes rule under fairly minimal assumptions (Ghosh, Delampady, and Samanta 2007). The lag selection findings are provided in the results section.

Once the optimal lag orders are selected, the model can be estimated using least-squares on Eq. (4). The difficulty occurs when trying to estimate standard errors on these estimated coefficients. Because there is potentially heteroscedasticity (each state is different) and almost certainly serial correlation, as productivity in any year is influenced by prior productivity, we need to use an estimator which corrects for both of these serious issues. A traditional Heteroscedasticity and Autocorrelation Consistent (HAC) estimator, such as the one found in Arellano (1987), requires $n > T^2$. For our model, $n = 50$ and $T^2 = 400$. We could use a bootstrapping procedure, but because computational resources are scarce and bootstrapping the model requires an amalgam of additional assumptions, we chose to use rolling subsamples instead of bootstrapping. Rolling subsamples means that we take slices of the data with $T = 5$ so that $T^2 = 25 < n$. This implies that we can use a HAC estimator similar to Arellano (1987) on these subsample slices of the data to obtain consistent standard errors. The results of these HAC estimations on subsamples can be found in the results.

Once the model has been estimated and tested for statistical significance, we can use the model to make back-of-the-envelope predictions. These predictions ballpark the effect on personal income of adding USDA research expenditures to a specific state. We assume that the urban growth in personal income and rural growth in personal income follow the structural model in Eq. (4) while USDA R&D funding follows an AR(1) process. Using this simple assumption and a fixed federal discount rate, it is possible to form a cost-benefit analysis of adding USDA research funding to any particular state on the present value of that state's urban and rural portions. The results of these predictions can be found below.

Results

In this section, we first explain the results of the model selection process identifying the optimal lag structure and testing for significance of the chosen lags. Then, we provide the results for the personal income predicted shocks from increasing USDA funding.

Table 1 shows the results of the lag selection process. In each row, a possible combination of lags is shown. In the columns, for both the metropolitan TFP model and the nonmetropolitan TFP model, the lags selected using the minimum BIC are shown along with the minimizing value of the BIC. The minimum BIC in each column has been differenced to 0 for readability. Table 1 shows that the optimal values for urban TFP are lags at years 4 and 6 for Non-USDA funding and lags at years 0, 1, 5, and 7 for USDA funding. Table 1 also shows that the optimal values for rural TFP indicate no effect from non-USDA funding and only an effect at a 7-year lag for USDA funding.

[Insert Table 1 Approximately Here]

In Table 2, the results of the coefficients on rolling subsamples along with their associated statistical significance are provided. Labor is found to be statistically significant at the 1% level in all cases. Capital is statistically significant at the 1% level in almost every time period for nonmetropolitan personal income, but capital is found to be insignificant for metropolitan personal income at the 5% level before 2003. Non-USDA research funding seems to have no significant impact on metropolitan personal income except possibly at a 6-year lag in the last period sampled (2009-2014), but the estimated coefficient is negative. USDA funding is found in 1/6 of cases to have a significant short-run (0-year lag) cost to urban personal income, but USDA has a statistically significant benefit in 3/6 cases for the 1-year lag, 1/6 cases for the 5-year lag, and 3/6 cases of the 7-year lag. USDA is also found to have a positive impact in 6/6 cases for the rural model at the 7-year lag, and a statistically significant positive impact in 3/6 cases. At the 7-year lag, USDA funding seems to positively affect rural and urban personal income at roughly the same rate, but the costs and benefits in the shorter-run (0- to 5- year lags) only affect urban areas.

[Insert Table 2 Approximately Here]

Figure 1 maps the present value total benefit to personal income of adding $1M of USDA R&D funding to each US state. In Figure 1, we assume a discount rate of 2.5%. Currently, the US T-Bill rate is around 2.1-2.3% on the 30-year T-Bill, so 2.5% is a conservative estimate. Panel A shows a map with the benefit to metropolitan (urban) personal income. Panel B shows the benefit to nonmetropolitan (rural) personal income. These are not net benefit pictures but total benefit since the entities paying the cost are not exclusively urban or rural. Clearly, the benefit to urban personal income is much greater than the benefit to rural areas, partially because urban personal income is much larger than rural personal income.

We found only weak correlations between the personal income shocks in Figure 1 and other related variables which suggests that USDA funding is not being allocated with a systemic bias to certain categories of states. The three states with the highest predicted urban present value personal income gains are New Jersey ($486.0 M), Connecticut ($392.2 M), and Rhode Island ($217.4 M). While these states might seem to have very small rural sectors, other states with large rural sectors (such as Nevada $191.5 M) also show large benefits, so it would be a mistake to generalize from this short list. The three states with the highest predicted rural present value personal income gains are Wyoming ($6.7 M), Ohio ($6.4 M), and Nevada ($5.3 M). Urban personal income shocks were weakly positively correlated with state population (0.15) and 2014 metropolitan personal income levels (0.21) and weakly negatively correlated with 2014 USDA funding levels (-0.23), 2014 nonmetropolitian personal income levels (-0.17), and EPSCoR status (-0.26). Rural personal income shocks were weakly positively correlated with the state's agricultural-to-total GDP ratio (0.19), 2014 nonmetropolitan person income levels (0.30), and EPSCoR status (0.14) and weakly negatively correlated with state population (-0.13) and 2014 metropolitan personal income levels (-0.18). Urban personal income was found to be negatively correlated with agricultural-to-total GDP ratio (-0.37), and rural personal income was found to negatively correlated with 2014 levels of USDA funding (-0.41).

[Insert Figure 1 Approximately Here]

Figure 2 shows the sensitivity of the Figure 1 analysis to the assumed discount rate. Figure 2 displays the percent change between the personal income boost of assuming a 0% discount rate to assuming a 5% discount rate. The percent change for the District of Columbia is not shown and is 260%. The mean percent change is 19.0% with an estimated standard deviation of 4.3% showing that the analysis is not especially sensitive to the assumed discount rate.

[Insert Figure 2 Approximately Here]

Discussion

The goal of this article was to develop a better understanding of the impacts of research investments by USDA and non-USDA agencies based on location, magnitude and timing. To achieve this goal, we employed a lagged variables modeling approach that uses the BIC to help distinguish between the effects on rural and urban areas. Our motivation for this research is as follows. There is evidence that rural and agricultural regions have valuable resources that are immediately needed to help address the global effects of climate change and projected population growth (Dutia, 2014; Lybbert and Sumner, 2012; Mowery, Nelson and Martin, 2010; Weber and Rohracher, 2012). Some argue that delays in action may mean missed opportunities, for example, any research policy changes would not occur immediately but would take time to move from legislation to implementation, and getting the necessary infrastructure in place to take advantage of new policies could take many years (Geels, 2004; Youtie and Shapria, 2008). Further, once new innovations are developed, the time to full scale commercialization leading to broad implementation by end users can also take many years (George and Prabhu, 2003; Mowery, Nelson and Martin, 2010; Youtie and Shapria, 2008). As highlighted in this study, however, it is also important to consider how USDA R&D investments may need to be allocated to achieve greater benefits.

Our finding that urban areas benefit from USDA research expenditures should not be unexpected to persons familiar with the research process. First, consider the immediate multiplier effects of the research. State-of-the-art biophysical research requires sophisticated equipment that is unlikely to be produced in rural areas. Similarly, basic supplies such as printers are likely to be sourced via channels passing through urban areas. Increased scale in researcher supplier firms could benefit other urban industries, thereby increasing productivity. In the middle of the lag structure, findings from research that is oriented toward agriculture, when published, could be applied in industries that are more able to rapidly adopt innovation than agriculture due to more concentrated ownership structure and more in-house research capacity. Further into the lag structure, the benefits of USDA research might come in the form of cheaper food delivered to urban areas.

The results with respect to rural areas should also not be unexpected. As noted in the literature review section, prior research has consistently found substantial lags in productivity-enhancing effects of investments in agriculture. If anything, our approach, unique in the literature, shows that the lag is shorter than that found by other authors. The spatial distribution of rural benefits across states, while significant for policy purposes, is also not entirely unexpected, with higher rural benefits tending to come to states more heavily invested in row crop or animal agriculture.

New potential for economic opportunities and emerging public needs may justify directing additional public research expenditure in rural America. Our findings that urban areas benefit, and benefit relatively quickly, from USDA research funding may help build a national consensus for increased USDA research funding.

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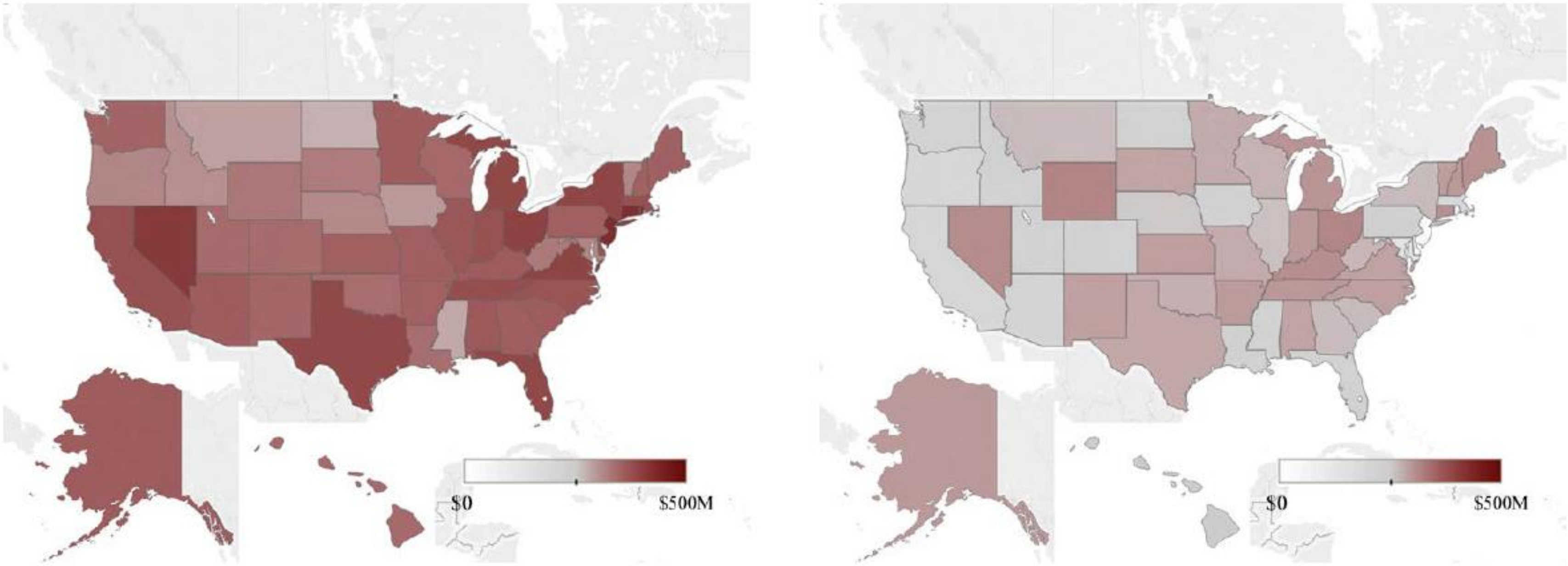
Table 1: Lag Selection using BIC (Minimum Normalized to 0; 1994-2014)

Lags		Urban TFP			Rural TFP		
Non USDA	USDA	BIC	Non USDA	USDA	BIC	Non USDA	USDA
0	0	37.26			2.24		
	1	16.22		7	0		7
	2	9.17		1,7	3.94		7,20
	3	4.27		0,1,7	7.17		7,19,20
	4	3.01		0,1,7,14	11.90		7,14,19,20
1	0	32.94	4		3.85	17	
	1	14.34	4	7	1.91	17	7
	2	8.12	6	1,7	5.65	17	7,18
	3	2.61	6	0,1,7	8.38	17	7,19,20
	4	1.41	6	0,1,5,7	12.97	17	7,14,19,20
2	0	32.37	4,6		8.77	10,17	
	1	12.89	4,6	7	6.76	10,17	7
	2	6.87	4,6	1,7	10.39	10,17	7,18
	3	1.51	4,6	0,1,7	13.15	10,17	7,19,20
	4	0	4,6	0,1,5,7	17.57	10,17	7,14,19,20
3	0	32.05	1,3,5		13.75	9,10,17	
	1	13.05	1,4,6	7	11.79	5,10,17	7
	2	8.42	1,4,6	1,7	15.44	9,10,17	7,18
	3	3.10	1,3,6	0,1,7	18.26	9,10,17	7,19,20
	4	2.15	4,6,17	0,1,5,7	22.81	5,10,17	7,14,19,20
4	0	34.14	1,3,4,6		19.20	9,10,14,17	
	1	14.89	1,3,4,6	7	17.12	5,9,10,17	7
	2	10.61	1,3,4,6	1,7	20.61	9,10,17,18	7,18
	3	5.44	1,3,6,17	0,1,7	23.54	9,10,14,17	7,19,20
	4	4.50	1,3,6,17	0,1,7,14	28.03	9,10,14,17	7,14,19,20

Table 2: Estimated Coefficients and Significance of Rolling Subsamples

Sample		Const.	Labor	Capital	Non USDA R&D		USDA R&D			
					Lag = 4	6	Lag = 0	1	5	7
Urban	1994-1999	0.01	0.79**	0.16	0.00	0.00	0.01	0.02**	0.00	0.03*
Personal	1997-2002	0.00	1.14**	0.21	0.00	0.00	-0.02**	0.01*	-0.01	0.02
Income	2000-2005	0.00	1.13**	0.29	0.00	0.00	0.00	0.00	0.00	0.00
	2003-2008	0.00	0.87**	0.34*	-0.01	0.00	0.00	0.00	0.00	0.02**
	2006-2011	0.02**	1.11**	-0.35*	0.00	-0.01	0.00	0.00	0.01	0.02*
	2009-2014	-0.02	0.82**	0.65**	-0.01	-0.01*	0.02*	0.03**	0.01*	0.02**
Rural	1994-1999	0.00	0.33**	0.44**						0.01
Personal	1997-2002	0.00*	0.54**	0.48**						0.03**
Income	2000-2005	0.00	0.71**	0.33**						0.02
	2003-2008	-0.01	0.54**	0.63**						0.01
	2006-2011	0.01*	0.82**	0.22*						0.02*
	2009-2014	0.00	0.92**	0.27**						0.01**

*-denotes significance at the 5% level; **-denotes significance at the 1% level



Panel A: Urban Total Benefit

Panel B: Rural Total Benefit

Figure 1. Predicted Total Benefit to Urban and Rural Personal Income from $1M Fixed Cost Investment in USDA R&D Funding on the Margin assuming a 2.5% Interest Rate

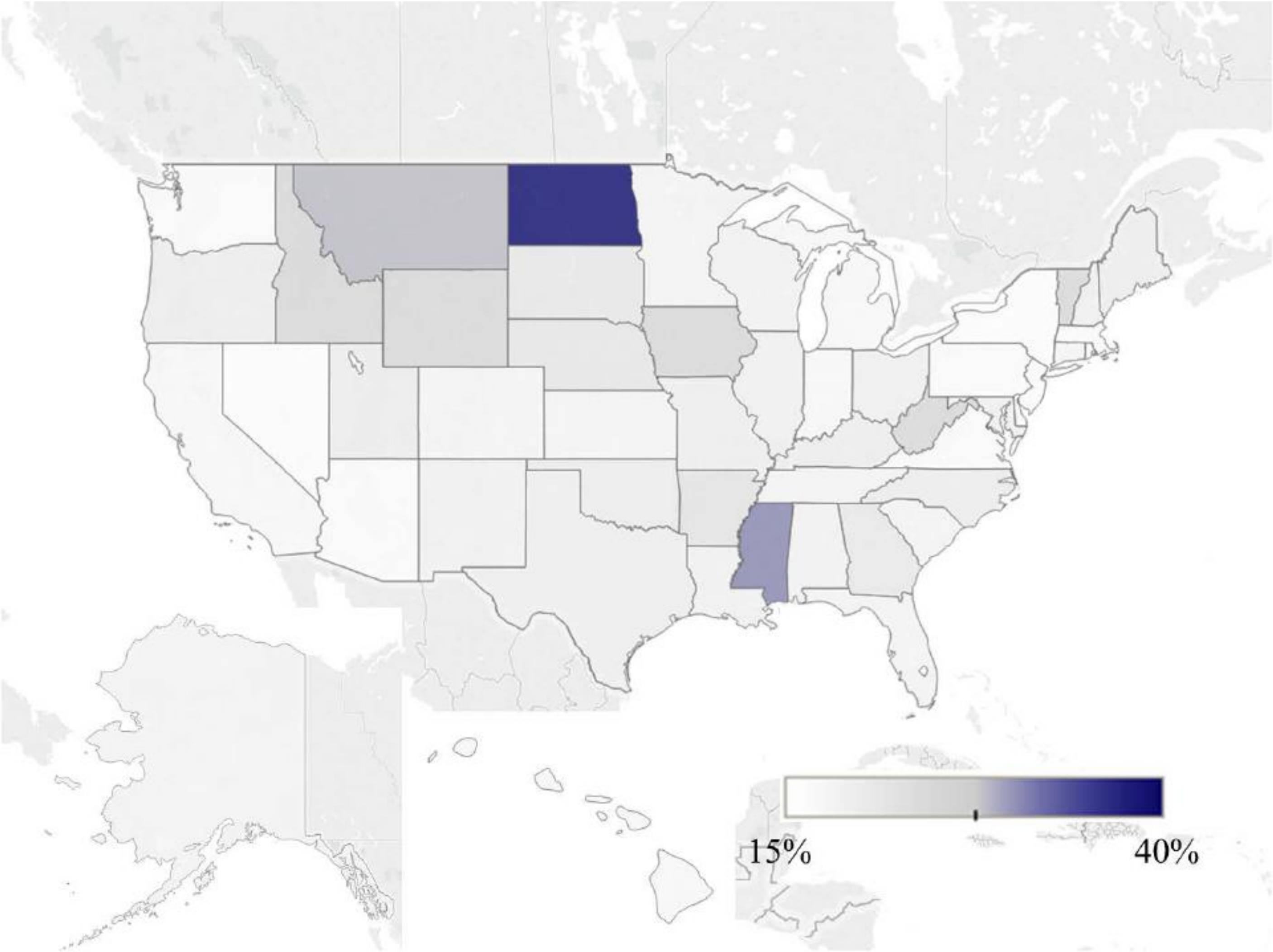


Figure 3. Percent Change in Net Benefit Between 0% and 5% Discount Rate