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Knowledge flows within a government supported program

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Abstract

This research investigates the role of a government sponsored network in promoting knowledge flows and technology diffusion. As new technologies and wider diffusion of existing technologies will be necessary to meet the challenges of global climate change, we investigate the ability of an environmentally oriented government network, the Climate Wise Program, to influence knowledge flows. Utilizing patent citations as a measure of knowledge flows, we investigate the extent to which the Climate Wise program created networks that affected citation patterns between co-participants of the program. We find that the Climate Wise program facilitated knowledge flows, though the effect was focused on inventors who already shared either a geographic network or social relationship.

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1. Introduction

Technology can play an important role in both promoting economic growth (Romer 1990) and ameliorating some of the negative environmental consequences of that growth (EPA 2012). For example, potential approaches to the issue of climate change in the post-Kyoto era have focused on the role of technology transfer in climate mitigating areas (Dechezlepretre *et al.* 2013). At a micro level, there is interest in correcting information asymmetries and information barriers that may prevent the widespread adoption of environmental technologies, such as energy efficient devices (Jaffe and Stavins 1994). While the role of geographical and social networks in facilitating knowledge flows has been well documented (Jaffe *et al.* 1993, Singh 2005), the role of government sponsored networks is less frequently studied. In this research, we consider the impact of a network formed by a voluntary environmental program, the Climate Wise program, on the diffusion of knowledge. The role of networks is particularly important for a problem like climate change which will likely require multi-dimensional solutions and collaborations between organizations with complementary capabilities (Selsky and Parker 2005, Lin 2012).

The structure and activities of the Climate Wise program make it an interesting case study of a network designed to facilitate knowledge flows. The program, which ran from 1994 to 2001, assisted firms in adopting innovative processes and procedures to reduce their greenhouse gas emissions. It brought together over 600 entities to form a network of parties interested in addressing their environmental impact in this area. The program had several information and knowledge sharing mechanisms, including background publications and free phone consultations that provided information on technical issues, workshops and seminars that facilitated learning opportunities about environmental practices, and a business-to-business exchange program that offered participants the potential to share with and learn from industry peers (EPA 1998).

In this paper, we utilize patent citations as a measure of knowledge flows. Patents have been widely used as a proxy for knowledge, and the act of citing another patent in a patent application demonstrates an understanding and appreciation of a given practice to a novel setting. Jaffe *et al.* (1993) introduced what has become a standard matched sample approach to control for the geographic clustering of economic activity in studies that examine knowledge flows. In addition to controlling for the geographic location of invention, we also control for prior social relationships that two inventors may share. Conditional on these geographic and social relationships, our interest in this paper is whether the Climate Wise program generated a government sponsored network that facilitated knowledge flows as measured through increased citations of patents.

2. Empirical Modeling Framework

2.1 Methods

We consider the knowledge flow K_{ij}^* between an inventor of patent *i* to another inventor and their associated patent *j*. Our unit of observation then is an 'inventor-patent' pair which recognizes that knowledge flows occur between inventors and that knowledge is codified within specific patents.

Knowledge flows that resulted in a citation on a patent application from a firm that participated in the Climate Wise program form the starting point of our sample. For each patent that was cited by a firm that participated in the Climate Wise program, we identify a control patent that could have been cited but was not. We define C_{ij} as an indicator variable for a citation between two potential patent pairs: $C_{ij} = 1$ indicates an actual citation between a citing and cited patent; $C_{ij} = 0$ indicates a potential citation between a citing and a *control* patent. In the spirit of Jaffe *et al.* (1993), we identify control patents through two criteria: they share as many 6-digit technology classes as possible and have the same application year as the cited patent.

With the sample of cited and control observations, we employ probit models to explain the probability a citation occurs between two inventor-patent pairs as follows

$$Pr(C_{ij} = 1) = \Phi\left(\sum_k \beta_k X_{kij}\right) \qquad i \neq j$$
$$Pr(C_{ij} = 0) = 1 - \Phi\left(\sum_k \beta_k X_{kij}\right) \qquad i \neq j \qquad (1)$$

where Φ is the standard normal cdf and the vector **X** contains our three network variables: *Climate Wise, Geography,* and *Social*. As we anticipate relationships between these variables, we add pair-wise interactions and a three-way interaction term in the model (Brambor *et al.* 2005). Relationships between social and geographic networks have been found in previous studies (Breschi and Lissoni 2005, Agrawal *et al.* 2006, Singh 2005, Sorenson *et al.* 2006), and we believe the Climate Wise network could complement or substitute for these networks. The two and three way interaction terms in the model allows for testing the impact of the *Climate Wise* variable on knowledge flows conditioned on the presence or absence of the other two networks. From the coefficient estimates of model (1), we compute the marginal effect of x_k on the probability of citation as:

$$\Phi\left(\beta_k x_{k1ij} + \sum_{l \neq k} \beta_l X_{lij}\right) - \Phi\left(\beta_k x_{k0ij} + \sum_{l \neq k} \beta_l X_{lij}\right) \qquad (2)$$

where $x_{k1ij} = 1$, and $x_{k0ij} = 0$.

2.2 Data

We use data on patent citations from the National Bureau of Economic Research Patent file (Hall *et al.* 2001). From this dataset and related studies (Lai *et al.* 2013), we extract information on the characteristics of each patent (application and grant year, 6-digit technology class(es), and cited patents) as well as the characteristics of the inventor(s) (name and geographical location). To focus on the impact of the Climate Wise program, we identified all patents in technology fields that relate to energy conservation and pollution control (IPC Green Inventory 2014) that were assigned to eventual Climate Wise participating firms. We limit the sample of patents to those applied for between 1994 and 2004 to capture the years the Climate Wise program was in operation.[1] In total, there are 125,237 such patents assigned to 627 firms. As most patents have multiple inventors and cite multiple patents (which also have multiple inventors), we note that a single patent in the NBER Patent file will generate several inventor-patent pairs between citing and cited patents. We impose the matching criteria to identify controls for each of the cited patents in our sample, and as is common in the literature, we exclude any inventor self-citations from our sample. Utilizing the matching criteria, our final sample is 26,940 inventor-patent pairs.

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[1] To allow for lags between the sharing of knowledge and the filing of patent applications, we evaluate the Climate Wise program for three years beyond the formal end of the program in 2001.

The dependent variable C_{ij} in our probit model takes on a value of one for each cited observation and zero for each control observation. By construction, half of our sample have $C_{ij} = 1$ and half have $C_{ij} = 0$. Among our independent variables, our first network variable is $Climate\ Wise_{ij}$. It is a dummy variable that takes on a value of one if, at the time of citation, at least one inventor from both the citing firm and the cited/control firm belong to the Climate Wise network. Our second network variable is $Geography_{ij}$, which takes on a value of one if at least one inventor of the citing patent is located in the same Metropolitan Statistical Areas (MSAs) as at least one inventor of the cited/control patent. Our third and final network variable is $SOCIAL_{ij}$, which takes a value of one if at least one inventor of the citing patent is listed as a co-inventor on a previous patent with at least one inventor of the cited/control patent in the past. Summary statistics of the matched sample is shown in Table I. We observe that in our sample just under a third of citations are to a patent belonging to another Climate Wise participant. Twelve percent of paired inventors are located in the same MSA and four percent of our paired patents have inventors that are listed as co-inventors on a prior patent.

Table I: Summary Statistics

Variables	All observations	Citing-cited observations	Citing-control observations
Climate Wise	0.305	0.345	0.266
Geography	0.124	0.177	0.071
Social	0.039	0.070	0.008
	n=26,940	n=13,470	n=13,470

3. Results

3.1 Key Results

In the estimated probit model, all the coefficients of the three network variables are individually statistically significant, and the interaction terms are jointly significant, which suggests that our model with the full set of interactions is appropriate (see column labeled 'base match' in Table A.I in the appendix). Since the marginal effects in a probit model depend not only on the coefficient estimates but also on the values of the regressors, we focus our discussion on the predicted probabilities which are presented in Table II. This table shows the impact of the Climate Wise program on the predicted probability of citation, controlling for different states of one's geographic and social relationships.[2]

While all of the differences in predicted probabilities of citation due to the Climate Wise network are statistically significant, we note that the effect is close to zero in two cases and strictly positive in two cases. When inventors share no network relationship (neither a geographic or social relationship), it appears that the impact of *Climate Wise* is modest; the difference in predicted probabilities of citation is less than 3 percentage points. Similarly, the

[2] Since already demonstrated in the literature, we do not focus our discussion on the marginal impact of geographic proximity or a social proximity on the likelihood of citation. Our results confirm existing studies that find both of these proximities lead to increased knowledge flows and higher likelihoods of citation between inventors.

effect of *Climate Wise* is small when inventors already share both a geographical and social relationship. In this case, we find that the impact of *Climate Wise* is a negative 1.2 percentage points. While both of these marginal effects are statistically different than zero, since the baseline probability of citation is 46% in the case of no networks and 92% in the case of both networks, we interpret these marginal effects to be of limited economic significance.

For the two intermediate cases, when inventors share one network relationship but not the other (either a social or geographic network), the impact of *Climate Wise* has a strong positive influence on the probability of citation. In these cases, the predicted probabilities of citation are approximately 9 percentage points higher for investors that belong to the Climate Wise network relative to investors that do not share the Climate Wise network. This suggests some complementarity between the Climate Wise network and the social or geographic network. When inventors are networked in one dimension (either the geographic or social dimension), the Climate Wise program has the potential to enhance knowledge flows and increase citations between individuals. On the other hand, the results suggests that it is challenging for the Climate Wise program to work on its own (when no other networks exist) or to have any additional marginal impact for inventors that already share many network relationships.

Table II: Predicted Probabilities of Citation

Status of 'other' networks (*Social* and *Geography*)		Climate Wise status	Predicted Probability of Citation
Share no other networks	*Geography* = 0 *Social* = 0	*Climate Wise* = 0	0.457 (0.004)
		Climate Wise = 1	0.485 (0.006)
Share one other network	*Geography* = 0 *Social* = 1	*Climate Wise* = 0	0.813 (0.044)
		Climate Wise = 1	0.906 (0.019)
	Geography = 1 *Social* = 0	*Climate Wise* = 0	0.610 (0.014)
		Climate Wise = 1	0.696 (0.012)
Share two other networks	*Geography* = 1 *Social* = 1	*Climate Wise* = 0	0.921 (0.025)
		Climate Wise = 1	0.909 (0.011)
Sample size			26,940

Standard errors are included in parentheses.
Inventor patent pairs share the same geography, a social relationship in the past, or membership in Climate Wise program when *Geography* equals one, *Social* equals one, or *Climate Wise* equals one, respectively.

3.2 Robustness checks

To ensure that our results are not dependent on the matching criteria, we utilize additional matching criteria as recommended by Thompson and Fox-Kean (2005) and Singh and Agrawal (2011). Additional matching criteria focuses the analysis of citation behavior on a set of patents that look increasingly similar to each other. The downside of refining the match too much, though, is that it reduces the possibility of identifying spillover knowledge flows that might exist between similar but not identical entities (Henderson *et al.* 2005). Given the trade-offs in imposing stricter matching, we examine if our results are sensitive to this issue.

In addition to matching application year and technology classes, we refine our matches by adding the following criteria: the area of economic activity of the firm (by recognizing the industry of the firm that holds the patent) and the quality of the patent (with the total number of citations received and the number of claims on the patent).[3] We re-run the model on this more restrictive match (coefficient estimates are reported in the 'full match' column of Table A.I in the Appendix), and we continue to find that (1) the Climate Wise program raises the likelihood of citation for inventors that share one of the two networks and (2) the impact is close to zero for firms that lack both a social and geographic network and for firms that maintain both networks. Finding a similar impact of the marginal effects of the program across different matching protocols suggests that knowledge flows arise from the Climate Wise program and is not due to spurious matching.[4]

4. Conclusions

In this research note, we demonstrate the potential role of a government sponsored network in promoting knowledge flows. As the voluntary Climate Wise program brought together different parties and had several information and knowledge sharing attributes, the program is an interesting case study of a government sponsored network. We find evidence of higher citations rates between two inventors that work for Climate Wise participating firms than between an inventor at a Climate Wise firm and an inventor at a non-participating firm. Interestingly, this impact is largely restricted to inventors that already share some network relationship (either a geographic or social relationship), but not both. In these cases, the Climate Wise program complements the other network to increase knowledge flows. Further research into the interplay between networks seems warranted by this work.

[3] In results not shown, we also match on the size/innovativeness of the firm by adding the number of firm-level patents applied for (and eventually granted). Adding this criterion significantly reduces the number of successful matches. The qualitative results are robust to this additional matching criterion, though we do note that the marginal effect of Climate Wise in the case that both inventors share a geographic and social network is much larger.

[4] A more robust matching also reduces the sensitivity of our estimates to functional form assumptions (Moffitt 2004), and to the extent that Climate Wise participation is correlated with any of these factors, the additional matching criteria alleviate potential endogeneity concerns (Singh and Agrawal 2011).

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Appendix

Table A.I: Probit model estimates of *Citation*

Variable	Base Match	Full Match
Climate Wise	0.069*** (0.019)	0.027 (0.022)
Geography	0.387*** (0.038)	0.383*** (0.046)
Social	0.994*** (0.162)	1.059*** (0.230)
*Climate Wise * Geography*	0.165*** (0.054)	0.119* (0.064)
*Climate Wise * Social*	0.361* (0.200)	0.344 (0.271)
*Geography * Social*	0.138 (0.239)	-0.038 (0.310)
*Climate Wise * Geography * Social*	-0.674** (0.278)	-0.654* (0.351)
Constant	-0.107*** (0.010)	-0.091*** (0.011)
Sample Size	26,940	19,426

Note, standard errors in parentheses.
*** significant at 1%, ** significant at 5%, * significant at 10%.