GENERATIONAL AND EDUCATIONAL EFFECTS ON BASIC U.S. ADULT CIVIC SCIENCE LITERACY

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Abstract

Most countries emphasize an effective science education, in part with the expectation that science-literate adults will understand, and often participate more fully in science-related policy decisions. However, in assessing adult basic civic science literacy over time, many factors change simultaneously, making definitive conclusions about educational effects difficult. For example, more recent generations often have more formal education and more exposure to science than earlier cohorts. Age and generational effects are confounded in "one-shot" cross-sectional analyses but can be disentangled to some degree in repeated cross-sectional sample survey designs.

I employ multivariate analyses of the U.S. National Science Foundation Surveys of Public Understanding of Science and Technology, 1979-2001 (total sample ~22,000) to study how recency of educational exposure (age), generation (e.g., "baby boomer"), gender, and educational factors affect basic science factual knowledge and understanding science inquiry. General levels of understanding inquiry were somewhat greater than basic factual knowledge, although both showed some increase by time and, especially, by generation or birth cohort. More sophisticated presentations in U.S. science education have increased U.S. basic science literacy across time by cohort, over and above one's formal degree level accomplishments.

This study examines how birth cohort and age, net of gender, high school science and math courses, and college science exposure, affected American adult civic science literacy (CSL) in the late twentieth century, using the NSF Surveys of Public Understanding of Science and Technology. Although Americans express sizeable interest in medicine, science, and technology, many controversies, e.g., biotechnology applications, require an understanding of basic science that many U.S. adults lack. In 2003 alone, U.S. expenditures on science and technology research and development comprised *284 billion dollar*s (U.S. Bureau of the Census, 2006, Table 774). Changes in teaching science also have occurred. Given such investments in public discourse, education, and R&D, it is vital to understand continuities from formal education among youth to adult science knowledge. CSL among adults in particular is often critical for intelligent policy discussions and a supportive research climate (Allum, *et al.*, 2006, in press).

Currently, many American journalists, politicians, social and behavioral scientists, and educators assert that our youth are unprepared for college science, that students switch from science concentrations and adults cannot discuss science at the level of a major newspaper (e.g., the *New York Times*). When we juxtapose spending cuts on science education research against national and international needs for trained personnel, these concerns become more urgent (Burris, 2006; Miller, 2000, Lemonick, *et al.,* 2006; Seymour, 2006, Wieman, 2006). Yet, in the last third of the 20th century, U.S. *secondary schools* greatly changed how science is taught.

In addition, Americans are better educated than their counterparts from 50 years ago, and probably have more formal science exposure. In particular, members of birth cohorts born after World War Two have more often entered college. In 1940, only 25% of U.S. adults had at least graduated high school and 5% had at least a bachelor's degree; 55% of 1970 Americans had at least a high school degree and 11% had a BA or higher. By 2004, 85% had at least graduated high school and 29% had a BA or more (National Center for Educational Statistics, 2004: Table 8). However, since most Americans still do not graduate college, the recent changes in secondary school science remain important.

Criticism from American *university* faculty about high school training (e.g., Weiman, 2006) contradicts the many changes that have occurred in secondary school science. There is now less emphasis on factual memorization and more on science inquiry, hands-on experience, and the context of science and technology (AAAS, 1993; Schiebiner, 1999; Schmidt, *et al*., 1997; Sunal & Sunal, 2003). Evidence that these approaches increase understanding among at least some youth at diverse grade levels is mixed (Burkam, *et al.*, 1997; Gess-Newsome, 2002; Lee & Burkam, 1996; Lilienfeld, *et al.,* 2001; Moss, *et al.,* 1998; Scanlon, 2000). *Yet we know virtually nothing about how these innovations have "trickled through," if at all, to the average adult.*

Issues of Age and Birth Cohort

If exposure to these recent perspectives in high school science has relatively lasting benefits, it can help create greater *adult CSL* in the long run. *Recent cohorts* of adults should be more knowledgeable because they have had a greater chance of being taught science using more engrossing methods. However, adult CSL analyses of "one-shot" cross-sectional general public surveys inevitably confound age and birth cohort, with the factor "chronological age" receiving cavalier treatment of. Age is typically used as a control or a vague background factor, and young adults often appear more interested than older ones in science (Losh, 2002; Office of Science and Technology, 2000). With several study years available, age can be disentangled from cohort and the separate impact of each can be assessed. Given changes in science education, the effects of cohort may turn out to be important indeed.

For example, an "average adult" in their early 50s in 2005 completed most of their formal education 30 years ago. *Memory decay* alone could cause older adults to recall less basic science than younger ones at any point in historical time. On the other hand, birth cohort can influence *what kind* of science education a youth received. Although changes in teaching high school science (especially methods) began about 30 years ago, the initial impact was limited largely to faculty and graduate students at major research universities. Allowing at least 10 years for these perspectives to "diffuse" to other universities and colleges means that any effects of cohort on civic science literacy should begin with the cohort often labeled "Generation X" and should be most pronounced for "Gen Y".

Simultaneous estimates of age, cohort *and* period effects in multivariate analyses present severe problems. Any of these three variables is logically and statistically dependent upon the other two. Although there are statistical attempts to handle the estimation issues (Mason, *et al*., 1973; Mason & Brown, 1975), in this study I build and track synthetic cohorts, contrasting cohort effects with those of age to partly assess how changes in science education may have affected CSL, leaving changes in science education *over time* to be reflected in the patterns of age and cohort effects. If more recent science teachings in American high schools have contributed to adult CSL, then not only should CSL, net of age, be higher among more recent than among earlier cohorts, *but the effects of cohort on understanding science inquiry should be particularly pronounced in more recent cohorts*, regardless of age. In addition, as noted earlier, cohort is also entangled with educational factors, since more recent cohorts have higher average educational levels. Thus, I control several educational variables in my analyses.

RESEARCH QUESTIONS:

How does birth cohort, compared with age and net of educational variables, affect civic science literacy (CSL) in American adults?

How does birth cohort, compared with age and net of educational variables, affect understanding science inquiry as compared with memory for basic science facts in American adults?

METHODS

The National Science Foundation Surveys of Public Understanding

American surveys about science and technology adult "literacy" date from at least the 1950s. I conducted original analyses of the **1979-2001 NSF Surveys of Public Understanding of Science and Technology** (directed by Jon D. Miller 1979-1999 and ORC-MACRO 2001, longitudinal cross-sectional data archive created by Susan Carol Losh, 2005), which coordinate with several international surveys (e.g., Bauer, *et al*., 1994). The *total archive* is the most comprehensive study of U.S. adult basic civic science literacy and comprises 21,955 unweighted (22,032 weighted) Random Digit Dial telephone interviews with U.S. adults in eleven probability sample surveys spanning

1979 to 2001 (note: the 1979 surveys were in-person). Items monitor several science and technology knowledge and attitude dimensions. There is also more detail on adult high school and college educational variables than in any other U.S. adult survey.

Constructing Birth Cohort

Considerable debate exists over when particular cohorts begin or end. Rather than using a constant interval (e.g., 20 years "per generation"), cohorts are often constructed with respect to both time duration *and* significant events occurring when individuals could experience them. Pragmatically, in these data, some cohorts are small. I coded 73 respondents born before 1891 to "missing" because of their scarcity and because dementia and Alzheimer's increase after age 80, making interpretation of CSL among them potentially unreliable. Cumulatively, by 2001, 358 respondents representing "Gen Y" were at least age 18, thus eligible for the survey. Future surveys will enlarge this cohort. Pre WWI respondents (total n = 1828) not only age (many had died by 2001), but many items analyzed in this paper were not asked until 1988, 1990, 1992 or 1995 decimating their numbers still further.

One example of cohort debates is when the U.S. "Baby Boom" ends. Scholars agree that it *began* in 1946. Some end "the boom" in 1957 when *birth rates* peak, others in 1961 when the *absolute number of births* peaks. Since "Generation X" is generally agreed to begin in the early 1960s, I ended the "Baby Boom" for this project in 1961, beginning "Generation X" in 1962. I created these six cohorts: **"Gen Y,"** born 1979 - 1983 (more years will be added as subsequent surveys are added to the archive); **"Generation X"** (1962 – 1978); **"Baby Boom"** (1946 – 1961); **"Depression-World War II"** (1930 – 1945); **Post WWI** (1918 – 1929); and **WWI** (1891 –1917). The oldest cohort experienced early telephone and radio communication, early air travel and world war. Cohort (5) matured in depression and watched newsreels of the atomic bomb, but also benefited from health developments, e.g., widespread antibiotics use. Cohort (4) began in the turmoil of depression and war, but grew up in the prosperous 1950s. "Boomers" matured in affluence, became well educated, and used computers early on—only to face stiff competition for college slots and jobs. Watching space flight was relatively routine for "Generation Xers" and all six cohorts saw "wonders" such as cloning, genetic splicing, and the diagnosis and medical treatment of "new" diseases such as AIDS.

Demographic and Educational Variables

Other independent variables include gender and degree level (coded as high school or less; two year college degree; baccalaureate; or advanced college degree). Gender has generally been an important predictor of college major, interest in science, and adult CSL (Aldrich, 1978; Burkam, *et al*., 1997; Fox & Firebaugh, 1992; Losh, 2001; Miller & Kimmel, 1998). Respondent age was coded in 5 categories: 18-24; 25-34; 35-44; 45-64; and age 65 and over. Whether the respondent had taken high school biology, physics or chemistry, and their highest achieved level of high school math, were available for 1990-2001**.** I use the sum of high school science courses (0-3) as a conservative estimate because courses that could be elected but were not part of the NSF questionnaire (e.g., earth science, ecology) could not be included. The number of college science courses ranges from 0 to 10 or more.

Civic Science Literacy

I use three major measures of CSL. First are 10 questions (1988 – 2001) with a mix of item formats about basic science facts that are usually taught in elementary school and reviewed in middle school (Cain, 2002; Sunal & Sunal, 2003). For example, true-false items ask whether "the center of the earth is hot," "humans co-existed with dinosaurs," "oxygen comes from plants," or "antibiotics kill viruses and bacteria." Balanced response items asked whether light or sound travels faster, and whether the earth goes around the sun or vice-versa. These are often called the "**Oxford items**" (Allum, *et al*., in press, 2006).

Second, I use an **additive probability index** of 4 items about a couple planning a family who have genes for a hereditary illness (1988 – 2001), consisting of the number correct about whether, e.g., a fourth child would inherit the disease, or if each child has an equal chance of inheritance. Third, in the **experimental drug question** (1995 – 2001), respondents were asked the best way to test a new blood pressure medicine: (1) to give it to 1000 patients and evaluate the outcome, or (2) to give 500 people the new drug and another 500 an inactive medication.

RESULTS

Cohort and Educational Background

More recent cohorts indeed have higher levels of education: 86% of those born before World War I had at most a high school degree compared with 68% of “Gen X” respondents (many “Gen Y” and some “Gen X” respondents were still in college or vocational school at the time of the survey). 9% of the eldest cohort had at least a BA degree compared with 16% of “Gen Xers” and 24% of “Baby Boomers” ($\chi^2_{(15)} = 901.24$ $v = 0.12$, $p < .001$).

Similarly, American exposure to high school math or science courses increased (Tables 1 & 2). 52% of those born before World War One either had no high school math or at most “general” or “business” math, compared with only 9% of the “Gen Y” cohort. In contrast, 38% of “Gen Y” had *at least* a pre-calculus high school course, compared with only 7% of the earliest birth cohort ($\chi^2_{(10)} = 832.21$ $\Phi = 0.27$, $p < .001$).

TABLE 1 ABOUT HERE

High school (Tables 2 and 3) and college (Table 4) science educational attainments similarly rose. Over twice as many of the youngest as the oldest cohorts had elected high school biology (86 vs. 35%, $\chi^2_{(5)} = 885.06$ $\Phi = 0.28$, $p < .001$) and three times as many had had a high school chemistry course (66 vs. 20%, $\chi^2_{(5)} = 404.28$ $\Phi = 0.19$, $p < .001$). For high school physics, comparable figures were 37 versus 22% ($\chi^2_{(5)} = 75.08$ $\Phi = 0.08$, $p < .001$), although it is unclear whether the oldest cohort meant physics, or a physical science, such as “earth science”. Even “Baby Boomers” elected less advanced high school math (24%), high school biology (77%), chemistry (44%), or physics (25%) than the youngest adult cohort. The overall mean number of high school science classes was 1.39, but Table 3 shows $\bar{Y}$ for high school courses by cohort and age. Reading from left to right and top to bottom indicates that more recent cohorts clearly had more high school science than earlier cohorts, and younger respondents tended to have more high school science than older ones (controlling gender and degree level: age $F_{4,11418} = 34.23$ $p < .001$; cohort $F_{5,11418} = 109.06$ $p < .001$, total η including degree level and gender = 0.52.)

TABLES 2 & 3 ABOUT HERE

Because younger cohorts more often attended and graduated from post-secondary institutions, they also took more college-level science courses. Although the median number of college science courses overall was 0 and the grand mean for Table 4 was 1.27, reading from left to right suggests that more recent cohorts had more college science courses than earlier ones. *Younger* respondents, however, did not always have more college science than older ones, partly because younger adults may not have completed their formal education at the time of the survey and because older adults may have taken classes through night school, advanced degrees, or office workshops. Overall, older adults had more science courses than younger ones (controlling gender and degree level: age $F_{4,18731} = 3.53$ $p < .01$; cohort $F_{5,18731} = 3.79$ $p < .01$. The total η including degree level and gender controls was 0.87).

TABLE 4 ABOUT HERE

Cohort, Education, and Basic Civic Science Literacy (CSL)

Table 5 shows how the three sets of CSL measures varied over time. The “Oxford Items” and the experimental drug item both showed clear and monotonic increases over time (for the Oxford items and time: $F_{6,13530} = 16.21$ $p < .001$ $\eta = 0.09$; for the drug question and time: $F_{3,7458} = 15.13$ $p < .001$ $\eta = 0.08$). Although the one-way ANOVA for the probability index was statistically significant ($F_{6,13530} = 8.29$ $p < .001$ $\eta = 0.06$), the relationship was curvilinear, with the earliest and latest surveys showing the highest scores.

TABLE 5 ABOUT HERE

Given that recent cohorts have more education overall, and more science and math courses in particular, than earlier ones, all else equal, we would expect later cohorts to score higher on CSL. The question is *whether cohort effects hold net of educational background*, which could indicate that recent ways of teaching high school science help create a more scientifically sophisticated American general public. Table 6 presents results by cohort and age category for the “Oxford items,” while Tables 7 and 8 present analogous results for the applied probability index and the experimental science inquiry item.

Younger adults from more recent cohorts knew more basic science facts, controlling gender, degree level, the number of high school science courses and the number of college science courses. The mean score on the 10 knowledge items was 6.58. In the ANOVA, age had modest effects but birth cohort had sizable effects net of educational variables (age $F_{4,11417} = 4.82$ $p < .01$; cohort $F_{5,11417} = 52.95$ $p < .001$. **Total** $\eta = 0.55$).

TABLE 6 ABOUT HERE

How age and cohort affected the applied probability score is less clear. The data in Table 7 show a tendency for more recent cohorts to score higher but age effects were smaller ($\bar{y} = 3.13$, age $F_{4,11417} = 14.87$ $p < .001$; cohort $F_{5,11417} = 77.24$ $p < .001$. **Total** $\eta = 0.34$). On the other hand, cohort had relatively strong effects on the experimental drug question (Table 8). 82% of “Gen Y” and 80% of “Gen X” respondents answered the question correctly, compared with only 61% of the post-World War I cohort and 42% of the pre-World War I cohort. Cohort had larger effects than did chronological age on the drug item ($\bar{y} = 0.73$, age $F_{4,7384} = 3.35$ $p = .01$; cohort $F_{5,7.84} = 38.18$ $p < .001$. **Total** $\eta = 0.26$).

TABLES 7 AND 8 ABOUT HERE

Table 9 presents the standardized beta weight coefficients from three regression equations, using the three CSL variables as dependent variables. Table 9 also shows the added contribution to the R^2 on CSL from in order (1) gender and degree level combined, (2) *n high school* science classes; (3) *n college* science classes, and (4) age and birth cohort combined.

TABLE 9 ABOUT HERE

Table 9 shows the robustness of birth cohort as a predictor of civic science literacy. The effect of cohort trumped age for all three CSL variables, with educational variables and gender controlled (age was not statistically significant in any of the regressions). Cohort also was the most important standardized predictor for both the applied probability score and the drug question. In addition, the number of high school science courses and the number of college science courses predicted all three CSL variables. With educational variables controlled, men scored higher on the Oxford item index, women slightly more often answered the drug question correctly, and there was no sex difference on the probability score. Even controlling gender and educational variables, cohort significantly added to the R^2, especially for science inquiry variables. In fact, despite forcing cohort and age to enter last in the regressions their contribution to the experimental drug question provided the greatest increment to the explained variance.

DISCUSSION AND CONCLUSIONS

Current pundits and scientists alike often declaim science achievement among ordinary Americans, expressing concerns that the quality of both science education and general public basic science literacy are declining. *Yet, my analyses of the NSF Surveys, when birth cohort is explicitly factored into the equations, find exactly the opposite.* More recent cohorts of Americans compared with their counterparts of 50 years ago are (1) better educated overall; (2) net of educational level have more exposure to both high school science and math courses, and to college science; and (3) show definite gains in basic science factual knowledge and the two forms of science inquiry studied in these surveys.

In part because the average American remains in the formal education system longer, they elect more science and math courses. Between those cohorts born before World War I and those born after 1978, the percentage taking advanced high school math quintupled, while the percentages taking high school biology and chemistry tripled. The mean number of high school science courses doubled, and the mean number of college science classes elected more than doubled. These changes occurred across birth cohorts despite the fact that many members of the youngest two cohorts were still in college. Even with educational level and the number of college science courses controlled, exposure to high school science significantly predicted CSL in the final regression equations. Thus, high school achievements are critical: even among Generation Xers, many of whom have mostly completed their formal educations, only one-third in these data had earned an associate's degree or higher. High school may be the last time educators can *formally* influence beliefs and knowledge about science.

One major goal of these analyses was to assess the viability of the birth cohort or "generation" variable as an explanatory construct for civic science literacy, and to see how cohort affected different dimensions of CSL. The net effects of cohort on CSL were consistently statistically significant. This was especially true for science inquiry measures among adults, where the net standardized regression effects of cohort on the two science inquiry measures were higher in absolute value than were the effects of educational variables.

In contrast, respondent age had virtually no net effect on CSL. These findings suggest that the effects of age on CSL in a single cross-sectional adult sample may reflect instead the uncontrolled and omitted effects of birth cohort, as opposed to representing processes such as memory decay. Greater CSL among more recent cohorts, net of age, does suggest that changes in teaching science may be trickling through to the adult general population. Although this inference is indirect at best, because we only know *which* high school science and math courses respondents took *and not how* the courses were taught, nevertheless, these analyses suggest more recent generations of high school students have been taught science in more fruitful ways than earlier cohorts were. If this speculation is true, the effects of birth cohort should become more pronounced as more years of "Gen X" and "Gen Y", and later generations are added to the data archive.

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Future Directions

For the immediate future, I will extend the study of birth cohorts and civic science literacy to other measures of CSL. For example, the NSF Surveys are rich in information about science attitudes and pseudoscience beliefs in the American general public. Both these areas are often considered part of CSL. *General attitudes* about science and technology have been found to link to some measures of knowledge (Allum, et al., 2006, in press) and almost certainly relate to *specific science policy attitudes*. Pseudoscience purveyors are common in virtually every culture; they drain consumer wallets, stir political as opposed to scientific controversy, and can lower the quality of everyday life.

The results in this study are promising in how recent changes in high school science methods may have boosted *adult* CSL, especially in dimensions of understanding science inquiry. They lend support to those who wish not only to see these recent innovations continue during secondary school, but also to those who advocate extending such pedagogical methods to undergraduate science courses to forestall the "brain drain" among talented college students away from a science major (e.g., Burris, 2006; Seymour, 2006). At a time when U.S. science educators face cuts in federal spending on science education research, it is important to assess possible positive consequences, indirect although they may be, of changes in science education on American adult civic science literacy.

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ANALYTIC TABLES

TABLE 1
High School Math Courses Elected by Cohort 1990-2001

Cohort∈ Math Level	Pre WWI	Post WWI	Depression	Baby Boom	"Gen X"	"Gen Y"
None/General	52%	40%	36%	24%	16%	9%
Algebra-Geometry	41	49	49	52	51	53
Pre-Calculus/ Calculus	7	11	15	24	33	38
	100%	100%	100%	100%	100%	100%
n	377	1288	2099	3652	3659	358

TABLE 2
Percent High School Science Courses Elected by Cohort 1990-2001

Cohort∈ % Elected	Pre WWI	Post WWI	Depression	Baby Boom	"Gen X"	"Gen Y"
Biology	35	47	62	77	79	86
Chemistry	20	27	35	44	49	66
Physics	22	25	24	25	31	37
Minimum n	377	1288	2099	3652	3659	357

TABLE 3
Mean Number of High School Science Classes by Age and Cohort 1990-2001

Age / Cohort	Pre WWI	Post WWI	Depression	Baby Boom	"Gen X"	"Gen Y"
18-24	--	--	--	--	1.72	1.89
25-34	--	--	--	1.38	1.54	--
35-44	--	--	--	1.48	1.40	--
45-64	--	1.08	1.24	1.41	--	--
65+	0.77	0.97	1.02	--	--	--

TABLE 4

Mean Number of College Science Classes by Age and Cohort 1979-2001

Age / Cohort	Pre WWI	Post WWI	Depression	Baby Boom	"Gen X"	"Gen Y"
18-24	--	--	--	0.81	1.21	0.44
25-34	--	--	0.69	1.49	1.90	--
35-44	--	--	1.31	1.77	1.63	--
45-64	0.45	0.69	1.11	1.86	--	--
65+	0.41	0.59	0.67	--	--	--

TABLE 5

Basic Civic Science Literacy Over Time

Year € Civic Literacy Variables	1988	1990	1992	1995	1997	1999	2001
Oxford Qs	6.27	6.37	6.49	6.53	6.60	6.72	6.82
Probability Score	3.29	3.10	3.18	3.09	3.09	3.15	3.21
Drug Question %correct				69%	73%	73%	79%
Minimum n	2041	2033	2000	2006	1999	1881	1574

TABLE 6

"Oxford Questions" Index Mean Scores by Cohort and Age Group 1990-2001

Age / Cohort	Pre WWI	Post WWI	Depression	Baby Boom	"Gen X"	"Gen Y"
18-24	--	--	--	--	6.85	7.05
25-34	--	--	--	6.66	6.86	--
35-44	--	--	6.84	6.99	6.82	--
45-64	--	6.04	6.31	6.90	--	--
65+	5.22	5.67	5.71	--	--	--

TABLE 7

Applied Probability Mean Scores by Cohort and Age Group 1990-2001

Age / Cohort	Pre WWI	Post WWI	Depression	Baby Boom	"Gen X"	"Gen Y"
18-24	--	--	--	--	3.22	3.09
25-34	--	--	--	3.23	3.38	--
35-44	--	--	3.59	3.30	3.28	--
45-64	--	2.94	3.15	3.23	--	--
65+	2.23	2.57	2.67	--	--	--

TABLE 8

Experimental Drug Question Mean Proportion Correct by Cohort and Age Group 1995-2001

Age / Cohort	Pre WWI	Post WWI	Depression	Baby Boom	"Gen X"	"Gen Y"
18-24	--	--	--	--	0.82	0.82
25-34	--	--	--	0.69	0.79	--
35-44	--	--	--	0.76	0.82	--
45-64	--	--	0.66	0.75	--	--
65+	0.42	0.61	0.56	--	--	--

TABLE 9
Standardized Multiple Regression Effects on Civic Science Literacy Variables

Predictors / Dependent Variable∈	Oxford Qs	Probability Score	Drug Question
Gender	0.22***	0.00	-0.03**
Degree Level	0.15***	0.11***	0.07***
Number High School Science Courses	0.18***	0.12***	0.08***
Number College Science Courses	0.21***	0.08***	0.06***
Age	0.02	0.03	-0.01
Birth Cohort	0.15***	0.18***	0.15***
R^2 Gender and Degree Level	0.199***	0.047***	0.019***
ΔR^2 Number High School Science Courses	0.054***	0.024***	0.015***
ΔR^2 Number College Science Courses	0.028***	0.005***	0.002***
ΔR^2 Cohort and Age Categories	0.016***	0.022***	0.024***
Total R^2	0.296***	0.098***	0.060***
R	0.544	0.313	0.245
n	11,433	11,433	7,399

Gender is a dummy variable with male = 1.
* $p < .05$ ** $p < .01$ *** $p < .001$

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