HOME COMPUTERS AND EDUCATIONAL OUTCOMES: EVIDENCE FROM THE NLSY97 AND CPS*

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Although computers are universal in the classroom, nearly 20 million children in the United States do not have computers in their homes. Surprisingly, only a few previous studies explore the role of home computers in the educational process. Home computers might be very useful for completing school assignments, but they might also represent a distraction for teenagers. We use several identification strategies and panel data from the two main U.S. data sets that include recent information on computer ownership among children—the 2000–2003 Current Population Survey (CPS) Computer and Internet Use Supplements matched to the CPS basic monthly files and the National Longitudinal Survey of Youth 1997 (NLSY97)—to explore the causal relationship between computer ownership and high school graduation and other educational outcomes. Teenagers who have access to home computers are 6–8 percentage points more likely to graduate from high school than teenagers who do not have home computers after controlling for individual, parental, and family characteristics. We generally find evidence of positive relationships between home computers and educational outcomes using several identification strategies, including controlling for typically unobservable home environment and extracurricular activities in the NLSY97, fixed effects models, instrumental variables, and including future computer ownership and falsification tests. Home computers may increase high school graduation by reducing nonproductive activities, such as truancy and crime, among children in addition to making it easier to complete school assignments. (*JEL* I2)

I. INTRODUCTION

The federal government has made the provision of computer and Internet access to schoolchildren a top priority. Spending on the E-rate program, which provides discounts to schools and libraries for the costs of telecommunications services and equipment, is roughly $2 billion per year (Puma, Chaplin, and Pape 2000; Universal Services Administration Company 2005). Recently, the U.S. Department of Education released the National Educational Technology Plan as part of the No Child Left Behind Policy. The plan calls for increased teacher training in

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ABBREVIATIONS

2SLS: Two-Stage Least Squares
CIUS: Computer and Internet Use Supplements
CPS: Current Population Survey
GPA: Grade Point Average
NLSY97: National Longitudinal Survey of Youth 1997
NELS: National Educational Longitudinal Survey

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technology, e-learning opportunities for students, access to broadband, digital content, and integrated data systems (U.S. Department of Education 2004). Several state and local governments and private programs have also created one-to-one computing in selected schools through the provision of laptop computers to schoolchildren and teachers.[1] In a recent national survey funded by the U.S. Department of Education, nearly all principals report that educational technology will be important for increasing student performance in the next few years, and a clear majority of teachers report that the use of technology is essential to their teaching practices (SRI International 2002). The result is that nearly all instructional classrooms in U.S. public schools have computers with Internet access, with an average of 3.5 computers per classroom (U.S. Department of Education 2005).

In contrast to the ubiquity of computers in the classroom, nearly 20 million children, representing 26% of all children in the United States, do not have computers in their homes. This disparity in access to technology at home or the so-called digital divide may have implications for educational inequality. Surprisingly, however, the role of *home* computers in the educational process has drawn very little attention in the literature. There is also no clear theoretical prediction regarding whether home computers are likely to have a negative or positive effect on educational outcomes. Home computers are clearly very useful for completing school assignments and may facilitate learning through research and educational software. The use of home computers may also alter the labor market returns to completing high school, "open doors to learning" encouraging some teenagers to stay in school (Cuban 2001; Peck et al. 2002), and reduce crime. On the other hand, home computers are often criticized for providing a distraction to children through video games and the Internet or for displacing other more active forms of learning (Giacquinta et al. 1993; Stoll 1995), and the Internet makes it substantially easier to plagiarize and find information from noncredible sources. Therefore, it is an empirical question as to which of the two opposing forces dominates and the magnitude of any effects.

Indeed, the few previous studies examining the relationship between home computers and educational outcomes find somewhat mixed results.[2] Using the National Educational Longitudinal Study of 1988, Attewell and Battle (1999) find that test scores and grades among eighth graders are positively related to home computer use. Using more recent data from the United States—the 2001 Current Population Survey (CPS)—Fairlie (2005) finds a positive cross-sectional relationship between home computers and school enrollment. Schmitt and Wadsworth (2006) also find evidence of a positive relationship between home computers and performance on the British school examinations from analysis of the British Household Panel Survey between 1991 and 2001. In contrast, Fuchs and Woessmann (2004) find a negative relationship between home computers and math and reading test scores using the international student-level Programme for International Student Achievement database. The conclusions drawn from this literature on the relationship between home computers and educational outcomes are limited; however, because of the mixed results, the primary focus is on test scores instead of other educational outcomes and on the lack of a comprehensive approach to addressing the potential endogeneity of computer ownership.[3]

The answers to whether home computers improve educational outcomes and whether the effects are sizeable are especially important in light of the large and persistent disparities in access to technology across racial, income, and other demographic groups. For example, estimates from the 2003 CPS indicate that roughly one-half of all African American and Latino children and less than half of all children living in families with incomes less than $30,000 have access to home computers. In comparison, 85%

1. See Stevenson (1999), Lowther, Ross, and Morrison (2001), Rockman et al. (2000), Silvernail and Lane (2004), Mitchell Institute (2004), and Urban-Lurain and Zhao (2004), for example, and Keefe, Farag, and Zucker (2003) for a summary of numerous programs.

2. A larger literature examines the classroom impacts of computers. See Kirkpatrick and Cuban (1998) and Noll et al. (2000) for reviews of this literature.

3. Schmitt and Wadsworth (2006) estimate regression models that include future computer ownership and find statistically insignificant estimates. A finding that future computer ownership has a positive relationship with achievement would raise concerns that computer ownership simply proxies for an unobserved factors such as educational motivation. Fairlie (2005) addresses the endogeneity issue by estimating instrumental variable models with cross-sectional data from the 2001 CPS. Computer ownership is found to increase school enrollment among teenagers.

of white, non-Latino children and 94% of children in families with incomes greater than $60,000 have access to home computers. If home computers are an important input into the educational process then disparities in access to technology may translate into future disparities in educational and labor markets and other economic outcomes.[4] Financial, informational, and technical constraints may limit the optimal level of investment in personal computers among some families.

In this study, we contribute to the sparse literature on the educational impacts of home computers by using the only two major U.S. panel data sets with recent information on computer ownership—the 2000–2003 CPS Computer and Internet Use Supplements (CIUS) matched to the CPS basic monthly files and the National Longitudinal Survey of Youth 1997 (NLSY97)—and employing several empirical strategies to attempt to identify the causal effects of home computers on high school graduation and other educational outcomes. The detailed panel data available in the CPS and NLSY97 allow for the estimation of specifications that include detailed home environment controls, instrumental variables, fixed effects, and future computer ownership. We explore the relationship between home computer and high school graduation, grades, school suspension, and criminal activities and present a simple theoretical model to shed light on potential mechanisms. This comprehensive approach has not been taken in the previous literature.

We find fairly consistent evidence that home computers have a strong positive relationship with high school graduation and additional educational outcomes. The estimated effects of home computers are generally similar even after controlling for detailed, and typically unobservable, measures of the home environment and extracurricular activities, instrumental variables, and fixed effects. We also perform several falsification tests with the data. Specifically, we do not find evidence of a strong relationship between educational outcomes and future computer ownership, cable television, or the presence of a dictionary at home, which may be correlated with unobservables but cannot or are unlikely to have causal effects. The estimates also suggest that home computers may increase high school graduation partly by reducing nonproductive activities, such as truancy and crime, among children.

4. See Noll et al. (2000) and Crandall (2000) for an example of the academic debate over the importance of the digital divide, and Servon (2002) for a discussion of policies addressing the digital divide.

II. THEORY

Before turning to the empirical results, we first present a simple theoretical model of high school graduation that illustrates the potential effects of home computers. A linear random utility model of the decision to graduate from high school is used. Define U_{i0} and U_{i1} as the ith person's indirect utilities associated with not graduating from high school and graduating from high school, respectively. These indirect utilities can be expressed as:

$$U_{i0} = \alpha_0 + \beta_0' X_i + \gamma_0 C_i + \lambda_0 t(W_i, C_i) + \theta Y_0(Z_i, C_i) + \varepsilon_{i0} \tag{1}$$

and

$$U_{i1} = \alpha_1 + \beta_1' X_i + \gamma_1 C_i + \lambda_1 t(W_i, C_i) + \theta Y_1(Z_i, C_i) + \varepsilon_{i1}, \tag{2}$$

where X_i, Z_i, and W_i are individual, parental, family, geographical, and school characteristics, C_i is the presence of a home computer, Y_0 and Y_1 are expected future earnings, and t is the child's achievement (e.g., test score), and ε_i is an additive error term. X_i, Z_i, and W_i do not necessarily include the same characteristics. Achievement is determined by the characteristics, W_i, and the presence of computers is allowed to have different effects on the utility from the two educational choices. Expected earnings differ between graduating from high school and not graduating from high school and are functions of the characteristics, Z_i, and home computers.

In the simple model, there are three major ways in which home computers affect educational outcomes. First, there is a direct effect of having a home computer on the utility of graduating from high school, γ_1. Personal computers make it easier to complete homework assignments through the use of word processors, spreadsheets, Internet browsers, and other software, thus increasing the utility from completing schoolwork (Lenhart et al. 2001). Although many students could use computers at school and libraries, home access represents the highest quality access in terms of availability and autonomy, which may provide the most benefits to the user. Access to a home computer may also familiarize the student with computers increasing the returns to computer use in the classroom or increasing preparation for class (Mitchell Institute 2004; Underwood, Billingham, and Underwood 1994). Estimates reported below indicate that approximately nine of ten high school students who have access to a home computer use that computer to complete school assignments. Furthermore, 46% of teachers report that lack of student access to technology/Internet is a barrier to effective use of technology in the classroom (SRI International 2002), and results from school laptop programs indicate very high rates of use of these computers for homework (Mitchell Institute 2004; Stevenson 1999; Urban-Lurain and Zhao 2004).

Access to home computers may have an additional effect on the utility of staying in school beyond making it easier to finish homework and complete assignments. In particular, the use of home computers may "open doors to learning" and doing well in school (Cuban 2001; Peck, Cuban, and Kirkpatrick 2002), and thus encourage some teenagers to graduate from school. The use of computers at home may also translate into more positive attitudes toward information technology potentially leading to long-term use (Selwyn 1998). Many teachers report that educational technology increases outside class time initiative among students (SRI International 2002).

Personal computers also provide utility from games, e-mail, chat rooms, downloading music, and other noneducation uses creating an opportunity cost from doing homework. The higher opportunity cost increases the utility of not graduating from high school. Computers are often criticized for providing a distraction for children through video games and the Internet or for displacing other more active forms of learning (Giacquinta, Bauer, and Levin 1993; Stoll 1995).[5] Fuchs and Woessmann (2004) find international evidence of a negative effect of home computers on test scores and suggest that it may be due to the distraction from effective learning. On the other hand, the use of computers at home, even for these noneducational uses, keeps children off the street, potentially reducing delinquency and criminal activities. Decreasing these nonproductive activities may decrease the utility of dropping out of school. The two opposing factors make it difficult to sign the effect of computers on the utility from not graduating from high school, γ_0.

Another way in which personal computers affect the high school graduation decision is through their effects on academic achievement. Computers could improve academic performance directly through the use of educational software. By making it more efficient to gather information, revise papers, and perform calculations, computers also could allow students to focus more on the content and substance of school assignments. As noted above, previous research finds that home computers are associated with higher test scores (Attewell and Battle 1999; Schmitt and Wadsworth 2006). Computers, however, may displace other more active forms of learning and decrease learning by emphasizing presentation (e.g., graphics) over content (Giacquinta, Bauer, and Levin 1993; Stoll 1995). The Internet also makes it substantially easier to plagiarize and find information from noncredible sources. Therefore, the theoretical effects of computers on academic achievement, $\delta t/\delta C$, and thus on the utility from graduating from high school, $\lambda_1 \delta t/\delta C$, is ambiguous.

Finally, home computers and the skills acquired from using them may alter the economic returns to completing high school. It is well known that information technology skills are becoming increasingly important in the labor market. The share of employment in information technology industries and occupations, and the share of employees using computers and the Internet at work have risen dramatically over the past decade (Freeman 2002). Computer skills may improve employment opportunities and wages, but mainly in combination with a minimal educational credential such as a high school diploma, implying that $\delta Y_1/\delta C > \delta Y_0/\delta C$.

Focusing on the high school graduation decision, we assume that the individual graduates from high school if $U_{i1} > U_{i0}$. The probability of graduating from high school, $y_i = 1$, is:

$$\begin{aligned} P(y_i = 1) = P(U_{i1} > U_{i0}) = F[(\alpha_1 - \alpha_0) \\ + (\beta_1 - \beta_0)' X_i + (\gamma_1 - \gamma_0) C_i \\ + \theta(Y_1(Z_i, C_i) - Y_0(Z_i, C_i)) \\ + (\lambda_1 - \lambda_0) t(W_i, C_i)] \end{aligned} \tag{3}$$

5. Computers may provide a similar distraction as television, although Zavodny (2006) does not find evidence of a negative effect of television on test scores.

where F is the cumulative distribution function of $\varepsilon_{i1} - \varepsilon_{i0}$. Following the standard random utility model framework (McFadden 1974), the equation can be estimated with a logit regression by assuming that $\varepsilon_{i1} - \varepsilon_{i0}$ has a type I extreme value distribution. In Equation (2.3), the separate effects of computers on the probability of graduating from high school are expressed in relative terms. Home computers have a direct effect on the graduation probability through relative utility and indirect effects through improving achievement and altering relative earnings.

Unfortunately, identification of the separate parameters is difficult. Relying solely on nonlinearities for identification of the separate functions is likely to produce unstable estimates, so preferably, we would like Z and W to contain variables that are not included in X.[6] However, instead of making these strong structural form and distributional assumptions and applying tenuous exclusion restrictions, we estimate the following reduced-form model:

$$(4) \qquad P(y_i = 1) = F[\alpha + \beta' \pi_\iota + \gamma C_i],$$

where π includes all individual, parental, family, and school characteristics.[7] The direct and indirect effects of the variables on the high school graduation decision are captured, but not separately identified. In particular, although the more detailed assertions of the theoretical model cannot be tested, the total effect of home computers on high school graduation can be estimated using Equation (2.4). The theoretical model does not provide a prediction regarding the sign or magnitude of the effect of home computers on high school graduation, and thus we turn to an empirical analysis.

III. DATA

The data sets used in the analysis are the matched CIUS and monthly basic files to the CPS and the NLSY97. These two panel data sets are the only major U.S. panel data sets with recent information on computer ownership and educational outcomes.

6. It is also difficult to find a good measure of achievement and calculate predicted earnings for both educational choices.

7. We are implicitly assuming, however, that Y(Z,C) and t(W,C) are separable in Z, W, and C.

The CIUS, conducted by the U.S. Census Bureau and the Bureau of Labor Statistics, is representative of the entire U.S. population and interviews approximately 50,000 households. It contains a wealth of information on computer and Internet use, including detailed data on types and location of use. To explore the relationship between computer ownership and subsequent high school graduation, we link CPS files over time to create longitudinal data. Households in the CPS are interviewed each month over a 4-mo period. Eight months later, they are reinterviewed in each month of a second 4-mo period. The rotation pattern of the CPS makes it possible to match information on individuals in a CIUS who are in their first 4-mo rotation period (e.g., October 2003) to information from the same month in their second 4-mo rotation period (e.g., October 2004). Thus, a 2-year panel can be created for up to half of all of the original CIUS respondents. To match these data, we use household and personal identification codes provided in the CPS and remove false matches using age, race, and sex codes.

The NLSY97 is a nationally representative sample of 8,984 young men and women who were between the ages of 12 and 16 on December 31, 1996.[8] Survey members were interviewed annually from 1997 to 2002. The NLSY97 contains an over sample of 2,236 black and Latino youth in the same age group. The NLSY97 contains information on computer ownership and detailed information on educational outcomes, criminal activities, and individual and family characteristics.

IV. HOME COMPUTERS AND HIGH SCHOOL GRADUATION

Although access to computers in the nation's schools is universal, access to home computers is far from 100% among children. Estimates from the 2003 CPS indicate that slightly more than one-fourth of all children in the United States do not have access to a computer at home. Among children aged 16–18 yr who have not graduated from high school, slightly more than 20% do not have access to a home computer (Table 1). Levels of access to home technology are substantially

8. See Center for Human Resource Research (2003) for additional details on the NLSY97 sample.

TABLE 1
Home Computer Use among Children Aged 16–18, CPS, 2003

	All Children	Enrolled in School	Not Enrolled
Percent of children with access to a home computer	79.6	81.1	56.4
Sample size	4,388	4,119	269
Percent of children with access to a home computer who use that computer	94.6	95.2	81.6
Sample size	3,543	3,392	151
Percent of home computer users who			
Use computer for school assignments	93.4	93.4	
Use computer for the Internet	86.9	87.4	74.5
Use computer for games	72.6	72.9	64.9
Use computer for electronic mail	78.2	78.8	62.9
Use computer for word processing	70.0	71.1	38.8
Use computer for graphics and design	45.0	45.5	33.4
Use computer for spreadsheets or databases	22.1	22.3	16.1
Sample size	3,357	3,234	123

Notes: The sample consists of children aged 16–18 who have not graduated from high school and live with at least one parent. All estimates are calculated using sample weights provided by the CPS.

lower for low-income and disadvantaged minority groups.[9]

Table 1 also reports estimates of patterns of computer use among teenagers. Not surprisingly, teenagers use their home computers—94.6% of teenagers who have access to a home computer use it. Computers also appear to be useful for completing school assignments. Conditioning on computer ownership, only 81.6% of teenagers not enrolled in school use computers at home compared to 95.2% of enrolled teenagers. Among school enrollees who use home computers, 93.4% report using them to complete school assignments. Another interesting finding is that 71.1% of enrolled computer users use their computer for word processing, whereas only 38.8% of nonenrolled computer users use their computer for word processing.

Teenagers also use home computers for many other purposes. The most common uses of home computers among teenagers are for the Internet (86.9%), games (72.6%), and e-mail (78.2%). Use of home computers for graphics and design (45.0%) and spreadsheets or databases (22.1%) in addition to word processing are also fairly common. None of these uses among high school students, however, is as prevalent as using home computers to complete school assignments. Concerns that home computers are only used for noneducational purposes such as playing games, listening to music, and e-mailing friends appear to be exaggerated.

At a minimum, estimates from the CPS indicate that home computers are useful for completing school assignments. Whether these students wrote better reports or could have completed similar quality school assignments at a library, community center, or school, however, is unknown. Furthermore, the prevalence of noneducational uses of home computers suggests that home computers may also provide a distraction that lessens or negates their educational impact. We now turn to examining the relationship between home computer ownership and high school graduation.

Table 2 reports estimates of high school graduation rates by previous computer ownership. The CPS sample includes children aged

TABLE 2
High School Graduation Rates, Matched CPS (2000–2004) and NLSY97

	No Home Computer	Home Computer	Difference
High school graduation rate by second survey year CPS (%)	56.7	73.3	16.6
Sample size	308	1,419	
High school graduation rate by age 19 NLSY97 (%)	70.7	94.2	23.5
Sample size	659	3,280	

Notes: The CPS sample consists of teenagers aged 16–18 who have completed 11th or 12th grade, but have not received a high school diploma in the first survey year. All estimates are calculated using sample weights provided by the CPS and NLSY97.

9. See Hoffman and Novak (1988). U.S. Department of Commerce (2002), Fairlie (2004), Goldfarb and Prince (2008), and Ono and Zavodny (2007) for more details on differences in computer and Internet use.

16–18 yr who live with at least one parent and report completing the 11th or 12th grade, but have not graduated from high school with a diploma in the first survey year. Computer ownership is determined in the first survey year, and high school graduation is determined in the second survey year.[10] Thus, the graduation rate that we use is defined as the percent of all teenagers at risk of graduating by the second survey date who actually graduate by the second survey date. In the NLSY97, home computer access is determined between the ages of 15 and 17 and high school graduation is measured by age 19. Using these definitions of high school graduation, we do not capture individuals eventually returning to complete high school or a General Educational Development test (GED) after age 19 in the NLSY97 or after the second survey year in the CPS.[11]

For both measures, high school graduation rates are much higher among teenagers with access to a home computer than teenagers without access to a home computer. Estimates from the CPS indicate that 73.3% of teenagers who have home computers graduate from high school by the following year compared to only 56.7% of teenagers who do not have home computers. Estimates from the NLSY97 provide evidence of a similarly large difference in graduation rates. Nearly 95% of children who had a home computer between the ages of 15 and 17 graduated from high school by age 19 compared to only 70.7% of children who did not have a home computer.

Estimates from the CPS and NLSY97 clearly indicate that teenagers with home computers are more likely to graduate from high school than children without home computers. The difference in graduation rates is large and not much smaller than differences generated by extreme changes in parental education or family income. Although these estimates indicate large differences, they do not control for other factors, such as parental education and family income, which are likely to be strongly correlated with computer ownership.

V. ESTIMATING THE EFFECTS OF HOME COMPUTERS ON HIGH SCHOOL GRADUATION

To control for parental education, family income, and other characteristics, we estimate probit regressions for the probability of graduating from high school using the two data sets. We discuss the results from the CPS first, which are reported in Table 3. All specifications include the sex, race, immigrant status' and age of the child; number of children in the household; family income; home ownership; region of the country; central city status; state-level unemployment rate; average expenditures per pupil; and dummy variables for the age requirements of compulsory schooling laws, in addition to home computer ownership (see Table A1 for means).[12] For both the mother and father, we control for presence in the household, education level, labor force status, and occupation. All the independent variables are measured in the first survey year before measurement of high school graduation. Mother's and father's education levels generally have a positive effect (although not statistically significant) on the graduation probability, and home ownership has a positive effect on graduation. Latino children, boys, and children with many siblings are less likely to graduate from high school, all else equal.

Home computers are associated with graduating from high school by the following year. The reported marginal effects on the home computer variable are large, positive, and statistically significant. It implies that having a home computer is associated with an 8.1 percentage point higher probability of graduating from high school.[13] The effect of this variable on the probability of high school graduation is roughly comparable in magnitude to that

10. Regression estimates are not sensitive to excluding the relatively small number of children reporting completing 12th grade, but not graduating in the first survey year, or the children graduating with a GED.

11. Dropping out of school, however, is associated with a much lower probability of returning to and completing high school. For example, estimates from the NLSY indicate that 50% of dropouts from 1979–1986 returned to school by 1986 (Chuang 1997), and estimates from the CPS indicate that only 42% of 22–24 yr olds who did not complete high school received a GED (U.S. Department of Education 2001).

12. State-level unemployment rates are from Bureau of Labor Statistics (2002), and the age requirements for compulsory schooling laws and average expenditures per pupil are from U.S. Department of Education (2002).

13. We also estimate a specification that includes Internet access at home in addition to home computer. The marginal effects estimate on home Internet access is small, negative, and statistically insignificant.

TABLE 3

Probit, Bivariate Probit, and 2SLS Regressions for High School Graduation and Home Computer (Marginal Effects) Matched CPS, 2000–2004

Explanatory Variables	Specification (1)	(2)	(3)		(4)
Dependent Variable	**High School Graduation**	**High School Graduation**	**Computer Bivariate**	**High School Graduation Bivariate**	**High School Graduation**
Model Type	**Probit**	**Probit**	**Probit**	**Probit**	**2SLS**
Female	0.0649 (0.0267)	0.0648 (0.0267)	0.0199 (0.0172)	0.0646 (0.0271)	0.0618 (0.0268)
Black	−0.0319 (0.0460)	−0.0318 (0.0459)	−0.0652 (0.0359)	−0.0305 (0.0477)	−0.0247 (0.0663)
Latino	−0.0997 (0.0513)	−0.0997 (0.0513)	−0.1279 (0.0431)	−0.0974 (0.0566)	−0.0857 (0.0910)
Immigrant	0.0186 (0.0564)	0.0186 (0.0563)	−0.0051 (0.0317)	0.0189 (0.0571)	0.0300 (0.0625)
Family income: missing	−0.0935 (0.0544)	−0.0938 (0.0543)	0.0291 (0.0265)	−0.0950 (0.0549)	−0.0845 (0.0691)
Family income: $15,000 to $30,000	−0.0322 (0.0558)	−0.0323 (0.0558)	0.0427 (0.0234)	−0.0334 (0.0566)	−0.0253 (0.0673)
Family income: $30,000 to $50,000	0.0270 (0.0479)	0.0267 (0.0479)	0.0715 (0.0205)	0.0248 (0.0551)	0.0261 (0.0910)
Family income: $50,000 to $75,000	−0.0490 (0.0552)	−0.0494 (0.0550)	0.0910 (0.0206)	−0.0517 (0.0638)	−0.0453 (0.1024)
Family income: greater than $75,000	−0.0093 (0.0519)	−0.0097 (0.0518)	0.0928 (0.0261)	−0.0116 (0.0581)	−0.0136 (0.0913)
Home ownership	0.0899 (0.0405)	0.0900 (0.0405)	0.0782 (0.0281)	0.0882 (0.0436)	0.0856 (0.0688)
Mother—high school graduate	0.0173 (0.0486)	0.0173 (0.0486)	0.0684 (0.0232)	0.0151 (0.0561)	0.0220 (0.0929)
Mother—some college	0.0741 (0.0487)	0.0741 (0.0487)	0.0957 (0.0228)	0.0714 (0.0600)	0.0743 (0.1170)
Mother—college graduate	0.0347 (0.0578)	0.0349 (0.0578)	0.0834 (0.0260)	0.0323 (0.0659)	0.0429 (0.1101)
Father—high school graduate	0.0747 (0.0512)	0.0746 (0.0512)	−0.0626 (0.0375)	0.0754 (0.0547)	0.0774 (0.0648)
Father—some college	0.0512 (0.0555)	0.0511 (0.0555)	0.0209 (0.0329)	0.0507 (0.0569)	0.0479 (0.0594)
Father—college graduate	0.0550 (0.0610)	0.0550 (0.0610)	0.0570 (0.0352)	0.0545 (0.0627)	0.0508 (0.0634)
Home computer	0.0811 (0.0414)	0.0819 (0.0419)		0.0961 (0.1780)	0.1067 (0.5110)
Newest computer purchased in first survey year		−0.0034 (0.0368)			
Father uses Internet at work			0.0610 (0.0232)		
Mother uses Internet at work			0.0454 (0.0212)		
Another teenager present in household			0.0500 (0.0238)		
Mother's occupation controls	Yes	Yes	Yes	Yes	Yes
Father's occupation controls	Yes	Yes	Yes	Yes	Yes
ρ			−0.0248 (0.2855)		
R^2/pseudo-R^2	0.1174	0.1174			0.1419
Mean of dependent variable	0.7050	0.7050	0.8211	0.7050	0.7050
Sample size	1,711	1,711	1,711		1,711

Notes: The sample consists of teenagers aged 16–18 who have completed 11th or 12th grade but have not received a high school diploma in the first survey year. Marginal effects and their standard errors (in parentheses) are reported. All specifications include a constant; number of children in household; dummy variables for age, region, central city status, survey year, rotation group, mother's and father's presence in the household, and labor force status; the state-level unemployment rate; expenditures per pupil; and age requirements of compulsory schooling laws. All estimates are calculated using sample weights provided by the CPS.

implied by being a girl or owning a home. It is also less than one-half the raw difference in high school graduation rates reported in Table 2, indicating that computer ownership is strongly correlated with the controls.

A. Additional Probit Estimates

One concern with these results is that some students may have limited exposure to recently purchased computers, thus reducing the estimated effect on high school graduation. Although the CPS does not provide information on the timing of when all computer purchases were made, it provides information on when the newest computer was obtained by the family. To insure longer exposure to having a computer and to further eliminate concerns regarding reverse causation or joint determination, we include an additional dummy variable measuring whether the newest computer was purchased in the first survey year (Specification 2). A problem with this measure is that a computer purchased in the first survey year may represent a replacement for an older model. The marginal effects estimate on home computer, which now measures the relationship for computers purchased at the latest in the year before the first survey year (or 21–34 mo before measurement of high school graduation), is very similar to the original estimate. The interaction estimate is small and statistically insignificant. Therefore, the large estimated relationship between home computers and high school graduation is not sensitive to the inclusion of recently purchased computers.

Although not reported, we also estimate a specification that includes the number of computers per person in the household. A limitation of the data, however, is that the measure of the number of computers in the CPS is censored at 3. Thus, we include a per capita measure for households with one or two computers and a dummy variable for three or more computers. We find a large, positive, and nearly statistically significant marginal effects estimate on the per capita computer measure. We also find a positive and statistically significant estimate on the dummy variable for three or more computers. Although we do not have complete information on the number of computers, the results indicate that the level of access to home computers is also associated with the probability of graduating from high school.

As a falsification test, we also examine whether cable television is associated with a higher probability of graduating from high school. The 2003 CPS includes information on whether the household has cable television. Similarly to computer ownership, cable television may be correlated with unobserved family wealth or permanent income. Because we do not expect access to cable television to increase the probability of high school graduation among teenagers, the finding of a similarly sized estimate as the one for home computers may indicate that the estimated home computer effect is simply capturing the correlation with an unobserved family characteristic. We find a small and statistically insignificant marginal effects estimate on the cable television dummy variable when it is included alone or in addition to the home computer dummy variable. The home computer estimate remains large, positive, and statistically significant.

B. Bivariate Probit Estimates from the CPS

Although the probit models include numerous controls for individual, parental, and family characteristics, estimates of the effects of home computers on high school graduation may be biased. For example, if children with higher levels of academic ability or children with more "educationally motivated" parents are more likely to have access to home computers, then the probit estimates may overstate the effects of home computers on high school graduation. On the other hand, if parents of children with less academic ability or time to spend with their children are more likely to purchase computers, then the probit estimates may understate the effects. In either case, the effects of unobserved factors, such as academic ability and parental motivation, may invalidate a causal interpretation of the previous results.

A potential solution to this problem is to estimate a bivariate probit model in which equations for the probability of high school graduation and the probability of having a home computer are simultaneously estimated. We exclude dummy variables for whether the child's mother and father use the Internet at work and whether another teenager is present in the household from the equation determining high school graduation. The exclusion of these variables is useful for identification, improving the stability of estimates.[14] These three variables should affect the probability of purchasing a computer, but should not have a large effect on high school graduation (after controlling for family income, parental education, parental occupations, and number of children). Internet use at work may be associated with higher earnings, but this effect should be controlled for by the inclusion of family income. Similarly, the presence of an additional teenager may increase demand for home computers because of high rates of use for this age group, but it is unlikely to have a large effect on high school graduation after controlling for the number of children in the household.

Before discussing the bivariate probit results, we provide some evidence on the validity of these exclusion restrictions by examining correlations with having a home computer and high school graduation (reported in Table 4). Computer ownership rates are higher when the mother uses the Internet at work, the father uses the Internet at work, and there is another teenager present in the household, indicating that all three instruments are strongly correlated with having a home computer. In addition, controlling for other variables in probit models, we find that the estimates on all instruments are individually and jointly statistically significant with low *p* values. On the other hand, all of the instruments are uncorrelated with high school graduation rates after controlling for other variables including home computer ownership in probit regressions. In all cases, the marginal effect estimates are small and statistically insignificant. Although this is not a formal test of the validity of the exclusion restrictions, it suggests that the excluded variables are correlated with home computers, but do not have a strong independent correlation with high school graduation.

Estimates from the bivariate probit model for the probability of high school graduation and having a home computer are reported in Specification 3 of Table 3. We first briefly discuss the results for the home computer equation reported in the first column of Specification 3. The probability of owning a home computer generally increases with parental education. Education may be a proxy for wealth or permanent income and have an effect on the budget constraint or may have an effect on preferences for computers through pure tastes, exposure, perceived usefulness, or conspicuous consumption. Family income and home ownership are also important determinants of owning a computer. The estimated positive relationships are likely to be primarily due to their effects on the budget constraint through income and wealth; however, they may also be due to effects on preferences. African American and Latino children have lower probabilities of having a home computer than do white children, all else equal.

All three excluded variables have large, positive, and statistically significant marginal effects estimates in the home computer equation. Father's Internet use at work, mother's Internet use at work, and having an additional teenager increase the probability of having a home computer by 6.1, 4.5, and 5.0 percentage points, respectively.

The second column in Specification 3 reports the bivariate probit results for the high school graduation equation. The marginal effects estimate on home computers remains large and positive but is no longer statistically significant.[15] The point estimate implies that the presence of a home computer increases the probability of school enrollment among children by 9.6 percentage points. The magnitude of the estimate is comparable to the probit estimate. In fact, we cannot reject the null hypothesis that the unobserved factors affecting home computer ownership and high school graduation are uncorrelated (i.e., $\rho = 0$). The test statistic is very small providing evidence that the original probit estimates are consistent and that estimation of the bivariate probit may not be needed.

The finding of a positive bivariate probit estimate is consistent with estimates from earlier data for school enrollment. Using cross-sectional data from the 2001 CPS, Fairlie (2005) estimates a bivariate probit model for home computer ownership and school enrollment and finds positive estimates. Only the relationship between home computers and school enrollment among teenagers is

14. Identification is possible using the nonlinearity of the bivariate probit, but the estimates are not very stable to alternative specifications.

15. The number of parameters being estimated in the bivariate probit is more than double the original probit using the same sample size.

TABLE 4
Selected Statistics for Excluded Variables, Matched CPSs, 2000–2004

	Home Computer				High School Graduation			
	Probit				Probit			
	Raw Difference	Marginal Effect	Wald Statistic	*p* value	Raw Difference	Marginal effect	Wald Statistic	*p* value
Father uses the Internet at work	0.2248	0.0624	5.22	0.0223	0.0594	−0.0475	1.55	0.2126
Mother uses the Internet at work	0.1828	0.0501	4.55	0.0330	0.0793	0.0081	0.05	0.8197
Another teenager present in household	0.0494	0.0528	4.51	0.0337	−0.0429	0.0019	0.00	0.9579
Joint significance test of all exclusion restrictions			12.99	0.0047			1.75	0.6260

Notes: See notes to Table 3. Probit regressions include the instrument (alone), and the independent variables listed in Table 3.

examined, however, because of the use of cross-sectional data. Computer and Internet use by the child's mother and father are used as excluded variables.

We also estimate the model with two-stage least squares (2SLS) to investigate whether the choice of functional form is driving the results (reported in Specification 4).[16] In the 2SLS regression, the coefficient estimate on home computer is roughly similar in magnitude to the bivariate probit marginal effects estimate (.1067 compared to .0961). The standard error, however, is large and the coefficient estimate is not statistically significant. Although the statistical imprecision is troubling and we cannot rule out zero effects with the 2SLS estimates, we are at least reassured that the estimates are similar to the bivariate probit estimates. The bivariate probit estimates do not appear to be driven simply by the functional form of the model. The results of a Hausman test also provide no evidence that home computers are endogenous in the 2SLS model and that ordinary least squares (OLS) estimates are biased. The OLS estimates are very similar to the probit marginal effects and are statistically significant.

Returning to the bivariate probit model, we also check the sensitivity of the bivariate probit estimates to various combinations of exclusion restrictions. Although we do not find evidence that the original probit estimates are inconsistent, the analysis is useful for completeness and addresses concerns that one of the excluded variables is problematic. Specifically, we estimate bivariate probit models in which we remove mother's Internet use at work (which had the weakest relationship with home computers), and use only father's Internet use at work or the presence of another teenager as the exclusion restriction (see Table 5). In all cases, the marginal effects estimate on home computer is large, positive, and roughly similar in magnitude to the original estimates. None of the estimates, however, is statistically significant. Overall, the home computer marginal effects estimate is not sensitive to the choice of exclusion restrictions in the bivariate probit models.

As a final check of the sensitivity of the bivariate probit estimates, we add another exclusion restriction to the model. If network effects exist in the adoption of computers then the rate of computer ownership in the local area should affect the probability of owning a computer (Goolsbee and Klenow 2002). At the same time, local levels of computer ownership should not have a large effect on high school graduation rates after controlling for education, family income, and home ownership. Therefore, we use computer ownership rates in the metropolitan area as an additional exclusion restriction in the bivariate probit. Estimates are reported in Specification 4 of Table 5. The addition of this exclusion restriction has little effect on the home computer marginal effects estimate.

The findings from the bivariate probit and 2SLS models do not contradict our original findings of a positive association between having a home computer and graduating from

16. The first-stage regressions are not reported, but include the same controls and additional variables as the home computer equation reported in Specification 3.

TABLE 5
Additional Bivariate Probit Regressions (Marginal Effects), Matched CPS, 2000–2004

	Specification			
Explanatory Variables	**(1)**	**(2)**	**(3)**	**(4)**
Home computer	0.0633 (0.1918)	0.0675 (0.1985)	0.0922 (0.1773)	0.0852 (0.1703)
Excluded variables				
Father uses Internet at work	0.0674 (0.0268)	0.0680 (0.0237)		0.0602 (0.0261)
Mother uses Internet at work				0.0464 (0.0230)
Another teenager present in household	0.0494 (0.0240)		0.0512 (0.0247)	0.0500 (0.0236)
MSA-level home computer rate				0.2019 (0.1195)
ρ	0.0296 (0.3102)	0.0226 (0.3256)	−0.0182 (0.2828)	−0.0067 (0.2740)
Sample size	1,711	1,711	1,711	1,711

Note: See notes to Table 3.

high school from probit regressions. Although the estimated magnitude of the relationship is roughly similar in the probit, bivariate probit, and 2SLS models, there is no evidence of correlated unobservables, and the bivariate probit estimates are not sensitive to different estimation techniques and exclusion restrictions, we are still left with some uncertainty because of the lack of precision in the bivariate probit and 2SLS estimates. We now turn to an analysis of the relationship using data from the NLSY97.

C. Estimates from the NLSY97

Estimates from probit regressions for the probability of graduating from high school using the NLSY97 are reported in Table 6. The dependent variable equals 1 if the individual graduates from high school by age 19. Computer ownership is measured between ages 15 and 17 and most other variables are measured in the first survey year, 1997.[17] All specifications include similar individual, parental, and family characteristics as in the CPS specifications. In addition to these controls, we include dummy variables for more detailed living arrangements, whether the child's mother was a teen mother, whether any grandparent is a college graduate, household net worth, and a continuous measure of household income in Specification 1. High school graduation generally increases with parents' and grandparents' education, household net worth, and household income.

The NLSY97 provides additional evidence of a strong positive relationship between computer ownership and high school graduation after controlling for individual, parental, and family characteristics. The marginal effects estimate on home computer is large, positive, and statistically significant.[18] Having a home computer as a teenager is associated with a .0685 higher probability of graduating from high school.[19] The estimate implies a larger difference in graduation probabilities than either having a college graduate mother or having a college graduate father (relative to high school dropouts).

The NLSY97 also includes information on religion and private school attendance. We include these measures as additional controls in Specification 2. Their inclusion has little effect on the home computer marginal effects estimate. To further account for potential unobserved factors correlated with having a home computer, we add two typically unobservable measures of the home environment in Specification 3—whether a language other than English is spoken at home and whether there is a quiet place to study at home. Although the estimate is insignificant at conventional levels, speaking another language at home is associated with a lower probability of graduation. The marginal effects estimate on whether there is a quiet place to study is very

17. Children living alone in 1997 are excluded from the sample.

18. We also estimate separate regressions that include interactions between home computers and race, income or gender and, in almost all cases, do not find large, statistically significant interaction effects.

19. We find a larger positive marginal effects estimate when the dependent variable is high school graduation in the last survey year, 2002.

TABLE 6
Probit Regressions for High School Graduation (Marginal Effects), NLSY97

	Specification				
Explanatory Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Female	0.0225 (0.0065)	0.0222 (0.0065)	0.0224 (0.0064)	0.0214 (0.0063)	0.0210 (0.0063)
Black	0.0251 (0.0070)	0.0278 (0.0071)	0.0266 (0.0070)	0.0246 (0.0071)	0.0245 (0.0071)
Latino	−0.0037 (0.0098)	−0.0128 (0.0113)	−0.0014 (0.0117)	−0.0007 (0.0116)	−0.0004 (0.0116)
Asian	0.0350 (0.0116)	0.0336 (0.0121)	0.0342 (0.0110)	0.0336 (0.0109)	0.0333 (0.0112)
Immigrant	−0.0165 (0.0156)	−0.0194 (0.0162)	−0.0157 (0.0154)	−0.0148 (0.0152)	−0.0141 (0.0151)
Lives with mom and step dad	−0.0338 (0.0152)	−0.0307 (0.0149)	−0.0303 (0.0147)	−0.0273 (0.0142)	−0.0261 (0.0141)
Lives with dad and step mom	−0.0425 (0.0331)	−0.0470 (0.0346)	−0.0466 (0.0341)	−0.0439 (0.0333)	−0.0425 (0.0329)
Lives with mom only	−0.0346 (0.0110)	−0.0324 (0.0108)	−0.0331 (0.0108)	−0.0324 (0.0107)	−0.0313 (0.0106)
Lives with dad only	−0.1173 (0.0396)	−0.1140 (0.0400)	−0.1176 (0.0406)	−0.1165 (0.0404)	−0.1165 (0.0403)
Lives with guardian	−0.0637 (0.0237)	−0.0632 (0.0238)	−0.0631 (0.0237)	−0.0632 (0.0237)	−0.0625 (0.0236)
Mom was teenager at first birth	−0.0128 (0.0088)	−0.0114 (0.0087)	−0.0111 (0.0086)	−0.0112 (0.0085)	−0.0112 (0.0085)
Mother high school graduate	0.0032 (0.0077)	0.0022 (0.0077)	0.0019 (0.0076)	0.0014 (0.0076)	0.0008 (0.0076)
Mother some college	0.0217 (0.0082)	0.0206 (0.0083)	0.0201 (0.0082)	0.0188 (0.0082)	0.0185 (0.0083)
Mother college graduate	0.0474 (0.0083)	0.0468 (0.0083)	0.0459 (0.0081)	0.0452 (0.0081)	0.0451 (0.0081)
Father high school graduate	0.0274 (0.0074)	0.0273 (0.0074)	0.0257 (0.0073)	0.0247 (0.0073)	0.0245 (0.0073)
Father some college	0.0248 (0.0083)	0.0257 (0.0082)	0.0247 (0.0081)	0.0235 (0.0081)	0.0233 (0.0082)
Father college graduate	0.0409 (0.0084)	0.0407 (0.0083)	0.0399 (0.0082)	0.0378 (0.0084)	0.0376 (0.0084)
Grandparent college graduate	0.0234 (0.0091)	0.0243 (0.0089)	0.0234 (0.0089)	0.0228 (0.0088)	0.0227 (0.0088)
Household net worth (10,000s)	0.0013 (0.0006)	0.0014 (0.0006)	0.0013 (0.0006)	0.0013 (0.0005)	0.0014 (0.0006)
Household net worth squared (10,000s)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)
Household income (10,000s)	0.0045 (0.0028)	0.0042 (0.0028)	0.0039 (0.0028)	0.0038 (0.0028)	0.0037 (0.0028)
Household income squared (10,000s)	−0.0001 (0.0002)	−0.0001 (0.0002)	−0.0001 (0.0002)	−0.0001 (0.0001)	−0.0001 (0.0002)
Private school		−0.0230 (0.0152)	−0.0227 (0.0150)	−0.0219 (0.0148)	−0.0216 (0.0148)
Other language spoken at home			−0.0225 (0.0153)	−0.0226 (0.0154)	−0.0228 (0.0154)
Quiet place to study in household			0.0036 (0.0096)	0.0040 (0.0096)	0.0028 (0.0095)
Youth attends extra classes				0.0189 (0.0066)	0.0184 (0.0067)
Dictionary present in household					0.0168 (0.0147)
Home computer by age 17	0.0685 (0.0133)	0.0691 (0.0134)	0.0679 (0.0133)	0.0648 (0.0130)	0.0632 (0.0129)
Religion dummies	No	Yes	Yes	Yes	Yes
Pseudo-R^2	0.2300	0.2344	0.2366	0.2389	0.2389
Mean of dependent variable	0.9028	0.9028	0.9027	0.9025	0.9027
Sample size	3,715	3,673	3,670	3,650	3,648

Notes: (1) The sample in all specifications consists of teenagers living with their parents in 1997. (2) All specifications include a constant, number of children in the househould, dummy variables for the quarter of birth, region, central city status, and missing categories for some variables, and school size, student-teacher ratio and local unemployment rate.

small and statistically insignificant. The addition of these home environment controls has no effect on the estimated relationship between home computers and high school graduation.

As a final sensitivity check, we estimate a specification that includes a dummy variable indicating whether the child takes extra classes or lessons, such as music, dance, or foreign language lessons. This variable is likely to represent a good proxy for educational motivation. Indeed, we find a positive and statistically significant marginal effects estimate on the variable. Even after controlling for this variable, however, we continue to find a strong positive relationship between access to a home computer and high school graduation.

Estimates from the NLSY97 indicate that home computers are associated with more than a .06 higher probability of graduating from high school, which is similar in magnitude to the estimates from the CPS. These estimates are extremely robust to controlling for the exceptionally rich set of individual, parental, family, and home environment characteristics available in the NLSY97.

D. Dictionaries as a Falsification Test

The NLSY97 provides another falsification test for interpreting the estimated relationship between home computers and high school graduation. The NLSY97 includes information on whether a dictionary is present in the household. It is likely that the presence of a dictionary is correlated with the educational motivation of the family, but it is unlikely that dictionaries have a large effect on educational outcomes. A dictionary may be useful for completing some school assignments, but it is unlikely to have a discernable effect on the likelihood that a child graduates from high school. Specification 5 of Table 6 reports estimates from a model that includes the home dictionary variable. The marginal effects estimate on the presence of a dictionary at home is statistically insignificant and is much smaller than the home computer estimate. The home computer marginal effects estimate is now .0632, which is only slightly smaller than the previous specification. Finally, we find a small and statistically insignificant estimate on the presence of a dictionary at home when we include it without the home computer variable. These results provide additional evidence that is consistent with the hypothesis that the presence of home computers increases the probability of graduating from high school.

E. Grades and Home Computers

Estimates from the CPS and NLSY97 indicate a strong positive relationship between home computers and high school graduation; however, we know very little about the underlying causes of this relationship. The similarity of the bivariate probit results and the rich set of controls included in the NLSY97 regressions suggest that the relationship is not solely driven by an unobserved factor. An examination of the relationship between home computers and additional educational outcomes may shed some light on the underlying causes of the relationship and provide further evidence on the educational impacts of home computers.

The NLSY97 includes information on overall grades obtained in high school, which can be used to estimate the student's grade point average (GPA). The theoretical model presented above indicates that home computers may increase GPAs by making it easier to complete school assignments, keeping children out of trouble, or increasing interest in schoolwork. On the other hand, home computers may decrease GPAs by providing a distraction through video games or emphasizing presentation over content.

Table 7 reports estimates for linear regressions for GPAs.[20] The mean GPA in the sample is a 2.8 or roughly a B average. We include the same sets of control variables as those reported in Table 6. Home computers are associated with higher GPAs. The coefficient on home computer is large, positive, and statistically significant. It corresponds to an increase of .216 points, which is roughly two-thirds the value of a plus or minus grade. The implied effect is comparable in magnitude to having a college-educated mother.

In Specifications 2–4, we include the additional measures of religion, private school,

20. The measure of GPA in the NLSY97 is categorical capturing major cutoffs. We also estimated an ordered probit model with fewer independent variables and find similar results as the linear regression. We find that home computers have a positive and statistically significant relationship with GPAs.

TABLE 7
OLS Regressions for High School GPA, NLSY97

	Specification				
Explanatory Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Female	0.3514 (0.0231)	0.3502 (0.0232)	0.3534 (0.0232)	0.3415 (0.0233)	0.3400 (0.0233)
Black	−0.1406 (0.0329)	−0.1425 (0.0345)	−0.1451 (0.0345)	−0.1590 (0.0345)	−0.1602 (0.0345)
Latino	−0.0488 (0.0357)	−0.0566 (0.0376)	−0.0580 (0.0439)	−0.0581 (0.0438)	−0.0586 (0.0439)
Asian	0.2307 (0.0919)	0.2189 (0.0919)	0.2176 (0.0928)	0.2356 (0.0935)	0.2338 (0.0935)
Immigrant	0.0285 (0.0510)	0.0312 (0.0513)	0.0245 (0.0517)	0.0412 (0.0516)	0.0432 (0.0516)
Lives with mom and step dad	−0.1504 (0.0395)	−0.1475 (0.0399)	−0.1451 (0.0399)	−0.1392 (0.0397)	−0.1396 (0.0397)
Lives with dad and step mom	−0.2104 (0.0800)	−0.2254 (0.0805)	−0.2279 (0.0804)	−0.2078 (0.0805)	−0.2072 (0.0806)
Lives with mom only	−0.1229 (0.0318)	−0.1216 (0.0320)	−0.1214 (0.0321)	−0.1191 (0.0320)	−0.1189 (0.0321)
Lives with dad only	−0.2168 (0.0643)	−0.2178 (0.0649)	−0.2191 (0.0649)	−0.2216 (0.0648)	−0.2234 (0.0648)
Lives with guardian	−0.0776 (0.0556)	−0.0808 (0.0562)	−0.0814 (0.0562)	−0.0784 (0.0562)	−0.0806 (0.0562)
Mom was teenager at first birth	−0.1141 (0.0332)	−0.1048 (0.0334)	−0.1043 (0.0334)	−0.1051 (0.0334)	−0.1047 (0.0334)
Mother high school graduate	0.0723 (0.0339)	0.0742 (0.0341)	0.0737 (0.0341)	0.0774 (0.0341)	0.0755 (0.0341)
Mother some college	0.1165 (0.0394)	0.1137 (0.0396)	0.1147 (0.0396)	0.1086 (0.0395)	0.1069 (0.0395)
Mother college graduate	0.2274 (0.0459)	0.2208 (0.0460)	0.2235 (0.0459)	0.2171 (0.0459)	0.2155 (0.0459)
Father high school graduate	0.1250 (0.0352)	0.1243 (0.0354)	0.1235 (0.0355)	0.1252 (0.0355)	0.1250 (0.0355)
Father some college	0.1859 (0.0441)	0.1868 (0.0442)	0.1828 (0.0443)	0.1731 (0.0443)	0.1726 (0.0443)
Father college graduate	0.2837 (0.0460)	0.2838 (0.0462)	0.2790 (0.0462)	0.2646 (0.0462)	0.2641 (0.0463)
Grandparent college graduate	0.0918 (0.0353)	0.0892 (0.0356)	0.0899 (0.0356)	0.0848 (0.0356)	0.0843 (0.0355)
Household net worth (10,000s)	0.0052 (0.0016)	0.0050 (0.0016)	0.0049 (0.0016)	0.0047 (0.0016)	0.0046 (0.0016)
Household net worth squared (10,000s)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)
Household income (10,000s)	0.0114 (0.0091)	0.0126 (0.0092)	0.0130 (0.0092)	0.0121 (0.0092)	0.0120 (0.0092)
Household income squared (10,000s)	−0.0005 (0.0004)	−0.0005 (0.0004)	−0.0005 (0.0004)	−0.0005 (0.0004)	−0.0005 (0.0004)
Private school		−0.0279 (0.0419)	−0.0286 (0.0419)	−0.0273 (0.0419)	−0.0297 (0.0420)
Other language spoken at home			0.0100 (0.0450)	0.0059 (0.0450)	0.0049 (0.0450)
Quiet place to study in household			0.1253 (0.0390)	0.1247 (0.0389)	0.1197 (0.0393)
Youth attends extra classes				0.1516 (0.0264)	0.1517 (0.0264)
Dictionary present in household					0.0540 (0.0545)
Home computer by age 17	0.2163 (0.0329)	0.2153 (0.0330)	0.2094 (0.0331)	0.2060 (0.0330)	0.2031 (0.0331)
Religion dummies	No	Yes	Yes	Yes	Yes
R^2	0.1993	0.1985	0.2004	0.2080	0.2080
Mean of dependent variable	2.8198	2.8252	2.8268	2.8272	2.8278
Sample size	4,067	4,008	4,001	3,978	3,975

Note: See notes to Table 6.

home environment, and whether the youth attends extra classes. Although some of these variables have large effects on GPAs, the coefficient estimate on home computer is not sensitive to their inclusion. Specification 5 reports the results of our falsification test using the presence of a dictionary at home. The coefficient is relatively small and statistically insignificant and essentially has no effect on the home computer estimate.

These estimates provide further evidence that is consistent with the hypothesis that home computers have a positive effect on educational outcomes. They are also consistent with earlier estimates from the 1988 National Educational Longitudinal Survey (NELS). Attewell and Battle (1999) find that test scores and grades are positively related to home computer use even after controlling for differences in individual, parental, and family characteristics. Similar to the NLSY97, the NELS allows them to control for several typically unobservable characteristics of the educational environment in the household.[21] These results also suggest that home computers may affect school performance instead of only affecting the likelihood that a child is enrolled and finishes high school.

F. School Suspension

Personal computers may provide utility from games, e-mail, chat rooms, downloading music, and other noneducation uses. Although these types of activities may provide a distraction for children as noted above in the theoretical model, they might reduce delinquency and criminal activities among children, thus increasing the likelihood of graduating from high school. The NLSY97 includes detailed information on delinquency and criminal activities. We first present results for the relationship between home computers and school suspension. Probit estimates for the probability of being suspended from school in the survey year are reported in Table 8. Access to a home computer is measured in the year before the school suspension measure. In our sample, 11.3% of children in any given year experience a suspension from school.

Having a home computer is associated with a lower probability of school suspension. The marginal effects estimate is large, negative, and statistically significant. Children who have access to a home computer are 2.8 percentage points less likely to be suspended from school than are children who do not have a home computer. The estimated effect is not sensitive to the inclusion of the additional controls. Even after including detailed home environment controls and whether the child takes extra classes, the marginal effects estimate on home computer remains large, negative, and statistically significant and similar to the estimate in the base specification. The marginal effects estimate is also not sensitive to the inclusion of the presence of a home dictionary. The presence of a dictionary at home is not associated with being suspended from school with or without controlling for home computers.

The time series variation in this variable allows us to estimate two additional models that may help identify causal effects. First, we estimate a fixed effects regression that controls for all unobserved individual, parental, and family characteristics that do not change over time and time-varying characteristics such as family structure and income. Estimates are reported in Specification 1 of Table 9. The home computer effect is now identified from changes over time in access to home computers and school suspension. The marginal effects estimate on home computer is smaller in magnitude and now statistically insignificant at conventional levels, but remains somewhat large. The point estimate implies an effect of −.0090, which is 8% of the mean school suspension probability of .1147. The lack of statistical significance of this estimate, however, may be due to the relatively short time span and lack of time series variation in having a home computer. We have at most 4 yr of data for each child while they are in school with 40% of children having 3 yr or less of data. Less than 20% of children experience a change in home computers from 1 yr to the next. Although our sample does not represent an ideal application for a fixed effects model, it is somewhat reassuring that the point estimates from these models do not contradict our previous results.

As a final check of the validity of our results for school suspension, we follow Schmitt and

21. They include measures of the frequency of child-parent discussions of school-related matters, parents' familiarity with the parents of their child's friends, attendance in "cultural" classes outside of school, whether the child visits science or history museums with the parent, and an index of the educational atmosphere of the home (e.g., presence of books, encyclopedias, newspapers, and place to study).

TABLE 8
Probit Regressions for School Suspension (Marginal Effects), NLSY97

	Specification				
Explanatory Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Female	−0.0753 (0.0054)	−0.0753 (0.0054)	−0.0768 (0.0054)	−0.0758 (0.0054)	−0.0758 (0.0054)
Black	0.0220 (0.0078)	0.0215 (0.0080)	0.0214 (0.0081)	0.0209 (0.0081)	0.0206 (0.0081)
Latino	−0.0264 (0.0074)	−0.0279 (0.0075)	−0.0282 (0.0089)	−0.0289 (0.0089)	−0.0293 (0.0088)
Asian	−0.0231 (0.0199)	−0.0195 (0.0206)	−0.0198 (0.0208)	−0.0185 (0.0212)	−0.0187 (0.0211)
Immigrant	−0.0214 (0.0101)	−0.0190 (0.0103)	−0.0183 (0.0105)	−0.0174 (0.0106)	−0.0176 (0.0106)
Lives with mom and step dad	0.0512 (0.0111)	0.0516 (0.0113)	0.0505 (0.0113)	0.0517 (0.0114)	0.0513 (0.0114)
Lives with dad and step mom	0.0669 (0.0237)	0.0681 (0.0241)	0.0692 (0.0243)	0.0714 (0.0245)	0.0707 (0.0245)
Lives with mom only	0.0412 (0.0083)	0.0397 (0.0083)	0.0393 (0.0083)	0.0400 (0.0083)	0.0402 (0.0083)
Lives with dad only	0.1057 (0.0241)	0.1046 (0.0243)	0.1055 (0.0245)	0.1045 (0.0246)	0.1042 (0.0246)
Lives with guardian	0.0845 (0.0180)	0.0812 (0.0179)	0.0788 (0.0179)	0.0778 (0.0180)	0.0772 (0.0179)
Mom was teenager at first birth	0.0239 (0.0076)	0.0251 (0.0077)	0.0251 (0.0077)	0.0251 (0.0077)	0.0248 (0.0077)
Mother high school graduate	−0.0090 (0.0070)	−0.0089 (0.0070)	−0.0088 (0.0070)	−0.0088 (0.0071)	−0.0089 (0.0071)
Mother some college	−0.0200 (0.0079)	−0.0193 (0.0078)	−0.0193 (0.0079)	−0.0190 (0.0080)	−0.0192 (0.0080)
Mother college graduate	−0.0360 (0.0089)	−0.0348 (0.0090)	−0.0344 (0.0091)	−0.0340 (0.0091)	−0.0341 (0.0091)
Father high school graduate	−0.0253 (0.0070)	−0.0255 (0.0070)	−0.0261 (0.0070)	−0.0259 (0.0071)	−0.0258 (0.0071)
Father some college	−0.0189 (0.0090)	−0.0207 (0.0089)	−0.0209 (0.0090)	−0.0198 (0.0091)	−0.0197 (0.0091)
Father college graduate	−0.0385 (0.0088)	−0.0400 (0.0087)	−0.0403 (0.0088)	−0.0397 (0.0089)	−0.0396 (0.0089)
Grandparent college graduate	−0.0149 (0.0080)	−0.0184 (0.0077)	−0.0188 (0.0077)	−0.0193 (0.0077)	−0.0193 (0.0077)
Household net worth (10,000s)	−0.0005 (0.0004)	−0.0005 (0.0004)	−0.0005 (0.0004)	−0.0005 (0.0004)	−0.0005 (0.0004)
Household net worth squared (10,000s)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)
Household income (10,000s)	−0.0001 (0.0022)	−0.0006 (0.0022)	−0.0007 (0.0022)	−0.0006 (0.0022)	−0.0005 (0.0022)
Household income squared (10,000s)	0.0000 (0.0001)	0.0000 (0.0001)	0.0000 (0.0001)	0.0000 (0.0001)	0.0000 (0.0001)
Private school		0.0258 (0.0105)	0.0260 (0.0106)	0.0264 (0.0107)	0.0264 (0.0107)
Other language spoken at home			−0.0003 (0.0103)	0.0019 (0.0104)	0.0020 (0.0104)
Quiet place to study in household			−0.0121 (0.0091)	−0.0124 (0.0091)	−0.0116 (0.0092)
Youth attends extra classes				−0.0060 (0.0061)	−0.0059 (0.0061)
Dictionary present in household					−0.0071 (0.0116)
Home computer	−0.0279 (0.0058)	−0.0272 (0.0058)	−0.0272 (0.0058)	−0.0274 (0.0058)	−0.0272 (0.0059)
Religion dummies	No	Yes	Yes	Yes	Yes
Pseudo-R^2	0.1069	0.1091	0.1095	0.1091	0.1095
Mean of dependent variable	0.1132	0.1126	0.1131	0.1129	0.1130
Sample size	17,326	17,081	16,926	16,806	16,794

Notes: See notes to Table 6. Age dummy variables are also included in all specifications. Robust standard errors that allow for correlated residuals over time are in parentheses.

TABLE 9
Additional Regressions for School Suspension (Marginal Effects), NLSY97

Explanatory Variables	**Specification** (1)	(2)	(3)	(4)	(5)
Home computer	−0.0090 (0.0075)	−0.0398 (0.0085)	−0.0384 (0.0086)	−0.0384 (0.0086)	−0.0384 (0.0086)
Future home computer		−0.0161 (0.0077)	−0.0151 (0.0077)	−0.0149 (0.0078)	−0.0155 (0.0077)
Main controls	Time Varying	Yes	Yes	Yes	Yes
Religion/private school	No	No	Yes	Yes	Yes
Home environment	No	No	No	Yes	Yes
Extra classes	No	No	No	No	Yes
Fixed effects	Yes	No	No	No	No
R^2/pseudo-R^2	0.0099	0.1064	0.1083	0.1088	0.1081
Mean of dependent variable	0.1147	0.1263	0.1255	0.1255	0.1252
Sample size	17,751	13,432	13,238	13,221	13,127

Note: See notes to Table 6. Age dummy variables are also included in all specifications. Robust standard errors that allow for correlated residuals over time are in parentheses.

Wadsworth (2006) and estimate a regression that includes future computer ownership in addition to previous computer ownership.[22] Future computer ownership may serve as a proxy for unobserved characteristics that are correlated with having a home computer and educational outcomes, but cannot have a causal effect on current school suspension. Thus, the finding of a negative coefficient estimate on future computer ownership of similar magnitude to the coefficient estimate on previous computer ownership suggests that the correlation in unobserved factors may be the underlying cause of the estimated negative relationship. Specifications 2–5 of Table 9 report probit estimates for the probability of school suspension. The marginal effects estimate on home computer remains large, negative, and statistically significant, whereas the estimate on future home computer is much smaller and statistically insignificant in three of four specifications.[23] Previous computer ownership, not future computer ownership, appears to have a strong negative correlation with the probability of school suspension, which is consistent with the hypothesis that home computers have a positive effect on educational outcomes. These findings for the relationships between home computers, future home computers, and school suspension are also consistent with Schmitt and Wadsworth's (2006) findings for the effects of home computers on British school examinations. They find statistically insignificant estimates on future computer ownership, whereas the estimate on past computer ownership generally remains positive and statistically significant in their regression models.

G. Criminal Activities

If home computers reduce criminal activities then they may have an indirect effect on educational outcomes. We investigate this hypothesis by estimating separate probit regressions for the probability of committing any criminal activity, being arrested, and gang activity. Estimates are reported in Table 10 for the main specification, a specification that includes the presence of a dictionary at home, a fixed effects model, and a specification that

22. Future computer ownership is measured in the 2 yrs after school suspension is measured.

23. The marginal effects estimate on future computer ownership is small and statistically insignificant when included alone.

includes future home computers. We first discuss the results for children committing any criminal activity, which includes damaging property, stealing, other property crimes, assaults, and selling drugs. The reported marginal effects estimates for home computers are generally negative but are not statistically significant at conventional levels. Most of the point estimates imply large effects, roughly equal to about 5% of the mean. The marginal effects estimate on the presence of a dictionary is negative, but has a large standard error, and the estimate on future home computers is positive, but statistically insignificant.

Table 10 also reports estimates for regressions for the probability of arrests. The marginal effects estimates are large, negative, and statistically significant in most of the specifications. The fixed effects estimate is not significant at conventional levels and is smaller than the other estimates but implies a large effect. The range of reported point estimates indicates that home computers are associated with a decrease in the probability of being arrested by .0080 to .0179. The average arrest probability in the sample is .06. The presence of a dictionary at home and future computer ownership appear to have no relationship with arrests.

The marginal effects estimate on home computers in the regressions for the probability of being in a gang are large and negative in all specifications. None of the estimates, however, is statistically significant at conventional levels. The marginal effects estimate on future home computers is very small, but the marginal effects estimate on the presence of a dictionary is negative and large, although not statistically significant.

Overall, the estimates provide some evidence of a negative relationship between home computers and criminal activities. The most consistent and statistically significant results are for arrests. For the other criminal activity measures, many of the estimates are large and

TABLE 10
Regressions for Criminal Activity (Marginal Effects), NLSY97

	Specification			
Explanatory Variables	**(1)**	**(2)**	**(3)**	**(4)**
Any criminal activity				
Home computer	−0.0120 (0.0088)	−0.0113 (0.0088)	0.0001 (0.0090)	−0.0074 (0.0132)
Dictionary present in household		−0.0154 (0.0197)		
Future home computer				0.0078 (0.0137)
Fixed effects	No	No	Yes	No
R^2/pseudo-R^2	0.0405	0.0394	0.0116	0.0355
Mean of dependent variable	0.2449	0.2448	0.2342	0.2641
Sample size	18,192	18,178	21,909	13,355
Arrests				
Home computer	−0.0179 (0.0041)	−0.0176 (0.0042)	−0.0080 (0.0055)	−0.0146 (0.0055)
Dictionary present in household		−0.0036 (0.0079)		
Future home computer				0.0023 (0.0055)
Fixed effects	No	No	Yes	No
R^2/pseudo-R^2	0.0758	0.0748	0.0000	0.0840
Mean of dependent variable	0.0597	0.0595	0.0604	0.0597
Sample size	18,178	18,164	21,895	13,300
Gang activity				
Home computer	−0.0020 (0.0013)	−0.0019 (0.0012)	−0.0022 (0.0031)	−0.0028 (0.0021)
Dictionary present in household		−0.0028 (0.0024)		
Future home computer				0.0002 (0.0016)
Fixed effects	No	No	Yes	No
R^2/pseudo-R^2	0.1246	0.1239	0.0000	0.1227
Mean of dependent variable	0.0211	0.0209	0.0200	0.0237
Sample size	18,240	18,226	21,966	13,380

Note: See notes to Table 6. Age dummy variables are also included in all specifications. Robust standard errors that allow for correlated residuals over time are in parentheses.

negative and consistent across specifications, but are not statistically significant.

VI. CONCLUSIONS

The personal computer is ubiquitous in the classroom; however, one-quarter of all children in the United States do not have access to a home computer. Although many children do not have a computer at home, surprisingly little previous research has examined the educational consequences of this disparity in access to technology. Using the two major recent U.S. panel data sets with information on computer ownership, the matched CPS and the NLSY97, we employ several empirical strategies to examine the causal effects of home computers on high school graduation and other educational outcomes. First, marginal effects estimates from probit regressions for the probability of high school graduation indicate that home computers are associated with a 6–8 percentage point higher probability of graduating from high school even after controlling for numerous individual, parental, family, and home environment characteristics (including several proxies for educational motivation using the NLSY97). Although we find no statistical evidence indicating that the probit estimates are biased, we also estimate bivariate probit and 2SLS models for the joint probability of computer ownership and high school graduation to further rule out the effects of unobserved factors. Using parental use of the Internet at work and the presence of another teenager in the household as instruments, we find marginal effect estimates that are similar to the original probit estimates, although statistically insignificant. Third, estimates from falsification tests using cable television and the presence of dictionaries at home provide some evidence that our results are not being driven by unobservables.

Estimates from the NLSY97 also indicate a strong positive relationship between home computers and grades and a strong negative relationship between home computers and school suspension. Fixed effects estimates, which control for individual, parental, and family unobservable characteristics that do not change over time, are smaller in magnitude and insignificant but continue to imply nontrivial effects. We also find that future computer ownership does not have a strong negative correlation with school suspension, whereas previous computer ownership continues to have a strong negative correlation. Finally, we find some evidence suggesting that home computers may decrease crime. This evidence may be used to suggest a possible mechanism by which home computers can increase high school graduation rates: by reducing nonproductive activities, such as truancy and crime, among children.

The general consistency of the sign and magnitude of estimates across data sets, inclusion of different sets of controls, timing of computer purchases, exclusion restrictions, and estimation strategies suggest that home computers may have positive effects on educational outcomes. The main weakness of the analysis is that some of the techniques, such as the bivariate probits, 2SLS, and fixed effects models, produced imprecisely measured estimates. On the other hand, the probit models, falsification tests, and future home computer results provide more precise estimates that are consistent with the hypothesis that home computers improve educational outcomes. More evidence, possibly from large random experiments, however, is needed on whether access to home computers improves educational outcomes and identifying the underlying mechanisms.

The findings presented here have important policy implications. They suggest that disparities in access to technology may translate into future disparities in educational, labor market, and other economic outcomes, thus making the low rates of access to home computers among disadvantaged minorities and poor children especially alarming. Policies that address the financial, informational, and technical constraints limiting the optimal level of investment in personal computers among disadvantaged families may be needed. One solution is to expand the relatively new programs that provide students with laptop computers to allow students to take computers home on a regular basis. Tax breaks or special loans for educational computer purchases, training programs, and computer donations represent a few additional examples. The findings also raise concerns about funding cuts for technology-related programs affecting disadvantaged groups, such as community technology centers (Servon 2002; Servon and Nelson 2001). Finally, home computers in the educational process may become more important over time as schools are increasingly digitizing content and there is growing momentum for the controversial issue of replacing textbooks with CD-ROMs or Internet-based materials.

APPENDIX

TABLE A1

Sample Means of Selected Explanatory Variables in the CPS and NLSY97

Variable	CPS	NLSY97
Female	0.4964	0.5075
Black	0.1399	0.1455
Latino	0.1329	0.1214
Asian		0.0247
Immigrant	0.0764	0.0504
Household net worth (10,000s)		12.8000
Household income (10,000s)		4.2162
Family income: missing	0.1332	0.2292
Family income: \$15,000 to \$30,000	0.1261	
Family income: \$30,000 to \$50,000	0.1856	
Family income: \$50,000 to \$75,000	0.1777	
Family income: greater than \$75,000	0.2427	
Home ownership	0.7860	
Mother—high school graduate	0.3209	0.3275
Mother—some college	0.2751	0.2264
Mother—college graduate	0.2300	0.2235
Father—high school graduate	0.2205	0.3195
Father—some college	0.1912	0.1521
Father—college graduate	0.2511	0.2256
Grandparent college graduate		0.1820
Lives with mom and step dad		0.1083
Lives with dad and step mom		0.0264
Lives with mom only		0.2303
Lives with dad only		0.0354
Lives with guardian		0.0433
Mom was teenager at first birth		0.1892
Private school		0.1095
Other language spoken at home		0.1171
Quiet place to study in household		0.9101
Youth attends extra classes		0.2918
Dictionary present in household		0.9631
Home computer	0.8043	0.8807
Father uses the internet at work	0.2669	
Mother uses the internet at work	0.2557	
Another teenager present in household	0.45141	

Notes: For the CPS, the sample consists of teenagers aged 16–18 who have completed 11th or 12th grade, but have not received a high school diploma in the first survey year. All variables are measured in the first survey year. For the NLSY97, the sample consists of teenagers living with their parents in 1997. Home computer access is measured between ages 15 and 17, fixed characteristics (e.g., gender and race) are measured in 1997, and possibly time-varying characteristics (e.g., household income) are measured at age 15. Sample weights provided by the CPS and NLSY97 were used to calculate these estimates.

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