Does childhood immunization lead to future gains in individual labor productivity?

Evidence from the Philippines

Philip J. Titcombe
Macalester College

INTRODUCTION

The field of development economics often explores ways to increase a nation's income per capita through improvements in productive capacity. The majority of the literature in this field has focused on technological improvements and capital productivity as the central driver of economic growth. Notwithstanding, a sizeable amount of literature, backed by the notion of human capital, stresses the comparative importance of a nation's laborers in the process of development. Perhaps the most exciting implication of this literature is that improvements in an individual's welfare can lead to productive gains for, not only an individual, but also a nation. Improvements in a laborer's welfare then has a vital feedback effect, where an investment that is made to improve the welfare of an individual translates into increased future returns for further investment in welfare. In this paper I examine the generation of this feedback effect from one of the most fundamental levels – investment in early childhood health. Specifically, I use evidence from the Philippines to show that investment in basic immunization of a young child generates a future productive premium for that individual in the labor market. I model this effect by first examining the impact of immunization on childhood cognitive ability, and then demonstrating how the acquired cognitive ability translates into greater labor market returns in a later period.

LITERATURE REVIEW

Although the importance of vaccines and other methods of infectious disease prevention have often been argued from an immunological and political view, the economic literature has only more recently begun to grasp its relevance. From an economic growth perspective, vaccines are important as a health-improving agent both in and of themselves, and as an indicator of an individual's access to health. The effect often has dynamic implications, with the decision or ability to vaccinate improving later health outcomes. As a very favorable consequence, improved health outcomes are expected to increase worker productivity as well as the number of productive years for a given individual. Unfortunately, the number of rigorous studies on this expected economic outcome are severely limited by the lack of longitudinal data.

In one of the more concise interpretations of health benefits in economic theory, Leung and Wang's (2003) revised neoclassical growth model of endogenous health care and life expectancy conveys the importance of disease-preventing initiatives on a macro-level. As one might predict from the Solow (1956) framework, they find that health leads to significantly higher levels of capital accumulation despite diverting resources away from goods production in the current time period. Leung and Wang implicitly find that savings and health care are complements in this neoclassical framework. Due to empirical limitations, they are only able to rigorously attribute the positive effect they find of health on aggregate output to the rise in saving from longer life expectancy. They do, however, note how efficiency gains should lead to an even more expressed macro-level economic return to health.

In one of the few studies that look directly at the impact of vaccine at a micro level, Whittington *et al.* (2000) observe an income-level complication when estimating the household value of malaria-preventing vaccines in Ethiopia. They estimate the household value of vaccine in this area to be roughly 36 USD. The presence of a malaria-preventing vaccine would thus provide a significant gain by this measure, as this value is 15% of imputed annual household income and more than twice the cost of the illness. The issue with this study is that which faces any willingness to pay study – the estimated value is completely self-generated by the participants in the questionnaire. Whittington and his colleagues construct a demand function based on individuals' estimated cost of illness and their expressed interest in a hypothetical vaccine. They then take the household value as the area under that demand function. Not surprisingly, they notice that the households' willingness to pay surpasses their ability to pay. In this way, a value of vaccine derived from demand seems to provide a poor estimate of the true returns to vaccination.

One reason for seeking a quantitative monetary value of health programs is to establish a statistic that could be used to compete for funds that would generally go to programs with more easily quantifiable ends (Gomes 1993). This endeavor is duly noted in the research of more developed economies. Since the extent of household-level research on the income effect of vaccines has been necessarily limited by data, much more substantial research has been done to assess the cost effectiveness of vaccines. Nichol (1995) performed a double-blind, randomized, placebo-controlled trial to determine the cost effectiveness of the influenza vaccination in healthy working adults during a flu season. They estimated a high net savings of almost 50 USD per vaccinated worker.

Much of the research of this nature, however, focuses on the societal cost effectiveness rather than the individual benefit. Bridges (2000) produced a comparable double-blind, randomized, placebo-controlled trial of healthy working adults. Their study included two flu seasons instead of one, and disaggregated the costs of being affected by influenza. In contrast to Nichol (1995), they find that the per-person societal cost of vaccination outweighs the economic benefit. The juxtaposing results of these two studies illuminate some key inconsistencies of vaccination research. Perhaps most importantly, the value of vaccines measured at a household level can differ greatly from the value of vaccines measured at a societal level. Another limitation in these studies' results is that their applicability to developing countries is probably quite limited. We suspect that relative costs and benefits would differ greatly in developing countries due to lower levels of available income and access to healthcare.

From an immunological standpoint, Ovsyannikova (2004) points out how different alleles of the immune system's human leukocyte antigen can lead to variations in the immune response to viral vaccines, such as the measles vaccine, hepatitis B vaccine, HPV vaccine, and influenza vaccine. This research and related immunology literature provides rationale for assessing the impact of particular vaccines (i.e. disaggregated) – instead of simply any type of vaccination (i.e. aggregated) – on later worker productivity.

To my knowledge, the only micro-level analysis prior to this paper to empirically study the effect of early childhood immunization on later individual worker productivity is the unpublished work of David Bloom and his colleagues, as discussed topically in Bloom *et al.* (2005). They use the same longitudinal data that I will use in my analysis to determine the effect of immunization on cognitive development. In summarizing the case study they performed, Bloom explains their use of vaccination data from the first two years of the child's life and educational test scores of the children roughly ten years later. Using propensity score matching, they control for the background characteristics of the children. They find that immunization for one or more of the basic diseases led to significantly better test scores for language and mathematics. The most important distinction between my work and theirs is the key connection I quantify between cognitive development (from investment in early childhood health) and future worker productivity. This measured effect provides much more interesting results for economic interpretation and subsequent assessment of potential policy implementation.

THEORY

This paper will take a two-step approach to assessing the impact of immunization on worker productivity. I will first look at the impact of immunization on a child's school performance and productivity. Next, I will explore the well-documented link between educational attainment and future worker productivity. I take this approach because, while most vaccines have demonstrated to be strongly effective in rendering a certain degree of immunity, the gained immunity is often found to wane or disappear after ten to fifteen years (Brenzel *et al.* 2006). We would therefore expect that the true health benefits of a vaccine are concentrated to the developmental years of an individual and should not be directly observable in labor market performance. Another reason for this approach is that I expect an explanatory variable like education to embody the effect of health factors like vaccination – systematically introducing a degree of multicollinearity. This multicollinearity would be particularly confounding for the intentions of this study because the more direct link between education and future productivity is likely to mask the less direct relationship between immunization and productivity. These issues are smoothly resolved by the proposed two-step approach without sacrificing any crucial aspects of meaning or interpretation.

Theoretical Relationship between Immunization and Education

In estimating the effect of immunization on educational achievement, I construct a theoretical model based on that outlined by Becker and Tomes (1979). I adjust their model to start with a household utility function in the current period that is a function of parent's current consumption (C_t) and future cognitive ability (i.e. human capital) of their child (A_{t+1}):

$$U_t = U_t(C_t, A_{t+1}) \tag{1}$$

where the subscript *t* refers to the present generation when the parents work and consume, and *t*+1 signifies the generation when the child works and consumes as an independent. The parents gain utility from the future cognitive ability of their child because they expect this to translate to improved labor market returns for the child. Parents might gain utility from this investment through altruistic concern, through the expectation that the child will use these improved returns to provide for them in later years, or through a combination of the two.

The parents face a budget constraint that reflects the trade-off between current period consumption and child human capital investments. Accordingly, y_t represents the amount invested in improving the child's cognitive ability and Π_t represents the foregone consumption associated with that investment. So the parent's budget equation is:

$$C_t + \Pi_t y_t = I_t \tag{2}$$

where I_t represents the household's wealth in the current period. If we assume that the child get a_{t+1} units of cognitive ability from each unit of capital, then the rate of return on human capital investments can be described by the following equation:

$$\Pi_t y_t = \frac{a_{t+1} y_t}{1 + r_t} \tag{3}$$

where r_t is the rate of return per generation. As a unique modification of Becker and Tomes' model, I define a child's cognitive skills to be a function of parent investment (y_t), the child's health (h_t), innate cognitive ability (α_t), and years of school attended (YS_t):

$$A_{t+1} = a_{t+1} y_t + a_{t+1} h_t + a_{t+1} \alpha_t + a_{t+1} YS_t \tag{4}$$

where the health variable (h_t) encompasses the effect that I intend to measure – immunization.

By substituting equation (3) and (4) into (2), I write the parent's full budget constraint as follows:

$$C_t + \frac{A_{t+1}}{1 + r_t} = I_t + \frac{a_{t+1} h_t}{1 + r_t} + \frac{a_{t+1} \alpha_t}{1 + r_t} + \frac{a_{t+1} YS_t}{1 + r_t} \tag{5}$$

When the household maximizes utility of equation (1) with respect to current consumption and future cognitive ability of the child, subject to the constraint described in equation (5), the following first order conditions can be derived:

$$\lambda = \frac{\partial U_t}{\partial C_t} \quad \text{and} \quad \frac{\lambda}{(1 + r_t)} = \frac{\partial U_t}{\partial A_{t+1}} \tag{6}$$

Most relevant from these conditions, we find the demand equation for $A_{t+1} = f(I, h, \alpha, YS)$. Since I want to look specifically at the effect of vaccination on human capital attainment, I will substitute the variable *immun* for the general health variable *h*. To further enhance the demand equation, I will control for the influence of parent's educational background (*fatheredu* and *motheredu*) on the child's education. I do this because more educated parents would be expected to have a more inelastic income elasticity of demand for education than less educated parents. A greater concern for education by the parents should ultimately have a positive impact on the child's cognitive achievement. We can express the final model for econometric analysis by this guiding equation:

$$A_{t+1} = \beta_0 + \beta_1 immun_t + \beta_2 HHincome_t + \beta_3 \ln \alpha_t + \beta_4 fatheredu_t + \beta_5 motheredu_t + \beta_6 YS_t + \varepsilon_t \quad (7)$$

Theoretical Relationship between Education and Worker Productivity

To outline the relationship between worker productivity and wage from the demand side of the labor market, I start by assuming that the average good producing entity in a developing country behaves as a competitive firm. We can then begin with a competitive firm's profit equation in standard two-factor input microeconomic theory. In this model, π is the firm's profit, TR is defined as total revenue, TC is defined as total costs, P signifies market price levels of a unit of output, Q is the level of output from the firm, L represents labor levels (with a real wage rate *w*), and K represents capital levels (with a real rental rate *r*):

$$\pi = TR - TC = P * Q - w * L - r * K \quad (8)$$

Now, if we assume that capital levels are fixed and prices do not change with respect to labor levels, taking the derivative of equation (8) with respect to L gives the following relationship:

$$\frac{\partial \pi}{\partial L} = P \frac{\partial Q}{\partial L} - w = 0$$
$$w = mpl * P \quad (9)$$

where *mpl* is the marginal product of labor, or the additional output associated with a one unit increase in labor input. The firm will choose a certain level of labor based on the *w* that they face in the competitive market. The amount of labor inputs selected at different wage rates construct a locus of points modeling the employer's demand for labor. This demand equation can be expressed in its simplest form by the following equation:

$$L^D = \alpha_0 + \alpha_1 w^D + \alpha_2 Z^D \quad (10)$$

where Z^D are other factors impacting the labor demanded by the employer, but not represented by *w*. Analogously, we derive the labor supply curve by aggregating the number of hours an individual will work to maximize their utility functions subject to differing budget constraint (in the trade-off between work in leisure). This yields the following relationship:

$$L^S = \gamma_0 + \gamma_1 w^S + \gamma_2 Z^S \quad (11)$$

where Z^S are other factors that impact the labor supplied by a worker, but not represented by *w*. Setting equation (10) and (11) equal to one another gives the following relationship:

$$\alpha_0 + \alpha_1 w^D + \alpha_4 Z^D = \gamma_0 + \gamma_1 w^S + \gamma_2 Z^S \quad (12)$$

Understanding that at market equilibrium the wage level will equalize aggregate supply and demand (i.e. $w^S = w^D$) under competitive conditions, we find the reduced form expression for *w*:

$$w = \beta_0 + \beta_1 Z \quad (13)$$

Plugging equation (9) into equation (13), gives us a generalized function for the marginal product of labor:

$$mpl = \beta_0 - \beta_1 P + \beta_2 Z \quad (14)$$

where Z represents a vector of supply-side and demand-side factors that affect *mpl.* The marginal product of labor is measured through the wage rate that is assumed to be positively correlated.

Conceivably, the vector Z can represent a very wide range of variables, such as market imperfections, extending beyond the scope of this paper. For this model, I will focus only on variables that affect productivity and those that control for characteristics specific to a certain labor market. Most significantly, we expect that the higher levels of accumulated human capital (*A*) discussed in the previous section will translate to more productive working hours. This should be apparent in the worker's wage rate. We can control for differences in capital levels, wage market dynamics, etc. by including categorical variables for the industry the individual works in (*Ind*), gender (*sex*), and region of employment (*region*). In this specification,

$$Z = Z(A, Ind, sex, region) \quad (15)$$

Plugging (15) into (14) leads to our guiding equation:

$$mpl = \beta_0 + \beta_1 edu + \beta_2 Ind + \beta_3 P + \beta_4 sex + \beta_5 region + \varepsilon \quad (16)$$

DATA DESCRIPTION AND EMPIRICAL MODEL

I have compiled my data from multiple stages of the Cebu Longitudinal Health and Nutrition Survey (CLHNS). The survey tracks a group of Filipino women who gave birth between May 1, 1983 and April 30, 1984. This includes a wide range of variables that observe the effect of various social, economic, health, and environmental characteristics on later outcomes of the Filipino mothers and their children. The initial sample began with 33 randomly selected *barangays* (communities) in the Metropolitan Cebu area. Of these *barangays*, 17 were characterized as urban and 16 as rural. A baseline interview was done with 3,327 women from these communities who were in their 6th or 7th month of pregnancy. After the child's birth, the households were interviewed on a fixed set of questions every 2 months for the first two years of the child's life. The CLHNS has followed the majority of these index children through their adolescence and early adulthood in a series of follow-up surveys that occurred approximately every three years until 2005. This longitudinal study of each index child provides strong empirical potential for observing the effect of early household decisions on later economic outcomes.

With an interest in looking at the effect of childhood immunization on economic outcomes, I merged characteristic immunization data from the bimonthly longitudinal studies taken over the first two years of the child's life. Each of the 12 surveys asks the household which types of immunization (if any) the child received since the previous survey. Combining data from the child's first two years, I found a measurable level of vaccination recipients, and recorded corresponding dummy variables, for the following: Diptheria, Pertussis, Tetanus (DPT) – typically given in 3 doses; tuberculosis; measles; and polio. From these vaccinations, I created a general dummy variable for whether the child received any form of immunization over his or her first two years. Through the creation of this variable, I could look at the difference between aggregated and disaggregated immunization data on educational productivity.

It is important to note that I have only recorded individuals receiving the third dose for DPT (i.e. DPT3) in Table I to use for primary regression analysis. The logic behind this is that the vaccine series will only demonstrate immunological longevity for individuals receiving the full-recommended dosage. I am able to rationalize this in later robustness checks. Notably from Table I, we find from the mean values of DPT3 and measles that few children received immunization for these diseases. This may dampen the statistical significance and visibility of these variables in my regression model. In both cases, however, more than 100 observations exist for children who received the vaccine. So both variables should be acceptable for use in econometric analysis.

Having immunization of the index child under the age of two set up as a health indicator, I merged these data with data from the 1994-1995 follow-up survey, which contained information on education achievement. Specifically, I averaged the child's performance on tests for Cebuano reading ability, English reading ability, and mathematics to serve as the dependent variable (measure of human capital) in my first regression. From this 1994-1995 survey, I also merged data to control for the background characteristics of the child. I was able to find variables or close proxies for all those described in equation (7): estimated household value (as a proxy for wealth/income), highest grade completed by father, highest grade completed by mother, IQ score (as a proxy for innate intellectual ability), and number of years of schooling. I ran this regression using ordinary least squares (OLS).

For my second main regression, looking to measure the impact of human capital gains on future worker productivity, I used the 1994 achievement test score average for each child used in the previous regression and more recent employment data on the indexed children from the 2005 follow-up survey. The variables used are summarized in Table II. I was able to find variables or close proxies for most of those described in my guiding equation (16). As a proxy for the dependent variable of worker productivity, I use the index child's wage in pesos per day from their primary job, and, if applicable, secondary job. I use the natural log of wage for my estimations so that the variable is more normally distributed. One point worth noting from Table II is that the standard deviation of wages is relatively large (considering the natural log scaling). This wide variance in the dependent variable should provide for robust analysis of the differences in educational productivity that lead to certain economic productivity outcomes.

The explanatory variables for this regression align with those defined in (16) with the exception of a variable for price. The absence of a price variable should not elicit any significant effect on my regression results because the categorical variables for business and *barangay* should similarly control for any differences in pricing across markets. Again, I will use the standard OLS method to estimate the empirical equation based on equation (16).

The most important subtlety to highlight in this section is that by merging 2005 employment data, I generated multiple observations for certain children. This explains why the number of observations in Table I and Table II sometimes exceed the number of children sampled by the baseline CHLNS survey. The multiples arose because the employment data individually recorded the sequential jobs (i.e. first job, second job, etc.) that the index child had worked up until 2005. This should not be an issue for the second-step regression because the multiple wage outcomes for an individual will be represented essentially as an average. This may, however, bias the results in my first estimation by adding weight to individuals who worked multiple jobs in later years, but are listed with the same immunization and cognitive ability characteristics.

RESULTS

Regression Results

Table III shows my regression results for the estimated effect of immunization on the accumulation of cognitive skills in the Cebu province of the Philippines. In the first column I have listed the results for the regression using an aggregated immunization variable. As mentioned in my descriptive statistics, this variable indicates whether an individual had any form of vaccination before the age of two. While aggregated immunization displays the expected sign and comparable magnitude to the coefficients of other explanatory variables, it is not statistically significant. Looking now at the other explanatory variables, we find that they each have the expected positive and statistically significant effect on the student's achievement test performance. Understandably, we find the years of schooling completed by the child to have the greatest effect on the student's test performance. Each coefficient is highly significant at the 1% level with the exception of the mother's education, which is still statistically significant at the 5% level. Overall, the regression in column (i) suggests correct specification of our model (with a relatively high R^2 of 0.526), but that general immunization of the child does not play a significant role in human capital accumulation. I will demonstrate in the following analysis, however, that this estimated insignificance of immunization is a misleading artifact of the aggregated data.

By regressing test scores using disaggregated immunization data (column (ii) of Table III) we find far more significant and interesting results. In this model, each immunization is highly significant in affecting the later educational outcomes of the index children. The individual immunization variables are all significant at the 1% level with the exceptions of measles, which is still statistically significant at the 5% level. Consistent with the findings from regression (i), all the other explanatory variables remain statistically significant with the expected signs. The relative magnitudes of the coefficients on these explanatory variables are also approximately the same. These similarities suggest a robust specification of the disaggregated regression model – consistent with that of the aggregated regression.

In addition to the individual variables coming out significant, the magnitude of their effect on cognitive ability in later years is relatively large. A child is estimated to increase his or her average test score on the three exams by about 1.4 points if vaccinated for measles or polio, and about 2.7 points if vaccinated for DPT. This can translate to as much as an 8-point difference for each subject test (each scored out of 50). Overall, this indicates a substantial gain in human capital provided by immunization and related early childhood health factors.

The only result from regression (ii) in Table III that does not appear to correspond with our economic theoretical model is the coefficient found for tuberculosis immunization. Unlike the other three immunizations, the regression suggests that receiving the commonly used tuberculosis vaccine, Bacillus Calmette-Guérin (BCG), had a negative impact on a child's educational productivity. The negative impact of this particular vaccine is actually somewhat consistent with scientific literature regarding its effect. Fine (1995) provides a comprehensive review of the scientific discussion surrounding the efficacy of BCG. In essence, scientific studies on the protection imparted by BCG against tuberculosis have produced a range of estimates from 0% to 80%. The range in efficacy of BCG has been explained in a large part by the regional differences of the environment-dependent mycobacteria that cause tuberculosis.

Djuardi *et al.* (2010) help further elucidate the potential negative effect of BCG from an immunological perspective. Specifically, these immunologists find that BCG significantly affects the highly-specific adaptive immune system, but shows no clear enhancement of the more general innate immune system. This means that an individual would have to encounter a very specific type of mycobacteria for the immune system to produce an effective response. While none of this literature claims that BCG is necessarily harmful for the health of an individual, it helps explain how the coefficient for tuberculosis could be statistically significant but not scientifically or economically significant. The negative coefficient estimated for tuberculosis immunization helps explain why the aggregated immunization variable in regression (i) was found to be statistically insignificant. If tuberculosis immunization actually has such a marginal effect on the immune protection and health of a child – as the scientific literature notes as a definite possibility – then the true aggregated effect of immunization should have a stronger (statistically significant) impact on human capital attainment than regression (i) from Table III suggests.

The regression results from Table IV show the effect of the child's improved test scores on his or her later labor productivity. The coefficients are all significant at the 1% level with the expected signs. The independent variable of interest can be interpreted to mean that the child experiences a 1.04% increase in wage from scoring one point higher in the average of his or her achievement tests. As is commonly found in labor market discrimination research, women are found to have lower wages. The F-statistics computed for the child's current *barangay* and industry both show joint significance in the regression model. While all of the variables in this model are calculated to have statistical significance, the R^2 of this model suggests that several key variables affecting worker productivity/wage are probably missing from this model specification. Overall, however, the significant results corroborate the economic theory that human capital accumulation affects future productive outcomes. Through the combined results of Tables III and IV, we can conclude that childhood immunization led to future gains in individual labor productivity.

Estimation Errors and Robustness

To assess the robustness of these regressions, I looked at the potential estimation errors that may have arisen. I looked first at the inter-correlation between explanatory variables for each regression. The inter-correlation estimates for my regression estimating the effect of immunization on student achievement are shown in Table V. There are two significant correlations that appear between independent variables in this model: father education and mother education; tuberculosis immunization and polio immunization. In future regressions, a combined parent's education variable could be used to depress the multicollinearity between the variable for each parent. The potential insignificance of the tuberculosis variable prevents extensive analysis of the substantial multicollinearity that arises with this variable. Overall, however, the variance inflation factor for each variable suggests that multicollinearity is not a significant estimation issue for this model. Next, I checked for heteroskedasticity using a Cook-Weisberg test. The test indicated significant heteroskedasticity in this regression. However, running a regression with robust standard errors yielded estimated coefficients with nearly identical statistical significance. I therefore took no action to correct for heteroskedasticity

Inter-correlation for the non-categorical variables used in my regression estimating the effect of human capital on worker productivity are shown in Table VI. Not surprisingly, we find that the child's achievement test score in 1994 is somewhat correlated with the grade levels that individual had completed by 2005. This slight multicollinearity is not an issue for my model because both end up highly significant despite their inter-correlation, and both indicate human capital (though in different time periods). A Cook-Weisberg test for this model similarly indicated heteroskedasticity in this regression, though to a lesser degree than the first model. I similarly concluded that heteroskedasticity is not a significant issue for this model.

Many different specifications could be used to test the robustness of my regression results. For the purposes of this paper I focus on simply two changes in the specification for immunization. The first examines the robustness of using the variable DPT3 (indicating that the child completed the dosage series) instead of a general variable for any DPT immunization. The second examines the robustness of aggregated immunization without the scientifically questionable variable for tuberculosis (BCG) immunization. As expected, in column (i) of Table VII, we see that the coefficient for DPT is no longer significant when considering children that received any number of the medically recommended three doses of DPT. With significant effects on cognitive ability from completing the set, this economic result corroborates scientific justifications for a three-dose series in DPT immunization. Column (ii) in Table VII also confirms our suspicion that the negative estimated effect of tuberculosis (BCG) vaccination was suppressing the statistical significance of aggregated immunization. In contrast to column (i) of Table III, the coefficient of aggregated immunization is significant at the 10% significance level when excluding tuberculosis from the set of immunizations observed. As discussed previously, this exclusion of tuberculosis from the aggregated measure of immunization is strongly supported by the scientific literature regarding BCG.

CONCLUSION

Overall, we find robust empirical evidence in the Philippines that childhood immunization effects future labor productivity of an individual. To assess the relationship between immunization and productivity, we took a two-step approach by first measuring the effect of immunization on the gains in cognitive ability for a child and then measuring the effect of those gains in cognitive ability on the labor market success of that individual. Despite the strength of these results, we recognize that immunization is only one factor of health and is likely to be highly correlated with other factors of health that could not be controlled for in this study. That is, an individual who received immunization at an early age is expected to have better access to other aspects of health and nutrition. In this way, the effect of immunization is therefore more accurately interpreted as a general indicator for a child's health.

The true effects of immunization are likely covered to an extent by the correlated effects of other health and nutrition variables that are not included in my model specification. Still, the statistical significance and variation of educational and, subsequently, economic outcomes suggests the importance of basic vaccination at an early age. Further analysis to more rigorously isolate the effect of vaccination could look at the responsiveness of productivity to different ages of immunization.

By comparing the effects of immunization in an aggregated and disaggregated model, I found evidence for targeted health strategies in improving economic outcomes of children. The specific example of the vaccine BCG, which is commonly administered for tuberculosis, appears particularly ineffective in this study. Interestingly enough, the questionable efficacy of the vaccine has been well documented in the scientific literature. Greater collaboration between efficacy studies of scientists and economists could lead to better targeting of health strategies with optimal outcomes for economic development.

REFERENCES

Becker GS & Tomes N (1979). An equilibrium theory of distribution of income and intergenerational mobility. *Journal of Political Economy*, 87(6), 1153-89.

Bloom DE, Canning D, Weston M (2005). The value of vaccination. *World Economics*, 6(3), 15-39.

Brenzel L, Wolfson LJ, Fox-Rushby J, Halsey NA (2006). Vaccine-preventable disease. In Jamison DT, Breman JG, Measham JR, *et al.* (Eds.). *Disease control priorities in developing countries* (2nd edition), New York: Oxford University Press, 389–411.

Bridges CB, Thompson WW, Meltzer MI, Reeve GR, Talamonti WJ, Cox NJ, Lilac HA, Hall H, Klimov A, Fukuda K (2000). Effectiveness and cost-benefit of influenza vaccination of healthy working adults: a randomized controlled trial. *Journal of the American Medical Association,* 284(13), 1655-1663.

Djuardi Y, Sartono E, Wibowo H, Supali T, Yazdanbakhsh M (2010) A longitudinal study of BCG vaccination in early childhood: the development of innate and adaptive immune responses. *PLoS One*, 5(11).

Fine PEM (1995). Variation in protection by BCG: implication of and for heterologous immunity. *Lancet*, 346(8986), 1339-1345.

Gomes M (1993). Economic and demographic research on malaria: a review of the evidence. *Social Science and Medicine*, 37, 1093-1108.

Leung MCM & Wang Y (2003). Endogenous health care, life expectancy and economic growth. *Pacific Economic Review*, 15(1), 11-31.

Ovsyannikova IG, Jacobson RM, Poland GA (2004). Variation in vaccine response in normal populations. *Pharmacogenomics,* 5(4), 417-427.

Nichol KL, Lind A, Margolis KL, Murdoch M, McFadden R, Hauge M, Magnan S, Drake M (1995). The effectiveness of vaccination against influenza in healthy, working adults. *New England Journal of Medicine,* 333, 889-952.

Solow RM (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, 70(1), 65-94.

Whittington D, Cropper ML, Haile M, Lampietti JA, Poulos C (2000). The value of preventing malaria in Tembien, Ethiopia. *The World Bank*, Policy Research Working Paper Series.

TABLES

Table I: Summary of Statistics for the Effect of Immunization on Human Capital (Regression 1)

Variable	Expected Sign	Observations	Mean	Standard Deviation	Minimum	Maximum
1994 Achivement Test Score (average of Cebuano, English, and Math)		2475	23.049	8.129	6.67	48
Immunization (any type)	+	3391	0.284	0.451	0	1
Diptheria, Pertussis, Tetanus Immunization - dose 3 (DPT3)	+	2475	0.047	0.212	0	1
Tuberculosis Immunization (BCG)	+	2475	0.301	0.459	0	1
Measles Immunization	+	2475	0.046	0.210	0	1
Polio Immunization	+	3391	0.265	0.441	0	1
Household Value (in ten thousands pesos)	+	3017	14.578	65.654	400	1841.6
Highest grade completed by father	+	3004	7.442	3.888	0	19
Highest grade completed by mother	+	3197	7.236	3.756	0	19
IQ Score	+	3160	68.832	11.440	21	99
Enrolled grade of child (94-95 school year)	+	3021	4.168	0.930	1	6

Table II: Summary of Statistics for the Effect of Human Capital on Productivity (Regression 2)

Variable	Expected Sign	Observations	Mean	Standard Deviation	Minimum	Maximum
Wage, natural log of pesos earned per day		2289	5.000993	0.651477	1.686399	8.766655
1994 Achivement Test Score (average of Cebuano, English, and Math)	+	2475	23.04943	8.128638	6.666667	48
Gender (0 for male, 1 for female)	-	2475	0.4715	0.4992888	0	1
Highest grade completed by child as of 2005	+	2475	10.27071	2.963032	0	16
Type of business of child's main job, categorical		2473	-	-	1	12
Barangay of child's residence in 2005, categorical		2475	-	-	1	376

Table III: Regression Results for the Effect of Immunization on Human Capital Attainment

Variables	*Test Score* regression coefficients (I)	(ii)
Diptheria, Pertussis, Tetanus immunization - dose 3 (DPT3)	-	2.719***
	-	(0.680)
Tuberculosis immunization (BCG)	-	-1.868***
	-	(0.441)
Measles immunization	-	1.373**
	-	(0.642)
Polio immunization	-	1.390***
	-	(0.421)
Household value (in ten thousands pesos)	0.0122***	0.0126***
	(0.00310)	(0.00311)
Highest grade completed by father	0.225***	0.207***
	(0.0429)	(0.0427)
Highest grade completed by mother	0.0942**	0.0874*
	(0.0457)	(0.0454)
IQ score	0.356***	0.352***
	(0.0133)	(0.0132)
Enrolled grade of child (94-95 school year)	2.665***	2.670***
	(0.156)	(0.155)
Immunization (any type)	0.255	-
	(0.266)	-
Constant	-14.71***	-14.30***
	(0.884)	(0.878)
Observations	1,893	1,893
R-squared	0.526	0.536

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Note: (I) OLS regression on aggregated vaccination (i.e. if individual had any vaccination in first two years of life); (ii) OLS with disaggregated vaccinations

Table IV: Regression Results for the Effect of Human Capital on Future Worker Productivity

	wage, natural log
1994 Achivement Test Score (average of Cebuano, English, and Math)	0.0104***
	(0.00218)
Gender	-0.221***
	(0.0305)
Highest grade completed by child as of 2005	0.0269***
	(0.00606)
Constant	4.381***
	(0.130)
F-Statistic: Child's barangay in 2005	1.579***
F-Statistic: Type of business of child's main job	6.060***
Observations	2,287
R-squared	0.184

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Note: Only F-statistics were recorded for 2005 barangay and type of business because independent categories of these variables are not of particular interest to this study

Table V: Inter-Correlation of Explanatory Variables for Immunization to Human Capital Regression

	DPT3	*tuber*	*meas*	*polio*	*housval*	*fatheredu*	*motheredu*	*iqscore*	*enrollgrade*
DPT3	1.000	-	-	-	-	-	-	-	-
tuber	0.273	1.000	-	-	-	-	-	-	-
meas	0.251	0.280	1.000	-	-	-	-	-	-
polio	0.295	0.794	0.283	1.000	-	-	-	-	-
housval	-0.003	0.061	0.180	0.026	1.000	-	-	-	-
fatheredu	0.145	0.143	0.083	0.105	0.152	1.000	-	-	-
motheredu	0.135	0.163	0.111	0.106	0.275	0.613	1.000	-	-
iqscore	0.093	0.103	0.141	0.107	0.093	0.303	0.347	1.000	-
enrollgrade	0.090	0.124	0.075	0.108	0.032	0.263	0.327	0.411	1.000
V.I.F	1.14	2.57	1.16	2.59	1.09	1.60	1.64	1.24	1.26

Table VI: Inter-Correlation of Explanatory Variables for Human Capital to Productivity Regression

	testscore	*gender*	*gradecom*
testscore	1.000	-	-
gender	0.249	1.000	-
gradecom	0.604	0.247	1.000

Table VII: Robustness Results for the Effect of Immunization on Human Capital Attainment

	Test Score regression coefficients	
Variables	(i)	(ii)
Diptheria, Pertussis, Tetanus immunization (any # of doses)	0.567	-
	(0.582)	-
Tuberculosis immunization (BCG)	-1.849***	-
	(0.467)	-
Measles immunization	1.822***	-
	(0.635)	-
Polio immunization	1.111*	-
	(0.573)	-
Household value (in ten thousands pesos)	0.0115***	0.0123***
	(0.00312)	(0.00310)
Highest grade completed by father	0.223***	0.223***
	(0.0427)	(0.0428)
Highest grade completed by mother	0.0858*	0.0907**
	(0.0456)	(0.0458)
IQ score	0.352***	0.356***
	(0.0132)	(0.0133)
Enrolled grade of child (94-95 school year)	2.676***	2.664***
	(0.155)	(0.156)
Immunization (any type except tuberculosis)	-	0.487*
	-	(0.269)
Constant	-14.45***	-14.69***
	(0.882)	(0.883)
Observations	1,893	1,893
R-squared	0.532	0.527

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Note: (i) OLS regression of disaggregated immunization using general variable for any DPT immunization (ii) OLS regression on aggregated vaccination (excluding