INVESTIGATING HEALTH DETERMINANTS IN OECD COUNTRIES:

A RANDOM EFFECTS ANALYSIS

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Jesse Daniel Adams, son of Kendal and Barbara Adams and brother of Joshua and Kelly Adams, was born on August 7, 1984 in Birmingham, Alabama. He spent the majority of his childhood in Birmingham, but also moved with his family to Talladega, AL and Berlin, Germany for one-year stints before settling in Auburn, AL. He graduated from Auburn High School in 2002 and entered Auburn University that fall where he would later graduate *magna cum laude* with his Bachelor of Science in Business Administration degree and a focus in International Business. Immediately following graduation, he continued to study at Auburn University where he entered the Master of Science in Economics program in Fall 2006 and subsequently entered the Master of Business Administration program in Spring 2007. He plans to graduate with both master degrees in December 2008.

THESIS ABSTRACT

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In previous literature, there has been contradicting results regarding what indicators serve as determinants of health. This paper re-examines the health production function by using the economic theory of production to establish factors to include in regression analysis. Data from 30 OECD countries from the years 1999 to 2005 were used to estimate a multiplicative random effects model explaining the variation in life expectancy due to health expenditure, health worker quantities, and other environmental and lifestyle factors. In addition to providing a basis for which the cost of life can be examined, the results indicate that physicians have a significant impact on health, but nurses do not. Furthermore, the capital-labor tradeoff suggests the average OECD health system in the study had an extremely inefficient allocation of inputs.

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I. INTRODUCTION

Rising health care costs have been at the center of public discussion in many industrialized nations for years. Institutions and individuals alike are concerned with the ability of the health care system to provide adequate coverage to growing populations. A substantial amount of research has been devoted to studying health care resources including some that examines health inputs in the framework of the economic theory of production.

This idea that a population's health outcome can be viewed as an output level opens the door for researchers to examine the relationships health care inputs have with health and with each other. Although previous literature have studied health determinants, they have largely ignored the implications of their results. Production theory is rich with relevance that, if applied correctly, provides a solid foundation on which decision makers can act. On the other hand, the neglect or misuse of theory to inform officials almost certainly leads to an inefficient and blind use of resources.

That said, it should be the objective of health care systems to maximize inputs to produce health at the highest level that can possibly be achieved. Oftentimes we hear about the apparent need for additional health care resources including doctors and nurses. But the question remains, can countries use what they have to improve the health of their people? Furthermore, which input levels must be addressed first so that increases in health will be realized?

This paper seeks to examine both medical and non-medical health determinants in this context in an effort to discover the state of health production and the relationships of the process' inputs so that health maximization can be achieved. Compensating for methodological shortcomings in previous research, a random effects model of health production is formulated that employs six factors to explain spatial and temporal variations in population health status as measured by life expectancy. Partial output elasticities for these factors are estimated using data from 30 OECD countries over the seven years spanning from 1999 to 2005. Subsequently, these data are used to examine the capital-labor marginal tradeoff and the state of health care resource allocation. Additional cost-of-life applications will demonstrate the benefit of increased health spending for different countries. It is hoped that through this analysis the effect of health input changes will become more transparent and predictable so that health-maximizing decisions can be made. The following chapter will review previous literature to provide a foundation for this study.

II. REVIEW OF LITERATURE

Before an empirical analysis of health determinants can be completed, it is imperative to examine what previous researchers have found regarding the production of health. There are many studies that have investigated health inputs and there are a variety of different applications of this research. The findings of previous literature will provide a basis on which health determinants can be chosen and subsequently used to estimate the production function.

Decision makers face increasing pressure to provide an adequate amount of health care on limited budgets. Accordingly, both public and private hospitals in the U.S. are operating under the strain of falling reimbursements, decreasing revenues, and rising costs. However, instead of pumping more money to cover these shortfalls, it has been argued that by prioritizing efficiency, improved health outcomes can be produced with current budgets (Williams, 1988). Efficiency, Williams contends, is the measure of whether resources in the health care system are being used to get the most value for their money.

The concept of *efficiency* refers to the maximization of health outcome for a given cost, or the minimization of costs for a given health outcome. In health care, productive efficiency enables the assessment of the relative value for the costs of interventions with directly comparable outcomes. In other words, resources are allocated efficiently only if the relative cost of two inputs is equal to their relative worth.

There have been various types of health care efficiency studies. The World Health Organization's (WHO) *World Health Report* in 2000 produced an aggregate study that used panel data from 191 countries across the globe to rank the efficiency of different health systems. It should come as no surprise that high income countries were among the most efficient health care systems (World Health Organization, 2000). Hollingsworth and Wildman (2002) use the same data to formulate alternative parametric and non-parametric models and reveal significant variations in efficiency estimates than those of the WHO. Furthermore, they suggest that different models should be used to estimate efficiency for OECD and non-OECD countries. Due to methodological problems in estimation, Williams (2001) criticizes the data used for these reports and indicates that their results may lead to inaccurate conclusions. Other country-level studies find a disparity between developed and developing countries' efficiency and suggest that increased spending may be the best policy for improving health in poor countries, but important gains can be made in most countries by using resources more efficiently (Evans *et al.*, 2001; Hutubessy *et al.*, 2003).

More specific studies tend to focus on assorted aspects of health care systems. Among them, a few have examined the efficiency of hospital administration in the U.S.; they tend to conclude that the U.S. has a very inefficient administrative structure (Woolhandler and Himmelstein, 1991; Redelmeier and Fuchs, 1993; Woolhandler and Himmelstein, 1997; Woolhandler *et al.*, 2003). Due to a lack of data (or hospitals' willingness to answer surveys), there are very few studies focusing on the administration of European health care providers (Dixon and Mossialos, 2000). Other literature has been directed at investigating the efficiency of a specified health program such as those related to HIV prevention or mental health partial care (Schinnar *et al.*, 1990; Holtgrave *et al*., 1995, Chesson *et al.*, 2002; Leaver *et al.*, 2004). The impact of technology on the efficiency of health care has been examined as well (Oliver *et al.*, 2004; Chaudhry *et al.*, 2006).

These studies suggest that the large variety of resources in the health care system provides ample opportunity to explore resource efficiency. But despite the many analyses of resource allocation, the input tradeoff relationship has not been investigated in this manner. There has been much talk by interest groups about input (e.g. physician and nurse) shortages but little has been done to examine whether or not current labor resources can be maximized to produce a higher amount of health. It would seem appropriate that applications of the economic theory of production can be used to estimate the determinants of health outcome.[1] Then, viewing these findings in the context of the health care system, a foundation on which a higher degree of efficiency can be achieved through alternative input allocation schemes can be established. The following section will examine previous literature to explore which determinants should be included in the production function.

Framework for the Production of Health

[1] From here forth, the terms *health status* and *health outcome* will be used interchangeably to describe the level of health production.

In determining which factors to include in a model explaining health status, a qualitative health production function was determined. The abstract function takes the form of a neo-classical production function and is specified as:

$$(1) \qquad H = f(K, L, E, F)$$

where *H* is a measure of health status, *K* is an indicator of capital resources used for health care, *L* is an indicator of health care labor available for use, *E* is a vector of environmental factors that bear an effect on a person's health, and *F* is an indicator that measures the degree to which a person's lifestyle affects his or her health. The capital and labor inputs in health production are what characterizes a country's health system. These are the doctors, nurses, surgeons, pharmacists and the buildings, machinery, and equipment they use to address health concerns. *Figure 1* is a flow chart representation of health care systems in relation to the health production function.

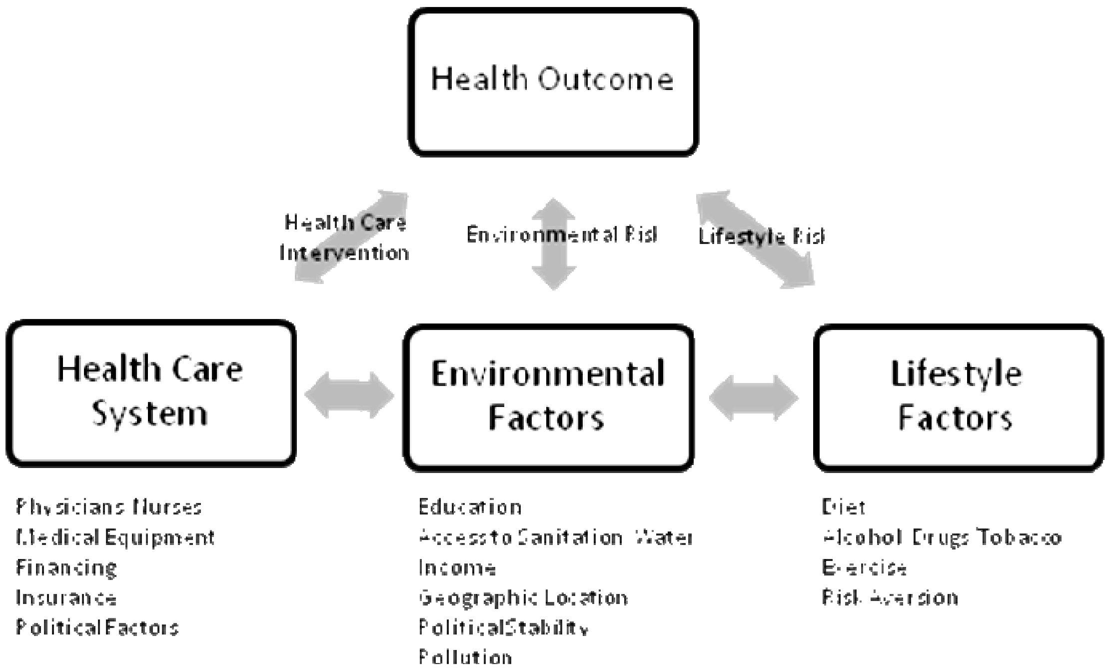

Figure 1: Determining Factors of Health

Within each factor are various facets that when combined, serve to make that factor what it is. For example, the health care system is made up of labor, financing, and physical resources among other things. The environment in which health is produced includes the many exogenous forces that can produce both positive and negative externalities. Lifestyle is comprised of every action in which an individual willingly engages. Unfortunately, these elements are impossible to fully quantify and therefore must be estimated using proxy variables. Consideration of proxy variables will now be discussed as well as their use in previous literature.

Health Status

In 1948, the WHO declared health is "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity (World Health Organization, 2006b)," a definition that is widely accepted today. Therefore, health is comprised on three dimensions (physical, mental, and social) with the physical dimension being the easiest to measure (Hansluwka, 1985). The physical dimension of health has been measured by statistical indicators that gauge mortality, morbidity and disability, with most empirical studies employing mortality rates because of their objectivity, precision and availability. Or (2000), however, discusses important limiting factors that relate to mortality measures. For instance, he notes that mortality rates are highly biased due to deaths in the older population and fail to account for the good health of the young population. Furthermore, mortality can only be improved to a certain point (i.e. an individual cannot live forever) and therefore it faces diminishing returns. It is difficult to assess how much lower mortality rates can fall. However, despite these disadvantages, mortality continues to be the most useful measure in comparing national and international health data (Brenner, 1987).

Many studies have used under-5 and infant mortality rates to measure health status (Filmer and Pritchett, 1997; Gupta *et al.*, 1999). These measures, however, are aggregated measures of health condition *and* socio-economic status/economic development (Reidpath and Allotey, 2003). Furthermore, Mathers *et al.* (2003) find that the infant mortality rate is not adequate for monitoring trends and differentials in population health.

Other studies employ the use of premature mortality measures such as potential years of life lost (PYLL) (Or, 2000; Macinko *et al.*, 2003). These measures are superior to typical mortality measures in that they weight the prematurity of death according to unexpectedness. For instance, an infant death will be weighted more than that of a 60-year old.

Similarly, healthy life expectancy (HALE) and disability-adjusted life years (DALE) provide better methods of studying the life years in which an individual is still productive. However, these indicators are not measured every year and therefore the scope of any analysis using them is limited (Robine *et al.*, 1992). This lack of regular data for a consecutive range of years requires this study to use life expectancy at birth as a measure of health status. The progression of health research cannot wait on the superior development of a refined measure, but instead should use available indicators that satisfy basic criteria for study (Murray *et al.*, 2000).[2] Furthermore, life expectancy at birth has been used for years as a generally accepted measure of health and has been found to be highly correlated with HALE (World Health Organization, 2000).[3]

Capital

Within the context of the health care system, funding is necessary to cover the cost of health production. This funding comes from two main sources: the government in

[2] With comprehensive reliability being the main criterion for data collection, life expectancy is a relatively sufficient measure.
[3] For a sample of studies that have used life expectancy as a measure of health status, see Tsevat *et al.* (1991), Wright and Weinstein (1998), Cremieux (2000), Levine *et al*. (2002), Macinko *et al.* (2003), Sarasin *et al.* (2003), Omran (2005).

the form of public spending and the patient or private insurance company in the form of private spending. Public spending takes different roles in different countries—such as Medicare in the United States and Australia—and in 2000 accounted for as little as 1.5% (Afghanistan) or as much as 99.1% (Kiribati) of a country's total health expenditures. Private spending includes patient out-of-pocket payments in addition to prepaid insurance plans. On average, private spending accounted for 57% of total health expenditures in 2000 (World Health Organization, 2006a).

Funds are typically used to purchase resources and pay for the labor that is necessary for health care intervention. Consequently, holding the labor input constant, it can be assumed that total health care spending is proportional to the amount of physical resources within a health care system. Physical resources include everything utilized by the health care system to alter health and include: hospital beds, pharmaceutical drugs, hospital equipment (MRI scanners, CT scanners, etc.), and hospital property among others.

The empirical results from studies that analyze the relationship between health care spending and health outcome have produced mixed results. Most studies using aggregated data for developed countries at a specific point in time have failed to find a significant relationship between health expenditures and health outcome. Using various mortality indicators as health measures, Poikolainen and Eskola (1988), Mackenbach (1991), Musgrove (1996), and Babazano and Hillman (1994) each find that health spending is not a significant determinant of health. Newhouse (1977) further asserts that health care is a luxury good that is more closely correlated with per capita GDP rather than health status. Other interesting explanations are *supplier-induced demand* theories (Evans, 1974; Fuchs, 1978) and Fox's *medicalization* theory (Fox, 1977).[4] Conversely, Wolfe (1986) and Wolfe and Gabay (1987) produce cross-country findings that propose health status is significantly and positively correlated with spending.

Various results from regional studies are likewise inconclusive. The majority of those who have examined the U.S. health care system have shown health care spending to have a negligible or negative relationship with health status (Auster *et al.*, 1969; Silver, 1972; Benham and Benham, 1975; Diehr *et al.*, 1979; Newhouse and Friedlander, 1980; Ruhm, 1996). Hadley (1982), on the other hand, found that increases in health care spending lead to a significant decline in mortality rates. Results from European studies tend to agree with the conclusion that health care spending demonstrates a positive relationship with health outcome (Collins and Klein, 1980; Forbes and McGregor, 1984; Elola *et al.*, 1995).

Ultimately, the conflicting empirical evidence does little to convince one that aggregate health care expenditures play no role in determining a country's health status. Furthermore, casual empiricism suggests that health care interventions serve to improve

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[4] Supplier induced demand is the amount of demand created by doctors, which exists beyond what would have occurred in a market in which consumers are fully informed. For example, it is proposed that when there are an increasing number of physicians, they each treat fewer patients and begin to provide health services where the marginal cost exceeds the marginal benefit in order contribute to their income. Fox's medicalization theory, on the other hand, states that physicians are filling the social support void that is left by the absence of family members in increasingly demoralized societies. This is a role where a doctor may not be very effective. Furthermore, this may cause dependence on health care providers where more spending leads to diminished health.

health, and therefore it is hypothesized that total health expenditures will have a positive impact on the status of health.

Labor

A second component in the health care system is the labor input. Health labor is undoubtedly a prerequisite for health care as most interventions require treatment from a trained physician or nurse (Dussault and Dubois, 2004). However, there has been very little literature that investigates the association between health worker density and health outcome. Robinson and Wharrad (2000, 2001) investigated this relationship and found that a high density of doctors is linked with improved mortality rates. On the other hand, Kim and Moody (1992) and Hertz *et al*. (1994) found that physician density did not bear a significant impact on health outcome. Furthermore, those studies that include nursing density tend to find that nurse density is not significantly correlated with health.

All of these studies have noteworthy limitations that should be considered when making statistical inferences. For one, they all use gross national income measured in US$ at exchange rates rather than international dollars at PPP. Measuring income using exchange rates tends to exaggerate the real income gap between the rich and the poor and leads to overstated estimates of regression coefficients. Another severe shortcoming is that each of these studies uses stepwise regression to select independent regressors. While this may find those variables which are statistically significant, it undoubtedly over fits the model and may also result in finding spurious statistical results that have no behavioral justification.

As with health expenditures, there have also been studies that are based on regional or intra-national data to examine the influence of health care human resources (Thomas *et al.*, 1991; Frankenberg, 1995; Frankenberg and Thomas, 2001; Gulliford, 2002; Needleman *et al.*, 2002; Aiken *et al.*, 2002). However, these studies have conflicting results and do little to provide closure on the issue.

Although there has been some evidence that doctors have a positive impact on health status, this information has not been applied very thoroughly. Moreover, an insignificant relationship between nurse density and health outcome would suggest that nurses do not play any role in improving health. Further investigation of the impact of these two occupations is needed to provide an important foundation on which administrators should base employment decisions. Based on casual empiricism, it is expected that both nurses and physicians have a positive influence on health status.

Environment

Of course, it should not be assumed that health is "produced" in a vacuum without any influence from exogenous factors. The *socio-economic environment* also has a bearing on health status. Many empirical studies have shown various socio-economic indicators to have a significant relationship with health outcome (Auster *et al.*, 1969; Silver, 1972; Grossman, 1972). Similarly, Valkonen (1988) finds a positive relationship between educational attainment and health status; a higher educational attainment presumably increases the knowledge on which a person bases his or her decisions. This, in turn, improves the consequences of decisions that affect health (e.g. the decision of exercising rather than watching television).

Low access to quality housing may limit a person's ability to escape harmful environmental factors including weather and warfare. Conway (2007) shows that housing is a key determinant of individual health and argues that expenditure on housing is an effective way to achieve improvements in health. Similar studies with slightly weaker recommendations also show a significant relationship between housing and health (Rauh *et al.*, 1988; Fuller-Thomson *et al*, 2000). Moreover, access to clean water and sanitation facilities has a direct impact on health such that low access magnifies the risk of disease and nutrition (Esrey, 1996; Kravitz *et al.*, 1999).

Perhaps because of its strong correlation with such factors as education, housing, and sanitation, per capita gross domestic product (GDP) is often included in health studies as an approximation for income. It is reasonable to expect that income has a positive relationship with health. When viewing this relationship on an aggregate level, however, contradicting results have been found in previous analyses (Auster *et al.*, 1969; Rodgers, 1979; Wilkinson, 1992; Christiansen, 1994; Ettner, 1996).

Even so, a sensible explanation suggests that higher incomes lead to increased consumption of goods that will positively affect quality of life such as schooling and food. Income can therefore serve as an all-inclusive indicator that has many socio-economic factors built in, including those previously listed. The majority of high income nations are well developed in terms of female literacy rate (often used to measure educational attainment) and access to water and sanitation (environmental risk factors) and are assumed to have 99% attainment levels by organizations such as UNICEF. Consequently, Occam's Razor suggests the inclusion of per capita GDP as an overall environmental indicator while excluding the aforementioned others. An increase in GDP would then imply an improvement in all socio-economic factors and is thus expected to have a positive relationship with health.

Separate from the socio-economic factors are determinants that stem from the *physical environment*. A lack of data makes it difficult for health studies include a variety of indicators relating to the physical environment. Nevertheless, pollution is thought to be a contributor to physical environment risk and therefore warrants inclusion as a health determinant. The WHO estimates that in 2002, nearly 2.4 million people died as a direct result to poor air quality.[5] Poor air quality generally affects the human body's respiratory and cardiovascular systems resulting in breathing problems and the aggravation of existing cardiac problems (Pope *et al.*, 1995). Pollution has become a popular political topic and has led to an increasing number of national emission standards. Recent regulation includes a 1990 extension to the Environmental Protection Agency's Clean Air Act and the Kyoto Protocol adopted in 1997 by the Framework Convention on Climate Change. Specifically, the majority of such legislation attempts to reduce ground-level ozone pollutants such as sulfur dioxide (SO_2), nitrous oxide (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), and lead.

An abundance of pollution indicators has allowed for the factor to be included in similar health studies. Among those analyses, pollution has been found to have a

[5] Retrieved from World Health Organization (2008).

significant negative impact health (Bates, 1980; Krupnick *et al.*, 1990; Dockery and Pope, 1994). Similarly, Touloumi (1994) shows a highly statistically significant inverse relationship between CO and daily mortality. Or (2000), on the other hand, finds a significant positive relationship between pollution and health outcome. A noteworthy limitation in Or's study is the use of NO_x emissions *per capita* as opposed to a spatial unit of measure. Pollutants should be examined in the context of their emissions densities and should therefore be measured relative to the size of the country.

The relative toxicity of various pollutants are not fully understood and biological studies have not provided convincing evidence to suggest one measure is better than the rest. Or (2000) states his decision to use NO_x as a pollution measure was the result of "the lack of better indicators." Nonetheless, CO emissions per square kilometer will be used to account for the effects of the physical environment on the production of health and is expected to have a negative relationship with life expectancy.

Lifestyle

In contrast to environmental risk factors included in a broad measure of socio-economic status are those risk factors that vary independently from environmental development. These are factors that are characterized by an individual's *lifestyle* and include illicit drug, tobacco and alcohol consumption among others. There is often a stigma associated with certain lifestyle factors (or legal issues in the case of drug consumption) thereby making it very difficult to find complete and reliable data on individual consumption patters. Westerberg *et al.* (2004) finds that current methods are fairly reliable in estimating the drug use of frequent consumers but not occasional users. Furthermore, cross-national differences in estimation techniques limit the capacity to compare country-level data.

To account for differences in lifestyles among countries, the per capita consumption of alcohol is included in this study. Because of the difficulty in quantifying the lifestyle factor, it can be argued that alcohol consumption is the best proxy. Previous studies have controlled for individual behavioral risk using smoking prevalence and butter and fat consumption in addition to alcohol consumption (Cremieux, 2000; Or, 2000). However, extensive longitudinal data for these indicators does not exist. Furthermore, Napier (1990) has found tobacco and alcohol to be complementary goods that are highly correlated.[6] The use of alcohol consumption is therefore the only variable used to proxy for lifestyle risk. Based on the results of prior literature and general knowledge, alcohol is expected to be negatively correlated with life expectancy.

In summary, there is a lack of literature regarding nurse and physician marginal productivity and an efficient allocation of these two resources. A study that examines the relative impact of these two inputs on health outcome should provide some insight as to the current state of health system efficiency in relation to labor. There is no generally accepted health production model in the literature, but there is an abundance of related statistical inquiry. From this knowledge, a neo-classical production function can provide the basis for which factors are deemed appropriate for the model. Furthermore,

[6] This is supported by Koopman *et al.*'s (1996) study on adult twins and Cremieux's (2000) province-level study on Canada's health.

conflicting results in previous literature fails to provide consistent expectations for the signs of coefficients of these factors. Based on previously discussed reasoning, the expectations for these signs in this study are found in *Table 1* along with previous literature that supports these expectations.

The production process can be used to examine the pattern of production for certain goods including health. The theory behind the production process is instrumental in understanding the impact that input relationships have on the production of health. This is essential in the interpretation of the regression results and considering the degree to which various health inputs interact and how they matter. In the next chapter, economic theory that explains the production process and the significance of the nurse-physician relationship and the capital-labor relationship in the production of health will be discussed.

Table 1: Expected Coefficient Signs and Related Literature

Variable	Measure	Expected Sign	Associated Results
TOTALSPEND	Per Capita Total Health Expenditures	+	Collins and Klein (1980); Hadley (1982); Forbes and McGregor (1984); Elola *et al.* (1985)
PHYSICIANQUANT	Quantity of Physicians per 1,000	+	Robinson and Wharrad (2000, 2001); Anand and Bärnighausen (2004)
NURSEQUANT	Quantity of Nurses per 1,000	+	*None*
PERCAPGDP	Per Capita Gross Domestic Product	+	Wilkinson (1992); Filmer and Pritchett (1997); Gupta *et al.* (1999); Or (2000); Anand and Bärnighausen (2004)
POLLUTION	Carbon Monoxide (CO) Emissions per Square Kilometer	-	Bates (1980); Krupnick *et al*. (1990); Dockery and Pope (1994); Touloumi (1994)
ALCOHOL	Per Capita Alcohol Consumption	-	Napier (1990); Cremieux (2000); Or (2000)

III. THEORY

The preceding Review of Literature chapter outlined six indicators that have been deemed significant health determinants by previous studies. This chapter will generalize the health production function and examine the theoretical lens through which the econometric results should be viewed.

The primary use of the production function is to investigate resource allocation in order that resource productivity can be maximized to produce the highest output possible. The production function is a mathematical description of the production process and can be used to find the marginal productivity of each input. With this information and information on input prices, it would therefore be possible to find the input which produces health at the highest rate relative to the cost of that input.

Inherent in any multivariate production function is the fact that there are many different ways to produce a given amount of output. Inputs can be altered such that different levels of each input produce the same amount of a product. Each input, therefore, has a relationship with the other factors of the production function. For example, with output held constant, one input must be reduced in order to compensate for an increase in another input. The rate at which the trade-off is made is called the *marginal rate of technical substitution* (MRTS). Estimating the MRTS between two inputs is central to the idea of optimal resource allocation. The underlying production theory and the subsequent derivation of the MRTS will then allow further exploration into technical efficiency.

The generalized classical production function from (1) was constructed based on *a priori* argumentation and previous literature on the production of health. It reveals that health outcome is a function of health care capital (*K*) and labor (*L*) among other environmental (*E*) and lifestyle (*F*) factors.

$$(1) \qquad H = f\left(K, L, E, F\right)$$

More specifically, think of health care labor as comprised of two inputs: physicians and nurses. Therefore, the labor factor can be extrapolated into divisions of physicians and nurses such that *H* is a function of physicians and nurses:

$$(2) \qquad H = f(K, P, N, E, F)$$

where *P* and *N* are factors that describe physicians and nurses, respectively.[7]

The derivative of any production function measures how the output changes when the values of the inputs change. Therefore, taking the total differential of (2) yields the change in health output with respect to changes in each input (3):

[7] It should be understood that in generalized models such as those described above, each factor's notation delineates all aspects of the factor. For example, the nurse input indicated by *N* describes all aspects of nurse labor including nurse quantity, quality (technical education and effort), location, availability, etc. While examining abstract relationships, it is assumed that these descriptive aspects are known.

$$(3) \qquad dH = \frac{\partial H}{\partial K} dK + \frac{\partial H}{\partial P} dP + \frac{\partial H}{\partial N} dN + \frac{\partial H}{\partial E} dE + \frac{\partial H}{\partial F} dF$$

where the coefficients $\frac{\partial H}{\partial K}, \frac{\partial H}{\partial P}, \frac{\partial H}{\partial N}, \frac{\partial H}{\partial E}, \frac{\partial H}{\partial F}$ refer to the respective *marginal productivity* (MP) of each input *K*, *P*, *N*, *E*, and *F*. In other words, the marginal product of an input is how much health increases or decreases when the input increases or decreases by one additional unit, *ceteris paribus*.

Consider the marginal products of the labor factors *P* and *N*. An increase in the physician factor ($dP>0$) will lead to a $\frac{\partial H}{\partial P}$ increase in health, *ceteris paribus*, while an increase in the nurse factor ($dN>0$) will lead to a $\frac{\partial H}{\partial N}$ increase in health, *ceteris paribus*. Each of these inputs have a marginal productivity that, when viewing a higher output of health as the objective, can be assigned relative values that describe how much each input is worth compared to the other.

The MRTS can then be found for each 2-factor combination of inputs by looking at how one factor changes with a corresponding change in another factor. It must be acknowledged that one factor within the model will affect the relationships the other factors have with health, and therefore all factors that aren't being examined must be held constant (i.e. dK, dE, $dF = 0$). Specifically, an examination of the trade-off between doctors and nurses for a given level of health care warrants that the level of health production also be held constant so that $dH = 0$.

(4) $$0 = 0 + \frac{\partial H}{\partial P} dP + \frac{\partial H}{\partial N} dN + 0$$

(5) $$-\frac{\partial H}{\partial N} dN = \frac{\partial H}{\partial P} dP$$

(6) $$\frac{dN}{dP} = -\frac{\frac{\partial H}{\partial P}}{\frac{\partial H}{\partial N}}$$

Solving for $\frac{dN}{dP}$, (6) shows the change in the quantity of nurses that must accompany a change in the quantity of physicians to maintain a fixed output of health. There are four possible combinations of marginal productivity signs that could determine the sign of the MRTS (*Table 2)*.

Table 2: MP and MRTS Signs

Combinations	$\frac{\partial H}{\partial P}$	$\frac{\partial H}{\partial N}$	Slope of MRTS
(A)	+	+	-
(B)	-	-	-
(C)	+	-	+
(D)	-	+	+

The MRTS is negative when both partials have the same sign. Two positive signs entail that both sources of labor have beneficial impacts on health and an increase in the two factors subsequently leads to an increase in health production. Two negative signs suggest that health is *taken away* with an associated increase in *P* and *N* and that additional physicians and nurses are harming individuals.

On the other hand, (C) and (D) produce a marginal rate of technical substitution that is positive. The implications of the positive MRTS slope for (C) and (D) are such that a given increase in the physician factor would necessitate an increase in nurses to keep the production of health constant. (C) is the converse of (D) and describes a situation where nurses have a negative marginal product and an increase in *N* must be accompanied by an increase in the physician factor to maintain health production.

The MRTS ratio is the slope of the isoquant—a curve that shows the combinations of inputs that can produce the same level of output. *Table 3* lists the four main properties of isoquants and *Figure 2* is an illustration of an isoquant map.

Table 3: Isoquant Properties

Properties	Explanation
Isoquants further from the origin represent greater outputs	There is a different isoquant for every level of health that could be produced with isoquants further from the origin indicating higher levels of health output.
Isoquants slope down and to the right	Along a given isoquant, the quantity of health care labor employed is inversely related to the quantity of capital employed giving the isoquant a negative slope. Both inputs' marginal productivity must be positive.
Isoquants do not intersect	Since each isoquant refers to a specific level of health, no two isoquants intersect. Such an intersection would indicate that the same combination of labor and capital could, with equal efficiency, produce two different levels of heatlh.
Isoquants are usually convex to the origin	Moving along the isoquant, as more units of capital and fewer units of labor are employed, the marginal product of capital declines and the marginal product of labor increases, so it takes more capital to make up for a reduction in labor.

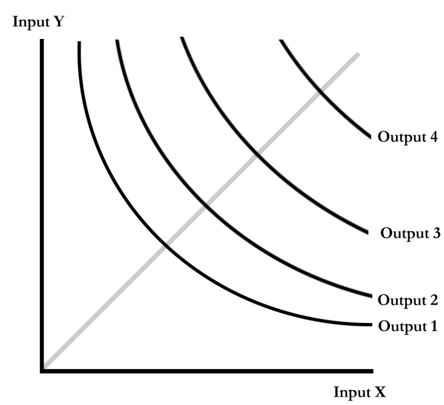

Figure 2: Isoquant Map

The second isoquant property states the curve is negatively sloped which means the isoquant framework can only be applied to gross substitutes. If the relationship between nurses and physicians takes the form of combination (C) and (D) from *Table 2*, the isoquant illustration cannot be used for *N* and *P*.

Now consider that the health production process is believed to have the Cobb-Douglas functional form in (7):

$$(7) \qquad H = AK^{\alpha}L^{\beta}$$

where *A* represents the *total factor productivity* and α and β are parameters that characterize the respective relationships of *K* and *L* with *H*. The total factor productivity addresses the impacts of any effects in output that are not caused by the capital or labor inputs or economies of scale.

In the review of literature, the logic behind the inclusion of certain factors in the health production function was discussed. It is reasonable that the factors which are not characterized by *K* and *L* are comprehensive components of the total factor productivity. In other words, *A* is comprised of environmental and lifestyle factors *E* and *F* such that each has a relationship with health. Furthermore, the labor factor is again divided into physician (*P*) and nurse (*N*) components (8).

$$(8) \qquad H = K^{\alpha}P^{\delta}N^{\vartheta}E^{\gamma}F^{\lambda}$$

Similar to the exponents for *K* and *L*; δ, ϑ, γ, and λ are real number parameters that characterize the factors *P*, *N*, *E*, and *F*, respectively.

The Cobb-Douglas functional form of health production provides a more specific approach to solving for the marginal rate of technical substitution between two inputs. When working with exponential relationships such as those in (8), natural logarithms permit easy factor manipulation with simple linear analysis. Transforming the fully logged form of (8) using the product and power rules then yields (9):

$$\text{(9)} \qquad \ln H = \alpha(\ln K) + \delta(\ln P) + \vartheta(\ln N) + \gamma(\ln E) + \lambda(\ln F)$$

so that:

$$\text{(10)} \qquad d\ln H = \alpha(d\ln K) + \delta(d\ln P) + \vartheta(d\ln N) + \gamma(d\ln E) + \lambda(d\ln F)$$

where (10) explains the percentage change in *H* that accompanies changes in the inputs as measured by percentages.[8] Consequently, the relevant coefficient of the natural log term is interpreted as the partial output elasticity of the input.

Contemplate an example where each of the inputs has an output elasticity such that $\alpha + \delta + \vartheta + \gamma + \lambda = 1$. In this case, a one percent increase in each of the inputs would add up to a one percent increase in *H* and the production process would have constant returns to scale. If the sum of the inputs were less than 1, the process would have decreasing returns to scale and if the sum of the inputs were greater than 1, returns to scale would be increasing.

[8] See Appendix 1 for a derivation of this interpretation.

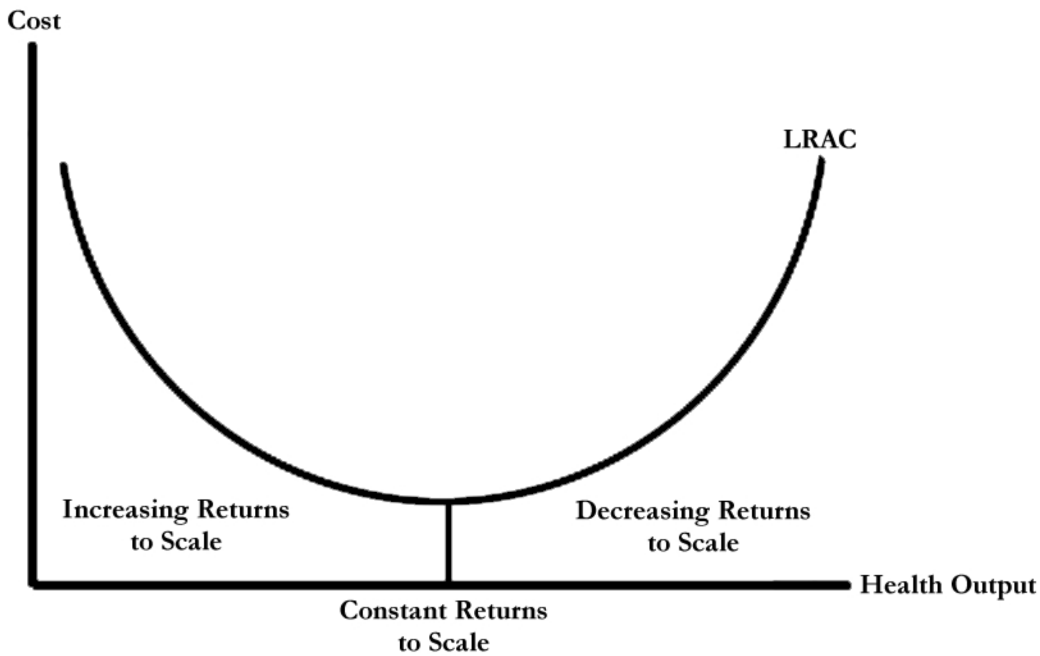

Figure 3: Returns to Scale

Casual empiricism suggests that returns to scale are indeed decreasing with respect to health production. Decreasing returns to scale states that the long-run average cost of health rises at a rate more rapidly than that of output (i.e. rising marginal cost; see *Figure 3*). Furthermore, increasing the inputs beyond a certain point (where they produce more output than that which achieves constant returns to scale) generates slower output growth suggesting that diminishing returns are associated with decreasing returns to scale. If the sum of the partial output elasticities is less than 1, the health production process is experiencing diminishing returns as well.

Holding *H*, *K*, *E*, and *F* constant so that $d \ln H = d \ln K = d \ln E = d \ln F = 0$ we have:

(11) $$0 = \delta(d \ln P) + \vartheta(d \ln N)$$

(12) $$-\vartheta(d \ln N) = \delta(d \ln P)$$

(13) $$-\frac{d \ln N}{d \ln P} = \frac{\delta}{\vartheta}$$

(14) $$-\frac{\frac{dN}{N}}{\frac{dP}{P}} = \frac{\delta}{\vartheta}$$

so that the MRTS of nurses for physicians is:

(15) $$\frac{dN}{dP} = -\frac{\delta}{\vartheta} x \frac{N}{P}$$

Capital-labor tradeoffs can also be determined by finding the MRTS of labor for capital. This is done by adding δ and ϑ so that a single elasticity is found for labor:

(16) $$d \ln H = \delta(d \ln P) + \vartheta(d \ln N)$$

Setting $d \ln P = d \ln N$:

(17) $$d \ln H = (\delta + \vartheta) d \ln L$$

(18) $$\frac{d \ln H}{d \ln L} = \delta + \vartheta = \beta$$

where L is the comprehensive labor factor with a coefficient β. Beta can then be compared with capital's coefficient α in the context of the isoquant. Applying (15) to capital and labor, we get the MRTS of labor for capital:

(19) $$\frac{dL}{dK} = -\frac{\alpha}{\beta} x \frac{L}{K}$$

Without any constraints, an unlimited amount of inputs would produce an infinite amount of health. Monetary resources are limited, however, and the health care system operates under the constraint of a budget. For each country there is a maximum output that can be achieved with a given budget and it is theoretically the purpose of a health care system to produce this maximum. For example, the output level H.1 in Figure 4 is associated with the maximum output that can be produced with a budget B.1. In order to increase output to H.2, a higher budget (B.2) would be necessary.

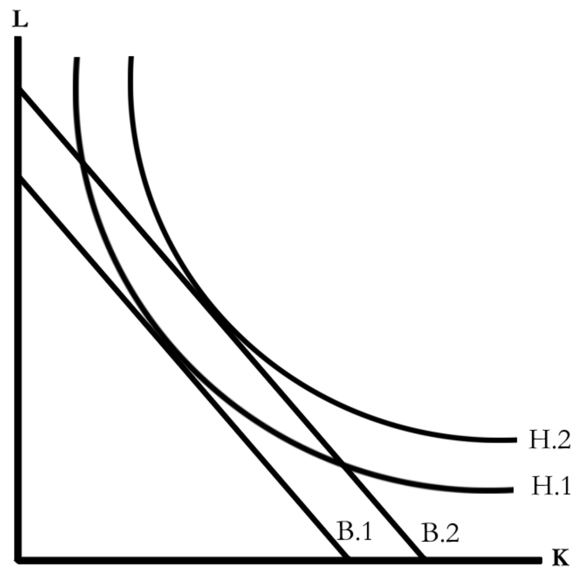

Figure 4: Efficient Input Allocation

Producing the maximum output with current inputs is the definition of efficiency. This point of efficiency is achieved when the slope of the isoquant (MRTS) is tangent with the slope of the budget line (isocost).

If a budget *B* is exhausted between capital *K* and labor *L*, the budget is equal to the factor cost of capital plus the factor payment to labor. The budget line would then look like (21) where P_K and P_L are the prices of capital and labor, respectively.

(20) $$B = P_K K + P_L L$$

(21) $$L = \frac{B}{P_L} - \frac{P_K}{P_L} K$$

If the prices of capital and labor are known, the Cobb-Douglas exponents α and β can be estimated to determine if a health system is operating with an efficient resource allocation.. Based on the Cobb-Douglas functional form in (9), this estimation is completed using the multiplicative (double log) econometric model.

The neo-classical and Cobb-Douglas production functions provide a theoretical explanation of how certain inputs interact in the production process to generate health. Not only does the marginal rate of technical substitution shed light on the tradeoff of certain inputs; it also permits an examination into the efficiency of resource allocation within health care systems. In order to maximize the production of health with a limited budget, the relative price of each input must equal the MRTS of the two factors. Fortunately, the Cobb-Douglas function can be estimated using an econometric exploration of available health data. The next chapter will present the data and methodology used in the health production regression.

IV. DATA AND METHODOLOGY

While the theory provides a lens through which empirical results should be interpreted, the data and methodology are the means to which the results are achieved. This chapter will present the data and the econometric methods that are used to estimate the health production function.

The definitions of the variables are ascertained through the following descriptions. The sources and validity of the data are discussed which is essential in determining how reliable the model is. The random effects model is the method used to analyze the panel data and will be described in the methodology subheading. Furthermore, methodology will include the descriptive statistics that convey the context to which the results can be applied.

Data

Initially, cross-sectional data for 191 countries from the year 2000 was used. The information was retrieved from a number of different sources. Substantial difficulties arose with the dataset, however. The majority of the data came from the World Health Organization's (WHO) World Health Report, and despite the organization's dedication to providing reliable statistical data, it did not provide results for enough observations.

Information was available for the year 2000, but not for consecutive preceding or succeeding years limiting the size of the dataset.

A second perceived difficulty was the fact that the dataset was cross-sectional. Health status cannot simply change overnight, but rather is affected by actions taken in previous time periods. For instance, smallpox vaccinations were introduced to the Horn of Africa in 1975 and were not completely circulated in the area until 1979. To affect the region's health status, its entire population needed access to the vaccination, and it can therefore be said that the vaccination had little effect in 1975 alone.

Another problem arose with the comparability of the data used in the original dataset. Health care labor is an essential factor within the health production function, but the WHO had very incomplete information for a single year. Physician quantity and nurse quantity, as a result, were retrieved from a variety of sources including national statistical bureaus. Because such data is estimated rather than observed, different methods of estimation lead to limited reliability.

These problems are typical of any cross-national health study, especially those examining low income countries with substantially flawed statistical estimation practices. The conclusion was made that data from a single source was the best alternative for a more reliable study. Therefore, the dataset was altered from cross-sectional observations consisting of 191 countries to longitudinal data consisting of the 30 OECD member nations for a seven year period from 1999 to 2005.

The OECD is generally considered a dependable and complete source for country-level data. The organization's Quality Framework and Guidelines adopted in

2003 have reinforced a commitment to extensive inspection and re-inspection of all statistical estimations. Unless otherwise noted, data is extracted from the SourceOECD general database and is defined using the sources and methods identified in the database (OECD, 2008).

The measure of health status that this study will use is life expectancy at birth represented by the variable *LIFEXPECT*. The OECD defines Life Expectancy at Birth as the average number of years a person can be expected to live assuming age-specific mortality levels remain constant. Life Expectancy is estimated by the OECD Secretariat for all countries utilizing various governmental sources including the EU's Eurostat and the US's National Center for Health Statistics among others.

TOTALSPEND is the proxy variable for the capital component of a health care system and is measured by total health expenditures. According to the OECD's *System of Health Accounts* statistical manual, total expenditure on health measures "the final use of resident units of health care goods and services plus gross capital formation in health care provider industries (institutions where health care is the predominant activity) (OECD, 2000)." Total Expenditure does not include exports of health care services such as health service spending by foreigners within the observed country, but does include spending by domestic residents while traveling abroad. Furthermore, health care providers are often compensated in the form of in-kind payments or may even go unpaid for their services. These services are valued a market value that corresponds to the size and scope of the services performed.

The OECD estimates health expenditures using constant Purchasing Power Parity (PPP) methods. PPP estimations are generally acknowledged as superior to exchange rate estimations due their considerations of cost of living and inflationary pressures and are therefore more effective for spatial and temporal comparisons (Callen, 2007).[9] The OECD's comparative price levels used in assessing PPP are listed in *Appendix 2*.

The physician factor will be indicated by the number of physicians per 1,000 population and will be described by the variable *PHYSQUANT*. The OECD measures physician density by quantifying the practicing physicians that provide services directly to patients. Furthermore, *PHYSQUANT* measures all physicians consisting of general practitioners as well as specialists.[10] In its estimation of physician density, the OECD includes:

- Persons who have completed studies in medicine at university level (granted by adequate diploma) and who are licensed to practice
- Interns and resident physicians (with adequate diploma and providing services under supervision of other medical doctors during their postgraduate internship in a health care facility)
- Salaried and self-employed physicians delivering services irrespectively of the place of service provision

[9] Callen notes in 2006 the World Economic Office estimated global economic growth to be 5.1 percent using PPP methods and only 3.8 percent at market rates.
[10] General practitioner refers to a physician who does not limit his or her practice to certain disease categories and assumes the responsibility for comprehensive care. Specialist refers to a physician who diagnoses and treats physical and mental diseases and disorders using special testing, diagnostic, medical and surgical techniques and includes: pediatricians, gynecologists and obstetricians, anesthetists, surgeons and psychiatrists/neuropsychiatrists.

- Foreign physicians licensed to practice and actively practicing in the country.

It is also noteworthy that the OECD excludes the following from the estimates:

- Students who have not yet graduated
- Dentists and stomatologists/dental surgeons
- Physicians working administration, research and in other posts that do not have direct contact with patients
- Unemployed and retired physicians
- Physicians working abroad.

NURSEQUANT is the proxy variable for the nurse labor factor and is used to measure the quantity of practicing nurses per 1,000 population. A nurse is a person who has completed a program of basic nursing education and is qualified and authorized in his or her country to practice nursing in all settings. Like physicians, nurses must provide services directly to patients to be included in the OECD's data. This data includes:

- Persons who have completed their education in nursing and who are licensed to practice (including both higher-level nurses and lower-level nurses such as associate/practical/vocational nurses)
- Salaried and self-employed nurses delivering services irrespectively of the place of service provision

- Foreign nurses licensed to practice and actively practicing in the country.

and excludes:

- Students who have not yet graduated
- Nursing assistants and care workers who do not have any recognized qualification/certification in nursing
- Midwives
- Nurses working in administration, research and in other posts that do not have direct contact with patients
- Unemployed and retired nurses
- Nurses working abroad.

PERCAPGDP is one of the two proxy variables used to measure environmental factors. Per capita gross domestic product is the measure of output in an economy and often represents all of the environmental and developmental factors that are related to socio-economic conditions such as education, access to water and sanitation, housing, income, etc. Per capita GDP figures were measured using constant PPP 2000 prices in US dollars.

There is an important distinction between current price and constant price measures. Current price GDP could grow rapidly just because prices are growing. Constant price GDP, however, shows how the quantity of output is changing.

Furthermore, constant prices are measured using PPP methods providing more accurate comparisons across countries.

The second component of the environmental factor is pollution. Pollution is accounted for by the *POLLUTE* variable which measures carbon monoxide man-made emissions retrieved from the OECD Environmental Data publication (OECD, 2007). Many studies have used pollution data that measures greenhouse gases such as carbon dioxide and methane, but these pollutants are not thought to have an immediate direct effect on human health and therefore the more aggressive carbon monoxide pollutant is used. Carbon monoxide is a pollutant that is produced primarily from internal combustion engines, including those found in automobiles and factories. Emission data is based on the best available engineering estimates at the time of collection.

The OECD provides carbon monoxide emission data in the form of total emissions in thousands of tons. To provide a spatial measure of pollution, the author manipulated emission data dividing total emissions by the country's land area (measured in square kilometers) to give the total emissions (1,000 tons) per square kilometer as the unit. It is believed that a spatial measure more accurately represents the pollutant's effect rather than a per capita measure.

The lifestyle factor is represented by the *ALCOHOL* variable which measures alcohol consumption in liters per capita, ages 15 and over. It should be recognized that alcohol consumption refers to *pure* alcohol rather than drinks that include alcohol. While consumption data are retrieved from various sources, the majority come from national statistical bureaus. The methodology to convert alcoholic drinks to pure alcohol may differ across countries, but typical conversions weight beer with 4-5% alcohol, wine with 11-16% alcohol, and spirits with 40% alcohol. Moreover, different collection methods warrant caution with any cross-country comparisons.

As with any econometric study, a model is only relevant within the scope of the data used in the study. For example, life expectancy estimations range from 71.8 (Turkey) to 84.0 (Japan) for all OECD countries in 1999. Inferences cannot be drawn from this study in relation to Ethiopia which had a life expectancy of 42.4 years in the same year (The World Bank, 1999). *Table 4* provides descriptive statistics about the entire dataset and the context in which the results must be interpreted. Furthermore, *Table 5* uses Germany's data to provide a single-country description of health determinants for the seven-year span, and *Table 6* is a summary of the variables for the median year, 2002.

The majority of the data comes from the SourceOECD database and is more reliable than would come from the WHO which has questionable estimations for some of the underdeveloped countries. The dependable data allowed for a dependable regression model. The next section will present the methodology used to estimate the health production function regression.

Table 4: Descriptive Statistics for Entire Dataset

	LIFEXPECT	TOTALSPEND	PHYSQUANT	NURSEQUANT	PERCAPGDP	POLLUTE	ALCOHOL
Mean	77.85	2,262.23	2.90	8.33	24,448.19	8.84	9.50
Standard Error	0.1794	75.92	0.0559	0.2961	608.8589	0.4702	0.2076
Median	78.50	2,280.00	3.10	7.90	26,225.50	8.33	9.60
Mode	78.90	1,913.00	3.40	10.10	25,619.00	14.05	10.00
Standard Deviation	2.5930	1,100.18	0.7970	4.0381	8,823.2033	6.7158	2.8535
Kurtosis	0.7791	0.92	-0.4499	4.0431	0.8956	1.7801	0.8489
Skewness	-1.1002	0.55	-0.0885	0.9850	0.1876	1.1493	-0.5404
Range	12.60	5,975.00	3.80	29.30	47,694.00	33.45	14.20
Minimum	69.50	372.00	1.20	1.70	5,889.00	0.20	1.30
Maximum	82.10	6,347.00	5.00	31.00	53,583.00	33.64	15.50
Count	209	210.00	203	186	210	204	189

Table 5: Descriptive Statistics for Germany

	LIFEXPECT	TOTALSPEND	PHYSQUANT	NURSEQUANT	PERCAPGDP	POLLUTE	ALCOHOL
Mean	78.61	2,930.29	3.33	9.57	25,544.00	13.25	10.31
Standard Error	0.1993	94.93	0.0286	0.0606	192.75	0.4647	0.0829
Median	78.50	2,937.00	3.30	9.60	25,579.00	12.95	10.40
Mode	78.50	#N/A	3.30	9.70	#N/A	#N/A	10.40
Standard Deviation	0.5273	251.16	0.0756	0.1604	509.96	1.2294	0.2193
Kurtosis	-0.6395	-1.6535	-0.3500	-0.3802	1.8392	-0.7404	-1.3657
Skewness	0.3937	-0.1241	-0.5953	-1.0532	-0.9031	0.3098	-0.2519
Range	1.50	659.00	0.20	0.40	1,619.00	3.56	0.60
Minimum	77.90	2,592.00	3.20	9.30	24,591.00	11.57	10.00
Maximum	79.40	3,251.00	3.40	9.70	26,210.00	15.13	10.60
Count	7	7	7	7	7	7	7

Table 6: Descriptive Statistics for 2002 (Median Year)

	LIFEXPECT	TOTALSPEND	PHYSQUANT	NURSEQUANT	PERCAPGDP	POLLUTE	ALCOHOL
Mean	77.85	2,261.43	2.88	8.13	24,412.30	8.57	9.57
Standard Error	0.4595	195.87	0.1499	0.7106	1630.15	1.2242	0.5222
Median	78.35	2,291.50	3.15	7.80	26,505.50	7.85	9.50
Mode	78.30	#N/A	3.30	6.90	#N/A	#N/A	9.20
Standard Deviation	2.52	1,072.85	0.82	3.69	8,928.68	6.71	2.86
Kurtosis	1.1411	0.8601	-0.5026	-0.6327	1.2873	2.9080	1.2411
Skewness	-1.1336	0.4120	-0.0087	0.1409	0.1843	1.3472	-0.5815
Range	11.00	4,822.00	3.20	13.60	43,604.00	30.71	13.30
Minimum	70.80	483.00	1.40	1.70	6,256.00	0.22	1.40
Maximum	81.80	5,305.00	4.60	15.30	49,860.00	30.93	14.70
Count	30	30	30	27	30	30	30

Methodology

The use of panel data was necessary to provide enough observations for a reliable study. In panel analysis, there are three models that are used depending on the effects displayed by the dataset: the naïve least squares model, the fixed effects model, and the random effects model.

A naïve least squares model, or pooled regression model, is applicable in situations where there are neither significant cross-country nor significant over-time effects that impact the coefficients of the model. Essentially, all of the data is pooled together and treated as a standard OLS model. Typically with panel data, however, there are country or temporal effects present so that the pooled regression model is not appropriate.

A second model uses the fixed effects method where the model's slopes are assumed to be constant but the intercept coefficient varies across countries. In other words, using dummy variables, the cross-sectional effects on the response variable are estimated for N countries and added to the intercept. The result is a shifting intercept that yields N best-fit parallel lines. Similarly, if significant variation over time is suspected, an additional temporal intercept can be added using a dummy variable for each year.

Because a fixed effects model is conditional on the units used in the dataset, they are typically used with longitudinal data that encompasses an entire population. A good example of this would be a sample employing every country in European Union from 2000 until now to assess the impact of an import tax. However, the dataset that is used in this study is not intended to account for the entire population (even for the 30 OECD countries). Rather, it is believed that through this analysis inferences can be drawn regarding other countries with similar levels of health determinants, or regarding OECD countries in future periods.

A third model is designed to allow for such inferences to be made and that is the random effects model. This model is intended for sample sets from large populations thereby making it appropriate for this study.[11] In contrast to the fixed effects model where the country-specific variation is estimable, the random effects model assumes the intercept is a random outcome variable that is a function of a mean and a cross-sectional random error (υ_i) (22):

$$\beta_{0i} = \beta_0 + \upsilon_i \tag{22}$$

where the random error υ_i is heterogeneity-specific to each country and does not vary over time.

Another error term is the traditional one that is unique to an individual observation (ε_{it}). This term accounts for the variation in the dependent variable that is not explained by the regressors and is in addition to cross-sectional error. The model's total error can therefore be thought of as the sum of υ_i and ε_{it}.[12]

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[11] A Hausman specification test determines whether the fixed effects or random effects model is appropriate by examining the correlation between the error terms and the regressors. The results of the Hausman test will be presented in the next chapter.

[12] A two-way model is one with a third error component addressing time variation. With only seven years included in the dataset and very little temporal variations, it was determined that a one-way model is appropriate.

The following generalized random effects model was used to estimate the determinants of health outcomes across OECD countries for the years 1999 to 2005:

$$(23) \qquad Y_{it} = \beta_0 + \sum \beta_j X_{itj} + \upsilon_i + \varepsilon_{it}$$

where *Y* is the dependent variable, *X* is a vector of independent variables, β is a vector of coefficients that is constant across country and time, subscript *i* refers to cross-sectional unit, subscript *t* refers to time, and subscript *j* refers to the independent variable.[13] Applying (23) to the production function discussed in the previous chapters then yields (24).

$$\textit{Equation 3:} \qquad H_{it} = \beta_0 + \alpha K_{it} + \delta P_{it} + \vartheta N_{it} + \gamma E_{it} + \lambda F_{it} + \upsilon_i + \varepsilon_{it}$$

Natural logs will be used in this study for two purposes. First, it is hypothesized that total health expenditures and per capita GDP have nonlinear relationships with health and taking the natural log will linearize the relationships. Second, logs on both sides of the equation provides the output elasticities for each factor and will transform the model into a Cobb-Douglas functional form (25).

$$(25) \qquad \ln(H_{it}) = \beta_0 + \alpha \ln(K_{it}) + \delta \ln(P_{it}) + \vartheta \ln(N_{it}) + \gamma \ln(E_{it}) + \lambda \ln(F_{it}) + \upsilon_i + \varepsilon_{it}$$

[13] See Appendix 3 for random effects model assumptions.

(26)

$$\ln LIFEEXPECT_{it} = \beta_0 + \alpha \ln TOTSPEND_{it} + \delta \ln PHYSQUANT_{it} + \vartheta \ln NURSEQUANT_{it} + \gamma \ln PERCAPGDP_{it} + \theta \ln POLLUTE_{it} + \lambda \ln ALCOHOL_{it}$$

Finally, inserting the proxy variables into Cobb-Douglas formula, (26) is the model that will be estimated.[14]

A proper investigation of the health determinants cannot be conducted unless the actual definitions of the variables are known. Furthermore, inferences couldn't be drawn without an understanding of how the model was estimated. Now that data and methodology behind this random effects analysis has been established, the next chapter will present the empirical results from the estimated model followed by a discussion of the results.

[14] Due to Assumptions 3 and 4 in Appendix 2, the error terms are dropped from the regression model.

V. RESULTS AND DISCUSSION

The following section will present and discuss the results of the multivariate health production function that was estimated using the *Limdep* statistical software. Overall, there were 60 omitted observations leaving a sample size of 150 observations. *Limdep* is already configured to account for unbalanced panel data.

To test for correct model specification, the Hausman Test deemed a random effects model more appropriate than the fixed effects model. The random effects assumptions state there is no correlation between the cross-sectional error term and the regressors. Under the null hypothesis of the Hausman Test, both random effects and fixed effects estimators are consistent, but only the random effects estimators are efficient. Under the alternative, the fixed effects estimators are consistent while the random effects extimators are not. Therefore, the Hausman test statistic of 5.88 suggests the random effects model is best.

There is some evidence of serial correlation among observation-specific error terms (0.9681). However, having only seven time periods and six regressors prevents reliable corrections.

The explanatory variables in the model accounted for more than 99 percent of the variation in life expectancy and the Lagrange Multiplier Test was significant at the one percent level. *Table 7* reports the regression results.

Table 7: Regression Results

Variables (natural logs)	Coefficient	Standard Error	t-ratio	P[|T|>t]
Constant	3.7973	0.0736	51.578	0.0000
TOTALSPEND	0.0277	0.0045	6.175	0.0000
PHYSQUANT	0.0218	0.0067	3.283	0.0010
NURSEQUANT	-0.0071	0.0046	-1.538	0.1240
PERCAPGDP	0.0371	0.0103	3.591	0.0003
POLLUTE	-0.0062	0.0027	-2.308	0.0210
ALCOHOL	-0.0095	0.0059	-1.621	0.1051
R-squared	0.9929			
Lagrange Multiplier Test	306.74	(0.0000)		
Hausman Test	5.88	(0.4366)		
Var [ε_{it}]	0.0000108			
Var [υ_i]	0.0003278			

The results display the relative elasticities of the determinants of health. Previously discussed in the Theory chapter was the notion that the sum of the coefficients determines what kind of returns to scale is inherent in the production of health. In this regression, the sum of the elasticities is 0.0638 suggesting extreme decreasing returns to scale. Furthermore, associated with the idea that health is being produced with an increasing average cost is the notion that the returns to input increases are diminishing. The nominal elasticity levels of health factors describe the diminishing slope found in Stage 2 of the health production curve. *Figure 5* is a general illustration of the point where the average OECD country is on the health production curve:

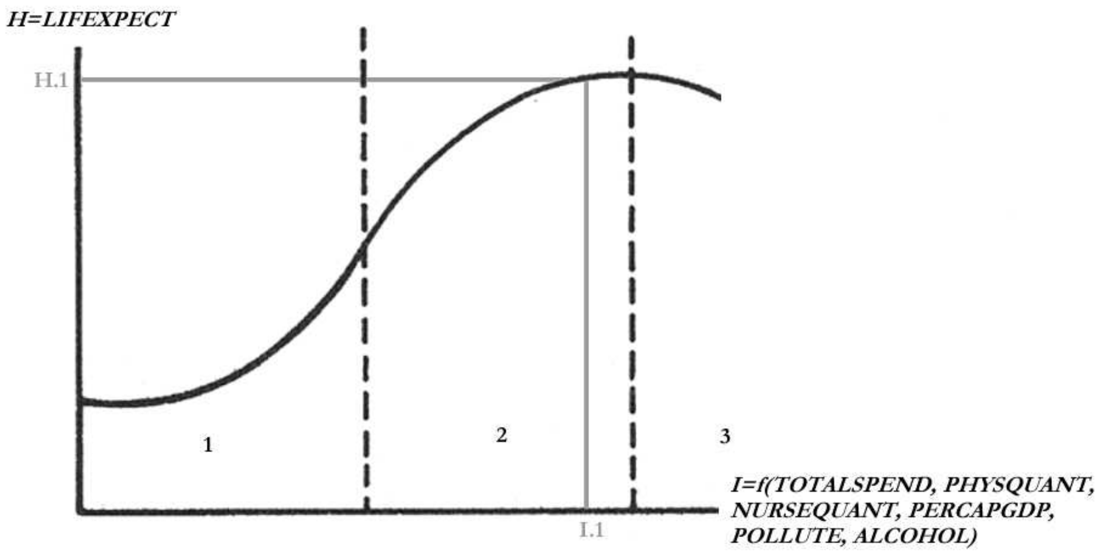

Figure 5: Health Production Curve

where *H.1* is the 77.85 sample average and *I.1* is a function of the input means for the sample.[15]

The implications of Law of Diminishing Returns are that more developed countries with higher levels of inputs will benefit less from factor increases. The OECD is comprised of industrialized nations and does not offer an accurate representation of underdeveloped and many developing countries. Therefore, low elasticity levels were to be expected for high-income representatives with low marginal products. Conversely, a study examining less developed nations would most likely have much higher health output elasticities as they have more to gain.

[15] i.e. *TOTALSPEND* = 2,262.23; *PHYSQUANT* = 2.90; *NURSEQUANT* = 8.33; *PERCAPGDP* = 24,448.19; *POLLUTE* = 8.84; *ALCOHOL* = 9.50.

Non-Medical Factors

Among the non-medical determinants of health, the results confirm the expected signs of all three variables. A 10 percent beneficial change in *PERCAPGDP*, *POLLUTE* and *ALCOHOL* would produce a 0.52 percent increase in life expectancy (i.e. roughly 150 days based on the sample average).[16]

Per capita gross domestic product is often used as an indicator for development. It is the measure of a country's output, or income, and is a main factor in quality of life. Increasing the average income is highly correlated with improvements in many developmental factors such as: access to clean water and sanitation, access to quality housing, resources for education, and the availability of nutritional food. Enhancing the all-inclusive socio-economic measure, therefore, should produce higher levels of health.

The results signify *PERCAPGDP*'s output elasticity is indeed highly significant and the 0.0371 slope is the largest among each of the six regressor coefficients. The average per capita GDP of OECD countries in the study was approximately $24,450 and a 100 percent increase would raise life expectancy by nearly three years.

Substantial GDP growth is an arduous task that may take years before significant results are seen. Although many factors affecting development are largely out of reach for policy makers, it is worthwhile for governments to focus on bolstering economic conditions in an effort to improve health.

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[16] A 10 percent beneficial change in *POLLUTE* and *ALCOHOL* would be a 10 percent reduction:

$$\%\Delta LIFEEXPECT = \lambda(\%\Delta PERCAPGDP) + \theta(\%\Delta POLLUTE) + \lambda(\%\Delta ALCOHOL)$$

$$\%\Delta LIFEXPECT = 0.0371(0.10) - 0.0062(-0.10) - 0.0095(-0.10)$$

$$\%\Delta LIFEXPECT = 0.00528$$

The *POLLUTE* variable is used to account for risks related to the physical environment. Carbon monoxide emissions were thought to have a negative impact on the respiratory and cardiovascular health of a population, an expectation confirmed by the results. The elasticity coefficient for *POLLUTE* is negative and significant at the five percent level ($\theta = -0.0062$). However, the magnitude of the elasticity is the lowest in the model.

The largest negative impact on health status comes from alcohol consumption. The variable *ALCOHOL* is statistically significant at the ten percent level for a one-tailed test. Decreasing a country's per capita alcohol consumption will, on average, lead to better health outcomes. Luxembourg, Ireland, and France are the countries that consume the most alcohol in a given year. In 2003, a 1.5 liter (ten percent) decrease in per capita alcohol consumption would have benefitted Luxembourg with expected 27 additional days (0.1 percent) to live. Additionally, if Luxembourg were to completely eradicate the consumption of alcohol, life expectancy would increase by 284 days.

Medical Factors

Within the health care system, the sum of the elasticities of medical factors is 0.0424.[17] Holding the non-medical factors constant, 33 percent increases in each health care input would lead to a 4.2 percent increase in life expectancy.

A priori, the relationship between health spending and health status was expected to be positive. The actual effect depends largely on the sources and the uses of the

[17] *TOTALSPEND*, *PHYSQUANT*, and *NURSEQUANT*.

capital. Funding for health care interventions comes from the public and private sectors, a factor distinction that numerous studies have found to be a significant determinant.[18] Furthermore, for health spending to have a positive impact on health, the assumption must be made that money entering the health care system is used in an appropriate manner to purchase the capital resources that are thought to improve health.

Similar to the literature of Collins and Klein (1980), Hadley (1982), Forbes and MacGregor (1984), and Elola *et al.*, the results indicate that health spending is a significantly positive determinant of health status within a country. The factor's 0.0277 elasticity, however, is substantially lower than was suggested by Or (2000).[19] A 100 percent increase in health spending leads to less than a 3 percent increase in health. Consider the sample means of $2,262 per capita health expenditure and 77.85 year life expectancy. On average, doubling health spending to $4,524 per person would result in a two year increase in life expectancy.

The elasticity result of the *TOTALSPEND* factor can be extended to determine how much one additional year of life expectancy is worth to a collective population. *Ceteris paribus*, the relationship between the change in capital and a change in life expectancy is characterized by the parameter α:

$$\frac{H_2 - H_1}{H_1} = \alpha\left(\frac{K_2 - K_1}{K_1}\right) \tag{27}$$

[18] See Leu (1986), Babazano and Hillman (1994) and Or (2000).
[19] Or (2000) found the output elasticity of total health expenditure to be 0.17.

where H refers to the health status measure *LIFEXPECT*, K refers to the capital resource measure *TOTALSPEND*, and α is the output elasticity of *TOTALSPEND*. The percent change in *TOTALSPEND* that is necessary for a one year increase in *LIFEXPECT* is represented by ϕ (28).

(28) $$\frac{1}{\overline{\overline{LIFEXPECT}}_{it}} = \alpha(\phi_{it})$$

(29) $$\frac{1}{\alpha\overline{\overline{LIFEXPECT}}_{it}} = \phi_{it}$$

where $\frac{1}{\overline{\overline{LIFEXPECT}}}$ is the percentage of one year life expectancy evaluated at the mean for a given country (i) and year (t). Therefore, inserting a value for α and taking the product of ϕ and *TOTALSPEND* yields the amount of money that is spent on health care to gain an additional year of population life expectancy (30).

(30) $$C_{it} = \frac{1}{(0.0277)\overline{\overline{LIFEXPECT}}_{it}} \; x\overline{TOTALSPEND}_{it}$$

(31) $$C_{it} = \frac{\overline{TOTALSPEND}_{it}}{(0.0277)\overline{\overline{LIFEXPECT}}_{it}}$$

There is a significant difference in health spending among OECD countries. Turkey, spending \$591 per person on health, is the lowest in 2005 while the United States is the predictably the highest at $6,347 per capita. For countries like Turkey that have very low levels of capital, the cost of an extra year of life expectancy is lower than countries with high levels of capital. For example, in Turkey, spending an additional $299 on health per person would have resulted in a one year increase in life expectancy on average. On the other hand, it would have taken the average person in the United States nearly $3,000 gain an additional year, a figure that is $1,000 more than the next highest price. *Table 8* ranks OECD countries' cost of an additional year based on 2005 C_{it} calculations.

Differences in the cost-of-life are due the notion that the marginal product of one more dollar spent on health in the US is smaller than the marginal product of health care spending in Turkey. A higher C_{it} results in lower marginal returns and as the total health expenditure gap decreases between countries, individual marginal products of health spending will converge and C_{it} will become homogenous among different populations. Similarly, as a country has successively higher health expenditures across time, the cost of an additional year of life becomes higher.

Table 8: Cost of Life Calculations

Country	1999	2000	2001	2002	2003	2004	2005
United States	2,032.39	2,148.20	2,301.39	2,480.78	2,646.79	2,790.64	2,945.16
Norway	1,280.11	1,392.27	1,494.37	1,658.36	1,741.56	1,839.76	1,945.77
Luxembourg	1,104.81	1,182.08	1,268.87	1,424.17	1,662.13	1,863.47	1,885.88
Switzerland	1,406.49	1,471.15	1,558.54	1,665.76	1,715.03	1,773.93	1,804.61
Austria	1,264.93	1,321.55	1,327.38	1,405.56	1,468.78	1,546.47	1,592.53
Belgium	1,011.02	1,102.99	1,148.21	1,239.53	1,455.58	1,514.96	1,561.34
Canada	1,103.14	1,144.04	1,238.59	1,301.81	1,381.69	1,448.54	1,553.60
Iceland	1,249.93	1,233.12	1,281.09	1,413.59	1,421.81	1,487.72	1,499.62
France	1,042.77	1,103.54	1,179.09	1,263.99	1,360.28	1,401.33	1,488.16
Germany	1,201.21	1,233.07	1,291.82	1,350.69	1,419.24	1,441.31	1,478.14
Denmark	1,075.02	1,116.83	1,181.96	1,262.37	1,317.18	1,405.99	1,461.10
Netherlands	1,009.35	1,081.64	1,178.47	1,304.52	1,372.39	1,438.57	1,451.32
Ireland	770.35	848.80	995.12	1,093.69	1,158.09	1,246.38	1,419.52
Sweden	966.78	1,034.57	1,134.54	1,223.10	1,278.84	1,327.59	1,349.09
Australia	956.91	1,031.13	1,085.75	1,157.94	1,207.57	1,292.20	1,338.28
United Kingdom	787.24	855.95	933.00	998.20	1,040.21	1,148.01	1,177.51
Finland	791.89	833.53	883.14	963.16	1,016.35	1,102.23	1,151.49
Japan	820.23	874.52	921.35	943.13	981.53	1,027.63	1,089.20
Greece	678.57	661.39	767.55	822.02	882.17	908.69	1,039.33
Spain	663.45	698.38	741.05	789.43	914.53	956.70	1,014.78
New Zealand	699.95	735.78	783.03	843.58	846.01	937.00	1,004.41
Portugal	629.64	710.25	735.62	774.86	850.75	882.01	937.89
Hungary	413.02	428.98	484.84	553.95	647.43	658.05	714.09
Czech Republic	452.11	471.09	518.06	572.16	642.44	660.19	686.44
Korea	321.80	357.69	428.58	447.28	480.88	518.84	586.82
Slovak Republic	295.82	296.98	326.19	357.10	386.90	515.45	551.27
Poland	284.54	284.80	311.94	354.72	361.98	388.93	405.24
Mexico	230.22	247.49	267.36	282.61	302.69	325.97	346.19
Turkey	193.23	221.22	233.17	246.28	255.25	292.05	298.82
Italy	851.12	926.44	997.06	999.41	1,025.27	1,071.43	

The relationship between health care workers and health outcome was also expected to be positive. An increase in the quantity of physicians and nurses would broaden the collective ability to treat patients. It was suggested, therefore, that an increase in the number of each health care worker would improve a population's access to health care.

The variable *PHYSQUANT* describes the number of physicians practicing in a country per 1,000 residents. The output elasticity of *PHYSQUANT* was estimated to be

0.0218. Similar to *TOTALSPEND*, *PHYSQUANT*'s elasticity is significant at the 1% level, but is much smaller than those estimated in other studies. Anand and Bärnighausen (2004) used infant mortality to suggest physician elasticity to be 0.18 while Robinson and Wharrad (2001) estimated elasticity to be as high as 0.92 using maternal mortality rates. Differences in measures of health status are undoubtedly major contributors to result discrepancies. For example, physicians are very effective in addressing simple childbirth concerns and therefore have a large impact on infant and maternal mortality. On the other hand, a wide variety of complications affect the life expectancy of an individual limiting the extent to which physician interventions are helpful.

Contrary to expectations, the coefficient of *NURSEQUANT* is negative. The elasticity estimate is -0.0071 and is not significant at the one, five, or ten percent levels. This statistically insignificant result is in line with those of previous studies, suggesting that the quantity of nurses does not have a substantial impact on health status.

An aggregate analysis of health care labor reveals a one percent increase in both physician and nurse quantities leads to a 0.015% increase in *LIFEXPECT*. Having a comprehensive estimate of labor elasticity permits an examination of a capital-labor isoquant function. The mean OECD health expenditure in the study is approximately $2,262 while adding the physician and nurse densities yields an average of 11.23 health care workers per 1,000 residents. Without a widely accepted unit of capital, it is assumed that the price of one unit of capital is $1,000 thereby normalizing the sample mean to be 2.262 units of capital. Applying *Equation 12*, the marginal rate of technical substitution of labor for capital within this study is -9.355. In order to keep health production constant, the average OECD country's tradeoff is a decrease in health workers by 9.355 for an additional unit of capital (or a 0.1069 unit capital reduction for each additional health worker).[20]

The capital-labor tradeoff from the study is illustrated in *Figure 6:*

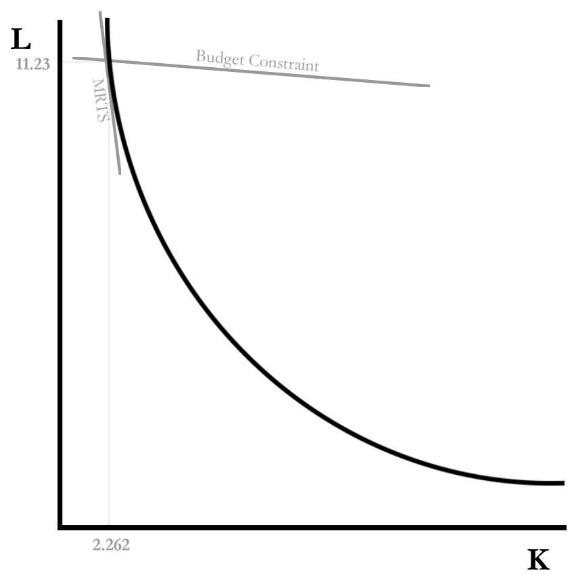

Figure 6: Capital-Labor Tradeoff

where the combination of 11.23 workers and 2.262 capital units yields an isoquant slope of -9.355 for a 77.85 year life expectancy.

Including a budget constraint determines if a health system is producing health with an efficient allocation of capital and labor. Again assuming the price of one unit of capital is $1,000 and the average wage for a health worker in OECD countries is

[20] Of course, this interpretation is based on the idea that health worker salaries constitute a slight fraction of total health expenditures.

$48,298,[21] the slope of the budget constraint is approximately -0.0207. There is a substantial difference between the relative input price and the capital-labor tradeoff suggesting that the average OECD health system is far from operating efficiently. It seems that health care workers do not have the capital resources they need to produce efficiently and that a drastic increase in capital is needed compared to labor.

The aggregate production function in this study not only supports many claims from previous literature; it also provides valuable insight into OECD health systems that has been somewhat unexplored in previous literature. Although the input elasticities confirm that OECD nations are experiencing extreme diminishing returns in the production of health, cost of life calculations have established direction as to which entities will benefit the most from capital resource additions. Furthermore, the complementary relationship between physicians and nurses has been substantiated through a positive MRTS while the MRTS of labor for capital suggests these inputs are allocated inefficiently relative to each other.

[21] See Appendix 4 for calculation.

VI. CONCLUSIONS

Over the past fifty years, a growing interest in human capital has led to increased research regarding the production of health. There have been a number of studies that have examined and estimated the health production function, but there has been little agreement among them as to what should be included as a determinant of health. Additional questions concerning the extent to which certain factors contribute to the production of health has prompted this study to further investigate health determinants.

Using country-level data from 30 OECD countries from 1999 to 2005, a random effects model was estimated to describe the production of health. Factors based on neo-classical production theory were represented using six indicators: per capita health expenditure, quantity of physicians per 1,000 population, quantity of nurses per 1,000 population, per capita GDP, carbon monoxide emissions per square kilometer, and per capita alcohol consumption.

The results of this study indicate that OECD countries are experiencing extreme decreasing returns to scale, an idea that has not been addressed in previous literature. If the average country doubles every health factor, its population would see a 6.38 percent rise in life expectancy which translates to roughly a five year increase. An important concept to realize, however, is that the less developed OECD nations benefit more from factor increases than developed countries.

Overall, the biggest contributor to the production of health is the general socio-economic environment as measured by per capita GDP. Improving certain factors such as educational attainment, access to housing, water, and sanitation, and income provide a higher return on investment than is realized by medical factor improvements. However, the difficulty in achieving developmental progress is a significant barrier to health production and must be addressed specifically in each country.

Within the health care system, the partial output elasticity of health expenditure was used to calculate the cost of an additional year of life expectancy for each observation. The calculations show that the cost of life for lower-income countries is much cheaper than that of higher-income countries. Furthermore, this cost has risen over time in each country illustrating the decreasing marginal production that the average country is experiencing.

Moreover, the capital-labor tradeoff was examined and it was determined that, in general, industrialized health care systems must first look to increase capital resources before hiring more labor. As it is, the average OECD country has too much health care labor in relation to capital based on current input prices. Consequently, health care systems are far from operating efficiently.

The goal of attaining efficiency is one that should be a top priority for every fiduciary institution, and decision makers must be equipped with results and sound economic interpretations. It is hoped that this study has provided a better understanding of the production of health and the interaction of health care inputs so that limited resources can be maximized.

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APPENDICES

APPENDIX 1: The Interpretation of Double Log Coefficients

The derivation of the interpretation that logarithms serve as an approximation of the percentage change in a factor

Logarithm Product Rule: $\ln(x_1 x_2) = \ln(x_1) + \ln(x_2)$

Logarithm Quotient Rule: $\ln\left(\frac{x_1}{x_2}\right) = \ln(x_1) - \ln(x_2)$

Assumption: $\ln(1+\delta) \approx \delta$ for small values of δ

(1) Take a natural log regression: $\ln(y) = \beta_0 + \beta_1 \ln(x)$

(2) Increase x by δ percent: $\ln(y^*) = \beta_0 + \beta_1 \ln[x(1+\delta)]$

(3) Transform using product rule: $\ln(y^*) = \beta_0 + \beta_1 \ln(x) + \beta_1 \ln(1+\delta)$

(4) Simplify: $\ln(y^*) \approx \beta_0 + \beta_1 \ln(x) + \beta_1 \delta$

(5) Subtract (1) from (4): $\ln(y^*) - \ln(y) \approx \beta_1 \delta$

(6) Transform using quotient rule: $\ln\left(\frac{y^*}{y}\right) \approx \beta_1 \delta$

(7) Manipulate the left hand side: $\ln\left(\frac{y^*}{y} + 1 - 1\right) \approx \beta_1 \delta$

(8) Substitute $\frac{y}{y}$ for 1: $\ln\left(\frac{y^*}{y} + \frac{y}{y} - \frac{y}{y}\right) \approx \beta_1 \delta$

(9) Simplify: $\ln\left(\frac{y^* - y}{y} + \frac{y}{y}\right) \approx \beta_1 \delta$

(10) Substitute 1 for $\frac{y}{y}$: $\ln\left(1 + \frac{y^* - y}{y}\right) \approx \beta_1 \delta$

(11) According to Assumption: $\ln\left(1 + \frac{y^* - y}{y}\right) \approx \frac{y^* - y}{y}$

(12) Simplify: $\frac{y^* - y}{y} \approx \beta_1 \delta$

$\therefore$

A δ percent change in x leads to an approximate $\beta_1 \delta$ percent change in y for small values of δ.

APPENDIX 2: Comparative Price Levels used by the OECD in Calculating PPP Figures

	1999	2000	2001	2002	2003	2004	2005
AUSTRALIA	1.30	1.31	1.33	1.34	1.35	1.37	1.39
AUSTRIA	0.917	0.901	0.917	0.896	0.884	0.873	0.874
BELGIUM	0.921	0.892	0.885	0.865	0.878	0.895	0.899
CANADA	1.19	1.23	1.22	1.23	1.23	1.23	1.21
CZECH REPUBLIC	14.14	14.23	14.22	14.32	14.02	14.27	14.40
DENMARK	8.47	8.42	8.46	8.30	8.53	8.39	8.52
FINLAND	1.003	0.996	1.011	1.003	1.01	0.974	0.983
FRANCE	0.960	0.940	0.918	0.905	0.937	0.939	0.923
GERMANY	0.97	0.968	0.955	0.942	0.917	0.895	0.893
GREECE	0.681	0.679	0.671	0.660	0.688	0.695	0.702
HUNGARY	101.07	108.02	110.61	114.88	120.44	126.13	128.51
ICELAND	79.68	84.42	88.89	91.34	94.42	94.12	97.06
IRELAND	0.930	0.963	0.993	1.00	1.01	1.00	1.02
ITALY	0.818	0.818	0.807	0.845	0.853	0.872	0.875
JAPAN	162	155	149	144	140	134	130
KOREA	755	749	757	770	796	794	789
LUXEMBOURG	0.941	0.941	0.948	0.934	0.941	0.921	0.922
MEXICO	5.63	6.11	6.31	6.55	6.82	7.12	7.13
NETHERLANDS	0.907	0.894	0.906	0.902	0.926	0.908	0.898
NEW ZEALAND	1.43	1.45	1.47	1.47	1.50	1.51	1.54
NORWAY	9.33	9.14	9.18	9.11	9.11	8.98	8.84
POLAND	1.74	1.84	1.86	1.83	1.84	1.86	1.90
PORTUGAL	0.697	0.701	0.705	0.708	0.706	0.715	0.707
SLOVAK REPUBLIC	15.08	15.86	15.71	15.90	16.71	17.23	17.20
SPAIN	0.733	0.735	0.739	0.733	0.752	0.758	0.768
SWEDEN	9.29	9.15	9.35	9.35	9.33	9.09	9.24
SWITZERLAND	1.87	1.85	1.84	1.77	1.77	1.75	1.74
TURKEY	0.202	0.283	0.428	0.613	0.773	0.811	0.868
UNITED KINGDOM	0.653	0.637	0.626	0.628	0.640	0.632	0.649
UNITED STATES	1.00	1.00	1.00	1.00	1.00	1.00	1.00

APPENDIX 3: Random Effects Model Assumptions

1. We have a random sample from the cross section.
2. There are no perfect linear relationships among the explanatory variables
3. $E(\varepsilon_{it} \mid X_i, \upsilon_i) = 0$: Given the explanatory variables in all time periods and υ_i , for each t the expected value of ε_{it} is zero.
4. $E(\upsilon_i \mid X_i) = \beta_0$: Given all explanatory variables, the expected value of υ_i is constant.
5. $Var(\varepsilon_{it} \mid X_i, \upsilon_i) = Var(\varepsilon_{it}) = \sigma_\varepsilon^2, \forall t = 1,...,T$: The variance of the sample's observation-specific error is equal to the variance of the population's observation-specific variance.
6. $Var(\upsilon_i \mid X_i) = \sigma_\upsilon^2$: Given all explanatory variables, the variance of υ_i is constant.
7. $Cov(\varepsilon_{it}, \varepsilon_{is} \mid X_i, \upsilon_i) = 0, \forall t \neq s$: For all time periods where $t \neq s$, the observation-specific error terms to not correlate over time for a single cross-sectional unit.

APPENDIX 4: Calculating the Average Health Worker Wage

Country	Currency Conversion	Year	Weekly Physician Wage, USD	Physicians per 1,000 Population	Weekly Nurse Wage, USD	Nurses per 1,000 Population	Weighted Average Health Wage, USD
Australia	1 AUD = 0.7468 USD	2004	1,288.98	2.7	762.78	10.1	873.78
Austria	1 Euro = 0.9763 USD	2002	915.04	3.3	673.40	7.1	750.07
Canada	1 CAD = 0.8507 USD	2005	884.24	2.1	752.38	8.7	778.02
Denmark	1 Krone = 0.1622 USD	2005	2,811.06	3.6†	1,140.33	14.8†	1,467.21
Finland	1 Euro = 1.2098 USD	2005	1,575.15	2.7	819.94	8.0	1,010.51
Germany	1 Euro = 1.2098 USD	2005	1,343.79	3.4	746.45	9.7	901.48
Hungary	1 Forint = 0.0048 USD	2005	1,094.02	2.8	798.21	5.9	893.41
Italy	1 Euro = 1.2098 USD	2005	1,389.36	3.8	581.27	7.0	865.60
Japan	1 Yen = 0.0087 USD	2005	1,801.86	2.0†	672.25	9.0†	877.63
Mexico	1 Peso = 0.0920 USD	2005	1,148.10	1.8	581.87	2.3	830.46
Poland	1 Zloty = 0.2926 USD	2004	905.54	2.3	853.12	4.9	869.87
Slovak Republic	1 Koruna = 0.0311 USD	2005	796.59	3.1†	445.88	6.3†	561.54
United Kingdom	1 Pound = 1.7837 USD	2005	2,116.18	2.4	823.53	12.3	1,034.57
United States	1 USD = 1 USD	2004	2,762.40	2.4	946.00	10.3	1,289.26

† Year's estimate not available. Figure is from 2004. Wage information taken from ILO Statistical Database.

To estimate an average country-level health worker wage, the weighted average was taken based on health worker density in each country. The arithmetic average of the country-level wages is then annualized to provide comparability with total health expenditure figures.

Average Weekly Wage: $928.82
Average Yearly Wage: $48,298.38