# The Effects of Female Human Capital on Economic Growth in Scandinavia

*An Instrumental Variables Regression Analysis*

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# Executive Summary

Following the notion of knowledge throughout the history of economic thought, knowledge was rather neglected, yet intricately entwined in the productive powers of labor, until Gary Becker's introduction of the productivity augmenting effects of human capital in the 1960s. While the effects from human capital as another variable in the production function led to insignificant results, theoretically, Benhabib and Speigel demonstrated human capital's ability to attract physical capital and increase a country's total factor productivity. Furthermore, Robert Barro empirically found positive and significant effects from male secondary and higher education; yet, the effects of female education were limited to capital deepening. As Bils and Klenow criticize the significance of human capital in economic growth due to the presence of simultaneous causality and omitted variables bias, Wolff further critiques the poor quality of education data, incomparability between education systems and that perhaps only certain forms of schooling have significant effects on economic growth. Barro integrates higher quality education data to incorporate international exam scores, finding a much stronger effect on growth, yet the effects of female human capital remain negative and insignificant.

Disappointed with the negative and insignificant effects from female human capital on economic growth, Barro's proposes that this may be due to a majority of countries underutilizing educated females in the workforce. By limiting our sample size to countries with comparable education systems and equal opportunities for women, the purpose of this paper is to investigate whether or not the negative and insignificant effects from female human capital on economic growth holds in countries with some of the lowest gender gaps in the world. As occupational opportunities converge, the prevailing hypothesis is that educated women should have positive and significant effects on economic growth, at a similar magnitude to men. Limiting our sample size to four of the top ten countries with the lowest gender gaps in the world and comparable education, we focus on Denmark, Finland, Norway and Sweden. After transforming our data for stationarity and confirming the presence of simultaneous causality, we panel our data and estimate a two-stage least squares instrumental variables regression to remove endogeneity. With our results holding to robustness through country fixed effects and in line with Barro's previous results, we build upon the previous literature to conclude that even in countries with some of the smallest gender gaps in the world, women may be underutilized in the workforce where we highlight potential economic interpretations ranging from limitations in our IV model to cultural implications and opportunity costs.

# Table of Contents

# 1. Introduction

In a world faced with scarcity, all the way back to the early developments of the human race, we investigate the productivity augmenting effects of knowledge. Learning by doing prevailed for over 10,000 years, mainly through serendipitous discoveries in tools and agriculture. As farming increased yields, sedentary civilization evolved, permitting specialization and the division of labor, later to be described by Adam Smith in the early years of the industrial revolution. Though knowledge and human capital would remain neglected from economic theory for over 12,000 years, the notion of knowledge was still a veiled value in economic thought, seemingly entwined in the productive powers of labor. Following the introduction of formal education, science-based knowledge dominated economic growth leading to many innovations still used today. In the turmoil leading to the world wars and in the wake of new scientific discoveries, Joseph Schumpeter criticized static economic theory to incorporate development, in his sense, of new combinations, goods of novelty and methods of production never seen before to fuel economic growth.

Following the world wars, in the pre-embryonic years leading to the birth of human capital, Robert Solow introduced a production function, finding significant effects from total factor productivity on economic growth. While technological change was still considered exogenous, in the 1960s, Gary Becker finally disentangled the quantities and qualities of labor to bring about human capital as we know today. Similar to Becker's age-earnings profiles, Mincer estimates the effects of education on wages, highlighting the complicated relationship between schooling and growth. As Romer endogenized TFP, the non-rival characteristics of knowledge led to the underprovision of innovation; and, Aghion and Howitt introduced qualitative improvements in innovation to accentuate that not only spillovers, but expectations and obsolescence to lead to suboptimal investment in innovation. Theoretically, expecting human capital to attract physical capital and increase a country's TFP, Benhabib and Spiegel confirm these expectations in a theoretical model while Barro empirically displays the positive effects of male education on technological progress; yet, the effects of female education are limited to capital deepening.

Bils and Klenow criticize the significance of human capital on economic growth, suggesting the presence of simultaneous causality and omitted variables bias; and, Wolff also highlights the poor quality of educational attainment data and problems of comparability between education systems across countries. Improving on the quality of data, Barro integrates a term for human capital through international exam scores, finding a much stronger effect on growth from science scores than simply from quantity in terms of years of schooling. Despite improved data, Barro still finds female education to be limited to a fertility effect, while male education can still be considered to raise a country's absorptive capacity for spillovers and innovation. Barro proposes the negative and insignificant effects of female secondary and higher education on economic growth may be due to the underutilization of educated females in the workforce. As Barro's sample size consists of around 100 countries, the purpose of this paper is to investigate whether or not females have a positive and significant effect in countries with some of the lowest gender gaps in the world. As Wolff criticized the problems of comparability between education systems, we focus exclusively on Scandinavia, assuming a reasonably comparable education system between Denmark, Finland, Norway and Sweden. Focusing on these Scandianvian countries with minimal gender discrimination and as occupational opportunities have converged over the years, the prevailing hypothesis is that educated women should have a positive and significant effect on economic growth, at a fairly similar magnitude to men.

To test our hypothesis, this paper is divided into two parts; the first part explores the history of economic growth and the importance of human capital from over 13,000 years ago through classical economic theory, neo-classical economic theory, until the birth of human capital and its understanding today. Dissatisfied with the negative and insignificant effects of female human capital on economic growth, the second part of this paper develops our hypothesis, expecting educated women to have positive and significant effects on economic growth in our Scandinavian countries. Section 3.2 describes our use of Barro and Lee's most recent educational attainment dataset as our proxy for female human capital and the Penn World Tables' real GDP per capita figures as our proxy for economic growth. Section 3.3 investigates the stationarity of our data, applies appropriate transformations and tests for the presence of simultaneous causality. Confirming bidirectional causality in our data, we first panel our data and then develop a two-stage least squares instrumental variables regression to control for endogeneity. Section 3.4 analyzes our regression results, provides potential economic interpretations and considers other implications before a final robustness check by controlling for heterogeneity bias through country fixed effects. With negative and insignificant effects from female higher education holding to robustness, section 4 concludes that even in countries with some of the lowest gender gaps in the world, females may still be underutilized in the workforce.

# 2. Part I: History of Economic Growth and the Importance of Human Capital

## 2.1 Pre-Economic Theory

Since the beginning of the development of the human race, we find evidence of humanity optimizing choices in the face of scarcity and storing gained knowledge. Before the end of the last Ice Age, all peoples were engaged in a hunter-gatherer lifestyle (Diamond 16). Typically, men focused on hunting with some gathering of wild plants, while women mostly participated in plant collection, food preparation and child care (Robson and Kaplan 380). Many assume sex and age always dominated task allocation; however, one study finds Aeta women who hunt have a 31 percent success rate as opposed to only 17 percent for men, and mixed hunting groups have a 41 percent success rate (Andrei 43). Here, one of the earliest known forms of human society existing suggests that people over 13,000 years ago were rationalizing ways to increase productivity by assessing individuals' opportunity costs to the marginal benefits associated with the division of labor, terms which would not come to light for over another 12,000 years. As knowledge grew and agriculture and tools slowly evolved in the Neolithic revolution, the production possibilities curve shifted outward, leading way to denser populations that lay the foundation for specialization and trade. Jared Diamond explains how knowledge in the domestication of plants and animals resulted in a settled existence, permitting food storage where, "…stored food is essential for feeding non-food-producing specialists, and certainly for supporting whole towns of them." (89) Until sedentary civilization, there was little room for specialization past food acquisition and survival for the hunter-gatherer.

It was knowledge in agriculture and technology which fostered the basis for exchange and the division of labor beyond child care and sustenance. Fast-forwarding through these early developments, philosophers of the fourth century could be argued to have pondered exactly that as seeking means of economic growth. One piece of evidence arises in Xenophon's *Cyropaedia* where in anticipation of Adam Smith, Xenophon describes the advantages of a large, as opposed to a small, city in the opportunity for specialization by trade, in other words, for the division of labor (Galbraith 16). Agriculture and innovations bolstered these large cities, while specialization further grew knowledge. Furthermore, in the writings of Greek philosopher, Aristotle, he focuses on the improvement in trade, considered a predecessor in the concern for economic growth, and accentuates the importance of efficient agricultural organization and practice (Galbraith 13). Perhaps it is no wonder why agricultural innovations were the confines of economic growth as cities were still growing and the Ancient Greek world relied on dependent labor to meet its needs (Finley 97). It was not until Pliny (c. A.D. 23-79) casted doubts on the efficiency of slavery and entrusted work to “men who live without hope,” that the underlying principle of voluntary exchange in commerce could commence (qtd in Gray 37).

Ironically, it can be argued voluntary exchange would not be found throughout the next ten centuries of the Middle Ages and economics as a known still did not yet exist beyond the mere product of humanity’s rather unconscious calculations and political philosophy. Up until about the fifteenth century, exchange was not necessarily arising out of mutual benefit, but rather was seeded in a form of surrender as “…in response to law, custom, and the fear of condign and markedly painful punishments.” (Galbraith 30). It was not until the onset of mercantilism that a true, although perhaps rather erroneous, commerce society erupted. As ships from far off lands brought goods, the mercantilists brought with them not only a shift in the ethical paradigm for the pursuit of wealth, prohibition of competition and tariff protection, but also “the great modern corporation” (Galbraith 41). Before the wane of mercantilism in the eighteenth century, the pre-industrial economy relied on a thin thread of knowledge and capital; the methods of increasing economic growth were through the gains from specialization or the division of labor, from learning by doing, and from trade based advantages due to regional differences in resources (Persson 22). Up until this time, knowledge, like economic theory, arose mainly through serendipitous discoveries for which occasion increased from specialization.

## 2.2 Classical Economic Theory

While lands opened up and trade flourished, so did aggregate demand and Adam Smith’s ideas of the invisible hand, division of labor, and theory of value in *An Inquiry into the Nature and Causes of the Wealth of* Nations published in 1776. Standing on the shoulders of Galiani, Hume, Quesnay and the physiocratic movement, *The Wealth of Nations* is considered to be monumental in the epoch marking “…the effective birth of economics as a separate discipline…” (Blaug 343). During the early wake of the Industrial Revolution, most productivity shifts stemmed from economies of practice and learning by doing through the division of labor; with the exception of the steam engine, it was not until the middle of the nineteenth century that, “…science-based knowledge became a major factor in economic growth…” (Persson 99). Smith, perhaps a victim of his time, in his scribed quest to uncover the natural roots of economic growth, eloquently depicts,

> “The annual labour of every nation is the fund which originally supplies it with all the necessaries and conveniences of life which it annually consumes… first, by the skill, dexterity, and judgment with which its labour is generally applied; and, secondly, by the proportion between the number of those who are employed in useful labour, and that of those who are not so employed. Whatever be the soil, climate, or extent of territory of any particular nation.” (1)

In other words, no matter the endowments of nature and availability of land, consumption and the standard of living increase through the input of knowledge embodied in the workforce and the overall size of the population in productive occupations, or improvements in the productive powers of labor. Smith continues to describe the greatest improvements in the productive power of labor have been in the effects arising from the division of labor (2). With the division of labor conceivable due to an expansion in the extent of the market, Smith is emphasizing the resulting economies of practice and learning by doing as the attributing factors toward the major advancements in economic growth at the time. Even though these productive powers of labor fueled the accumulation of capital, "It is by means of an additional capital only, that the undertaker of any work can either provide his workmen with better machinery, or make a more proper distribution of employment among them." (141) Generally, Smith accredits labor and capital to economic growth, but in this time the increasing role of knowledge, entangled in the skills and dexterities of labor, later to be called human capital, would become a veiled value in economic thought. Smith recognizes this as workers' skills improve, time is saved from no longer passing between tasks, and "Men are much more likely to discover easier and readier methods of attaining any object, when the whole attention of their minds is directed towards that single object…" (5). While these knowledge creation effects of learning by doing certainly led to incremental process innovations, Smith perhaps indirectly recognizes a role for human capital beyond learning by doing in,

> "All the improvements in machinery, however, have by no means been the inventions of those who had occasion to use the machines. Many improvements have been made by the ingenuity of the makers of the machines… and some by that of those who are called philosophers, or men of speculation, whose trade it is not to do anything, but to observe everything, and who, upon that account, are often capable of combining together the powers of the most distant and dissimilar objects." (5)

It is through philosophers' observations, theoretical inquiry, systematic experiments, and perhaps a scientific mentality, that the most distant and dissimilar objects arise into radical new process and product innovations, fueling the early years of the Industrial Revolution that Smith was able to briefly observe.

Moving from the merchant to the industrialist, factories rose and the mercantilist trade barriers crumbled to the economic arguments of most notably Adam Smith and David Ricardo. Smith's reproach toward mercantilism was sown from objection toward trade restraints and the monopolistic methods of the time. Smith criticizes the regulations in trade by, "Though the encouragement of exportation, and the discouragement of importation, are the two great engines by which the mercantile system proposes to enrich every country, yet with regard to some particular commodities, it seems to follow an opposite plan…" (266). The tariffs and prohibitions designed to promote and protect home industry seemed to achieve the contrary and monopolistic menageries limited the extent of the market and knowledge spillovers, seen when Smith expresses, "Such exclusive companies, therefore, are nuisances in every respect; always more or less inconvenient to the counties in which they are established, and destructive to those which have the misfortune to fall under their government." (266) Despite Smith's clever cracks, Ricardo's theory of comparative advantage would decimate the mercantilist trade barricades. Ricardo composed,

> "The produce of the earth…is divided among three classes…the proprietor of the land, the owner of the stock and capital necessary for its cultivation, and the labourers by whose industry it is cultivated…rent, profit, and wages, will be essentially different; depending mainly on the actual fertility of the soil, on the accumulation of capital and population, and on the skill, ingenuity and instruments employed in agriculture." (Ricardo preface a)

Similar to Smith, Ricardo attributes economic growth to the functions of labor and capital; however, he contradicts Smith in that the fertility of the land plays a star role. The fertility of the land would come to fuel Ricardo's argument through his observation of the Corn Laws in England. He proposed if corn imports are restricted, then the limited amount of land suitable for cultivation diminishes; and, as farmers attempt to cultivate these arid, infertile lands, this redirected investment in agriculture increases the rent share to the proprietor and diminishes the profit share to the capitalist (Screpanti and Zamangi 95). With profits fueling the accumulation of capital according to Ricardo, his contention was that any protectionist measures diverting more income to rent over profit would reduce economic growth. The arguments of Smith and Ricardo helped obliterate trade barriers and bring "about the first era of free trade, from about 1850 to 1875." (Persson 160)

As trade barriers were left in destitute ruins and science as a means of production fueled innovations, cities flourished, factories surged, and the diffusion of knowledge reached epidemic proportions never before witnessed. This surmounting knowledge was seen throughout the nineteenth century with grand industrial exhibitions diffusing knowledge, as the traveling writers of the time were reporting back new methods of production for foreign products, and catalogs of useful inventions were edited (Persson 97). This production and absorption of new knowledge reached unprecedented magnitudes. Patent applications proliferated in nineteenth century in most notably Norway and Denmark as well as France and Germany where, "The learning by doing process we know from the pre-industrial period remained, but science-based technology turned out to be much stronger in its effect on growth." (98-99) In the time of classical economics, it can be said that both incremental and radical innovations prevailed in the wake of knowledge, and it was the first time, beginning in "…the nineteenth century that formal education has played an important role."

(1) Though the idiom of human capital had not yet emerged, it can be argued that the effects of knowledge were not completely unseen throughout the classical works of Smith, Ricardo and Karl Marx.

Concluding our classical authors, Marx observes the impacts of knowledge imbedded in productiveness of labor through the state of science, the degree of its practical application, the skills of workmen, and the social organization of production (47). These factors influence the value of a commodity, and under Marx's general formula for capital, "M-C-M', where M'=M+ΔM= the original sum advanced, plus an increment… The value originally advanced, therefore, not only remains intact while in circulation, but adds to itself a surplus-value or expands itself. It is this movement that converts it into capital." (168) It is through the capitalists' monetary advancement in the form of wages and machinery for the dictation of the production of a commodity that a profit or surplus-value is drawn, as long as the capitalist produces a use-value that has value in exchange and value that is greater than the sum of the commodities used for production (207). Here, workers are producing goods or commodities whose value is greater than the labor power used to produce it, creating more capital and fabricating grander factories through investments of this accumulated capital. However, capitalism was far from utopia according to Marx, as he observed the susceptibility towards the concentration and centralization of capital where, "…the unequal decrease in the rate of profit will allow the big fish to swallow up the little ones." (Screpanti and Zamangi 158) This increasing concentration to Marx was, "…an organic tendency of capitalism, one that proceeded with irresistible force." (Galbraith 136) Despite the burgeoning manufactories, cities and bourgeoisie barracudas, the late nineteenth century was marked by the anxieties and sorrows of financial volatility, agricultural depressions, and a world-wide decrease in the growth of international trade and a reduction in prices (Screpanti and Zamangi 164).

## 2.3 Neo-Classical Economic Theory

While capital found its way back to fewer and more corpulent pockets, collusions, mergers and cartels spread across the brick mortared landscape. Carl Menger, subsumed in the movement from the classical focus on accumulation and growth to the Marginalist neoclassical ideas of utility and the allocation of finite resources, describes the characteristic inefficiencies of monopolies enrooted in the self-economizing individual where under certain circumstances, "…he [the monopolist] may even have occasion to abandon part of the quantity of the monopolized good at his disposal to destruction instead of bringing it to market, or, with the same result, to leave unused or to destroy part of the corresponding means of production at his command instead of employing them…" (212). Competition is the force which restrains this monopolistic massacre and misuse of material, "...since the smaller the profit on each unit the more dangerous becomes every uneconomic waste…" (225). Any inefficiency under competition accrues to competitors, thus reducing any incentive to squander resources. Under the emerging theory of marginal utility at the time, this rivalry leads to "…a kind of organization in which the market rule would allow an optimum allocation to be reached and, with it, the harmony of interests and the maximization of individual objectives." (Screpanti and Zamangi 172) At this equilibrium, supply equals demand, resources are employed in the most efficient ways, and individuals maximize their utility, dependent upon the number of firms, the number of consumers, the endowments of resources, the consumers' preferences and the techniques available (184). An equilibrium of given knowns.

Later in the preface of the twentieth century, Joseph A. Schumpeter came to criticize this static equilibrium theory through that "…it can neither explain the occurrence of such productive revolutions nor the phenomena which accompany them. It can only investigate the new equilibrium position after the changes have occurred." ("Economic Development" 62-63) Perhaps it was the embryonic breakthrough technologies of the late nineteenth century that would bring Schumpeter to his theory of development, for, in his time, he was to observe the birth and technological trajectories of innovations that were later developed into articles of mass consumption such as the telephone, sound recording, cameras and movies, wireless communication including radio, chemical fertilizers, plastics, dynamite, and even the bicycle (Persson 107). These radical, architectural, competence destroying process and product innovations were possibly the rousing muse to Schumpeter's new combinations, where, "The slow and continuous increase in time of the national supply of productive means and of savings is obviously an important factor…but it is completely overshadowed by the fact that development consists primarily in employing existing resources in a different way, in doing new things with them, irrespective of whether those resources increase or not. " ("Economic Development" 68) Here, Schumpeter emphasizes the significance in the accumulation of capital and incremental innovations. However, more importantly, he stresses the magnitude of radical innovations on economic growth through new combinations of inputs to produce goods of novelty, new methods of production never seen before and the entrepreneurial activities of opening new markets, discovering new sources of supply and the new organization of industry (66). While still a topic of discussion today, Schumpeter challenged the prevailing view of monopolies by suggesting, "Innovation, the contribution of the entrepreneur, was best financed, encouraged and rewarded when the innovator was free from the threat of imitation and competition, and such freedom was most possible given monopoly." (Galbraith 181-182) Schumpeter, perhaps, contributing to not only the importance of knowledge and thinking upstream in new and creative ways, but more importantly the application and incentives provided for an invention to become an innovation and disrupt the existing equilibrium to bring about economic development in his sense.

Despite the cultivating forces of groundbreaking invention, scientific innovations, international trade and the diffusion of knowledge, the anxieties and sorrows of the late nineteenth century proliferated, like necrosis on leaves, into the interwar period during the first half of the twentieth century. Calamity and misery danced their duet across the global stage with "the breakdown of the system of international payments, abandonment of the Gold Standard…competitive devaluations, harsh protectionism, the contraction in international trade; and then, increasing instability in growth, increasingly bitter crises, rampant unemployment, the Wall Street Crash, and the suicides of speculators." (Screpanti and Zamagni 233) The bereavement of the Gold Standard caused the already existing financial unsteadiness to soar out of control like hurricane winds, decay crept while prices fell like Zeppelin bombs digging the trenches deeper for the resurrection of skyscraping trade barriers. Crops withered, deflation-marred debts became due, factories idled, and the banks collapsed into rubble as bears devoured, limb by limb, the last gleam of hope on Wall Street. The Great Depression struck the hearts of the acquitted and wicked, in the United States alone, real GDP fell by over 33 percent and over 25 percent of people actively seeking work failed to find jobs (O'Sullivan et al. 113). Governments stood still amidst the babies' cries and ever darkening skies under Hawtrey's Treasury view that government taxation or public debt could not increase the level of employment (Screpanti and Zamagni 247). However, John Maynard Keynes came to contradict this government malingering, postulating that "…given the psychology of the public, the level of output and employment as a whole depends on the amount of investment." (Keynes 221) Here, the marginal efficiency of capital, or the expectation of future return from investment, depends on psychological factors more than just investment in the factors of production under classical theory. This ingredient was de rigueur for Keynes' economic prescription of monetarism where the interest rate is lowered through an expansion in the money supply; then, given psychological expectations driving the marginal efficiency of capital, investments increase, and finally, output, income and aggregate demand also increase, but at a diminishing rate through the effect of the multiplier (Screpanti and Zamagni 255). However, even Keynes himself would come to question the validity of these expansionary policies and whether or not "investments are inelastic with respect to the interest rate." (257) Unfortunately, Keynes would not come to see his antidote in full action.

As darkness flooded souls and fascism rose, the Second World War detonated. Up until the fall of the cantillating fat man, military spending helped boost the economy by increasing total demand to alleviate the economy from its decade of poor performance (O'Sullivan et al. 217). This increased demand along with a coalescence of banking security, monetary policy and trade agreements set the stage for a golden age. In 1933, the U.S. government began to provide deposit insurance to prevent bank runs at the magnitude seen during the great depression (266). With integrity restored in the financial system, an improved gold standard was enacted during the summer of 1944, when forty-four countries signed the Articles of Agreement of the International Monetary Fund (IMF) (Persson 180). The IMF called for fixed exchange rates similar to the gold standard, but allowed for a sort of government "…concerted and deliberate management of the economy…" (Screpanti and Zamagni 249). Finally, as the war drew to an end, trade barriers were dismantled and rays of light gleamed through the cracks with the General Agreement on Tariffs and Trade in 1947 (Persson 164). These factors of a more stable financial environment and trade agreements highlight the underlying importance in the diffusion of knowledge. This can be seen in the contrasting difference between the pre and post war economy where"…the 1914-1950 period lacked the vital mechanisms for technology transfer, that is openness to trade, capital and people… The years from 1950 to 1975 saw a reduction in trade restrictions inherited from the interwar period; and trade grew two to three percentage points faster than GDP growth...Capital chased technology and vice versa." (114) A perfect example of this atavistic technological pursuit arises in combustion engines.  The automobiles we know today were not a breakthrough technology until following the Second World War, despite the application of combustible engines in automobiles since the 1890s, at the beginning of the twentieth century, the total number of cars worldwide did not exceed 10,000 (107). Banking institutions lowered transaction costs for investments while capital, people and ideas flowed easier between nations. The economy roared from the kindling embers of increased demand during the war, "These were the years of great exoduses of the labour force, from agriculture to industry and from countryside to the cities; years of great social and cultural transformations, such as the growth of urban areas, changes in consumption patterns and cultural models, increased population mobility, the large expansion in the number of cars, and the achievement of a general rise in the standard of living." (Screpanti and Zamangi 324) The storm had cleared and the economy flourished like a field of tulips in the early break of spring, emerging from the cool, crisp, once battered and barren soil of winter and knowledge diffused like pollen in the wind.

## 2.4 Human Capital Theory

### 2.4.1 The Birth of Human Capital

During the 1950s, the dust from the war settled and Robert Solow published a paper developing a production function where the "…purpose was to examine what might be called the tightrope view of economic growth and to see where more flexible assumptions about production would lead a simple model." (Solow 91) Solow sought to seek economic growth by modeling the quantity of output to the quantity of input through $Y = A\,f(K, L)$, where *Y* represents GDP or output, which is dependent on *K* for capital, *L* for labor, and the level of technology, *A* (Greenhalgh and Rogers 215). This exogenous force of the level of technology, *A*, is commonly referred to as total factor productivity (TFP) and can be generalized as the remaining residual of output not attributable to the inputs of labor or capital. The following year, though later challenged, Solow found that 88 percent of increases in GDP per capita in the United States over the period 1909-1949 were attributable to TFP growth, or technical change (78). Perhaps the deteriorated financial environment, trade restrictions limiting the flow of capital and high unemployment rates coupled with government demand for technologies of war are attributable to such a high residual beyond capital and labor during this time period, or maybe Solow's critics were right and there was little to no residual at all. One thing is for certain, the importance of knowledge and innovation would be emphasized in the years to come while, "Such a sustained, rapid, and widespread growth had never before been experienced. The war and crises were rapidly forgotten; it seemed that there were no limits to economic expansion. When the first man landed on the moon in 1969, it seemed that any challenge could be met." (Screpanti and Zamagni 324) The level of technology was rising and no longer was the sky the limit.

The economy during the 1960s roared like the engine of a supercharged Pontiac GTO with horsepower never experienced before. Knowledge came to the forefront with Gary Becker's development of human capital or, "activities that influence future real income through the imbedding of resources in people." (9) Prior economic theory suggested earnings differences were attributable to mainly physical capital, ability, technology and institutions (43). Becker, however, did recognize that previous literature had noticed the importance of knowledge, yet the formalities of human capital had largely been underdeveloped. While speaking of one form of human capital, on-the- job training, he emphasizes, "This is not to say that no one recognizes that productivity is affected by the job itself; but the recognition has not been formalized, incorporated into economic analysis, and its implications worked out." (10) We found allusions to human capital throughout the classical works of Smith, Ricardo and Marx, while the neo-classical marginal approach, perhaps with the exception of Schumpeter, pursued more of, "…a calculus of pleasure and pain…" (Jevons 23). The absence of human capital and instead focus on physical capital and labor supply in prior literature perhaps is due more to that the qualitative differences of human capital, in terms of psycho-physical effort, is nearly impossible to measure at the operational level (Screpanti and Zamagni 177). Becker, dissatisfied with the vague significance of human capital, sought to integrate the importance of mental aptitude and application into economic theory. However, human capital is not only limited to learning by doing, investments such as, "…schooling, on-the-job training, medical care, vitamin consumption, and acquiring information about the economic system… all improve the physical and mental abilities of people and thereby raise real income prospects." (Becker 9) Recognizing the productivity effects of physical capital, technology and the given environment, Becker shows human capital investments also have an important effect on earnings because, after deducting capital expenditures, the remainder of return is earnings, as income is net of investment costs and gross of returns (43). This effect was pronounced in that almost all studies of age-earnings profiles are steeper for more skilled and educated individuals (43). This steepening arises from the direct and indirect initial outlays for human capital which lowers the net of earnings in earlier periods for anticipated higher earnings in later periods, much like physical capital outlays; though, "The typical investor in human capital is more impetuous and thus more likely to err than is the typical investor in tangible capital." (10) Conceivably, individuals may overestimate the return to investment in human capital while underestimating the opportunity cost. Overall, proliferation in stock of human capital occurred during the nineteenth century when formal education became customary, while increasing agricultural innovations led to more diverse and available nourishment, and learning by doing present in the previous centuries still prevailed. Imbedded knowledge, despite difficulties of measurement, was finally integrated into economic theory in the 1960s. Even the quintessential muscle cars of the time were more the product of brains than brawn.

Accelerating, the economy redlined, RPMs maxed as the gold standard disintegrated from the weakened dollar by the Vietnam War, and the only thing left to do was shift gears. Beginning in the early 1970s, first the devaluation of the dollar and then its inconvertibility led to the abandonment of the Gold Exchange Standard (Screpanti and Zamagni 324). This downshift in the economy created a rather unintended floating exchange rate; however, Germany's reputation for low inflation led many countries to peg their currency to the German mark (Persson 182). Not only was this deteriorating international monetary system encumbering the economy but, "Growing realization of the exhaustibility of resources and the gradual increase in the autonomy of the producing countries led to inevitable price rises which noticeably altered the terms of trade, especially in regard to oil." (Screpanti and Zamagni 324) The deeply embedded monopolistic tendencies of the past were in the present as countries formed cartels limiting already scant natural resources. The economic engine bogged from supply shocks as production prices soared, and then the stock exchange crisis hit, not causing the detrimental effects of the previous occasion, but this was most likely due to improved government intervention (324-325). The effects were not as pronounced as during the Great Depression; however, a new pattern emerged, stagflation (Persson

194). With unemployment and inflation increasing, the Keynesian theory which evolved from unemployment and deflation during the 1930s served no match for this new dynamic duo, where the inflation rate increased by over 6 percentage points between 1969 and 1970, almost 8 in 1972 and 1973, and hit double digits in 1974 to 1975 with an increase of nearly 14 percentage points (Galbraith 267). As inflation inflicted the economy with these double digit figures, output fell by over 4 percent from peak to trough and unemployment rose to 8.5 percent; at the time, it was the most severe recession since the Great Depression (O'Sullivan et al. 112).

Despite economic decline, knowledge and human capital would not fade from economic theory. Following in Becker's footsteps, during the mid-1970s, Jacob Mincer proposed a human capital earnings function where, "The positive relation between an individual's schooling and his subsequent earnings may be understood to reflect productivity-augmenting effects of education." (1) Mincer postulated that human capital in the form of schooling raises an individual's productivity, measured by earnings. Theoretically, there are two ways education can affect productivity and economic growth, first as skills and knowledge compliment investment in physical capital and second as education enables the creation and adoption of new ideas (O'Sullivan et al. 172). Here, the former is accentuating skills to compliment physical capital; a perfect example of this arises in the works of  Oliver Williamson during the late 1970s, where he highlights this role for human capital through Polanyi description of, "…an art which has fallen into disuse for the period of a generation is altogether lost…It is pathetic to watch the endless efforts—equipped with microscopy and chemistry, with mathematics and electronics—to reproduce a single violin of the kind the half-literate Stradivarius turned out as a matter of routine more than 200 years ago." (qtd. in Williamson 243) Here, Polanyi is describing that even possession of the most sophisticated physical capital fails to produce when ample demand for specialized skills and knowledge exist, like a bun without a hot dog. As human and physical capital are compliments, the latter of the effects from education emphasizes technological innovations and knowledge spillovers, where again in the works of Oliver Williamson, he highlights through Polanyi's discussion of personal knowledge that, "Indeed even in modern industries the indefinable knowledge is still an essential part of technology. I have myself watched in Hungary a new, imported machine for blowing electric lamp bulbs, the exact counterpart of which was operating successfully in Germany, failing for a whole year to produce a single flawless bulb." (242-243) Without an adequate base of human capital, innovations from abroad cannot become integrated into production readily, let alone invented. While schooling theoretically enhances productivity through the above mentioned ways, it should be noted, "This relation is by no means direct or simple. Schooling and education are not synonymous: the educational content of time spent at school ranges from superb to miserable. The absorption of learning and marketability of knowledge and of skills acquired through learning also differ a great deal among individuals, places, and times." (Mincer 1) The comparability amongst education in terms of quality, and subsequently even quantity, is nearly impossible given differences between continents, countries, cities, colleges, courses and especially characters. Furthermore, Mincer highlights that"… school is neither the only nor necessarily the most important training ground for shaping market productivities." (1) Williamson displays the negative effects on productivity given lack of human capital, yet the measurability of schooling as a form of human capital is arduous, grueling and dubious. Despite these drawbacks, education remains our most feasible measure of human capital.

### 2.4.2 Spillovers and Expectations

While integrating human capital into economic models proved challenging and technological innovation was still considered an exogenous phenomenon, the upset from the oil shock was not over; and, the international scene during the 1970s and 1980s was filled with uncertainty and instability, as governments and companies were finding difficulty in formulating long-term plans and policies (Screpanti and Zamagni 325). There was presentiment echoing throughout the economic system, no one knew what to do, would disinflationary policies exasperate unemployment levels or would rational expectations supersede?  At the beginning of the decade, production declined throughout the industrial world (Galbraith 291). Output waned like the slivered moon on a dark winter night; and, companies were constructing all new networks, flexible, new organizational methods linking upstream, downstream and between one another in ways much more complicated than had been witnessed before (Screpanti and Zamagni 325). The bells of uncertainty tolled, companies were adjusting to demand, and so were economists when Paul Romer during the mid-1980s developed an endogenous growth model, "… in which knowledge is assumed to be an input in production that has increasing marginal productivity. It is essentially a competitive equilibrium model with endogenous technological change." (Romer 1002) Since long-run growth is fueled by technological innovation arising from the accumulation of knowledge as a public good, the main idea of Romer's paper is there are diminishing returns to knowledge investment for individual firms, yet at the economy level, the returns to knowledge can be increasing (Greenhalgh and Rogers 227). The diminishing returns at the firm-level can be attributed to the externalities of knowledge, while the subsequent technological spillovers to other firms allow for increasing returns at the economy level. Theoretically, spillovers can occur through worker migration as well as upstream and downstream between firms. Occurring in a time when companies are intricately weaving newfangled supply webs, Romer finds that the externalities of knowledge are essential in explaining economic growth and why firms in competitive markets may invest too little in knowledge, causing growth rates to be lower than optimal (Greenhalgh and Rogers 229). As spillovers were postulated to lead to the under provision of innovation through suboptimal investment in knowledge creation by firms, inflation curtailed and the Greenspan era prevailed.

During the late 1980s, Alan Greenspan was appointed chairman of the Federal Reserve, collusion agreements amongst OPEC members fell apart, and inflation and unemployment fell due to this favorable supply shock (Mankiw 495). The falling oil prices drove down transportation and production costs, the subsequent outward shift in supply lowering prices, arousing employment and demand. Despite a small recession during 1991, after inflation rose, unemployment fell, the Fed raised interest rates contracting demand, and the rest of the 1990s was marked as a period of economic prosperity (494-495). Presumably, the tranquility of the market can partially be attributed to swift monetary policy by Greenspan and a long run outlook by OPEC where over the long-term, consumers purchase more efficient cars or opt for alternative transportation, while oil producers outside of the OPEC agreement respond to higher prices through new exploration methods and extraction capacities (107). This long run effect arises from OPEC's own creative destruction as technological progress is, "The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates." (Schumpeter "Creative Destruction" 83) Elaborating on Romer and budding from the roots of Schumpeter, in 1992, Philippe Aghion and Peter Howitt improved upon prior endogenous growth models to introduce quality improvements in industrial innovations (323). Considering the high prices during the reign of OPEC, as quality improves, consumers become more inelastic in their purchasing decisions, companies find greater returns on knowledge investments and new markets open way in the name of technological change. The old falls victim to the new; yet, the expectation of more future research threatens the rents of current research and this may discourage current research (323). This can be seen in the slow market movement toward more fuel-efficient and environmentally friendly vehicles where no one was sure whether or not hybrids would become obsolete by other alternative fuel technologies such as clean diesel, electric vehicles, fuel cells, and hydrogen combustion; many believed hybrids to be quickly replaced by fuel-cell-powered vehicles (Schilling 45). Hence, expectations, as well as, spillovers and obsolescence drive the underprovision of innovation and suboptimal economic growth.

While technological knowledge was shown to impact economic growth through innovation, in 1994, Jess Benhabib and Mark Spiegel sought to seek how educational attainment entered in the equation. When considering years of schooling in a cross-country production function, they find human capital growth to have an insignificant and usually negative effect on economic growth

(Benhabib and Spiegel 144). On the contrary, however, throughout the history of economic thought, human capital directly or indirectly played a significant role in the productive powers of a nation; where only since the nineteenth century has formal education entered the stage, we still find the power of science-based knowledge half a century later starting to play a major role in economic growth and contributing towards many commodities today. Since we have seen when Polanyi described the detrimental effects due to lack of human capital in Hungary, one would expect a positive and significant effect; however, perhaps, "As pointed out by Nelson and Phelps (1966), by treating human capital simply as another factor in growth accounting we may be misspecifying its role." (Benhabib and Spielgel 144) Instead of allowing human capital to enter in the production function as its own factor, Benhabib and Spiegel introduce a theoretical model, which holds to some degree empirically, where human capital can act both as an engine in affecting the magnitude of a country's Solow residual and in attracting physical capital (167). Thus, considering human capital as a contributing factor in a nation's capacity to innovate and adopt innovations from abroad, empirically, after introducing initial income levels to capture a catch-up effect, human capital enters positively and significantly, suggesting that higher education facilitates the adoption of technology and closes the technology gap at a faster rate (160). Supporting convergence theory, the growth in total factor productivity tends to approach the technological leader at the frontier more readily as years of schooling increases. In addition, human capital fuels the attraction of physical capital which aids in spillovers and domestic innovation where, empirically, human capital is positively correlated with physical capital and significant at the 5 percent level (165). We find human capital bolstering its influence in economic growth theory as a stimulating factor in the growth of total factor productivity and the accumulation of physical capital.

### 2.4.3 Significance of Education

Following in 1996, Robert Barro estimated the growth effects of human capital in a panel of nearly 100 countries from 1960 to 1990; he found, "For a given starting level of real per capita GDP, the growth rate is enhanced by higher initial schooling and life expectancy, lower fertility, lower government consumption, better maintenance of the rule of law, lower inflation and improvements in the terms of trade." ("Determinants" 2) This model supports the previous neo-classical convergence theories involving a catch-up effect from initial real GDP, while also integrating factors to account for spillover effects and long-run growth from the more recent endogenous growth theories. Considering human capital, Barro includes three variables, years of educational attainment for males above the age of 25 in secondary and higher education, the log of life expectancy at birth and an interaction term between the log of initial GDP and male educational attainment"(15). While duration of schooling, life longevity and an interaction term were all variables in determining the magnitude of human capital among nations, Barro found males over the age of 25 in secondary and higher education to have a positive and significant effect on growth (15). Thus, given the initial starting level of GDP, one more year of male schooling results in a 1.18 percentage point increase in economic growth (15). However, surprisingly, female education fails to enter significantly (16). Since the sample consists of around 100 countries, one may expect female occupational opportunities to vary across regions and cultures. Therefore, Barro finds no statistically significant effect on growth from female education; however, he does emphasize that additional results suggest female schooling is important through other indicators of economic development such as lowered fertility and infant mortality as well as a signal for political freedom (16). As females become more educated, family planning becomes more efficient in the economic system. Since capital per worker is lowered as the population grows and investment is redirected to provide capital for workers, inefficient family planning can lower economic growth (17). Thus, based on statistically significant results, educated males in the workforce can be considered to affect technological progress, while educated females can be considered to improve capital deepening, both boosting economic growth.

The sun was setting on the twentieth century with commodity prices declining, time constants decreasing and technological progress soaring, where "Advances in information technology, such as the Internet, have been profound and have influenced many parts of the economy." (Mankiw 496) News and information were traveling between continents in mere seconds. The last rays of sunlight gleamed over the mountain peaks, storm clouds blushed while new ideas and innovations boosted productivity. The economy was thriving, where the outlook in 1999 by the *New York Times* suggested, "The economic expansion that began in 1991 is about to become the second longest since America entered the industrial age in the late 19$^{th}$ century. This alone suggests that the likelihood of recession is rising, but almost no one is predicting one in the foreseeable future." (Nasar 1) Standing amongst the mountain tops, the valley seems so far; during this time inflation was a mere 1.3 percent per year and unemployment was all the way down to 4.2 percent (Mankiw 495). With such remarkable measures and one of the longest expansion phases since the late nineteenth century, was innovation and potentially human capital responsible for this growth in GDP? Growth accounting methods adjusted for the elevated GDP growth and low unemployment rate found a significant impact from technological progress (O'Sullivan et al. 170). The economy floated like a bubble, iridescent in the wind, expanding with employment and labor productivity; but, leeriness grew as even the 1999 outlook saw that, profit margins were decreasing, labor markets were getting tight and pushing wages up faster than the gains to productivity (Nasar 1). These productivity gains were crippling under the pressure of increased wages; and, as the equilibrium began to shift and investments decreased, fears flashed across kaleidoscope eyes.

In 2000, not only was apprehension looming in the economy, but economists such as Mark Bils and Peter J. Klenow were skeptical towards the significance of human capital on economic growth. They concluded that Barro's empirical findings may not necessarily reflect the impact of schooling on growth, but may partly reflect the impact of growth on schooling (Bils and Klenow 1161). This proposes a type of simultaneous causality, a type of what came first, the chicken or the egg. Even considering the students' opportunity cost, Bils and Klenow create a channel emphasizing the effects of TFP growth on schooling where higher growth induces more schooling by acting like a lower market interest rate (1164). As we saw in Becker's steepened age-earnings profiles, investors in human capital forego earnings today for higher anticipated earnings in the future; therefore, one can reasonably assume given optimistic expectations and impetuous investors, predicted future growth will be projected into theoretical steepened age-earnings profiles and provoke more schooling. While Bils and Klenow suggest the plausibility of this two-way causal relationship, the second possibility arises from omitted variables associated with rapid growth in TFP and high educational attainment (1161). In considering the effects of schooling on growth, say a government policy absent from the model is positively correlated with schooling and a determinant of economic growth then an omitted variable bias would occur causing schooling to be over-estimated in relation to growth due to this positive correlation. Thus, Bils and Klenow suspect simultaneous causality and/or omitted variable bias to constitute much of the effects of education on growth found in previous studies.

Furthermore, Edward N. Wolff found similar results questioning the impacts of human capital investment on economic growth. Composing his study among OECD countries, Wolff benefits from the advantage of a relatively comparable sample and education quality. Calibrating three models investigating a catch-up effect, a human capital approach and an interaction between education and technology, he finds minimal evidence suggesting effects from schooling on economic growth. In the threshold model, theoretically, as we saw in the Hungarian light bulb factory, a baseline of education should be necessary for technological adoption; conversely, Wolff finds insignificant educational attainment rates with the exception of primary school and a significant emphasis on a variable measuring the number of engineers and scientists per capita (465). Consequently, this suggests only an average of elementary education, with the exception of scientists and engineers, is necessary for technological catch-up in a statistical sense. Next, the following human capital approach model finds that the growth in levels of formal schooling has no significant effect on the growth in labor productivity (467). As Wolff finds no relation between growth in educational attainment and growth in the productiveness in the labor force, even their final and third model finds no interaction effect between the educational level and R&D intensity

(467). These regression results contradict Benhabib and Spiegel where growth in TFP tends to close the technology gap at a faster rate given more years of schooling, though this may be largely due to different samples and specifications.

Reflecting on his results, Wolff postulates a series of potential reasons why these may differ from predicted theory, ranging from poor quality of educational data, problems of comparability of education across countries to specification errors (467-468). Considering quality and comparability, we found in Mincer that education based on quantity of schooling can range from superb to miserable; and, furthermore the absorption and application of skills and knowledge differ greatly between places, time and individuals (Mincer 1). Here, even amongst OECD countries, measurements of educational content, quality and application can vastly differ. Similar to Wolff's third suggestion of specification error, Bils and Klenow suggested the possibility of omitted variable bias arising from specification error. Again, similar to Bils and Klenow, Wolff also proposes a chance of simultaneous causality in which, "A fourth possibility is that the casual relation between productivity and schooling may be the reverse of what I have assumed—namely, that schooling levels respond to per capita income levels instead of productivity growth to educational levels." (469) Where Bils and Klenow found expected growth to positively influence educational enrollment rates through a lower market interest rate in human capital, Wolff puts forth that as long as schooling is a luxury good, any rise in per capita income would raise schooling levels, particularly at the university level (469). Here, we find two postulating rationalizations for simultaneous causality blurring the line between the cause and effect of growth and education. Finally, Wolff suggests that the diversity of formal education may affect its relevance to productivity growth, where perhaps only certain forms of schooling may be related to growth (469). This point is seemingly validated in the threshold model through the significant effects of, perhaps a more homogenous, primary education; and, since students diversify into more heterogeneous disciplines later in education, the number of scientists and engineers were found to have statistically significant effects on growth in real GDP. Needless to say, better quality data and more accurate specifications are crucial to understanding the effects of education on growth.

### 2.4.4 Quality vs. Quantity

Following up on the issue of data quality, Eric A. Hanushek and Dennis D. Kimko set to proxy the level of human capital through international mathematics and science test scores. They highlight that most prior models relied on quantity of schooling to proxy the level of knowledge embodied in the labor force where, "Data limitations have, however, forced severe compromises. Paralleling analyses of wage determination, empirical implementation virtually always employs some readily available measure of the quantity of formal schooling to reflect human capital, but this appears inadequate.” (Hanushek and Kimko 1184) As human capital models employing quantity of schooling have been questionable through insignificant and often negative results, when considering the quality of schooling, international mathematics and science scores measuring labor force quality have a strong relation to growth (1184). Here, we find the quality of human capital to have a much stronger, positive effect on economic growth than quantity variables were able to produce. Hanushek and Kimko measure this difference, finding that nine years in average schooling would equal the estimated growth effect of one standard deviation increase in quality of schooling as measured by math and science scores (1204). Though questionable, perhaps arising from simultaneous causality or specification issues, these results indicate that an increase of nine years in average schooling will increase economic growth to the same magnitude as one standard deviation increase in student mathematics and science test scores. The authors continue to measure the effect of international tests score by suggesting that one standard deviation increase reflects a more than one percentage point increase in growth, though they suggest this looks implausibly large (1204). Again, only addressing the issues of quality while ignoring underlying specification issues may be a malefactor leading to potential overestimation; yet, Hanushek and Kimko attempt to tackle these issues where, “A number of plausible factors have been ruled out by the specification analyses and by the consideration of alternative models of causal effects…The precise cause or magnitude of this overstatement is unclear.” (1204) Unsure of the exact extent human capital plays in economic growth, perhaps due to specification or simultaneous causality, Hanushek and Kimko still find a statically significant effect from the quality of education on growth.

The rest of 2000 was afflicted with bitter pessimism; perhaps the precise pin to prick the puncture point as the economy came to its peak in March 2001(O’Sullivan et al. 112). In early 2001, uncertainty haunted the market as the *New York Times* depicted, “Economists blamed the dismal outlook among consumers on the steep drop in the stock market late last year and a recent wave of layoff plans announced by major corporations even though the unemployment rate remains at a three-decade low.” (Leonhardt 1) As we found tight labor markets increasing wages and squeezing corporate profits, layoffs ensued, investments decreased and storm clouds filled the blue chip skies. At the dawn of the twenty-first century, anxieties spread like foreboding cumulonimbi not only across the economy, but in the role for human capital as well with doubts casted by Bils, Klenow and Wolff. While the fed cut interest rates, Robert Barro elaborated on the work of Hanushek and Kimko by integrating the quality of education through international exam scores into his human capital model where the regressors on log GDP include rule of law, international openness, terms of trade, the ratio of investment to GDP, government consumption, the inflation rate, the fertility rate and the quantity and quality of schooling (“Human Capital” 12). Theoretically all affecting economic growth, Barro incorporates these variables in a three-stage least squares estimation to curb a potential omitted variable bias and simultaneous causality. Considering human capital attainment for males in secondary and higher education, quantitatively, an additional year of schooling translates into a 0.44 percent increase in economic growth (14). While Barro finds male higher education statistically significant, female educational attainment rates at the secondary and higher level remain insignificant, while one interpretation is that countries following discriminatory practices may prevent the efficient exploitation of educated females in the workforce (14-15). Given the large sample size of 100 countries, in many cultures, norms may prevent many women from efficiently participating in the workforce. For instance, even as recent as 2012, in Qatar, women outnumber the men in the university population with 63 percent being woman, yet, only 12 percent the labor force is female (Davies 1). Here we find a higher percentage of women than men in tertiary education; however, only 12 percent of women participate in the labor market. Nevertheless, apart from potential barriers preventing the efficient exploitation of women in the workforce, the education of women at the primary level indirectly promotes growth by lowering the fertility rate (Barro "Human Capital" 16). Thus, quantitatively, we find similar results as before where male secondary and higher education has a statistically significant positive effect on economic growth, and female education is limited to an indirect growth effect through a lower fertility rate.

Qualitatively, after Barro adds international exam scores, the picture begins to change. Despite a smaller sample size, science scores seem to have the strongest positive effect on growth with a one standard deviation increase in test scores translating into an increase in the growth rate by 1.0 percent per year (15). While Barro's findings are fairly close to that of Hanushek and Kimko's implausibly large results, perhaps the relation of science scores to growth does occur at this magnitude, or perhaps more suitable instruments may be needed to remove the correlation between the regressor and error term occurring from simultaneous causality or the presence of omitted variable bias. Nonetheless, Barro concludes that once international test scores are included, the coefficient on male educational attainment is still positive, but only slightly significant; suggesting that quantity and quality both influence growth, yet quality appears to have a much stronger effect (15). Here, we find quality as a more appropriate proxy for human capital in determining growth rates than quantity, where quality more than quantity of human capital appears to aid in the absorption and adoption of technology from leading countries (14). Barro's findings suggest higher science scores translate into easier adoption of spillover technologies. However, in 1999, Brian J. Aitken and Ann E. Harrison in a study on horizontal spillover effects in Venezuela find that many benefits of horizontal spillovers tend to accrue solely to joint ventures (Aitken and Harrison 617). Nevertheless, whether or not these spillover effects are significant, Barro also stipulates, “human capital tends to be more difficult to adjust than physical capital. Therefore, a country that starts with a high ratio of human to physical capital (such as in the aftermath of a war that destroys primarily physical capital) tends to grow rapidly by adjusting upward the quantity of physical capital.” (“Human Capital” 14) We conclude the quantity of male secondary and higher education, as measured by years of schooling, and the quality of education, measured by science test scores, significantly affect economic growth; first perhaps by raising the absorptive capacity for spillovers and innovations and second in the accumulation of physical capital, while female education still remains limited to the lower fertility effect and capital deepening.

Following Barro’s results, the economy took a nosedive after the terrorist attack in the United States on September 11, 2001, where the attack negatively affected economic activity, and the damaged consumer and producer confidence led the economy into a recession (O’Sullivan et al. 111). As pessimism rose all the way into 2002, light flickered through the clouds, but the economy was still struggling. Some economists were suggesting a threat of a double dip recession (“U.S. Economic Growth Slows.” 1). While growth was muddled and fears of another recession loomed, by the end of 2003, “It was the year the economy roared back, the markets went up, a Wall Street boss was taken down and financial scandals spread.” (Holguin 1) In 2004, optimism began to sprout, the sun began to shine, and even new light was cast on technology spillovers in Beata S. Javorcik’s study on Lithuanian firms with significant results suggesting the presence of productivity spillovers through backward linkages (625). Instead of looking at intra-industry spillovers, since most companies actively circumvent the diffusion of knowledge to local competitors, Javorcik found statistically significant backward linkages as knowledge is transferred upstream to suppliers for benefits of higher quality or faster delivery of intermediate goods. By 2005, the *New York Times* illustrated, “Consumer confidence is bouncing back from what were arguably some of its worst readings in years. Gasoline prices – the national average is now $2.15, according to the Energy Information Administration—have fallen because higher prices held down demand and Gulf Coast supplies have been slowly restored.” (Bajaj 1) Again, we find favorable expectations and supply shocks; yet, “Many analysts, including Mr. Shapiro, say a housing slowdown is already under way. Along with rising interest rates and anemic job growth, any such drop-off could sap the economy next year—by just how much is still subject to debate.” (1) While the fed turned up the air conditioning to prevent overheating, continued lack of new jobs and a falling housing market were perhaps the main key combinational blows right to the breadbasket where, “The recession that began in December 2007 followed a sharp decline in the housing sector and the financial difficulties associated with this decline. It deepened during the financial crisis that hit in September and October of 2008.” (O’Sullivan et al. 111) The economy, off to a rough start in the first half of 2000, followed with a slight comeback toward the beginning of the second half. As the bell rang in the seventh round, the economy, tired and shaky in the knees, took some quick jabs from the Fed; job cuts delivered an upsetting uppercut, while the deflation of the housing bubble was brutal like a liver punch, injured and wounded, a hard hitting haymaker delivered the final hit as tightened credit from the financial crisis reduced investment and consumer demand.

The economy struggled to see straight into 2010 when Benjamin S. Cheng and Robert C. Hsu investigated the effects of schooling on productivity in Japan, where they find a bidirectional causality occurring between human capital and economic growth (393). This two-way causality confirms the doubts and fears of Bils and Klenow, Wolff, as well as Hanushek and Kimko that regression results may reflect this bias. After testing for stationarity and ensuring the absence of co-integration between human capital and economic growth, a version of the Granger causality test is applied, and the results suggest "…that if a country plans to stimulate growth, investment in human capital is an effective way to achieve its goal. Conversely, a country that achieves rapid economic growth can better afford more spending on education. Thus, human capital investments and economic growth promote and reinforce each other." (Cheng and Hsu 395) While Cheng and Hsu recommend increasing investment in human capital as a means to raise productivity and increased growth enables this investment, they also mention, that two variables may be highly correlated but not causally linked (Chen and Hsu 395). In other words, the degree to which a change in education brings about a chance in economic growth is not necessarily causal and may merely only reflect a correlation. Barro emphasized the difficulty in adjusting human capital and Hanushek and Kimko's analysis on science and math scores found that increased spending in education does not increase student performance differences (1184). Perhaps the autonomous differences and difficulties in adjusting and measuring human capital are the contributing reasons why the magnitude in the impact from knowledge on economic growth remains questionable.

## 2.5 Synopsis

Throughout the history of economic thought, from the end of the last ice age until today, it can be argued that knowledge and its non-rival nature have played a vital role in economic growth. Learning by doing championed for over 10,000 years with agricultural innovations furthering civilizations into specialization and the division of labor found in the classical works of Smith, while medical care increased when science as a means of production took the stage in the middle of the nineteenth century following the introduction of formal education and Ricardo's emphasis on skill, ingenuity and instruments employed in agriculture. Later, Marx highlights not only skill, but the state of science, the degree of its application and the organization of production in the productivity of labor. Moving to neo-classical theory, Menger defended competition, Schumpter supported monopolies in their ability to bring about new combinations, productive revolutions, and economic development through radical innovation, and Keynes put forth the notion that business cycles, perhaps, rely more on expectations and psychological factors than just the factors of production under prior classical theory. While no specific role for human capital emerged, it can be argued the seeds were being sown.

Dust settled from the world wars, trade barriers fell and knowledge diffused across borders like the sweet scent of lilies in spring. Solow's production function and TFP set the foundation, while Becker detangled the quantities and qualities of labor to bring about the birth of human capital as we know today; schooling, learning by doing, on-the-job training, health, well-being and actively seeking information, all improve mental abilities and raise the productivity of labor. Mincer, following Becker's age-earnings profiles, postulated higher earnings were a reflection of this productivity-augmenting effect of education; yet, he describes the relation between schooling and productivity is by no means simple as the comparability and measurement of education in terms of quality and subsequently quantity is arduous, grueling and dubious, a problem still faced today. Romer, elaborating beyond Solow's exogenous technology, found the non-rival and rather non-excludable nature of knowledge to lead to increasing returns at the economy level, while decreasing returns at the firm level distorted incentive to innovate through spillover effects. Furthermore, as oil prices shocked the economy, Aghion and Howitt find that it is not only these externalities which lead to the underprovision of innovation, but also expectations that future research may destroy prospective profits from current activities. Even with rising oil prices, automakers were unsure whether to continue up the hybrid technology s-curve with expectations of fuel cells and fully electric vehicles posing as disruptive technologies. Benhabib and Spiegel further built upon Solow's production function to incorporate human capital, but as Nelson and Phelps suggest treating human capital as another factor in production may be misspecifying its role, they introduce a theoretical model to find that education is significant in attracting physical capital and raising TFP through innovation and spillovers, which is somewhat supported by empirical evidence.

During the nirvanic 1990s, Barro using a 100 country time-series analysis finds a positive and significant effect from male secondary and higher education on growth, while other contributing factors include higher life expectancy, lower fertility, lower government consumption, lower inflation, better rule of law and better terms of trade. Despite significant effects from male education, the effects of female education are insignificant beyond indirect fertility effects. Therefore, male educational attainment can be reasoned to affect technological progress, while females contribute towards capital deepening, both empirically positive effects on economic growth. However, Bils and Klenow suggest Barro's results may be inflicted by reserve causality or omitted variable bias. Perhaps, it is growth which affects education, or even an overlooked variable correlated with education and a determinant of economic growth. Furthermore, Wolff finds similar results questioning the impact of schooling on growth due to potential simultaneous causality and omitted variable bias, along with the poor quality of education data, the difficulty in comparability already mentioned by Mincer, and finally, as the number of scientists and engineers enter significantly, Wolff suggests perhaps only certain forms of schooling may contribute to economic growth.

Aiming to improve the quality and comparability of education as a measure of human capital, Hanushek and Kimko using science and math test scores find a much higher effect from the quality of education on growth than quantity; however, reverse causality and omitted variables may be responsible for this upward bias. Barro building upon this new quality outlook, integrated internationally comparable science, math and reading scores into his previous model, including the same factors as before to curb an omitted variable bias and a three-stage least squares estimation to control for reverse causality. However, as quality was found to have a much stronger effect on growth than mere quantity of education, the effects of female education are still limited to the indirect fertility effect. Finally, after the economy struggled through the 2000s, Cheng and Hsu support the notion of bidirectional causality, suggesting that human capital Granger causes economic growth, while, in turn, economic growth Granger causes human capital in Japan.

As the notion of human capital finally came to light, its role in economic growth remains questionable. While in the case of Cheng and Hsu, Japan's lack of natural resources elevates human capital and the labor force as major contributors in economic growth, where in Barro's 100 country sample, spillover effects perhaps dominate in significance and perhaps the effects of female education are burdened with cultural differences. Generally, it is regarded that economic growth occurs "As long as there are new ideas, inventions, and new ways of doing things, the economy can become more productive and per capita output can increase." (O'Sullivan et al. 168) Theoretically, as many of our previous studies suggest, human capital is necessary for these new ideas, adoption of spillovers and innovation. However, Schumpeter pointed out "Thorough preparatory work, and special knowledge, breadth of intellectual understanding, talent for logical analysis, may under certain circumstances be sources of failure." ("Economic Development" 85) Perhaps new combinations are not best brought about by standardized education and testing, perhaps only certain forms of education are responsible for economic growth as the new quality approach suggests. Perhaps the negative and insignificant effects for women are due to tendency of concentrating in less productive fields. Nonetheless, we conclude that the "Comparative and historical appraisals of economic growth remind us of the complexity of factors involved, with the idea that growth required multiple ingredients, although there is no unique recipe." (Greenhalgh and Rogers 240) As continents, countries, courses and individuals differ and causation is more a correlation, maybe the recipe for economic growth all depends on the cultural palate.

# 3. Part II: Effects of Female Tertiary Education on Economic Growth in Scandinavia

## 3.1 Hypothesis

Throughout history, we find evidence of human capital affecting economic growth through learning by doing, schooling, on the job training, vitamin consumption, medical care, and acquiring information to optimize choices in the face of scarcity. Learning by doing championed for over 10,000 years with agricultural innovations furthering civilizations into specialization and the division of labor where we also observe the positive effects of on the job training. Following the introduction of formal education, medical care and vitamin consumption increased when science as a means of production took the stage in the middle of the nineteenth century. The learning by doing process remained, but science-based technologies had a much stronger effect on growth. Schooling, formalizing the transfer of knowledge, yet, not without opportunity costs, seems plausibly responsible for the rapid creation and adoption of these science-based innovations. However, Schumpeter cautions, perhaps it is the rigid regularities of specialized knowledge that may limit these radical, architectural, competence destroying process and product innovations, leaving us questioning the magnitude in the significance of education in economic growth.

Human capital remained largely neglected from economic theory until only 50 years ago when Becker and Mincer displayed the productivity augmenting effects from education on wages. While Romer, Aghion and Howitt describe human capital's role in expectations and spillovers, consistent with the convergence effect, Benhabib and Spiegel emphasized its importance in a country's TFP and attracting physical capital. Furthermore, Barro finds empirical significance in secondary and higher male education; yet, as other factors enter rather as predicted, female education remains insignificant beyond an indirect lowered fertility effect. However, Bils and Klenow argue a potential omitted variable bias or reverse causality; and, Wolff, attempting to achieve the appropriate specification, searching for that growth even amongst OECD countries close to the technological frontier, finds only a threshold of primary education is significant; yet, the significance of scientists and engineers suggests perhaps what Mincer already emphasized, all education is not created equal. Even after Hanushek and Kimko integrate human capital in terms of quality over quantity and Barro subsequently expands his model, quality seemingly has a much higher effect on growth than quantity; yet, the role for females is still limited to indirect fertility effects.

Recognizing the theoretical effects of human capital on the absorption and adoption of innovation and attracting physical capital, we are disappointed with the insignificant role for female human capital, perhaps quality in terms of international test scores still leaves the effects of human capital largely to cultural influence. Perhaps, focusing instead on a region with comparable education and lack of discrimination would yield superior results as, “Economies where women have a high and lasting participation in the labour market, such as the Nordic countries, have lower gender gaps than economies where labour market participation is interrupted by long and frequent spells of childcare.” (Persson 212) With these Nordic countries having a smaller gap between male and female wages, Norway also appears to be paving a path against discrimination with “…Ansgar Gabrielsen…Back in 2003, as minister of trade and industry, he was responsible for shepherding through Norway’s law stipulating that publicly traded companies transform their boards beginning in 2006, and appoint 40 percent female members, or risk forced dissolution by delisting from the Oslo Stock Exchange.” (Smale 1) Furthermore, Scandinavia appears to be a perfect proxy to measure the effects of female higher education on economic growth seeing as women have made a substantial impact in obtaining education to participate in high-wage sectors over the past 100 years as, “A telling example from the Nordic countries is the fact that women constituted more than half the students enrolled at Medical Schools around the year 2000 while they were virtually absent a century earlier.” (Persson 213) Therefore, the purpose of this paper is to investigate whether or not female education has a statistically significant effect on economic growth; while focusing on Scandinavian countries allows us the advantages of comparable education and equal opportunity for women, we expand on Barro’s research, testing the prevailing hypothesis that the negative and often insignificant effect of female higher education on economic growth arises from discriminatory practices as many countries fail to efficiently exploit the female labor market (“Human Capital” 15). Through limiting our sample size to the Nordic countries, we expect a positive and significant effect on growth as more females participate in tertiary education, perhaps at a similar magnitude to males given convergence in occupational opportunities.

## 3.2 Data

### 3.2.1 Human Capital

To examine effects on economic growth in Scandinavia, we first set out for an appropriate proxy of human capital. As education remains the most feasibly measured portion of human capital, we observe whether or not higher levels of female educational attainment increase productivity. We utilize Barro-Lee's dataset as the most distinguished and au courant given that by 2010 alone, the papers "…published in 1993, 1996, and 2001 have been cited in journals over 740 times, according to the *Social Science Citations Index.*" (Barro and Lee 19) As we consider higher education a prerequisite for high wage occupations, we use the percentage of females aged 25 and over in total tertiary education in Denmark, Finland, Sweden and Norway for the time period, 1950 to 2010. Given the role of human capital in the creation and adoption of innovation, we hypothesize that by narrowing the sample size to a region comparable in education and equal opportunity, we will obtain a positive, significant effect from female tertiary schooling on productivity.

Benefits from Barro-Lee's dataset arise in uniform methodology, disaggregation between age and levels of schooling, and up to date survey and census data. Developments in the new 2010 dataset reduce measurement error by using disaggregated 5-year age intervals for the previous or subsequent 5 year periods where this helps to improve the accuracy of the backward- and forward-estimation procedure. In other words, for gaps in the data, missing observations are extrapolated for given age groups by a weighted average least squares estimation from earlier and later census records, where educational attainment in the younger age group is used for forward estimates and attainment within the older age group is used for backward estimates, given an appropriate time lag. Forward estimates assume a constant distribution of education where, "…attainment of age group *a* at time *t* is the same as that of the age group that was five years younger at time *t-5*…" (4). As Barro and Lee recognize the possibility of students not completing tertiary education before the age of 25, a backward estimation is assumed in these circumstances. This better methodology is improved from the previous perpetual inventory method, complimented with the disaggregation of data regarding educational attainment and age, and enhanced by up to date census and survey information from UNESCO, Eurostat and other sources (3). Therefore, we find Barro-Lee's dataset the most appropriate proxy for human capital, hoping these updated and revised measurements will yield more accurate results regarding female human capital on economic growth.

However, one problem still remains from the previous datasets in that our variables are not available for periods finer than 5 or 10 years. We observe this shortcoming in the availability of educational attainment census and survey information for our Nordic country 2010 dataset in that out of 13 observation points for each country, Norway and Finland take the lead with 8 data points, while Denmark and Sweden tail with less than half, having only 4 and 5 total censuses observations, respectively (Barro and Lee 47). These missing observations not only lower the quality of the data, but give rise to additional issues. The first problem arises in the forward extrapolation method where the proportion of educated individuals may be over or under estimated in regard to the true population, though Barro and Lee attempt to curb this by including different mortality rates by education level for the population over the age of 65. Furthermore, a second problem results in the backward estimation procedure which assumes an individual's educational attainment remains unchanged from 25 to 64. While this assumption may be unrealistic as higher levels of tertiary education are usually completed after the age of 25, additionally, a second assumption from the backward extrapolation method assumes a uniform mortality for age groups between 25 and 59, which may then cause a downward bias in the estimation of total education in our population. As one may expect more educated people to have lower mortality rates, applying a uniform mortality rate may overestimate the proportion of less educated individuals within the population while underestimating the number of educated individuals between the ages of 25 and 59. Nonetheless, despite these drawbacks, we still refer to Barro-Lee's dataset and new method of extrapolation as an optimal proxy for female human capital attainment.

Therefore, we observe the percentage of females age 25 and up in total tertiary education from Barro-Lee's dataset as our proxy for human capital due to the benefits of uniform methodology, disaggregation between age and levels of schooling, and up to date survey and census data. While limiting our data to Scandinavian countries allows for comparability between education and equal opportunity, we recognize this severely limits our sample size as we only have an initial 13 observations for each of our Scandinavian countries. Consequently, weighing cons, benefits and time constraints, we utilize Barro-Lee's most current dataset while emphasizing the importance of further future research for better quality data.

### 3.2.2 Economic Growth

Up until now, we have referred to economic growth without formal definition. Economic growth in modern day economic textbooks is defined as "…sustained increases in the real GDP of an economy over a long period of time." (O'Sullivan et al. 101) This can be considered long-term continual enhancements in productivity that bring about a higher standard of living for the citizens of a nation. Dating back to Smith, we found the annual flow of national wealth to grow steadily through specialization and the division of labor; while the more Marginalist approach could be considered to bring about a change in the quantity supplied through allocation, Schumpeter championed radical creative destruction to bring about an all-new shift in the equilibrium of output. Furthermore, we saw the effects on productivity from the detriments of the Great Depression, the velocity following the World Wars, supply shocks from oil cartels all the way to the 1990s boom of rapid innovation and knowledge creation in information technology. As productivity, GDP or "Gross domestic product is the total market value of all the final goods and services produced within an economy in a given year. GDP is also the most common measure of an economy's total output." (100) Since price changes such as inflation can affect nominal GDP, to compare output over time, economists have developed the concept of real GDP that controls for changes in prices from one year to the next. Furthermore, since GDP is calculated the same across countries, after exchange rate adjustments, we can compare this measure across countries. Therefore, given the comparability across time and countries, we choose to proxy economic growth with measurements of real GDP for our Scandinavian countries.

While utilizing real GDP allows us to measure consumption expenditures, private investment, government purchases and net exports, we must remember it is just that (O'Sullivan et al. 102). Caution must be taken when considering real GDP to reflect social welfare, but "Because most people would prefer to receive higher income and enjoy higher expenditure, GDP per person seems a natural measure of the economic well-being of the average individual." (Mankiw 216) However, drawbacks to GDP include that, it does not take into account household work and childcare, leisure time, other informal transactions in the underground black market, or pollution (O'Sullivan et al. 113). This inability to measure transactions outside formal markets is one disadvantage of real GDP, since informal activities such as household production, childcare, as well as, "Volunteer work also contributes to the well-being of those in society, but GDP does not reflect these contributions." (Mankiw 218) Additionally, one might expect countries with a high tax rate to promote incentive for black market transactions as individuals attempt to avoid taxation. As all these unmeasured informal transactions lead to an underestimation in the true output of an economy, a possible severe and long term overestimation may occur from negative externalities associated in production. Pollution affecting the quality of air and water could potentially lead to irreversible health effects, not only in the planet and the entire eco-system, but also in humans and possibly even their future offspring, which could more than offset the gains from greater productivity. Beyond the fact that environmental impacts, whether good or bad, are not considered, "GDP also tells us nothing about the distribution of income." (218) In other words, real GDP per capita perhaps measures average value more than utility.

Despite the weaknesses of real GDP, it appears our best measure for the value of output and proxy for economic growth, and now "By economic growth we mean the growth in the amount of gross domestic product (GDP) per head of the population." (Greenhalgh and Rogers 74) We obtain our data from the Penn World Table (PWT) to fit the years 1950-2010, where the PWT is a distinguished and reputable"…set of national accounts economic time-series covering many countries. Its expenditure entries are denominated in a common set of prices in a common currency so that *real* quantity comparisons can be made, both between countries and over time." ("The Penn World Table") Benefiting from the real quantity comparisons between countries and over time, we utilize the PWT to proxy economic growth with purchasing power parity (PPP) converted GDP per capita in chain series at 2005 constant prices. Here, the data is in real terms; that is, they are measured in constant 2005 prices. By focusing on real GDP, we are able to measure the change in the volume or quantity of goods and services produced across time, while PPP allows comparisons between countries as it is, "A theory of exchange rates whereby a unit of any given currency should be able to buy the same quantity of goods in all countries." (O'Sullivan et al. 393) Though PPP is not perfect as most infamously known through the Big Mac Index, we utilize this measure as our best method to determine the relative value across our Scandinavian countries. Furthermore, the use of chain series is just a general method for calculating price changes by taking an average of price changes using consecutive base years, which improved estimations considering only a single base year. As constant prices and the purchasing power parity allow us to compare real quantity across countries and time, a chain weighted index is customary and allows for more accurate measure in the standard of living. Therefore, we utilize PWT's PPP converted GDP per capita measured by method of chain series at constant 2005 prices as our proxy for economic growth from 1950 to 2010.

## 3.3 Methodology

### 3.3.1 Data Transformations

#### *3.3.1.1 Trends in Human Capital*

Considering the effects of female human capital on economic growth, before we begin to develop our model, a closer look at the data is in order, first beginning with human capital and then concluding with economic growth. Since our proxy for human capital is the percentage of females above the age of 25 in total tertiary education from Barro-Lee's educational attainment dataset, we first plot our data for Denmark, Finland, Norway and Sweden from 1950 to 2010 for a better look[1]. Focusing on Denmark, we find the highest percentage of females in total higher education from 1950 until 1970; however, this may be more driven by extrapolation methods, as the earliest Danish

[1] See Appendix: Data Plots for Female Human Capital, Initial Data

census in our dataset is 1985 (Barro and Lee 47). Nonetheless, up until 1985, there was a continual increase in the percentage of females in total tertiary education across all of our Scandinavian countries; and even in 1985, Denmark had the highest percentage of females in higher education with Sweden nipping at its heels. We observe this upward trend to continue with only minor hiccup until about 1995, where the percentage of females over the age of 25 spikes rapidly for Finland, Norway and Sweden, and Denmark tails the gang. Generally, the percentage of females in tertiary education was below 5 percent in 1950 for Scandinavia. While countries fairly coincided on an upward trend until 1995, after in 2005 Finland, Norway and Sweden flirted with over 30 percent and Denmark fell behind with a little over 15 percent. Suspecting a gradual upward trend in the probability distribution over the period 1950 to 1995 and discrete changes following 1995, we question the stationarity of this time-series.

Reason for concern over the presence of nonstationarity arises in that our conventional confidence intervals and hypothesis tests can be misleading (Stock and Watson 588). Therefore, we investigate the presence of nonstationarity in the percentage of females over 25 in total tertiary education before developing our model. First, our graphical analysis showed an upward trend from 1950 to 1995, where "A trend is a persistent long-term movement of a variable over time." (Stock and Watson 588) While trends can be stochastic or deterministic in nature, we suspect that our female human capital time-series has a deterministic upward trend as our variable appears to be governed by a nonrandom function of time (588). Since our intuition suspects something is suspicious, we turn to more formal tests of stationarity. As one test of stationarity is based on the autocorrelation function (ACF), we utilize a variation of this known as the sample correlogram (Gujarati and Porter 749). Running a correlogram for each of our Scandinavian countries[2], we find a typical pattern of nonstationarity as the autocorrelation coefficient starts at a very high value and then decays slowly as lags increase; where, "In short, if a time-series is stationary, its mean, variance, and autocovariance (at various lags) remain the same no matter at what point we measure them; that is, they are time invariant." (Gujarati and Porter 741) Thus, as our correlogram depicts nonstationarity and graphical analysis suggested a deterministic trend, we now turn to detrending our female human capital time-series.

Since we suspect our female human capital time-series to follow a linear deterministic trend, "…the simplest way to make such a time-series stationary is to regress it on time and the residuals from this regression will then be stationary." (Gujarati and Porter 761) Therefore, for each of our Scandinavian countries, we run the following regression:

[2] See Appendix: Correlograms of Human Capital

$$Y_t = \beta_1 + \beta_2 t + u_t \quad \text{Equation 1}$$

where $Y_t$ is the percentage of females in total tertiary education for each country, and where $t$ is the time trend variable measured chronologically. Subtracting $\beta_1$ and $\beta_2 t$ from $Y_t$, we isolate the predicted residuals for each of our countries, which should now be stationary. To check this, we rerun our correlograms[3] and plot our predicted residuals[4], finding a substantial improvement in each of our Scandinavian countries. Where we initially observed nonstationarity across all of our Scandinavian countries, after detrending, our correlogram lags appear to hover around zero, visually confirming a stationary series, which is further supported by our Box-Pierce Q statistic tests and autocorrelation coefficients. Therefore, we conclude that our initial time-series for the percentage of females in total tertiary education for Denmark, Finland, Norway and Sweden was nonstationary with a linear deterministic time trend, and we resolve this issue through detrending; however, when developing our model, we should keep in mind the potential for a break in the data given the discrete change following 1995.

#### *3.3.1.2 Differences in Economic Growth*

So far, we measure economic growth by PPP converted GDP per capita in constant 2005 prices from the Penn World Table. Glancing at this raw data, dating back to the 1950s, we observe Sweden to have the highest real GDP per capita with approximately $11,000 per person in constant 2005 prices and Finland coming in last with roughly $6,000 per person. Sweden maintained this lead well into the 1970s; and then, after Norway spears ahead. Concluding in 2010, Norway triumphs with $50,000 per capita while Finland trails in last with a little under $33,000 per person. Over the entire dataset, Norway has the highest mean real GDP per capita of a little under $28,000, followed by Sweden and then Denmark with around $22,000, and finally Finland just shy of $19,000. Plotting the data for real GDP per capita[5], we find what appears to be nonlinear, almost exponential growth across all of our Scandinavian countries for our time period, 1950 to 2010; thus, before developing our model, we perform a logarithmic transformation to the data.

This nonlinear transformation is common, where the"…reason for this is that many economic series, such as gross domestic product (GDP), exhibit growth that is approximately exponential, that is, over the long run the series tends to grow by a certain percentage per year on average; if so, the logarithm of the series grows approximately linearly." (Stock and Watson 562) Plotting the log of real GDP per capita[6], we find exactly this as the logarithmic transformations

[3] See Appendix: Correlograms of Human Capital
[4] See Appendix: Data Plots for Human Capital, Detrended Data
[5] See Appendix: Data Plots for Real GDP Per Capita, Initial Data
[6] See Appendix: Data Plots for Real GDP Per Capita, Logarithmically Transformed Data

smoothed the data, taking away the exponential growth while we still observe what appear to be the same proportional changes throughout the level and log of real GDP per capita. This relative change arises as dispersions from the average are well expressed in a percentage of the level of the series (562). Therefore, as we now have a linear estimator and are still able to observe proportional fluctuations, we conclude it was advantageous to perform these logarithmic transformations on real GDP per capita as our proxy for economic growth. Visually, the natural log of real GDP per capita for all our Scandinavian countries exhibits smooth, steady growth, although the growth rate appears to slow in the 1970s and late 1990s, rather consistent with the 1970's oil shocks and burst of the 1990's dot com bubble, remembering this represents snapshots of growth over five year periods to match our quinquennial human capital data.

Now that we have taken a brief look at the log of real GDP per capita, we can check the stationarity of this time-series. Contrasting from our deterministic trend in female human capital, the trend depicted by economic growth appears more random and varied over time, or in other words, stochastic. Considering our data plot for the log of real GDP per capita, it appears as though future values are dependent on previous values but with an unpredictable change. Therefore, we investigate if our data is, in fact, inflicted by a stochastic trend, presumably a random walk without drift modeled below:

$$Y_t = Y_{t-1} + u_t \qquad \text{Equation 2}$$

where $Y_t$ is our log of real GDP per capita at time $t$, and this is best explained by the log of real GDP per capita at time $t\text{-}1$, plus a random unpredictable change with a conditional mean of zero, $u_t$. If $Y_t$ follows a random walk, our series is not stationary because this trend causes the variance to increase over time and therefore changes the distribution of $Y_t$ over time (Stock and Watson 589-590). From this changing variance, one problem arising is that confidence intervals and test statistics will now follow a non-normal distribution, which violates our second OLS assumption and can potentially bias our results, even in large samples. Thus, we turn to more formal tests of stationarity before developing our model to help avoid the potential of misleading coefficients and test statistics.

As we have now defined a random walk and the possibility of estimation errors that can arise from nonstationarity, we test for the presence of a stochastic trend. First, we observe a sample correlogram for each country, and then perform a Dickey-Fuller test as it is the one of the most commonly used tests in practice and one of the most reliable (Stock and Watson 593). Plotting our sample correlogram from the log of real GDP per capita[7], we observe the typical pattern of a random

[7] See Appendix: Correlograms of Real GDP Per Capita

walk series with large autocorrelation coefficients in the first few lags that slowly decay as the lags lengthen for all of our Scandinavian countries (Gujarati and Porter 751). Therefore, as our correlograms confirm our graphical suspicions of a stochastic trend, we further investigate for the presence of a unit root with the Dickey-Fuller test:

$$H_o\colon \beta_1 = 1 \text{ vs. } H_1\colon \beta_1 < 1 \text{ in } Y_t = \beta_0 + \beta_1 Y_{t-1} + u_t \qquad \text{Equation 3}$$

where our null hypothesis is that the series contains a unit root and our alternative hypothesis is that our series is stationary, possibly with a deterministic trend (Stock and Watson 593). As $Y_t$ is our log of real GDP per capita, if $\beta_1$ is equal to one, then we can see our time-series follows a random walk as expressed in equation 2. In Stata, we run an augmented Dickey-Fuller test[8] for each of our Scandiavian countries. Stata applies a slight modification to equation 3 by subtracting $Y_{t-1}$ from both sides and includes additional autoregressive lags to capture any further serial correlation where our null hypothesis is still that the series contains a unit root (Stock and Watson 594). Observing our test statistic to follow a tau distribution, we compare these results with their respective critical values for each of our Scandinavian countries. We find that we are unable to reject the null hypothesis of a unit root across all of our Nordic countries at the 1 percent significance level. While we accept the presence of a unit root well beyond the 10 percent critical level for Finland, Norway and Sweden, we are able to accept stationarity for Denmark up to 5 percent significance; however, considering equation 3, $\beta_1$ may be significantly different than one, yet very close as the significance of this test may be affected from our small sample size, matching our quinquennial human capital data and severely limiting our degrees of freedom. Nonetheless, as theory suggests the log of GDP to be nonstationary and our correlogram and Augmented Dickey Fuller test further support this prediction, we confirm the presence of a unit root in all of our Scandinavian countries.

Concerned over the potential estimation errors of this stochastic trend in our log of real GDP per capita, "The most reliable way to handle a trend in a series is to transform the series so that it does not have the trend; that is, if the series has a unit root, then the first difference of the series does not have a trend." (Stock and Watson 597) We find that by subtracting $Y_{t-1}$ from either side from equation 2, in essence, differencing the log of real GDP per capita, we isolate our stationary predicted residuals; thus, first differencing removes the unit root to make our stochastic data stationary. Plotting the first difference of our log of real GDP per capita in a correlogram[9], we find a significant improvement across every Scandinavian country where we no longer observe the slow decay of a random walk series. Now, after first differencing, autocorrelation coefficients hover

[8] See Appendix: Augmented Dicker-Fuller Test for Log of Real GDP Per Capita
[9] See Appendix: Correlograms of Real GDP Per Capita

around zero, resembling a correlogram similar to that of white noise process. Therefore, by transforming our log of real GDP per capita through first differencing, we increase our confidence in our coefficients and test statistics, albeit a small sample size.

### 3.3.2 Model Development

After detrending human capital, performing logarithmic transformations to real GDP per capita and furthermore differencing for stationarity, we now feel as though we have the best linear unbiased estimators to determine our model. We proxy human capital with our detrended percentage of Scandinavian females over 25 in total tertiary education while keeping in mind a discrete change in our data following 1995; also, our proxy for economic growth is the first differenced log of real GDP per capita for Denmark, Finland, Norway and Sweden from 1950 to 2010. With an initial 13 quinquennial observations for each country, first differencing further reduced our sample size by eliminating an additional observation; therefore, we must be even more conscious in our model development not to impede our degrees of freedom. Nonetheless, despite these drawbacks, we hypothesize the benefits of Barro and Lee's improved dataset and the comparability of education and equal occupational opportunity in Scandinavia will predict positive effects on economic growth from female human capital.

#### *3.3.2.1 Checking for Simultaneous Causality*

When considering the effects of female education on economic growth, one would expect a positive and significant effect as human capital compliments and attracts physical capital, as well as promotes technological innovation and the adoption of knowledge spillovers. However, reasonably as the creation and adoption of innovation and increased physical capital boosts productivity, one might also expect increased investment in education, since investors expect rising growth to translate into a lower market interest rate for education and as well as in the effects of the income elasticity of demand. As education affects growth and growth affects education, we expect the presence of simultaneous causality. This was also put forth by Bils and Klenow, Wolff and even Hanushek and Kimko where they criticized the integrity of results concerning the effects of human capital on economic growth because the problem is this causality runs forward and backward, and the standard OLS estimations become biased and inconsistent as it registers both effects (Stock and Watson 366). The root of this bias arises from this simultaneous causality causing a correlation between the estimated parameter and error term, or endogeneity (367). This correlation violates the first of our least squares assumptions as the error term no longer has a conditional mean of zero, threatening the internal validity of our regression (240). Thus, to ensure the integrity of our model and coefficients, we first perform a Granger causality test similar to Cheng and Hsu.

The Granger causality statistic is essentially an F-statistic testing the null hypothesis that our regressor holds no predictive content for our dependent variable beyond our other regressors in the model (580). In other words, we are testing if human capital has no useful information in determining economic growth, if all the coefficients on the lags of human capital are zero. Visa versa, we simultaneously tests whether or not the lags of economic growth hold any predictive content for determining human capital beyond human capital's own autoregressive lags. To begin, we first select our lag length. Too many lags limit our degrees of freedom, especially given our small sample size, and may cause estimation errors; however, too few lags could leave out potentially valuable information (584). Therefore, to balance the marginal benefits of including more lags against the marginal cost of estimation uncertainty, we utilize both the Bayes information criterion (BIC), as well as the Akaike information criterion (AIC). As adding an additional lag decreases our sum of squared residuals, the BIC determines whether an increase in our measure of fit or $R^2$ is large enough to justify an additional lag (585). Thus, by minimizing our BIC, we are able to predict a lag length to utilize in our Granger causality test. The AIC differs from our BIC where a minor change in the second term allows for a smaller decrease in our sum of squared residuals to justify an additional lag (586). Due to this minor difference, the AIC may overestimate our lag length, while the BIC may lead to an underestimation. Nonetheless, we observe both the AIC and BIC to determine the best lag length for our Granger causality test.

Observing the BIC and AIC for our Scandinavian countries[10], both suggest 3 lags are the optimal length for Finland, Norway and Sweden. Despite Denmark's conflicting results, we utilize 3 lags given the small sample size and low p-value on the 3rd lag. Now that we have determined an appropriate lag length, we can estimate our Granger causality tests for each of our Scandinavian countries[11]. Beginning with Denmark, we are unable to reject the null hypothesis that economic growth holds predictive content for determining female human capital; however, we find that female human capital significantly Granger causes economic growth at the 1 percent significance level. Next, we find that economic growth in Finland holds predictive power for female human capital with significance at the 1 percent level; and, the predictive content in female human capital is significant for economic growth at the 10 percent significance level. Furthermore in Norway, we find that both human capital and economic growth hold predictive content for one another, while finally in Sweden, only economic growth Granger causes female human capital, again all at the 1 percent significance level. In other words, a bilateral causality exists in Norway and somewhat for Finland, while Denmark exhibits a unidirectional causality from human capital to economic growth and

[10] See Appendix: Lag Length Selection
[11] See Appendix: Granger Causality Test

Sweden displays the opposite with a unidirectional causality running from economic growth to female human capital. Therefore, as Bils and Klenow, Wolff and even Hanushek and Kimko criticize the presence of simultaneous causality in previous models and Cheng and Hsu empirically demonstrate this bi-directional causality in Japan, due to the presence of endogeneity as indicated by our Granger causality test, we consider utilizing an instrumental variables (IV) regression to remove any potential correlation between our regressor and the error term; but, first we structure our data into a panel.

#### *3.3.2.2 Paneling*

Where we compile our quinquennial time-series data for our four Scandinavian countries, Denmark, Finland, Norway and Sweden, into a panel, we essentially stack our four entities observed in 12 time periods after first differencing, for a total of 48 observations. This larger number of data points increases our degrees of freedom despite a small sample size; and, an additional benefit of panel data allows us to control for omitted variables without observing them. This is particularly advantageous, again due to our small sample size, as we do not have to include additional variables that may be correlated with human capital and a determinant of economic growth (Stock and Watson 222). The presence of omitted variables bias violates our first least squares assumption as our error term no longer has a conditional mean of zero, causing our coefficients to be biased and inconsistent (224). Therefore, paneling our data not only increases our degrees of freedom but also allows us to remove potential omitted variables bias by focusing on changes that differ between countries but are constant over time, through country fixed effects (389). Since the presence of simultaneous causality led us to consider an IV regression, this also helps to control for omitted variables, so after first determining our model with a simple IV regression, we utilize country fixed effects as a robustness check to control for any heterogeneity bias between countries.

#### *3.3.2.3 Instrumental Variables Regression*

Now that we have structured our stationary data into a panel to help increase our degrees of freedom and our confidence, we can begin to determine our model. Considering the effects of female human capital on economic growth, our equation looks a little something like this:

$$Y_{i,t} = \beta_0 + \beta_1 X_{i,t-1} + u_{i,t} \qquad \text{Equation 4}$$

where $Y_{i,t}$ is the first differenced log of real GDP per capita at time *t* for country *i* with $\beta_0$ as our intercept, $\beta_1$ as a coefficient for *X*, which is our lagged female tertiary educational attainment for country *i* and $u_t$ as our error term. In other words, equation 4 is estimating the magnitude in the effect of female human capital five years ago on economic growth today amongst our four Scandinavian countries, where we hypothesize a significant and positive effect relating female human capital to economic growth. Traditionally, we would run equation 4 in an ordinary least squares (OLS) regression; however, we recall the presence of simultaneous causality between economic growth and female human capital as indicated by our Granger causality test. This dual causality will cause $\beta_1$ to be biased and inconsistent as *X* is correlated with our error term, $u_t$. Therefore, to remove any correlation between female human capital and the error term, we propose the best model for our data is an instrumental variables regression. An IV regression will allow us to isolate the variation in human capital that is uncorrelated with our error term through the use of an instrument (461). However, we must first identify a valid instrument that is exogenous to essentially eliminate any endogeneity imposed by simultaneous causality or omitted variables bias.

An ideal instrument is not only exogenous, but also relevant (463). Satisfying both of these conditions, an instrument is related to *X*, or in our case female human capital; and, the instrument has no correlation with the error term $u_t$ in equation 4. Once we have this exogenous instrument, we are able to find a consistent and efficient estimate for $\beta_1$ using a two-stage least squares (TSLS) technique. Theoretically, a TSLS estimation will allow the instrument to dissect our female human capital variable by capturing the exogenous movements which we can then use in a second stage regression, hence the name two-stage least squares (463). Mathematically, to segregate the problematic competent of female human capital that is correlated with our error term in equation 4, the first-stage essentially sets our endogenous variable, female human capital, as our dependent variable; and, we regress our instrument as we would any OLS regression. Slightly similar to Barro, we opt to utilize a lagged value of real GDP per capita as our instrument because we consider real GDP per capita 10 years ago to be exogenous from our error term $u_t$ in equation 4, yet still have relevance by affecting the variation in female human capital five years later. Also similar to Barro, we incorporate a second instrument with a cross product between the second lag of female human capital and the second lag of our real GDP per capita. Thus, our first-stage equation looks like:

$$X_{i,t-1} = \pi_0 + \pi_1 Y_{i,t-2} + \pi_2 (X_{i,t-2} \times Y_{i,t-2}) + v_{i,t} \qquad \text{Equation 5}$$

where *X* is our endogenous female human capital variable for country *i* at time *t-1*, $\pi_0$ is our intercept, $\pi_1$ is our coefficient for $Y_{i,t-2}$, our instrumented lagged real GDP per capita, $\pi_2$ is our second instrumental coefficient for the interaction between the second lag of female human capital and the second lag of real GDP per capita and $v_i$ is our error term. As we consider our instruments to be relevant and exogenous, theoretically we are capturing the external component in female human capital through the predicted values for our intercept and coefficients, $\pi_0 + \pi_1 + \pi_2$, while the problematic component remains contained in the error term, $v_i$ (463).

After we set real GDP per capita lagged by two periods and our interaction term as our instruments in the first-stage, we use these exogenous fitted values for female human capital to estimate our second-stage regression:

$$Y_{i.t} = \beta_0 + \beta_1 \hat{X}_{i,t} + u_{i,t} \qquad \text{Equation 6}$$

only differing slightly from equation 4 in that the *X* values are now the predicted values from equation 5, as indicated by $\hat{X}$. Similar to equation 4, *Y* is our real GDP per capita for country *i* at time *t*, $\beta_0$ is our intercept, $\beta_1$ is our slope coefficient for our fitted values of female human capital and $u_t$ is our error term. However, equation 6 is not your standard OLS estimation because this is a second-stage regression (478). Since modern econometrics software packages are capable of calculating this two-stage process and adjusting for our TSLS standard errors, we can estimate equation 6 using Stata's ivreg2 command with robust standard errors. The reason we utilize robust standard errors is to control for any heteroskedasticity in our error term *u,* as we might expect the variance in our residuals to differ across our Scandinavian countries (478). However, before estimating these results, we check to ensure all of our OLS assumptions hold.

As simultaneous causality and a potential omitted variable bias existed, we remedied any correlation between our *X* variable and error term by utilizing an IV technique, satisfying our first OLS assumption that the conditional distribution of $u_t$ given *X* has a mean of zero (169). Skipping the second assumption for a moment, and noting no noticeable large outliers in our data, we satisfy our third OLS assumption (240). Since no regressor is a perfect linear combination of another, we satisfy our fourth and final assumption of no multicollinearity. Apart from our second assumption, we confirm the internal integrity of our model as estimated in equation 6. Returning to our second assumption, as we are estimating time-series data, the second OLS assumption that our regressand and regressor are independently and identically distributed is slightly altered, considering that observations falling close to one another in time tend to be correlated with one another rather than independent (167). Thus, our second assumption for an OLS time-series regression consists of two parts, the first part assuming a stationary distribution and the second part requires variables to be independently distributed as the time period grows larger (579). Detrending female human capital and first differencing our log of real GDP per capita has helped to ensure stationarity; however, we cannot forget the discrete change in our female human capital data following 1995 which may potential violate this second OLS assumption. Therefore, before estimating equation 6, we test for the presence of a break to ensure our regression model does not provide misleading results.

After graphical analysis, we expect the relationship between female human capital and economic growth to change following 1995. With a predicted break, we perform a Chow test to ensure all of our OLS assumptions hold before estimating our final model. The Chow test is essentially a binary variables interaction regression with a dummy variable that equals zero before the break date and one after, and this is interacted with the lag of our dependent and independent variables. Allowing for a different intercept and slope, we are essentially estimating the following equation:

$$Y_{i,t} = \beta_0 + \beta_1 X_{i,t-1} + \gamma_0 D_t + \gamma_1 (D_t \times Y_{i.t-1}) + \gamma_2 \left(D_t \times X_{i,t-1}\right) + u_{i,t} \qquad \text{Equation 7}$$

where the first half of this equation is essentially the same intercept and slope as equation 4, however we introduce three additional coefficients, our break and interaction terms on the lagged dependent and independent variables. Looking at equation 7, we can see if there is no break then $\gamma_0 = \gamma_1 = \gamma_2 = 0$, and the slope and intercept is the same over the entire sample. The Chow test is essentially an F-statistic testing the null hypothesis that the intercept and slope before and after the break is the same. Estimating our Chow test[12], we reject the null hypothesis that there is no break at the 95 percent confidence level. Due to this discrete change in our data as indicated by the Chow test, we propose to estimate equation 6 with a break following 1995. Even though including a break will eliminate essential observations, we ensure the stationarity of our series, satisfying our second OLS assumption and the internal validity of our model.

Satisfying all of our OLS assumptions, we fulfil our first assumption with our IV estimation, while we ensured stationarity with detrending female human capital, first differencing the log of real GDP per capita, and also including a break in our data following 1995, satisfying our second assumption; and, finally, observing no large outlier or multicollinearity we further satisfy our third and fourth assumptions. Therefore, estimating the effects on economic growth from the detrended percentage of females in tertiary education five years ago, we perform a TSLS estimation using Stata's ivreg2 command with robust standard errors and real GDP per capita lagged two periods and an interaction term as our exogenous and relevant instruments. Incorporating a break following 1995 to yield more accurate estimates and assuring the internal validity of our model, we expect to find the prevailing hypothesis that as more females enter higher education, economic growth will be improved in the next period.

[12] See Appendix: Chow Test

## 3.4 Analysis

### 3.4.1 Results

Considering the effects of female human capital on economic growth, we estimate a TSLS regression, instrumented with our two period lagged real GDP per capita and an interaction term, while incorporating a break following 1995 and controlling for robust standard errors. Utilizing Stata's ivreg2 command, we begin with checking the validity of our instrument in the first-stage to ensure reliability in the second-stage, and then turn to interpretation. Assuming Barro's negative and insignificant effects from female human capital in his large sample size to be due to a majority of countries underutilizing females efficiently in the workforce, perhaps due to cultural norms, we expect to find a positive and significant effect in Scandinavia as Denmark, Finland, Norway and Sweden all rank within the top ten positions of the *Global Gender Gap Report 2013,* suggesting a more efficient utilization of females in the workforce (8).

Stata's ivreg2 command allows us to test for the presence of weak instruments and observe our first-stage regression, equation 5, which generates our fitted values for the second-stage, equation 6. Since an invalid instrument does not help us capture the exogenous variations in *X*, the covariance between our instruments and female human capital essentially becomes zero; and, our beta estimation in our second-stage becomes inconsistent when the denominator is zero (Stock and Watson 481). Therefore, first we observe our first-stage F-statistic, essentially for equation 5 with a break following 1995, where we test the null hypothesis that the instruments are weak and equal to zero. In the first-stage regression of our TSLS[13], we observe a favorable F-statistic of 17.00. Since an F-statistic higher than ten is a good indication of the Stock and Yogo test, we can reject the null hypothesis of weak instruments (507). However, as the Stock and Yogo test allows us to test for bias in our TSLS estimator for a large number of instruments, due to our use of robust standard errors to control for heteroskedasicity, we utilize Stata's robust Kleibergen-Paap Wald rk F-statistic with Stock and Yogo's critical values. Formally rejecting that our model is weakly identified, we find our first-stage coefficients for our break and interaction term between the second lag of female human capital and the second lag of real GDP per capita to have the most significant explanatory power. Therefore, as our F-statistic and formal test for weak identification confirmed the integrity of our first-stage fitted values, we can confidently precede to interpret the second-stage of our TSLS estimation.

Since we were able to reject the presence of a 5 percent maximal bias according to our Kleibergen Paap Wald rk F-statistic and Stock and Yogo's critical values, we confirm the validity of

[13] See Appendix: Two-Stage Least Squares Instrumental Variables Regression

our instruments and confidence in our second-stage. Observing our second-stage regression results, we are somewhat surprised to find a negative and insignificant effect from female human capital on economic growth across Scandinavia. On average, across our Nordic countries, we find a decrease of 0.72 percentage points in GDP for a one percent increase in the percentage of females with tertiary education five years earlier, technically with borderline significance at the 80 percent confidence level. Conflicting with our expectations, we turn to potential economic interpretations of our negative and insignificant results.

### 3.4.2 Economic Interpretation

Since Barro also found a negative and insignificant effect with an estimated coefficient of -0.0011 and a standard error of 0.0040 from female secondary and higher level educational attainment, conflicting with the hypothesis that female education is fundamental in economic growth, our findings further support these results ("Human Capital" 15). However, as Barro proposed one possible interpretation to be that many countries may underutilize educated females in the workforce, we limited our sample to four of the top ten countries with some of the lowest gender gaps and comparable education. Where in Scandinavia we find some of the smallest salary gaps between men and women in the world, although still existent, some of the highest female labor force participation rates, egalitarian opportunities for leadership and equal distribution of labor at home in the *Global Gender Gap Report 2013 (20)*, we would expect the efficient utilization of women in the workforce.

Even though policies exist across Scandinavia to help females re-enter the labor market following maternity and also offer mandatory paternal and maternity leave (20), we still find a negative and rather insignificant effect on economic growth from female higher education. First, perhaps, given our small sample size and subsequent limit to a single lag for our female human capital variable, it may take females longer than five years to efficiently integrate into the workforce, especially since education does not come without an opportunity cost. Reasonably, if it takes females, say at least six years to integrate into the workforce and provide value as measured by GDP per capita, our model with only a single lag on female human capital is unable to capture this effect. Second, as Barro, and Hanushek and Kimko, both found stronger effects from male quality of education in science scores than quantity in years of schooling, perhaps females have an insignificant effect due to gravitation toward low productivity sectors over our sample period from 1950 to 2010. Today as occupational opportunities have converged drastically over the last century, this perhaps explains the significance in the explanatory power of the break coefficient in our first-stage TSLS regression. Reasonably, cultural norms may take longer to degrade and despite an increase of females in tertiary education, it may be that only since 1995, women have begun to actively pursue education for high productivity sectors. A third potential explanation, as pointed out by Wolff, suggests that education may be more of a screening function to signal productive ability, more than productive ability itself (469). Perhaps as employers expect women to eventually take maternity leave, a discriminatory screening function may also still exist, potentially underutilizing educated females in the workforce even within Scandinavia.

A fourth potential interpretation of our negative and rather insignificant effect from female higher education on economic growth involves the finite property of time. Dating back to the hunter-gatherer society, when hunting was very learning intensive and many years of hunting were required for the marginal benefits to equal the marginal cost, males primarily hunted (Robson and Kaplan 380). Reasonably, we can extend this to today and Becker's age-earnings profiles. Education, like hunting, requires an opportunity cost today with the expectation of higher wages in the future and a larger overall net income; however, as investors in human capital can be rather impetuous, the time and opportunity cost of education may outweigh the future benefits if females take long periods of maternity leave or drop out of the workforce, causing perhaps an insignificant and potentially negative effect from females obtaining higher education. Finally, our fifth interpretation involves the effect of a brain drain. A common feature across Scandinavia is the state typically bears a portion of the opportunity cost to education; and, if females in Scandinavia are more apt to move and work outside of our Nordic country set following their education, say due to marriage, then we may capture a negative and insignificant effect considering female human capital on economic growth as females exit our sample.

With all of these plausibilities of it taking longer than five years for females to efficiently integrate into the workforce, females gravitating toward low-wage sectors and being victim of discriminatory screening functions despite academic achievement, we also find other economic implications to be the high opportunity costs of education and the brain drain effect, even despite Scandinavia's egalitarian institutional setting. While anyone of these interpretations or a combination there of may be responsible for the negative and insignificant effect of female higher education on economic growth, we also consider other implications of our model before checking for robustness by controlling for unobserved spatial heterogeneity across our four Scandinavian countries through country fixed effects.

### 3.4.3 Other Implications

After transforming our data to ensure stationarity and controlling for simultaneous causality through a TSLS estimation, we look at further implications concerning our data and the model. Considering the economic inferences concerning our negative and insignificant findings for female human capital on economic growth, we highlight the repercussions associated with our proxy for female human capital; and, then we assess the implications of our proxy for economic growth as well. Finally, given our small sample size and specifications, we consider improvements for further research.

Ultimately, the explanatory quality of our female human capital data must be considered when interpreting our results. Even though Barro's improved methodology and up-to-date census information make up for the large gaps in the data, extrapolation methods may still yield some bias and the five year intervals severely impact our degrees of freedom. Furthermore, referring back to Becker, human capital extends far beyond simply education, incorporating on-the-job training, learning by doing, health care, vitamin consumption, and the ability to acquire and apply information. Also, Mincer proposed the effects of schooling differ all the way down to the individual level, as well as that education may not be the most important training ground in regards to human capital. Whether education serves more as a signaling function or females gravitate toward low wage occupational sectors, the percentage of females in higher education above the age of 25 may not be a perfect proxy for the true level of human capital embodied in the female population across Scandinavia. Even though we expect there to be relatively comparable education, health care, occupational training opportunities and adequate vitamin consumption across Scandinavia, country fixed effects will allow us to control for these omitted variables by focusing on changes differing between countries but that are constant over time. This robustness check will help us to feel more confident in our economic interpretations.

Next, while real GDP per capita as our proxy for economic growth is not perfect, we are only able to measure formal transactions such as consumption expenditures, private investment, government purchases and net exports. Informal activities are difficult to measure; and, subsequently, household work, child care, leisure time and pollution are all ignored, creating a potential bias in the measurement of value in the marketplace. Since utility remains only partly proxied by real GDP per capita, this measure of productivity fails to incorporate any benefits from leisure time. Observing an increase in real GDP per capita, do we necessarily observe an increase in social welfare? Most importantly, considering pollution, productivity today may come at a severe cost tomorrow. As real GDP per capita may not necessarily capture how well human capital is utilized, it still remains one of our best proxies; however, we must consider these limitations as we reflect on our results.

The negative and insignificant effects from female human capital conflicted with our prevailing hypothesis. While the small sample size limited our model, perhaps higher quality data considering females' fields of academic studies in Scandinavia would allow us to further disaggregate our data and identify if all higher education obtained by females strains economic growth. This would allow us to test whether or not our negative and insignificant effects arise from females gravitating toward low wage sectors on average. While this higher quality data would essentially allow us to observe the marginal costs and benefits for females in each academic field, we still find that our measure for economic growth may not capture how well human capital is utilized in Scandinavia. Perhaps research and development expenditures may provide a more accurate reflection as in one model proposed by Wolff, or perhaps economic growth would be better proxied through individual income levels corresponding with levels of education, more similar to the models of Becker and Mincer. Whether increasing our data sample to include more countries with a low gender gap or improved specification would allow us to further interpret the role of female human capital on economic growth, our findings can be considered a stepping stone, building upon the previous literature, suggesting even in countries with low gender gaps, females with tertiary education above the age of 25 have a negative and rather insignificant effect on economic growth five years later, on average. To further confirm our findings, we provide a robustness check to increase our confidence by controlling for country fixed effects.

### 3.4.4 Robustness Check

Where we compiled our quinquennial time-series data for our four Scandinavian countries, Denmark, Finland, Norway and Sweden, into a panel, we provided an opportunity to control for country fixed effects which account for unobserved spatial heterogeneity. Even though utilizing our TSLS technique allowed us to control for omitted variables, as we expect heterogeneity even within Scandinavia, we provide a robustness check by assigning 3 dummy variables, avoiding a dummy variable trap. The reason we only include a dummy variable for Finland, Norway and Sweden, and not Denmark, is to avoid perfect collinearity with our intercept, satisfying our fourth OLS assumption (Gujarati and Porter 281). Therefore, with a balanced panel and Denmark as our base, we only eliminate three additional degrees of freedom while checking our confidence in the structural validity of our model.

Considering our general equation 4 from before, measuring the effects of female human capital on economic growth, now we control for country fixed effects by incorporating a dummy variable for three of our Scandinavian countries:

$$Y_{i,t} = \beta_0 + \beta_1 X_{i,t-1} + \gamma_i + u_{i,t} \qquad \text{Equation 8}$$

where $Y_{i,t}$ is the first differenced log of real GDP per capita at time *t* for country *i* with $\beta_0$ as our intercept, $\beta_1$ as a coefficient for *X*, which is our lagged female tertiary educational attainment for country *i,* and $u_t$ as our error term, similar to before. Now, equation 8 differs from equation 4 in that $\gamma_i$ is our dummy variable for country *i.* In other words, equation 8 is estimating the magnitude in the effect of female human capital five years ago on economic growth today, but allowing each country to hold its own effect. Here, we are able to control for unobserved factors that differ between countries, such as cultural values, which may potentially impact the utilization of educated females in the workforce. Therefore, incorporating country fixed effects, reducing any heterogeneity bias and increasing our confidence in our results and structural validity, we perform a TSLS estimation as before; but, we modify our model by adding these additional regressors, $\gamma_i$.

Our first-stage and second-stage estimations only slightly differ from our previous equations 5 and 6, through that now we include a dummy variable for three of our Scandinavian countries to control for country fixed effects. Our first-stage equation still captures the exogenous variations in female human capital with:

$$X_{i,t-1} = \pi_0 + \pi_1 Y_{i,t-2} + \pi_2 (X_{i,t-2} \times Y_{i,t-2}) + \gamma_i + v_{i,t} \qquad \text{Equation 9}$$

where *X* is our endogenous female human capital variable for country *i* at time *t-1*, $\pi_0$ is our intercept, $\pi_1$ is our coefficient for $Y_{i,t-2}$, our instrumented lagged real GDP per capita, $\pi_2$ is our second instrumental coefficient for the interaction between the second lag of female human capital and the second lag of real GDP per capita and $v_i$ is our error term. The only difference is that now we incorporate our dummy variables for Finland, Norway and Sweden. Again, similar to our initial model, the first-stage predicts our fitted values, however, now we control for country fixed effects and estimate our second-stage regression:

$$Y_{i.t} = \beta_0 + \beta_1 \hat{X}_{i,t} + \gamma_i + u_{i,t} \qquad \text{Equation 10}$$

where equation 10 only differs from equation 6 through the inclusion of our country dummy variables. Equation 10 differs from equation 8 in that the *X* values are now the predicted values from equation 9, as indicated by $\hat{X}$; yet, similar to equation 8, *Y* is our real GDP per capita for country *i* at time *t*, $\beta_0$ is our intercept, $\beta_1$ is our slope coefficient for our fitted values of female human capital, $\gamma_i$ represents our dummy variables, and $u_t$ as our error term. Expanding our initial model to include country fixed effects incorporates a few additional variables to help increase robustness by controlling for heterogeneity bias between our Scandinavian countries.

Estimating equations 9 and 10, incorporating a break following 1995 and utilizing Stata's TSLS ivreg2 command[14], we find our first-stage F-statistic to still be greater than 10, while we

[14] See Appendix: Robustness Check

attribute the decrease from our initial model to be due to the increased number of variables limiting our degrees of freedom in an already pressured sample size. With our F-statistic suggesting the instruments are a good fit and relevant to our female human capital variable, we again confirm this through a formal weak identification test comparing the Kleibergen-Paap Wald rk F statistic with Stock and Yogo's weak ID test critical values; however, now we accept a little more bias in our second-stage estimations than before with a 5 percent maximal IV relative bias. Still confident in our instruments, we find the second-stage results to be robust to our inclusion of country fixed effects with a negative and insignificant effect of a 0.70 percentage point decrease in real GDP per capita on average, five years following a one percent increase in female tertiary education in Scandinavia. Even though our results considering the effects of female higher education on economic growth essentially are no different than zero, holding to robustness and in accordance with Barro's previous literature, our model emphasizes that even in countries with some of the lowest gender gaps, females may be underutilized in the workforce in Scandinavia.

## 4. Conclusion

Throughout the history of time, evidence suggests humanity has been optimizing choices, refining and storing this knowledge, all in the face of scarcity. Learning by doing prevailed for over 10,000 years with serendipitous discoveries in agriculture leading to sedentary civilization, permitting specialization. While no specific role for human capital would evolve for over another 12,000 years, the notion of knowledge remained a veiled value in economic thought. From Adam Smith's division of labor to Ricardo's opposition of the Corn Laws drastically increasing the diffusion of ideas and bringing about the first era of free trade, human capital in classical economics remained neglected, yet seemingly entwined in the productive powers of labor. Leading up to the industrial revolution, formal education became the norm and in the wake of new discoveries, science –based knowledge fueled economic growth like never before. While the calculus of pleasure and pain in the neo-classical school of economic thought left little room for the difficulties of measuring the qualitative differences in human capital, Schumpeter highlighted the importance of new combinations with radical, competence destroying innovation.

In the pre-embryonic years before the birth of human capital, Solow introduced a production function, accentuating total factor productivity to be attributable for up to 88 percent of the increases in economic growth. Despite perceiving such a large ascription toward technological change, TFP and innovation essentially remained exogenous in economic models. In the 1960s, Becker detangled the quantities and qualities of labor to bring about the parturition of human capital as we know today. Quantifying the different levels of skills embodied in individuals, Becker's age-earnings profiles captured the productivity augmenting effects of knowledge. While Mincer captures this effect through schooling and income, the underlying economic intuition suggests education compliments physical capital, as well as, aids in the creation and adoption of innovation. However, Mincer also emphasizes the incomparability of schooling between places, individuals and time. Romer, in the mid-1980s, building upon the previous literature to endogenize technological change in a competitive equilibrium, finds spillovers and the externalities of knowledge to lead to suboptimal investment in innovation. Aghion and Howitt introduced qualitative improvements in innovation in an endogenous growth model to highlight that not only spillovers, but expectations and obsolescence also drive the underprovision of innovation. Understanding the productivity enhancing effects of innovation and the effects from the non-rival nature of knowledge, human capital plays a star role as Benhabib and Spiegel sought to seek how education entered into the equation.

As Benhabib and Spiegel find years of schooling to influence economic growth by stimulating TFP and the accumulation of physical capital in a theoretical model, Barro empirically displays the positive effects of male education on technological progress; yet, the effects of female education remain limited to a fertility effect and subsequently capital deepening. However, Bils and Klenow cast doubts on the impacts of human capital on growth, suggesting the presence of simultaneous causality and omitted variables bias. Wolff also criticizes the significance of human capital on economic growth for the same reasons as Bils and Klenow, as well as, due to the poor quality of educational data, problems of comparability of education across countries, and in that perhaps only certain types of education are related to growth. Improving on the poor quality of educational data, Hanushek and Kimko integrate the quality of education, finding a much stronger effect on economic growth from math and science scores. Barro, also, incorporates quality and quantity of human capital through international test scores, finding a much stronger effect from the quality of human capital in the form of science exam scores than simply in the quantitative years of schooling. Even after including the quality of human capital, the effects from male education are still positive and significant, yet the effects from female education remain negative and insignificant. For that reason, we conclude male secondary and higher education, as measured by years of schooling, and quality of education, measured by science test scores, significantly affects economic growth by raising absorptive capacity for spillover and innovation, while female education still remains limited to capital deepening.

Perplexed with the insignificant and often negative effects of female human capital on economic growth, the potential explanation put forth by Barro is that females may be underutilized in the workforce. Considering Barro's large sample size of around 100 countries, we investigate whether or not limiting our sample to countries with a small gender gap and comparable education will project positive effects from female human capital on economic growth. We limit our sample size to four Scandinavian countries, Denmark, Finland, Norway and Sweden, while utilizing Barro-Lee's most current educational attainment dataset as a proxy for human capital and the PWT's real GDP per capita figures as our proxy for economic growth. Analyzing our data through plots and correlograms, we find a deterministic trend in the percentage of females above the age of 25 in higher education remedied for stationarity by detrending. Also, visually observing exponential growth and a stochastic trend in our real GDP per capita data, we first perform a logarithmic transformation; and then, we apply an augmented Dickey-Fuller test, suggesting first differencing for stationarity. After transforming our data, we test for the presence of simultaneous causality with a Granger causality test similar to Cheng and Hsu. Finding bi-directional causality in Finland and Norway, and contrasting unidirectional causalities between Denmark and Sweden, we opt to estimate our model with an IV regression.

First, essentially stacking our data, we organize our four Scandinavian countries into a panel to increase our degrees of freedom and to allow for the opportunity to provide a robustness check to control for heterogeneity bias. Next, we assign exogenous but relevant instruments to capture and remove any endogeneity caused by simultaneous causality or omitted variables bias. Designating two instrumental variables, we include a two period lag for our real GDP per capita variable as well as an interaction between the second lag of real GDP per capita and the second lag of our female human capital variables. Finally, as we observed a discrete change in our female human capital data following 1995, we include a break following 1995. After controlling for simultaneous causality and omitted variables bias, we expect Barro-Lee's updated and improved dataset as well as our limited sample size to countries with comparable education and some of the smallest gender gaps in the world to project positive and significant effects from female higher education on economic growth in Scandinavia.

Estimating our IV model, our results indicate a negative and insignificant effect from female human capital on economic growth, supporting Barro's previous findings. As the prevailing hypothesis was that the negative and insignificant results may reflect the underutilization of females in the workforce, we build on the previous literature to suggest that even countries with some of the smallest gender gaps in the world may still underutilize females in the workforce. We find an insignificant decrease of 0.72 percentage points in real GDP per capita five years following a one percent increase in the percentage of females in tertiary education above the age of 25, on average.

One potential economic explanation for this negative and insignificant effect may be ascribed to that it may take females longer than five years to efficiently integrate into the workforce which our data limitations and model are unable to capture. A second probable explanation arises from that females, despite academic achievement, may gravitate to low-wage sectors as "…traditional job choices and occupational strategies endorsed by social conventions direct women in to low-paid occupations." (Persson 213) A third prospective explanation may be due to that education acts merely as a screening function as put forth by Wolff. If education acts solely as a screening function, and if women are discriminated based on gender, they may not benefit from this screening function as much as men. A fourth possible explanation may be attributed to opportunity costs and the limits of time. If on average women drop out of the workforce following pregnancy or take long periods of maternity leave, then on average, we may find the opportunity costs of female education to outweigh the benefits, as we have seen dating all the way back to the hunter-gatherer societies. Our fourth and final rationalization may be because of a brain drain effect. If females, on average, partake in education and then exit our sample countries, say due to marriage, then we are unable to capture any productivity enhancing effects due to data limitations. As one of these potential explanations or a combination there of may be responsible for our negative and insignificant effects, we turn to other implications.

In interpreting our results, we must recall our severe data limitations and impeded degrees of freedom strangling our explanatory power, as well as the implication of imperfect proxies. While better quality data and expanding our sample size may increase the explanatory quality of our results, we check the robustness of our results by controlling for heterogeneity bias. Even after our robustness check by including dummy variables for three of our Scandinavian countries to control for country fixed effects, we find our results hold up to robustness and remain in line with Barro's previous findings. Considering the economic interpretations and other implications, we must remember generally women were denied equal access to education in the first half of the twentieth century; and, it was not until the 1970s that female educational choices even began to become similar to men (Persson 213). Perhaps more years are needed before we have enough data to accurately depict the effects of female higher education on economic growth, or perhaps better quality data considering the academic fields of study may help determine whether or not our negative and insignificant effects are, in fact, due to females, on average, gravitating toward low productivity sectors or whether or not females are underutilized regardless of educational attainment. However, overall, we must again remember, real GDP per capita as our proxy for economic growth neglects to account for leisure time, pollution and informal transactions in the marketplace; and, what is productivity today without happiness or a better tomorrow?

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# Appendix

## Correlograms of Human Capital

Below we include a correlogram of our human capital data for each of our Scandinavian countries with up to 11 lags. We opt for 11 lags to get a full picture of any autocorrelation present. Furthermore, we couple the results from our initial data with our transformed data for easy comparison. All output has been produced using Stata statistical software. We provide a brief summary of the data for Denmark, as the results remain similar across our Scandinavian countries, we allow the reader to interpret Finland, Norway and Sweden similarly.

### Denmark

```
. corrgram  dkft, lags(11)
```

| LAG | AC | PAC | Q | Prob>Q | -1 0 1 [Autocorrelation] | -1 0 1 [Partial Autocor] |
|---|---|---|---|---|---|---|
| 1 | 0.7525 | 0.9184 | 9.2022 | 0.0024 | | |
| 2 | 0.5884 | 0.4543 | 15.339 | 0.0005 | | |
| 3 | 0.3652 | 0.0252 | 17.94 | 0.0005 | | |
| 4 | 0.1000 | -0.2564 | 18.156 | 0.0012 | | |
| 5 | -0.0630 | . | 18.253 | 0.0026 | | |
| 6 | -0.3140 | . | 21 | 0.0018 | | |
| 7 | -0.4254 | . | 26.882 | 0.0004 | | |
| 8 | -0.3898 | . | 32.806 | 0.0001 | | |
| 9 | -0.4003 | . | 40.618 | 0.0000 | | |
| 10 | -0.3221 | . | 47.362 | 0.0000 | | |
| 11 | -0.2417 | . | 53.06 | 0.0000 | | |

```
. corrgram  dkftd, lags (11)
```

| LAG | AC | PAC | Q | Prob>Q | -1 0 1 [Autocorrelation] | -1 0 1 [Partial Autocor] |
|---|---|---|---|---|---|---|
| 1 | 0.1466 | 0.1499 | .34914 | 0.5546 | | |
| 2 | 0.0783 | 0.0757 | .45782 | 0.7954 | | |
| 3 | -0.2573 | -0.3239 | 1.7489 | 0.6261 | | |
| 4 | -0.5079 | -0.6633 | 7.3391 | 0.1190 | | |
| 5 | -0.2804 | . | 9.2548 | 0.0993 | | |
| 6 | -0.0189 | . | 9.2648 | 0.1592 | | |
| 7 | 0.1730 | . | 10.238 | 0.1755 | | |
| 8 | 0.1022 | . | 10.645 | 0.2226 | | |
| 9 | 0.1145 | . | 11.284 | 0.2567 | | |
| 10 | 0.0092 | . | 11.29 | 0.3354 | | |
| 11 | -0.0431 | . | 11.471 | 0.4047 | | |

The correlogram of our initial data displays decay due to our deterministic trend, which disappears after detrending. The AC shows the correlation between the current value of human capital with its lags. We find our detrended data to show substantial improvement from our initial nonstationary data, as our autocorrelation coefficient decreased from 0.7525 to 0.1466 in just the first lag. Our Box-Pierce Q statistic tests the null hypothesis that all correlation up to its respective lag is equal to zero. We observe that we cannot reject the null hypothesis that all lags are not autocorrelated, until after detrending.

## Finland

. corrgram fift, lags(11)

| LAG | AC | PAC | Q | Prob>Q |
|---|---|---|---|---|
| 1 | 0.7984 | 1.0370 | 10.358 | 0.0013 |
| 2 | 0.4943 | -0.7099 | 14.689 | 0.0006 |
| 3 | 0.2243 | 0.9771 | 15.671 | 0.0013 |
| 4 | 0.0409 | 2.3134 | 15.707 | 0.0034 |
| 5 | -0.0701 | . | 15.827 | 0.0074 |
| 6 | -0.1894 | . | 16.826 | 0.0099 |
| 7 | -0.2852 | . | 19.468 | 0.0068 |
| 8 | -0.3537 | . | 24.347 | 0.0020 |
| 9 | -0.3966 | . | 32.016 | 0.0002 |
| 10 | -0.3668 | . | 40.762 | 0.0000 |
| 11 | -0.2709 | . | 47.917 | 0.0000 |

. corrgram fiftd, lags(11)

| LAG | AC | PAC | Q | Prob>Q |
|---|---|---|---|---|
| 1 | 0.5994 | 0.6025 | 5.8383 | 0.0157 |
| 2 | 0.0845 | -0.6770 | 5.9648 | 0.0507 |
| 3 | -0.2354 | 0.0141 | 7.0454 | 0.0705 |
| 4 | -0.2581 | 0.1553 | 8.4883 | 0.0752 |
| 5 | -0.2811 | . | 10.415 | 0.0643 |
| 6 | -0.3540 | . | 13.905 | 0.0307 |
| 7 | -0.3428 | . | 17.723 | 0.0133 |
| 8 | -0.2345 | . | 19.869 | 0.0108 |
| 9 | 0.0611 | . | 20.05 | 0.0176 |
| 10 | 0.2241 | . | 23.316 | 0.0096 |
| 11 | 0.1984 | . | 27.153 | 0.0044 |

## Norway

. corrgram noft, lags(11)

| LAG | AC | PAC | Q | Prob>Q |
|---|---|---|---|---|
| 1 | 0.8024 | 1.0810 | 10.462 | 0.0012 |
| 2 | 0.5482 | -0.2719 | 15.79 | 0.0004 |
| 3 | 0.3131 | 0.3377 | 17.701 | 0.0005 |
| 4 | 0.1071 | -1.4120 | 17.949 | 0.0013 |
| 5 | -0.0800 | . | 18.105 | 0.0028 |
| 6 | -0.2298 | . | 19.576 | 0.0033 |
| 7 | -0.3353 | . | 23.229 | 0.0016 |
| 8 | -0.3975 | . | 29.39 | 0.0003 |
| 9 | -0.4161 | . | 37.831 | 0.0000 |
| 10 | -0.3817 | . | 47.303 | 0.0000 |
| 11 | -0.2856 | . | 55.256 | 0.0000 |

. corrgram noftd, lags(11)

| LAG | AC | PAC | Q | Prob>Q |
|---|---|---|---|---|
| 1 | 0.6039 | 0.6196 | 5.9271 | 0.0149 |
| 2 | 0.1818 | -0.5204 | 6.513 | 0.0385 |
| 3 | -0.0442 | -0.0110 | 6.5511 | 0.0877 |
| 4 | -0.2586 | -1.1252 | 7.9999 | 0.0916 |
| 5 | -0.4613 | . | 13.188 | 0.0217 |
| 6 | -0.4706 | . | 19.356 | 0.0036 |
| 7 | -0.3411 | . | 23.138 | 0.0016 |
| 8 | -0.2026 | . | 24.739 | 0.0017 |
| 9 | -0.0748 | . | 25.012 | 0.0030 |
| 10 | 0.1734 | . | 26.966 | 0.0026 |
| 11 | 0.2902 | . | 35.175 | 0.0002 |

### Sweden

```
. corrgram seft, lags (11)
```

| LAG | AC | PAC | Q | Prob>Q |
|---|---|---|---|---|
| 1 | 0.8020 | 1.0268 | 10.452 | 0.0012 |
| 2 | 0.5318 | 0.9464 | 15.466 | 0.0004 |
| 3 | 0.3179 | 0.6567 | 17.436 | 0.0006 |
| 4 | 0.1205 | -0.2518 | 17.751 | 0.0014 |
| 5 | -0.0719 | . | 17.877 | 0.0031 |
| 6 | -0.2197 | . | 19.222 | 0.0038 |
| 7 | -0.3428 | . | 23.041 | 0.0017 |
| 8 | -0.4140 | . | 29.725 | 0.0002 |
| 9 | -0.4094 | . | 37.897 | 0.0000 |
| 10 | -0.3763 | . | 47.101 | 0.0000 |
| 11 | -0.2968 | . | 55.688 | 0.0000 |

```
. corrgram seftd, lags(11)
```

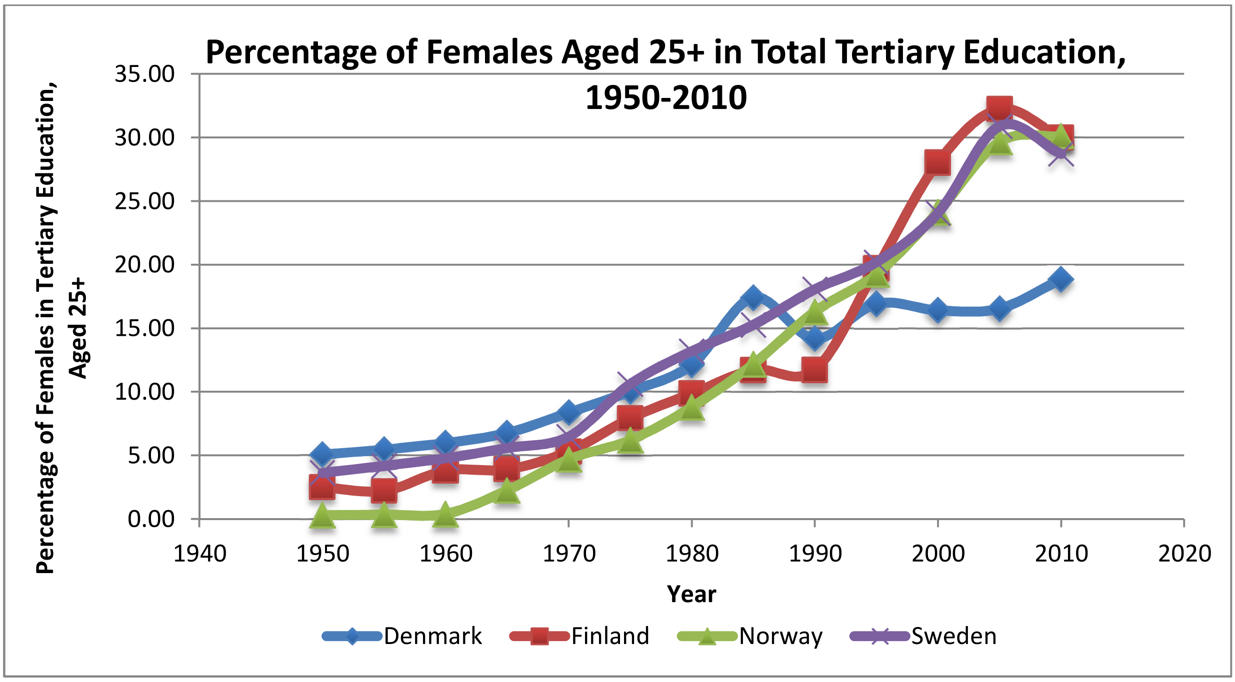
| LAG | AC | PAC | Q | Prob>Q |
|---|---|---|---|---|
| 1 | 0.3880 | 0.3874 | 2.4465 | 0.1178 |
| 2 | 0.0195 | -0.3234 | 2.4532 | 0.2933 |
| 3 | -0.1339 | -0.0411 | 2.803 | 0.4230 |
| 4 | -0.2373 | -0.7170 | 4.0234 | 0.4028 |
| 5 | -0.1243 | . | 4.3998 | 0.4934 |
| 6 | -0.2028 | . | 5.5457 | 0.4759 |
| 7 | -0.3781 | . | 10.191 | 0.1780 |
| 8 | -0.2350 | . | 12.345 | 0.1365 |
| 9 | -0.0714 | . | 12.594 | 0.1819 |
| 10 | 0.1641 | . | 14.343 | 0.1579 |
| 11 | 0.3013 | . | 23.195 | 0.0166 |

We observe across all of our Scandinavian countries initial nonstationarity, where after detrending, we can visually confirm a series that represents stationary, which is further supported by our Box-Pierce Q statistic tests and autocorrelation coefficients. While for Denmark and Sweden, our Box-Pierce Q statistic confirms zero correlation throughout the lags after detrending, Norway and Finland show a substantial improvement; however, the small sample size may be responsible for our inability to reject the presence of autocorrelation.

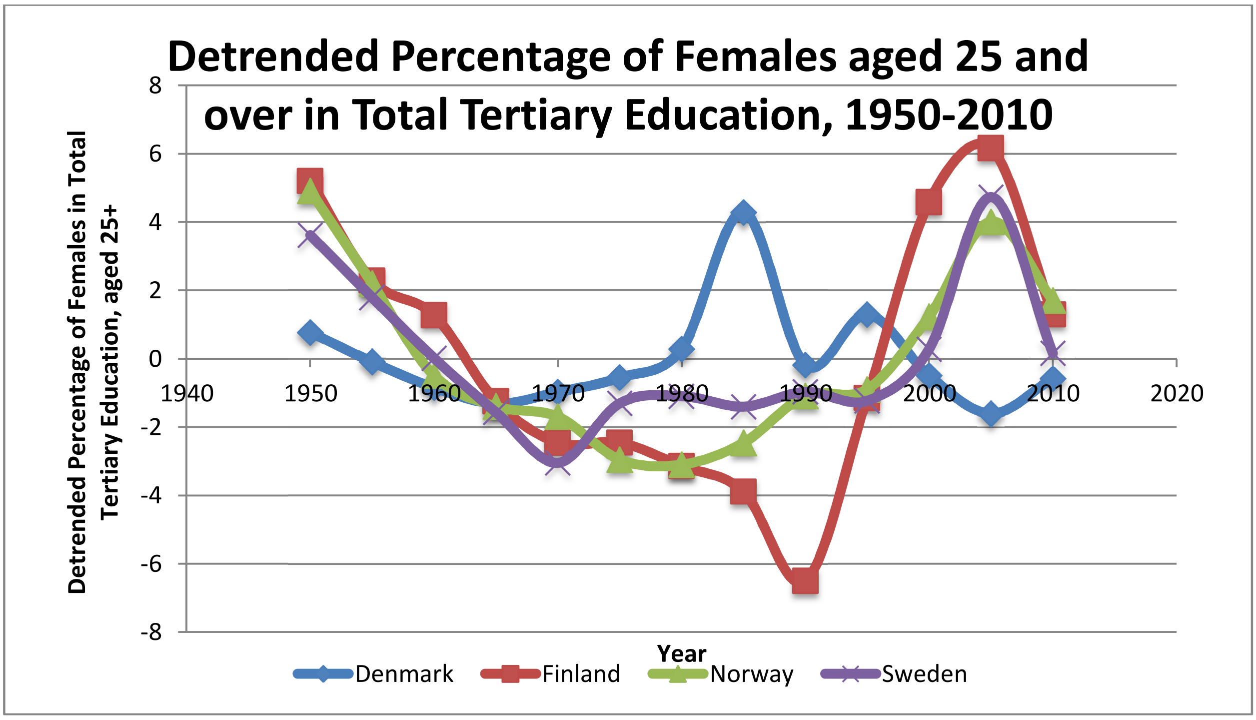
## Data Plots for Female Human Capital

Below we provide a plot of our initial data for the percentage of females above the age of 25 in higher education from 1950-2010 as provided by Barro-Lee's most recent dataset. We observe an obvious upward trend and a discrete change in our data following 1995 across all of our Scandinavian countries with Denmark represented by the blue diamond line, Finland by the red square, Norway by the green triangle, and Sweden by the purple X. Following, we also plot our detrended data for the percentage of females above the age of 25 in tertiary education from 1950 to 2010. Confirming our correlogram results, we visually observe the absence of a trend and stationarity across all of our Scandinavian countries.

## Initial Data



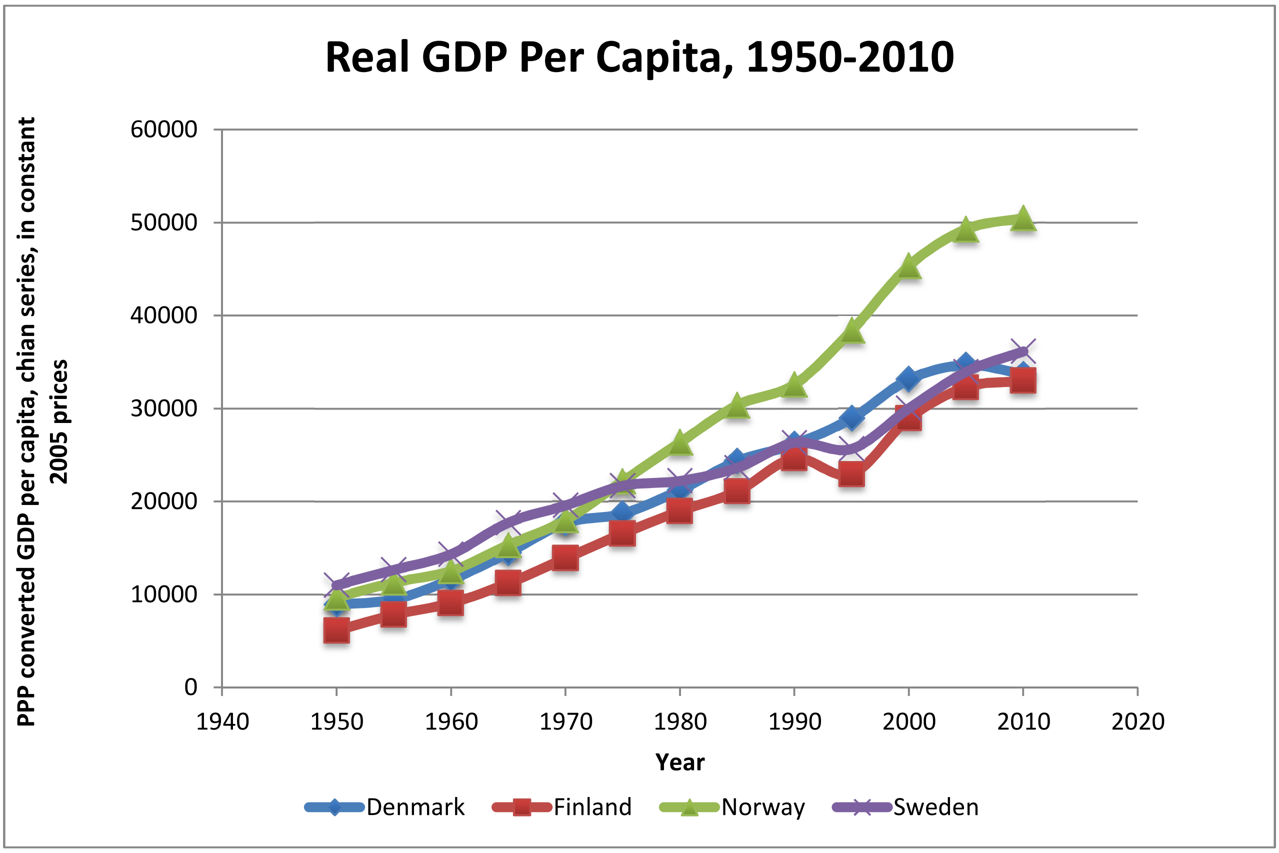

## Detrended Data



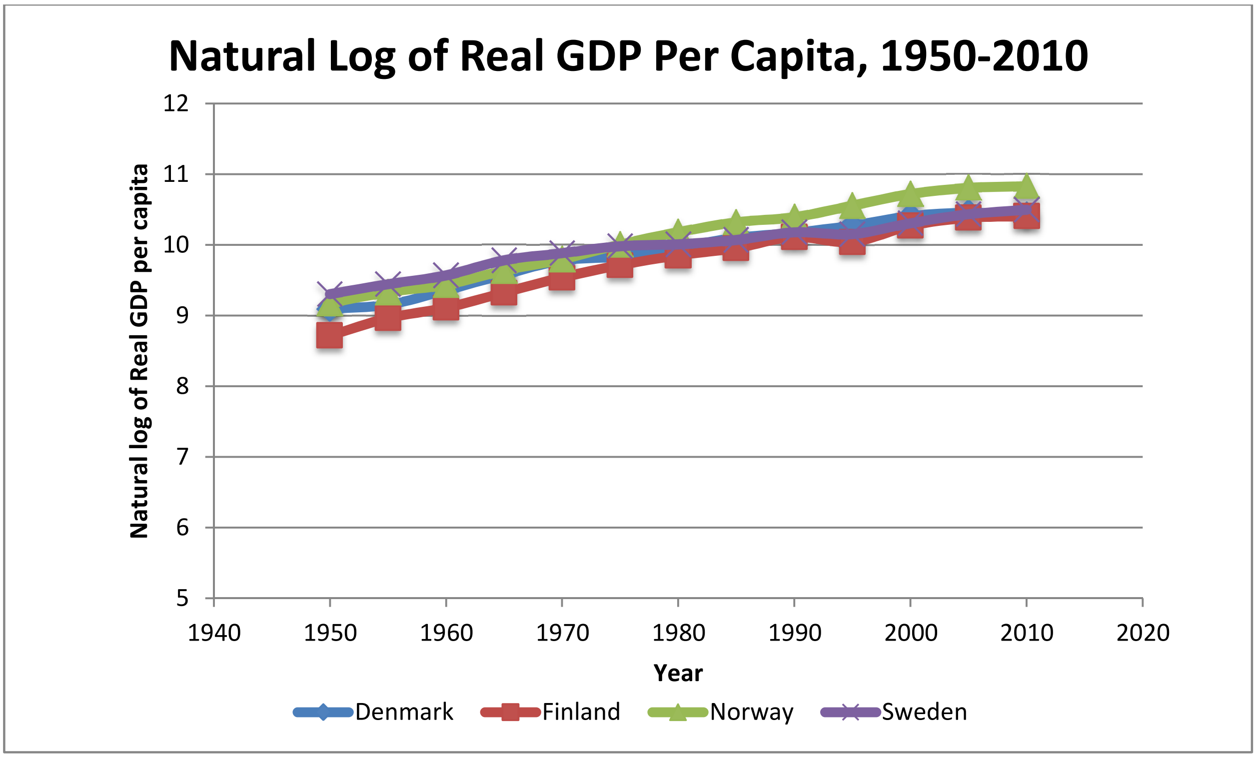
## Data Plots for Real GDP Per Capita

Below we provide a plot of our initial data for real GDP per capita from 1950-2010 as provided by the Penn World Tables. We observe what appears to be exponential growth across all of our Scandinavian countries with Denmark represented by the blue diamond line, Finland by the red square, Norway by the green triangle, and Sweden by the purple X. After applying a logarithmic transformation to the data, we plot the natural log of real GDP per capita for the same time period. Observing the log of real GDP per capita, we observe what appears to be a stochastic trend in our data, suggesting that future values of real GDP per capita rely on past values with an unpredictable change. As a stochastic trend will augment the probability distribution in our estimations, we first difference for stationarity. After differencing for stationarity, we visually observe stationarity across all of our Scandinavian countries.

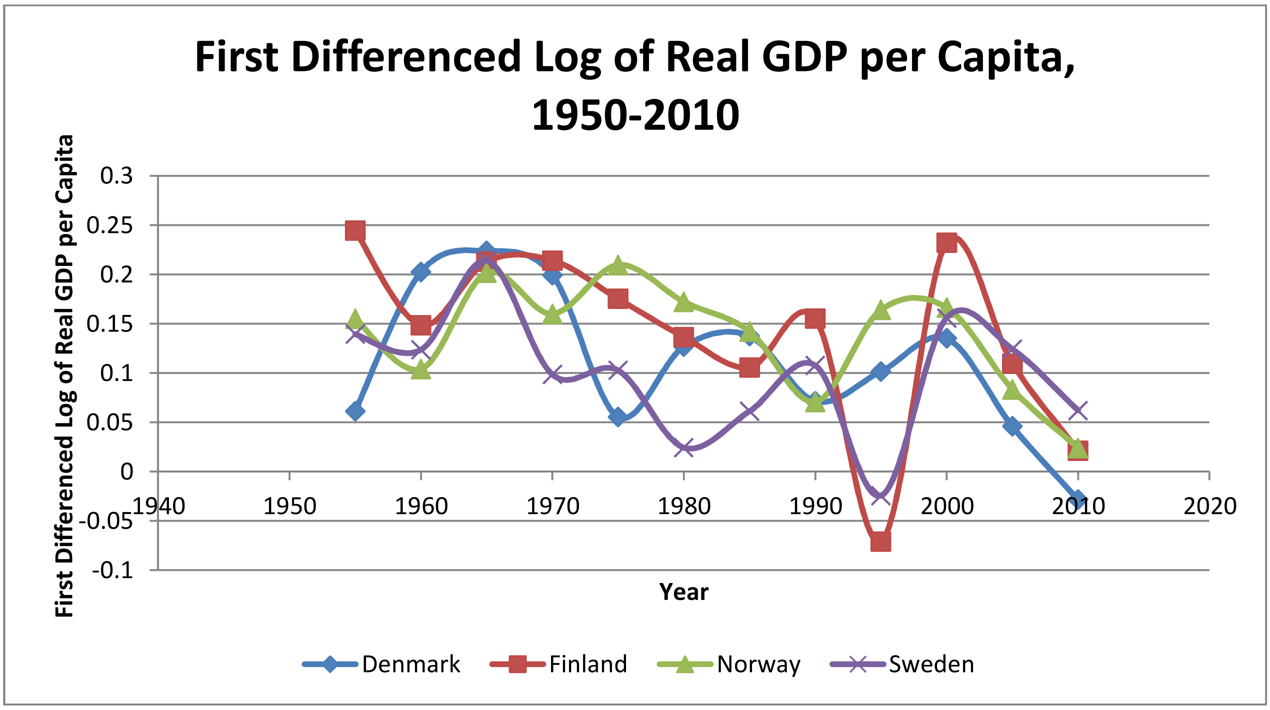
### Initial Data



### Logarithmically Transformed Data




### First Differenced Data



## Augmented Dickey-Fuller Test for Log of Real GDP Per Capita

Testing for the presence of nonstationarity or a unit root in the log of real GDP per capita, we estimate equation 3 in Stata with an Augmented Dickey-Fuller test that applies a slight modification, by subtracting $Y_{t-1}$ from both sides and including additional autoregressive lags to capture any further serial correlation. The null hypothesis is that the series contain a unit root, or in other words a stochastic trend as indicated by our data plot. Observing the output below, we accept the the null hypothesis of a unit root across all of our Nordic countries at the 1% significance level. As we accept the null hypothesis well beyond the 10% significance level, we are unable to reject the null for Denmark at the 5% confidence level, although we attribute this to our limited data.

```
. dfuller  dklngdp, lag(3)

Augmented Dickey-Fuller test for unit root         Number of obs   =         9

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value            Value
------------------------------------------------------------------------------
 Z(t)            -3.180            -3.750            -3.000            -2.630
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0212

. dfuller filngdp, lag(3)

Augmented Dickey-Fuller test for unit root         Number of obs   =         9

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value            Value
------------------------------------------------------------------------------
 Z(t)            -1.928            -3.750            -3.000            -2.630
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.3191

. dfuller  nolngdp, lag(3)

Augmented Dickey-Fuller test for unit root         Number of obs   =         9

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value            Value
------------------------------------------------------------------------------
 Z(t)            -1.950            -3.750            -3.000            -2.630
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.3090

. dfuller selngdp, lag(3)

Augmented Dickey-Fuller test for unit root         Number of obs   =         9

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value            Value
------------------------------------------------------------------------------
 Z(t)            -0.023            -3.750            -3.000            -2.630
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.9566
```

## Correlograms of Real GDP Per Capita

Below we include a correlogram of real GDP per capita for each of our Scandinavian countries with up to 11 lags. We opt for 11 lags to get a full picture of any autocorrelation present. Furthermore, we couple the results from our initial data with our transformed data for easy comparison. All output has been produced using Stata statistical software. We provide a brief summary of the data for Denmark, as the results remain similar across our Scandinavian countries, we allow the reader to interpret Finland, Norway and Sweden similarly. The correlogram of our initial data displays decay due to our stochastic trend, which disappears after first differencing. The AC shows the correlation between the current value of human capital with its lags. We find our first differenced data to show substantial improvement from our initial nonstationary data. Our Box-Pierce Q statistic tests the null hypothesis that all correlation up to its respective lag is equal to zero. We observe that we cannot reject the null hypothesis that all lags are not autocorrelated, until after first differencing.

### Denmark

```
. corrgram dklngdp, lag(11)
```

| LAG | AC | PAC | Q | Prob>Q | -1 0 1 [Autocorrelation] | -1 0 1 [Partial Autocor] |
|---|---|---|---|---|---|---|
| 1 | 0.7918 | 0.9079 | 10.189 | 0.0014 | | |
| 2 | 0.5323 | -0.0895 | 15.211 | 0.0005 | | |
| 3 | 0.2923 | 0.4432 | 16.877 | 0.0007 | | |
| 4 | 0.1023 | 0.3082 | 17.104 | 0.0018 | | |
| 5 | -0.0465 | . | 17.156 | 0.0042 | | |
| 6 | -0.1947 | . | 18.213 | 0.0057 | | |
| 7 | -0.3051 | . | 21.238 | 0.0034 | | |
| 8 | -0.3732 | . | 26.671 | 0.0008 | | |
| 9 | -0.4236 | . | 35.417 | 0.0001 | | |
| 10 | -0.4090 | . | 46.292 | 0.0000 | | |
| 11 | -0.3098 | . | 55.65 | 0.0000 | | |

```
. corrgram d1dklngdp, lag(11)
```

| LAG | AC | PAC | Q | Prob>Q | -1 0 1 [Autocorrelation] | -1 0 1 [Partial Autocor] |
|---|---|---|---|---|---|---|
| 1 | 0.2773 | 0.4083 | 1.1742 | 0.2785 | | |
| 2 | -0.1378 | -0.3068 | 1.4932 | 0.4740 | | |
| 3 | 0.0203 | 0.2700 | 1.5009 | 0.6821 | | |
| 4 | 0.1367 | 0.2576 | 1.8933 | 0.7554 | | |
| 5 | -0.1585 | . | 2.4961 | 0.7771 | | |
| 6 | -0.0399 | . | 2.5407 | 0.8639 | | |
| 7 | 0.0947 | . | 2.8418 | 0.8992 | | |
| 8 | -0.2773 | . | 6.0703 | 0.6394 | | |
| 9 | -0.3733 | . | 13.876 | 0.1268 | | |
| 10 | -0.1551 | . | 15.897 | 0.1026 | | |
| 11 | 0.1130 | . | 18.04 | 0.0807 | | |

### Finland

. corrgram filngdp, lag(11)

| LAG | AC | PAC | Q | Prob>Q |
|---|---|---|---|---|
| 1 | 0.7551 | 0.8929 | 9.2649 | 0.0023 |
| 2 | 0.5248 | 0.4668 | 14.147 | 0.0008 |
| 3 | 0.2965 | 0.3925 | 15.861 | 0.0012 |
| 4 | 0.1185 | 0.4063 | 16.166 | 0.0028 |
| 5 | -0.0559 | . | 16.242 | 0.0062 |
| 6 | -0.1876 | . | 17.222 | 0.0085 |
| 7 | -0.2912 | . | 19.979 | 0.0056 |
| 8 | -0.3690 | . | 25.289 | 0.0014 |
| 9 | -0.3841 | . | 32.481 | 0.0002 |
| 10 | -0.3999 | . | 42.877 | 0.0000 |
| 11 | -0.3210 | . | 52.924 | 0.0000 |

-1 0 1 [Autocorrelation] -1 0 1 [Partial Autocor]

. corrgram d1filngdp, lag(11)

| LAG | AC | PAC | Q | Prob>Q |
|---|---|---|---|---|
| 1 | -0.1401 | -0.1536 | .29965 | 0.5841 |
| 2 | 0.1449 | 0.1648 | .65238 | 0.7217 |
| 3 | 0.3022 | 0.5896 | 2.3568 | 0.5017 |
| 4 | -0.0677 | -0.0004 | 2.453 | 0.6531 |
| 5 | -0.0832 | . | 2.6191 | 0.7585 |
| 6 | -0.1370 | . | 3.1444 | 0.7905 |
| 7 | 0.0013 | . | 3.1445 | 0.8713 |
| 8 | -0.3489 | . | 8.2562 | 0.4089 |
| 9 | 0.0073 | . | 8.2592 | 0.5083 |
| 10 | -0.0449 | . | 8.4285 | 0.5871 |
| 11 | -0.1340 | . | 11.444 | 0.4068 |

-1 0 1 [Autocorrelation] -1 0 1 [Partial Autocor]

### Norway

. corrgram nolngdp, lag(11)

| LAG | AC | PAC | Q | Prob>Q |
|---|---|---|---|---|
| 1 | 0.7927 | 0.9480 | 10.21 | 0.0014 |
| 2 | 0.5680 | -0.1474 | 15.929 | 0.0003 |
| 3 | 0.3292 | 0.2596 | 18.042 | 0.0004 |
| 4 | 0.1224 | 0.3255 | 18.366 | 0.0010 |
| 5 | -0.0591 | . | 18.451 | 0.0024 |
| 6 | -0.2130 | . | 19.715 | 0.0031 |
| 7 | -0.3286 | . | 23.223 | 0.0016 |
| 8 | -0.3994 | . | 29.445 | 0.0003 |
| 9 | -0.4309 | . | 38.495 | 0.0000 |
| 10 | -0.4046 | . | 49.137 | 0.0000 |
| 11 | -0.3063 | . | 58.286 | 0.0000 |

-1 0 1 [Autocorrelation] -1 0 1 [Partial Autocor]

. corrgram d1nolngdp, lag(11)

| LAG | AC | PAC | Q | Prob>Q |
|---|---|---|---|---|
| 1 | 0.1823 | 0.3189 | .50736 | 0.4763 |
| 2 | -0.0807 | -0.1639 | .61674 | 0.7346 |
| 3 | -0.0836 | -0.0939 | .74718 | 0.8621 |
| 4 | 0.2657 | 0.6829 | 2.2301 | 0.6935 |
| 5 | -0.1044 | . | 2.4918 | 0.7777 |
| 6 | -0.0930 | . | 2.7337 | 0.8415 |
| 7 | -0.2798 | . | 5.3641 | 0.6156 |
| 8 | -0.1901 | . | 6.8824 | 0.5494 |
| 9 | -0.1445 | . | 8.0525 | 0.5289 |
| 10 | 0.0850 | . | 8.6588 | 0.5648 |
| 11 | -0.0568 | . | 9.2013 | 0.6033 |

-1 0 1 [Autocorrelation] -1 0 1 [Partial Autocor]

```
. corrgram selngdp, lag(11)
```

| LAG | AC | PAC | Q | Prob>Q | -1 0 1 [Autocorrelation] | -1 0 1 [Partial Autocor] |
|---|---|---|---|---|---|---|
| 1 | 0.7280 | 0.9153 | 8.6111 | 0.0033 | | |
| 2 | 0.4677 | 0.1578 | 12.489 | 0.0019 | | |
| 3 | 0.2385 | 0.0978 | 13.598 | 0.0035 | | |
| 4 | 0.1051 | -0.0819 | 13.838 | 0.0078 | | |
| 5 | -0.0308 | . | 13.861 | 0.0165 | | |
| 6 | -0.1231 | . | 14.283 | 0.0266 | | |
| 7 | -0.2141 | . | 15.773 | 0.0273 | | |
| 8 | -0.3116 | . | 19.561 | 0.0121 | | |
| 9 | -0.3615 | . | 25.932 | 0.0021 | | |
| 10 | -0.4206 | . | 37.432 | 0.0000 | | |
| 11 | -0.3614 | . | 50.167 | 0.0000 | | |

```
. corrgram d1selngdp,lag(11)
```

| LAG | AC | PAC | Q | Prob>Q | -1 0 1 [Autocorrelation] | -1 0 1 [Partial Autocor] |
|---|---|---|---|---|---|---|
| 1 | -0.0374 | -0.0354 | .02132 | 0.8839 | | |
| 2 | 0.0986 | 0.1043 | .18481 | 0.9117 | | |
| 3 | 0.0791 | 0.0928 | .30148 | 0.9597 | | |
| 4 | -0.2788 | -0.5317 | 1.9343 | 0.7478 | | |
| 5 | -0.0732 | . | 2.063 | 0.8404 | | |
| 6 | -0.2948 | . | 4.4969 | 0.6098 | | |
| 7 | 0.0859 | . | 4.7449 | 0.6911 | | |
| 8 | -0.0156 | . | 4.7552 | 0.7834 | | |
| 9 | -0.0315 | . | 4.8107 | 0.8505 | | |
| 10 | 0.0024 | . | 4.8112 | 0.9034 | | |
| 11 | -0.0346 | . | 5.0127 | 0.9305 | | |

## Lag Length Selection

Below we provide our lag selection output as provided by Stata. To balance the marginal benefits of including more lags against the marginal cost of estimation uncertainty, we utilize both the Bayes information criterion (BIC), as well as the Akaike information criterion (AIC). Observing the BIC and AIC for our Scandinavian countries, both suggest 3 lags are the optimal length for Finland, Norway and Sweden. Despite Denmark's conflicting results, we utilize 3 lags given only nine observations and a low p-value on the 3rd lag. *Note: d1dklngdp = d1lGDPDK

```
. varsoc  d1lGDPDK dkftd, maxlag(3)
```

Selection-order criteria
Sample:  1970 - 2010                                    Number of obs      =         9

| lag | LL | LR | df | p | FPE | AIC | HQIC | SBIC |
|---|---|---|---|---|---|---|---|---|
| 0 | -4.6935 | | | | .0152* | 1.48744* | 1.39286* | 1.53127* |
| 1 | -3.23163 | 2.9237 | 4 | 0.571 | .028119 | 2.05147 | 1.76773 | 2.18296 |
| 2 | -2.47177 | 1.5197 | 4 | 0.823 | .072734 | 2.7715 | 2.2986 | 2.99064 |
| 3 | 2.916 | 10.776* | 4 | 0.029 | .114765 | 2.46311 | 1.80105 | 2.7699 |

Endogenous:  d1lGDPDK dkftd
Exogenous:  _cons

```
. varsoc d1lGDPFI fiftd, maxlag(3)
```

Selection-order criteria
Sample:  1970 - 2010                                    Number of obs      =         9

| lag | LL | LR | df | p | FPE | AIC | HQIC | SBIC |
|---|---|---|---|---|---|---|---|---|
| 0 | -16.0368 | | | | .18905 | 4.00817 | 3.91359 | 4.052 |
| 1 | -12.881 | 6.3116 | 4 | 0.177 | .240022 | 4.19577 | 3.91203 | 4.32725 |
| 2 | -8.24723 | 9.2675 | 4 | 0.055 | .262498 | 4.05494 | 3.58204 | 4.27408 |
| 3 | 17.2107 | 50.916* | 4 | 0.000 | .004789* | -.713493* | -1.37555* | -.4067* |

Endogenous:  d1lGDPFI fiftd
Exogenous:  _cons

```
. varsoc d1lGDPNO noftd, maxlag(3)
```

Selection-order criteria
Sample:  1970 - 2010                                    Number of obs      =         9

| lag | LL | LR | df | p | FPE | AIC | HQIC | SBIC |
|---|---|---|---|---|---|---|---|---|
| 0 | -4.81535 | | | | .015617 | 1.51452 | 1.41994 | 1.55835 |
| 1 | .135881 | 9.9025 | 4 | 0.042 | .013304 | 1.30314 | 1.0194 | 1.43462 |
| 2 | 23.3953 | 46.519 | 4 | 0.000 | .000232 | -2.97673 | -3.44963 | -2.75759 |
| 3 | 54.6457 | 62.501* | 4 | 0.000 | 1.2e-06* | -9.03238* | -9.69444* | -8.72559* |

Endogenous:  d1lGDPNO noftd
Exogenous:  _cons

```
. varsoc  d1lGDPSE seftd, maxlag(3)
```

Selection-order criteria
Sample:  1970 - 2010                                    Number of obs      =         9

| lag | LL | LR | df | p | FPE | AIC | HQIC | SBIC |
|---|---|---|---|---|---|---|---|---|
| 0 | -4.70074 | | | | .015224 | 1.48905 | 1.39447 | 1.53288 |
| 1 | -3.57661 | 2.2483 | 4 | 0.690 | .030359 | 2.12813 | 1.84439 | 2.25962 |
| 2 | 2.37528 | 11.904 | 4 | 0.018 | .024771 | 1.69438 | 1.22148 | 1.91352 |
| 3 | 15.1322 | 25.514* | 4 | 0.000 | .0076* | -.251589* | -.913649* | .055205* |

Endogenous:  d1lGDPSE seftd
Exogenous:  _cons

## Granger Causality Test

Utilizing three lags as indicated by our BIC and AIC, we estimate our Granger Causality test, again with Stata. The Granger causality statistic is essentially an F-statistic testing the null hypothesis that our regressor holds no predictive content for our dependent variable beyond our other regressors in the model. Beginning with Denmark, we are unable to reject the null hypothesis that economic growth holds predictive content for determining female human capital; however, we find that female human capital significantly Granger causes economic growth. Next, we find that economic growth in Finland holds predictive power for female human capital; and, the predictive content in female human capital is nearly significant for economic growth. Furthermore in Norway, we find that both human capital and economic growth hold predictive content for one another, while finally in Sweden, only economic growth Granger causes female human capital. In other words, a bilateral causality exists in Norway and somewhat for Finland, while Denmark exhibits a unidirectional causality from human capital to economic growth and Sweden displays the opposite with a unidirectional causality running from economic growth to female human capital.

### Denmark

```
. quietly var  d1lGDPDK dkftd, lags (1/3)

. vargranger
```

Granger causality Wald tests

| Equation | Excluded | chi2 | df | Prob > chi2 |
|---|---|---|---|---|
| d1lGDPDK | dkftd | .60832 | 3 | 0.895 |
| d1lGDPDK | ALL | .60832 | 3 | 0.895 |
| dkftd | d1lGDPDK | 19.019 | 3 | 0.000 |
| dkftd | ALL | 19.019 | 3 | 0.000 |

### Finland

```
. quietly var d1lGDPFI fiftd, lags(1/3)

. vargranger
```

Granger causality Wald tests

| Equation | Excluded | chi2 | df | Prob > chi2 |
|---|---|---|---|---|
| d1lGDPFI | fiftd | 60.249 | 3 | 0.000 |
| d1lGDPFI | ALL | 60.249 | 3 | 0.000 |
| fiftd | d1lGDPFI | 6.7848 | 3 | 0.079 |
| fiftd | ALL | 6.7848 | 3 | 0.079 |

### Norway

```
. quietly var d1lGDPNO noftd, lags (1/3)

. vargranger
```

Granger causality Wald tests

| Equation | Excluded | chi2 | df | Prob > chi2 |
|---|---|---|---|---|
| d1lGDPNO | noftd | 191.08 | 3 | 0.000 |
| d1lGDPNO | ALL | 191.08 | 3 | 0.000 |
| noftd | d1lGDPNO | 94176 | 3 | 0.000 |
| noftd | ALL | 94176 | 3 | 0.000 |

### Sweden

```
. quietly var  d1lGDPSE seftd, lags(1/3)

. vargranger
```

Granger causality Wald tests

| Equation | Excluded | chi2 | df | Prob > chi2 |
|---|---|---|---|---|
| d1lGDPSE | seftd | 17.549 | 3 | 0.001 |
| d1lGDPSE | ALL | 17.549 | 3 | 0.001 |
| seftd | d1lGDPSE | 5.3048 | 3 | 0.151 |
| seftd | ALL | 5.3048 | 3 | 0.151 |

## Chow Test

Visually observing a discrete change in our female human capital data plot following 1995, with a known break date, we perform a Chow test in Stata as presented below. The Chow test is essentially an F-statistic testing the null hypothesis that the intercept and slope before and after the break is the same. Performing an F-test for the break, we reject the null hypothesis that there is no break at the 95% confidence level, confirming our suspicion of a discrete change in our data following 1995.

```
. reg lngdp100  L1ftotaldetrended break2 break2_l1lngdp100 break2_FHC

      Source |       SS       df       MS              Number of obs =      44
-------------+------------------------------           F(  4,    39) =    2.79
       Model |  502.159083     4  125.539771           Prob > F      =  0.0393
    Residual |  1753.33973    39  44.9574289           R-squared     =  0.2226
-------------+------------------------------           Adj R-squared =  0.1429
       Total |  2255.49881    43  52.4534607           Root MSE      =   6.705

------------------------------------------------------------------------------
    lngdp100 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
L1ftotalde~d |   .6135073   .4985283     1.23   0.226    -.3948613    1.621876
      break2 |  -5.970587   3.773668    -1.58   0.122    -13.60355    1.662378
break2_l~100 |  -.0093197   .2663301    -0.03   0.972     -.548023    .5293837
  break2_FHC |  -2.533537   .9191985    -2.76   0.009    -4.392792   -.6742827
       _cons |   13.55194   1.298648    10.44   0.000     10.92517     16.1787
------------------------------------------------------------------------------

. test break2 break2_l1lngdp100 break2_FHC

 ( 1)  break2 = 0
 ( 2)  break2_l1lngdp100 = 0
 ( 3)  break2_FHC = 0

       F(  3,    39) =    3.63
            Prob > F =    0.0211
```

## Two Stage Least Squares Instrumental Variables Regression

Below we estimate a two-stage least squares instrumental variables regression, instrumented with a two period lagged real GDP per capita and an interaction term between the second lag of our female human capital variable and real GDP per capita. We incorporate a break following 1995 and control for robust standard errors. We begin with checking the validity of our instrument in the first stage to ensure reliability in the second stage. Since an invalid instrument does not help us capture the exogenous variations in X, the covariance between our instruments and female human capital essentially becomes zero; and, our beta estimation in our second stage becomes inconsistent when the denominator is zero. Therefore, first we observe our first-stage F-statistic, essentially for equation 5 with a break following 1995, where we test the null hypothesis that the instruments are weak and equal to zero. In the first-stage, we observe a favorable F-statistic of 17.00. Since an F-statistic higher than ten is a good indication of the Stock and Yogo test, we can reject the null hypothesis of weak instruments (507). However, as the Stock and Yogo test allows us to test for bias in our TSLS estimator for a large number of instruments, due to our use of robust standard errors to control for heteroskedasicity, we utilize Stata's robust Kleibergen-Paap Wald rk F-statistic with Stock and Yogo's critical values. Formally rejecting that our model is weakly identified, we find our first-stage coefficients for our break and interaction term between the second lag of female human capital and the second lag of real GDP per capita to have the most significant explanatory power. Observing our second stage regression results, we are somewhat surprised to find a negative and insignificant effect from female human capital on economic growth across Scandinavia. On average, across our Nordic countries, we find a decrease of 0.72 percentage points in GDP for a one percent increase in the percentage of females with tertiary education five years earlier, technically with borderline significance at the 80 percent confidence level.

```
. ivreg2 D1lngdp ( L1ftotaldetrended= L2D1lngdp  FHCwGDP break2 break2_L1D1lngdp), first robust

First-stage regressions
-----------------------

First-stage regression of L1ftotaldetrended:

OLS estimation
--------------

Estimates efficient for homoskedasticity only
Statistics robust to heteroskedasticity

                                                      Number of obs =       40
                                                      F(  4,     35) =    17.00
                                                      Prob > F      =   0.0000
Total (centered) SS     =  246.4083213                Centered R2   =   0.5833
Total (uncentered) SS   =  259.9853079                Uncentered R2 =   0.6051
Residual SS             =  102.6801788                Root MSE      =    1.713

------------------------------------------------------------------------------
             |               Robust
L1ftotalde~d |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   L2D1lngdp |   2.334993   3.406708     0.69   0.498    -4.580993    9.250979
     FHCwGDP |    3.61785   .6250331     5.79   0.000     2.348965    4.886735
      break2 |   1.762378   .9952767     1.77   0.085    -.2581408    3.782898
break2_L1D~p |    6.44922   7.670398     0.84   0.406    -9.122516    22.02096
       _cons |  -1.295489    .672581    -1.93   0.062    -2.660902    .0699227
------------------------------------------------------------------------------
Included instruments: L2D1lngdp FHCwGDP break2 break2_L1D1lngdp
------------------------------------------------------------------------------
F test of excluded instruments:
  F(  4,    35) =    17.00
  Prob > F      =   0.0000
```

```
Angrist-Pischke multivariate F test of excluded instruments:
  F(  4,     35) =     17.00
  Prob > F       =    0.0000


Summary results for first-stage regressions
-------------------------------------------

                                           (Underid)            (Weak id)
Variable     | F(  4,     35)  P-val | AP Chi-sq(  4) P-val | AP F(  4,     35)
L1ftotaldetr |      17.00     0.0000 |      77.70    0.0000 |       17.00

NB: first-stage test statistics heteroskedasticity-robust

Stock-Yogo weak ID test critical values for single endogenous regressor:
                                    5% maximal IV relative bias    16.85
                                   10% maximal IV relative bias    10.27
                                   20% maximal IV relative bias     6.71
                                   30% maximal IV relative bias     5.34
                                   10% maximal IV size             24.58
                                   15% maximal IV size             13.96
                                   20% maximal IV size             10.26
                                   25% maximal IV size              8.31
Source: Stock-Yogo (2005).  Reproduced by permission.
NB: Critical values are for Cragg-Donald F statistic and i.i.d. errors.

Underidentification test
Ho: matrix of reduced form coefficients has rank=K1-1 (underidentified)
Ha: matrix has rank=K1 (identified)
Kleibergen-Paap rk LM statistic          Chi-sq(4)=10.21    P-val=0.0370

Weak identification test
Ho: equation is weakly identified
Cragg-Donald Wald F statistic                                      12.25
Kleibergen-Paap Wald rk F statistic                                17.00

Stock-Yogo weak ID test critical values for K1=1 and L1=4:
                                    5% maximal IV relative bias    16.85
                                   10% maximal IV relative bias    10.27
                                   20% maximal IV relative bias     6.71
                                   30% maximal IV relative bias     5.34
                                   10% maximal IV size             24.58
                                   15% maximal IV size             13.96
                                   20% maximal IV size             10.26
                                   25% maximal IV size              8.31
Source: Stock-Yogo (2005).  Reproduced by permission.
NB: Critical values are for Cragg-Donald F statistic and i.i.d. errors.

Weak-instrument-robust inference
Tests of joint significance of endogenous regressors B1 in main equation
Ho: B1=0 and orthogonality conditions are valid
Anderson-Rubin Wald test           F(4,35)=         0.90     P-val=0.4747
Anderson-Rubin Wald test           Chi-sq(4)=       4.11     P-val=0.3910
Stock-Wright LM S statistic        Chi-sq(4)=       5.99     P-val=0.1998

NB: Underidentification, weak identification and weak-identification-robust
    test statistics heteroskedasticity-robust

Number of observations               N  =         40
Number of regressors                 K  =          2
Number of endogenous regressors      K1 =          1
Number of instruments                L  =          5
Number of excluded instruments       L1 =          4
```

```
IV (2SLS) estimation
--------------------

Estimates efficient for homoskedasticity only
Statistics robust to heteroskedasticity

                                                      Number of obs =       40
                                                      F(  1,     38) =     1.54
                                                      Prob > F      =   0.2227
Total (centered) SS     =  .217347262                 Centered R2   =  -0.0144
Total (uncentered) SS   =  .7651070796                Uncentered R2 =   0.7118
Residual SS             =  .2204873718                Root MSE      =    .07424

------------------------------------------------------------------------------
             |               Robust
     D1lngdp |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
L1ftotalde~d |  -.0072163   .0056739    -1.27   0.203     -.018337    .0039043
       _cons |   .1128171   .0113102     9.97   0.000     .0906495    .1349847
------------------------------------------------------------------------------
Underidentification test (Kleibergen-Paap rk LM statistic):             10.212
                                                   Chi-sq(4) P-val =    0.0370
------------------------------------------------------------------------------
Weak identification test (Cragg-Donald Wald F statistic):               12.248
                         (Kleibergen-Paap rk Wald F statistic):         16.996
Stock-Yogo weak ID test critical values:  5% maximal IV relative bias    16.85
                                         10% maximal IV relative bias    10.27
                                         20% maximal IV relative bias     6.71
                                         30% maximal IV relative bias     5.34
                                         10% maximal IV size             24.58
                                         15% maximal IV size             13.96
                                         20% maximal IV size             10.26
                                         25% maximal IV size              8.31
Source: Stock-Yogo (2005).  Reproduced by permission.
NB: Critical values are for Cragg-Donald F statistic and i.i.d. errors.
------------------------------------------------------------------------------

------------------------------------------------------------------------------
Hansen J statistic (overidentification test of all instruments):         1.903
                                                   Chi-sq(3) P-val =    0.5927
------------------------------------------------------------------------------
Instrumented:         L1ftotaldetrended
Excluded instruments: L2D1lngdp FHCwGDP break2 break2_L1D1lngdp
------------------------------------------------------------------------------
```

## Robustness Check

Below we provide a robustness check by utilizing for country fixed effects to control for heterogeneity bias between countries while still estimating a two-stage least squares instrumental variables regression, instrumented with a two period lagged real GDP per capita and an interaction term, incorporating a break following 1995 and controlling for robust standard errors. Assigning 3 dummy variables, avoiding a dummy variable trap, we include a dummy variable for Finland, Norway and Sweden, and Denmark as our base. We find our first-stage F-statistic to still be greater than 10, while we attribute the decrease from our initial model to be due to the increased number of variables limiting our degrees of freedom in an already pressured sample size. With our F-statistic suggesting the instruments are a good fit and relevant to our female human capital variable, we again confirm this through a formal weak identification test comparing the Kleibergen-Paap Wald rk F statistic with Stock and Yogo's weak ID test critical values; however, now we accept a little more bias in our second-stage estimations than before with a 5% maximal IV relative bias. Still confident in our instruments, we find the the second-stage results to be robust to our inclusion of country fixed effects with a negative and insignificant effect of a 0.70 percentage point decrease in real GDP per capita on average, five years following a one percent increase in female tertiary education in Scandinavia.

```
. ivreg2 D1lngdp  DumFin DumNor DumSwed ( L1ftotaldetrended= L2D1lngdp  FHCwGDP break2 break2_L1D1lngdp), first robu
> st

First-stage regressions
-----------------------

First-stage regression of L1ftotaldetrended:

OLS estimation
--------------

Estimates efficient for homoskedasticity only
Statistics robust to heteroskedasticity

                                                      Number of obs =       40
                                                      F(  7,     32) =    10.73
                                                      Prob > F      =   0.0000
Total (centered) SS     =  246.4083213                Centered R2   =   0.5895
Total (uncentered) SS   =  259.9853079                Uncentered R2 =   0.6109
Residual SS             =  101.1527382                Root MSE      =    1.778

------------------------------------------------------------------------------
             |               Robust
L1ftotalde~d |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      DumFin |  -.5354358   .9793685    -0.55   0.588    -2.530344    1.459473
      DumNor |  -.4301918   .8347582    -0.52   0.610    -2.130539    1.270155
     DumSwed |   -.202187   .9094204    -0.22   0.825    -2.054616    1.650242
   L2D1lngdp |   3.247337    5.00813     0.65   0.521     -6.95389    13.44856
     FHCwGDP |   3.482292   .6481965     5.37   0.000     2.161958    4.802625
      break2 |   1.718518     1.1244     1.53   0.136    -.5718099    4.008845
break2_L1D~p |   7.458109     8.9184     0.84   0.409    -10.70808     25.6243
       _cons |  -1.157116   1.118008    -1.03   0.308    -3.434425    1.120192
------------------------------------------------------------------------------
Included instruments: DumFin DumNor DumSwed L2D1lngdp FHCwGDP break2
                      break2_L1D1lngdp
```

```
F test of excluded instruments:
  F(  4,    32) =     14.87
  Prob > F      =    0.0000
Angrist-Pischke multivariate F test of excluded instruments:
  F(  4,    32) =     14.87
  Prob > F      =    0.0000


Summary results for first-stage regressions
-------------------------------------------

                                           (Underid)            (Weak id)
Variable     | F(  4,    32)  P-val | AP Chi-sq(  4) P-val | AP F(  4,    32)
L1ftotaldetr |      14.87    0.0000 |      74.33    0.0000 |       14.87

NB: first-stage test statistics heteroskedasticity-robust

Stock-Yogo weak ID test critical values for single endogenous regressor:
                                    5% maximal IV relative bias    16.85
                                   10% maximal IV relative bias    10.27
                                   20% maximal IV relative bias     6.71
                                   30% maximal IV relative bias     5.34
                                   10% maximal IV size             24.58
                                   15% maximal IV size             13.96
                                   20% maximal IV size             10.26
                                   25% maximal IV size              8.31
Source: Stock-Yogo (2005).  Reproduced by permission.
NB: Critical values are for Cragg-Donald F statistic and i.i.d. errors.

Underidentification test
Ho: matrix of reduced form coefficients has rank=K1-1 (underidentified)
Ha: matrix has rank=K1 (identified)
Kleibergen-Paap rk LM statistic          Chi-sq(4)=8.10     P-val=0.0878

Weak identification test
Ho: equation is weakly identified
Cragg-Donald Wald F statistic                                     11.09
Kleibergen-Paap Wald rk F statistic                               14.87

Stock-Yogo weak ID test critical values for K1=1 and L1=4:
                                   5% maximal IV relative bias    16.85
                                  10% maximal IV relative bias    10.27
                                  20% maximal IV relative bias     6.71
                                  30% maximal IV relative bias     5.34
                                  10% maximal IV size             24.58
                                  15% maximal IV size             13.96
                                  20% maximal IV size             10.26
                                  25% maximal IV size              8.31
Source: Stock-Yogo (2005).  Reproduced by permission.
NB: Critical values are for Cragg-Donald F statistic and i.i.d. errors.

Weak-instrument-robust inference
Tests of joint significance of endogenous regressors B1 in main equation
Ho: B1=0 and orthogonality conditions are valid
Anderson-Rubin Wald test           F(4,32)=        1.68     P-val=0.1791
Anderson-Rubin Wald test           Chi-sq(4)=      8.40     P-val=0.0781
Stock-Wright LM S statistic        Chi-sq(4)=      7.07     P-val=0.1323

NB: Underidentification, weak identification and weak-identification-robust
    test statistics heteroskedasticity-robust

Number of observations               N  =         40
Number of regressors                 K  =          5
Number of endogenous regressors      K1 =          1
Number of instruments                L  =          8
Number of excluded instruments       L1 =          4
```

```
IV (2SLS) estimation
--------------------

Estimates efficient for homoskedasticity only
Statistics robust to heteroskedasticity

                                                      Number of obs =       40
                                                      F(  4,    35) =     1.19
                                                      Prob > F      =   0.3317
Total (centered) SS     =  .217347262                 Centered R2   =   0.0401
Total (uncentered) SS   =  .7651070796                Uncentered R2 =   0.7273
Residual SS             =  .2086308388                Root MSE      =   .07222

------------------------------------------------------------------------------
             |               Robust
     D1lngdp |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
L1ftotalde~d |  -.0070099   .0058774    -1.19   0.233    -.0185294    .0045095
      DumFin |   .0163387   .0362167     0.45   0.652    -.0546448    .0873222
      DumNor |   .0264785    .028053     0.94   0.345    -.0285044    .0814614
     DumSwed |  -.0180605   .0303882    -0.59   0.552    -.0776201    .0414992
       _cons |   .1067482    .022598     4.72   0.000     .0624569    .1510394
------------------------------------------------------------------------------
Underidentification test (Kleibergen-Paap rk LM statistic):              8.104
                                                   Chi-sq(4) P-val =    0.0878
------------------------------------------------------------------------------
Weak identification test (Cragg-Donald Wald F statistic):               11.088
                         (Kleibergen-Paap rk Wald F statistic):         14.866
Stock-Yogo weak ID test critical values:  5% maximal IV relative bias    16.85
                                         10% maximal IV relative bias    10.27
                                         20% maximal IV relative bias     6.71
                                         30% maximal IV relative bias     5.34
                                         10% maximal IV size             24.58
                                         15% maximal IV size             13.96
                                         20% maximal IV size             10.26
                                         25% maximal IV size              8.31

Source: Stock-Yogo (2005).  Reproduced by permission.
NB: Critical values are for Cragg-Donald F statistic and i.i.d. errors.
------------------------------------------------------------------------------
Hansen J statistic (overidentification test of all instruments):         4.188
                                                   Chi-sq(3) P-val =    0.2418
------------------------------------------------------------------------------
Instrumented:         L1ftotaldetrended
Included instruments: DumFin DumNor DumSwed
Excluded instruments: L2D1lngdp FHCwGDP break2 break2_L1D1lngdp
------------------------------------------------------------------------------
```