

THREE ESSAYS ON DISTRIBUTION OF EARNINGS, INCOME, AND WEALTH

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Abstract

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The first essay considers several education finance systems and asks which one yields a more equal earnings distribution without incurring large tax distortions. A 2T-period heterogeneous agent overlapping generations model is used. It is solved numerically and calibrated to the U.S. data. The model introduces two novel features. First, parents are allowed to leave altruistic bequests to their offspring, and second, rental rates on physical and human capital are determined by market clearing conditions in a closed economy. This makes it possible to evaluate the distortionary costs of alternative education finance policies in a more realistic general equilibrium framework. It is shown that a policy of partial subsidization of education expenditures generates higher earnings equality. More importantly, such a policy, funded by taxes on labor and capital income, and consumption, does not necessarily lead to a smaller steady state capital stock.

The second essay proposes a theoretical model to account for persistence of intergenerational income and wealth inequality. Credit constraints have been used by previous studies to explain inequality and its persistence. However, in the long run, credit constraints become less binding thanks to “trickle down” effects and do not generate sufficient degrees of persistence. This essay introduces endogenous technological change with externalities and demonstrates that this generates higher persistence by making it more difficult for the credit constrained agents to catch up as the gap they have to overcome widens due to further technological change.

The third essay investigates whether international trade has contributed to increasing wage inequality between skilled and unskilled workers in Argentina, Chile, Colombia, Costa Rica, Malaysia, Mexico, the Philippines, and Uruguay after they adopted more open trade regimes in the 1980s and 1990s. It is shown that, a few sub-sectors of “Fabricated Metals, Machinery and Equipment” industry have begun to account for large shares of exports and imports simultaneously in most of these developing countries. The implications for demand for skilled labor are evaluated. It is shown that the limited amount of available data do not suggest that trade has increased demand for skilled labor, and thus contributed to wage inequality in a significant degree.

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Introduction

This dissertation consists of three essays, each examining a different aspect of the subject of distribution of earnings, income, and wealth. The first essay considers earnings inequality and alternative education finance systems. The second one examines the persistency of intergenerational income and wealth inequality. The last essay investigates the role of international trade in the increased wage inequality observed in some developing countries during the 1980s and 1990s.

The first essay considers several different methods of financing the cost of primary and secondary education and asks which one yields a more equal earnings distribution without generating large tax distortions. It estimates the size of distortionary costs of alternative education finance policies within a general equilibrium framework.

Similar questions have been entertained by previous studies in the related literature. However, these studies suffer from three main shortcomings. First, some of them claim that any deviations from a locally funded education system create inefficiencies. But the size of these inefficiencies has not been assessed in a general equilibrium framework. Second, most of them, due to reasons concerning analytical tractability, exclude physical assets and/or precautionary savings from their models. Third, even if precautionary savings are allowed, agents are assumed to hold their savings in certain assets that yield a fixed rate of return.

The model proposed in the first chapter introduces two novel features: first, parents are allowed to leave altruistic bequests to their offspring, and second, rental rates on physical and human capital are determined by market clearing conditions in a closed economy. Introduction of these features enables me to evaluate the distortionary costs of alternative education finance policies in a more realistic general equilibrium framework.

A 2T-period heterogeneous agent overlapping generations model (OLG) is used. The amount of human capital produced is a function of innate ability and spending on education. Agents face borrowing constraints while the educational investment is made. The source of uncertainty is the ability type: everybody is born with either high or low innate ability. The model is solved numerically and calibrated to the U.S. data. In addition to the benchmark economy, four different policy experiments are carried out.

It is demonstrated that a policy of partial subsidization of education expenditures generates higher earnings equality. Such a policy, funded by taxes on labor and capital income, and consumption, does not necessarily lead to a smaller steady state physical capital stock by distorting savings decisions. Two factors generate this result. First, education subsidies lead to a larger human capital stock; this decreases the physical to human capital ratio, and therefore increases the rate of return on physical capital in a Cobb-Douglas production function. The higher rate of return generates a larger physical capital stock at the steady state so long as the increase in the rate of return is not completely taxed to pay for the education subsidies. Second, agents in this model save in part so that future members of their dynasty can invest in human capital. For this reason,

savings, and thus the physical capital stock, do not decline as much as they would in a framework without a bequest motive in response to taxation of capital income.

Loury (1981), Fernandez and Rogerson (1998), Benabou (2002), among others, have shown that public financing of education may be preferred to local or private financing for various reasons. But none of these studies include physical assets that can be directly bequeathed to the future generations by the altruistic parents. The model proposed in the first essay includes such an asset and shows that a policy of subsidizing educational investment outperforms other education finance systems in generating a more equal distribution of earnings, and most importantly, such a scheme does not necessarily cost the society a decline in its steady state physical capital stock.

The second essay examines persistence of intergenerational income and wealth inequality. It has been motivated by the findings of a relatively recent literature demonstrating that intergenerational income and wealth inequality in the U.S. has been persistent (Solon, 1992; Zimmerman, 1992; Mulligan, 1997).

The existence of credit market imperfections has been used by previous studies to generate persistence of income and wealth inequality. It has been shown that in the long run, under certain conditions, the influence credit constraints diminishes thanks to “trickle down” effects working via equilibrium interest rates or wages. As a result, persistence declines.

The second essay introduces endogenous technological change as a new factor, which can generate higher persistence of intergenerational inequality, in combination with credit constraints by offsetting a part of trickle down effects or reversing them. A

two period overlapping generations framework is used where individuals choose to be unskilled or skilled workers. Skills are acquired by investing in human capital accumulation or education at the beginning of the first period of life, which requires payment of up-front costs in real resources in addition to commitment of one's own time. In any period t , there is only one vintage technology used by the skilled workers. Technological change is defined as the innovation and diffusion of a new vintage or generation of this technology. In addition to positive externalities to technological change, negative externalities are also considered. It is assumed that the up-front costs paid to receive further education increase as the level of technology advances.

The model presented in the second chapter can generate a trickle-down effect similar to the ones proposed by previous studies if the cost of human capital investment is constant. However, the introduction of negative externalities from technological progress changes this result. It is possible to have the opposite of the trickle-down effect if the increases in the cost of human capital investment are sufficiently large.

The rich have incentives to invest in new technologies. However, as technology advances the amount of investment the poor need to make to catch up with the rich increases. This process generates higher persistence of inequality. A number of extensions of the basic model are considered; they generate more realistic steady state distributions but do not affect the main findings.

The findings of the second essay are important in the following sense. Previous studies in the literature use the existence of credit constraints to explain the persistence of intergenerational inequality, and predict that, in the long run under certain conditions,

persistence will decrease thanks to trickle-down effects. However, the lack of empirical findings showing declining persistence over time, and the recent findings indicating higher persistence, does not lend much support to this prediction. The model presented in the second chapter introduces endogenous technological change and demonstrates potential limitations of trickle-down effects in reducing persistence of inequality, within a relatively simple framework.

The goal of the third essay is to investigate whether international trade has played a role in increasing demand for skilled workers in a sample of developing economies (Argentina, Chile, Colombia, Costa Rica, Malaysia, Mexico, the Philippines, and Uruguay) during the last two decades. Two potential effects of trade on demand for skilled labor are considered. First, a direct effect via exports: exports may become more skill intensive and increase demand for skilled workers. Second, an indirect effect via skill-biased technological change: trade may promote skill-biased technological change and increase demand for skilled labor. The third chapter attempts to show if there is any empirical support for these two potential effects of trade on demand for skilled labor. This is done by, first, documenting the changes in the trade patterns of the developing countries after they liberalized their trade regimes, and then evaluating potential indicators of higher skill-intensity or skill-biased technological change, especially in high-growth export sectors.

It is demonstrated that the most important change in trade patterns of these countries has been the increased significance of a manufacturing industry called “Fabricated Metals, Machinery and Equipment”. The growth in trade volumes have been

concentrated in a few sub-sectors within this industry; mainly, “Radio, Television, and Communication Equipment and Apparatus”, “Motor Vehicles”, and “Office, Computing and Accounting Machinery”. More interestingly, these sectors have become the largest export and import sectors at the same time. This is caused by the integration of these developing countries into the global production networks in these industries.

The answer to the question of whether international trade has increased demand for skilled labor in our sample of developing countries either by changing the composition of exports (direct effect via exports), or by promoting skill-biased technological change (indirect effect via technological change) is a “qualified” no. The answer is “qualified” because the available data that can be used to assess skill-intensity of sectors is very limited. This chapter does not refute the claim that trade has increased demand for skilled labor. But it concludes that the available data does not support this claim. The extent of analysis carried out by this paper has been limited by the lack of reliable data for developing countries. Therefore, the findings should be taken as the first attempt in this direction rather than final results.

The findings of the third essay are important in the following sense. Unlike previous studies, it presents a detailed analysis of changes in the trade patterns of a group of developing countries that have experienced increasing wage inequality after trade liberalization. It demonstrates that the major change in their trade patterns has been caused by their integration into the global production networks of a small number of industries. This new development, in addition to shaping trade patterns, may influence choice of technologies or skill-intensity of production, thus demand for skilled labor, and

wage inequality in the these countries. Although the lack of data limits the analysis that can be done, this factor should be incorporated into the study of increasing wage inequality and technological change resulting from international trade in developing countries.

Chapter 1

Promoting Earnings Equality via Education Finance System: Benefits versus Tax Distortions

1.1 Introduction

Earnings inequality has increased significantly in the U.S. during the last two decades. The skilled and better educated have enjoyed higher real wages while those at the bottom of wage distribution have experienced losses. Inequality within groups defined by education, age, and experience has also increased.¹ Consequently, attention has turned towards the education system as the main producer of human capital. Giving all children an adequate level of education has begun to be viewed as a way of avoiding higher inequality later in their lives.² Concerns regarding the capacity of the already overburdened education system to fulfill these expectations have resulted in calls

¹ Katz and Murpy (1992), Levy and Murnane (1992), Juhn, Murphy and Pierce (1993), Gottschalk and Smeeding (1997).

² In 1998-99, the U.S. spent an average of \$6,508 per student enrolled in primary and secondary public schools. The share of total education spending financed by the local sources, historically, has been very high. Therefore, per pupil education spending has been, to a large extent, determined by the property values in the school district where the student happens to reside. Despite the improvements resulting from court mandates in the 1970s, it can be argued that there are still large differences in per student educational expenditure depending on where the students happen to live (Ladd and Hansen, 1999). Moreover, evidence suggest that two other sources of inequality; disparities between states and within districts, may be sizeable (Murray, Evans and Schwab, 1998; Stiefel, Rubenstein, and Berne 1998).

for reform. This study argues that the method of financing the cost of education is an important determinant of the distribution of educational spending, human capital accumulation, and later earnings of the young.

This paper considers several education finance systems and asks which one yields a more equal earnings distribution without generating large tax distortions.³ It estimates the size of distortionary costs of alternative education finance policies within a general equilibrium framework. Moreover, it examines their effects on earnings, human and physical capital accumulation, and welfare. Within the framework of this study, education refers only to primary and secondary schooling.⁴

This study aims to fill in the following gaps in the related literature. First, some studies claim that any deviations from a locally funded education system, as described in Tiebout (1956), create inefficiencies. But the size of these inefficiencies has not been assessed in a general equilibrium model. This study argues that estimates of the size of these inefficiencies, compared with the potential benefits of the same policies, are essential, especially, if any policy implications are to be drawn.^{5,6}

³ Education finance system refers to all the different ways of paying the cost of education, ranging from a full private system, where the entire cost is borne by the beneficiary, to a fully state funded system, where the full cost is paid by the society using tax revenues.

⁴ College education is not considered here because there are less borrowing constraints to acquire post secondary education. In addition, it has been argued that characteristics that determine future earnings are formed well before going to college (Keane and Wolpin, 1997).

⁵ Tiebout (1956) assumes the existence of a mobile population and sufficiently large number of local communities or jurisdictions. Each community offers a varying quantity (or quality) of public good and charges a local tax to cover the cost of the provision. Individuals choose to reside in the jurisdiction that provides their most preferred bundle of public good and tax. Costless mobility ensures “voting by one’s feet” to reveal true preferences. Under very strict assumptions, a perfect sorting equilibrium exists and is Pareto efficient. Local tax, mostly a property tax, is viewed as a benefit tax. Deviations from this equilibrium, especially the ones that involve distortionary taxes, are considered to be inefficient.

Second, most of the studies, due to reasons concerning analytical tractability, exclude physical assets and/or precautionary savings from their models. The only way that altruistic parents are allowed to contribute to the future welfare of the children is to invest in their education. However, exclusion of savings and altruistic bequests from these models may significantly overstate the benefits of public finance of education. Moreover, the large size of bequests and their potential impacts on household decisions regarding savings and human capital investment makes it very hard to ignore them for the sake of obtaining closed form solutions.^{7, 8}

Finally, even if precautionary savings are allowed by some of the studies, agents are assumed to hold their savings in certain assets that yield a fixed rate of return, such as bonds or physical capital in an open economy.⁹ This assumption makes solution of the models more tractable, but it rules out the effect of complementarities between human and physical capital accumulation processes.

The model proposed in this paper introduces two novel features: first, parents are allowed to leave altruistic bequests to their offspring, and second, rental rates on physical and human capital are determined by market clearing conditions in a closed economy.

⁶ For example, Hoxby (1996) in footnote (4) states that “A number of strong assumptions are needed to extract efficiency” of local funding of public education in the Tiebout framework. Then, in the rest of the paper, she compares local and centralized (or state) financing of public education as if all those assumptions are satisfied in real economies.

⁷ The estimates of bequest share in total accumulated U.S. wealth range from 20 up to 80 percent. Kotlikoff and Summers (1981) estimate that the share of life cycle savings in total net worth is as low as 20 percent. On the other hand Modigliani (1988) argues that it is around 80 percent. Gale and Scholz (1994) find out that intergenerational transfers including bequests account for 51 percent of the U.S. wealth. If college expenses are added the ratio gets even higher.

⁸ See Becker (1986) for a discussion of interdependence of human capital investment and saving decisions.

⁹ As an example see Aiyagari, Greenwood and Seshadri (2002). Benabou (2002) does not have any physical capital but he argues that output is net of cost of physical capital which has a fixed rate of return in an open economy.

Introduction of these features enables me to evaluate the distortionary costs of alternative education finance policies in a more realistic general equilibrium framework. A $2T$ -period heterogeneous agent overlapping generations model (OLG) is employed. Human capital is produced by investing in education. The amount of human capital produced is a function of innate ability and spending on education. Agents face borrowing constraints while the educational investment is made. The source of uncertainty is the ability type: everybody is born with either high or low innate ability.

The model is solved numerically and calibrated to the U.S. data. In the benchmark model, the government subsidizes education investment and taxes income and consumption to finance these investment subsidies. In addition to the benchmark economy, four different policy experiments are carried out, including a private school model, where the entire cost of education investment is paid by the beneficiary; and an equal-spending model, where everybody receives exactly the same amount of publicly funded educational investment. Furthermore, two additional experiments are carried out to assess the impacts of bequests on the outcomes of different education finance policies. The first one assumes that there is no bequest motive in the benchmark economy while the second one eliminates bequests from the private school model.

The main finding of the paper is the following. It is shown that a policy of partial subsidization of education expenditures generates higher earnings equality. More importantly, such a policy, funded by taxes on labor and capital income, and consumption, does not necessarily lead to a smaller steady state physical capital stock by

distorting savings decisions.¹⁰ Two factors generate this result. First, education subsidies lead to a larger human capital stock; this decreases the physical to human capital ratio and therefore increases the rate of return on physical capital in a Cobb-Douglas production function. The higher rate of return generates a larger physical capital stock at the steady state so long as the increase in the rate of return is not completely taxed away to pay for the education subsidies. Second, agents in this model save in part so that future members of their dynasty can invest in human capital. For this reason, savings, and thus the physical capital stock, do not decline as much as they would in a framework without a bequest motive in response to taxation of capital income.

Another important finding is the following: comparison of the results of the two versions of the benchmark economy, with and without bequests, to the corresponding results of the private finance model shows that the existence of bequests makes a significant difference. The benchmark model compared to the private finance model generates larger stocks of physical and human capital in both cases. The difference, however, is more significant if bequests are not allowed. This happens because without any bequests a larger part of the population is credit constrained. The benchmark model, by subsidizing the education investment, relaxes credit constraints for more agents; therefore it generates a relatively larger stock of human and physical capital.

This finding is important in the following sense. Loury (1981), Fernandez and Rogerson (1998), Benabou (2002), among others, have shown that public financing of

¹⁰ Labor supply is assumed to be inelastic for tractability of solution. Therefore, distortionary effects of wage income taxes on labor supply are not directly considered. However, part of the labor supply distortions is accounted for by capturing the impact of labor income taxes on human capital investment.

education may be preferred to local or private financing for various reasons. But none of these studies include any physical assets that can be directly bequeathed to the future generations by the altruistic parents. The model proposed in this paper includes such an asset, physical capital, and shows that a policy of subsidizing educational investment outperforms other education finance systems in generating a more equal distribution of earnings, and most importantly, such a scheme does not necessarily cost the society a decline in its steady state physical capital stock.

The findings of this paper may be useful in the following ways as well. First, they may provide a rationale for the popular support for state funding for education in many industrialized countries. Second, they may shed some light on the recent U.S. labor market experience. In the 1960s and 1970s, increases in human capital accumulation depressed skilled wages initially.¹¹ This higher level of human capital stock could be one of the factors that fueled a strong boom during the 1990s by increasing productivity of physical capital, which in turn increased demand for complementary human capital and widened the gap between skilled and unskilled wages.

This paper relates to two lines of literature. The first one treats education similar to any other public good to be provided at the local level in the framework of Tiebout (1956). A mobile population and sufficiently large number of local communities or jurisdictions are assumed. Under very strict assumptions, a perfect sorting equilibrium exists and is Pareto efficient.¹² Deviations from this equilibrium are considered to be

¹¹ Acemoglu (1998).

¹² For the list of assumptions and a discussion of the Tiebout model see Rubinfeld (1985) and Fernandez (2000).

inefficient. Local tax, mostly a property tax, is viewed as a non-distortionary benefit tax.¹³ A number of studies, which are called multi-community or bidding/sorting models, use the basic intuition of Tiebout (1956) with more realistic assumptions. They include Benabou (1996a, 1996b), Fernandez and Rogerson (1997, 1998), Epple and Romano (2000), Hoxby (1998), and Nechyba (2000).¹⁴

A second line of research starting with Loury (1981) considers dynamic gains from a state funded education system. Other papers include Fernandez and Rogerson (1998), and Benabou (2002). It has been shown that although local funding of education has static efficiency gains, it may be dynamically inefficient. That is, if the talent levels of children are unknown and if capital and insurance markets are imperfect, a state funded education system may be preferred since it provides insurance benefit against uncertainty. Altruistic parents may be willing to pay taxes to finance a public education system to make sure that future members of their family can receive educational investment, even if their parents are not able to pay for it.¹⁵

The rest of the paper is organized as follows. The next part presents the model and its solution. Calibration is discussed in the third part. The fourth part covers policy experiments and findings.

¹³ See Mieszkowski and Zodrow (1989) for a critique of benefit view of property tax.

¹⁴ See Ross and Yinger (1999), and Fernandez (2000) for a discussion of the sources of inefficiencies in this type of models.

¹⁵ See Glomm and Ravikumar (1992), and Benabou (2000) for two other explanations for choice of state funded public education systems.

1.2 A 2T-Period Heterogenous Agent Overlapping Generations Model

1.2.1 Environment

Time is discrete. The model economy is composed of $2T$ overlapping generations with total measure one. Life span is equal to $2T$ periods and there is no lifetime uncertainty. A $2T$ -period overlapping generations model is used because this framework allows us to consider separately the different episodes of the agent's life that are important for the objectives of this study such as, going to primary and secondary school, entering the labor market, and starting a new household.¹⁶ In the solution of the model, T is set equal to 6. This particular number of periods is chosen since it is large enough to allow us to avoid potentially misleading aggregations in calibration, such as compressing thirty to thirty-five years in one model period. On the other hand, it is small enough to have computational parsimony, especially compared to 55 to 65-period OLG models.

The first T periods of each generation's life overlap with the second T periods of their parent's life while the second T periods overlap with first half of their offspring's. No population growth is assumed for the sake of simplicity. Thus, each cohort has the same size. A household consists of a parent and his child. An individual spends the first T periods of his life as a member of the household formed by him and his parent. At the end of T periods the parent, who is now $2T$ years old, dies and his offspring starts a new household with his own child.

¹⁶ Most of the analysis that are done in this paper can be done within a two- or three-period overlapping generations model as well. Using a $2T$ -period model enables me to treat primary and secondary education separately to emphasise the importance of early education, and consider an extension of this paper to study college education.

Two-sided altruism is assumed; each person cares about the well being of both his own parent and child. A current household can influence the wellbeing of future members of its family line (or dynasty) in two ways: by investing in education, and/or by leaving physical bequests. Individuals are heterogeneous in the amount of bequest they inherit. The other source of heterogeneity in the model economy is innate ability. Two types are possible; high and low ability. An individual receives a realization of a random variable $z \in Z = \{H, L\}$ at birth which determines his lifetime ability. It is assumed to be a two state, first-order Markov process with the transition probability matrix

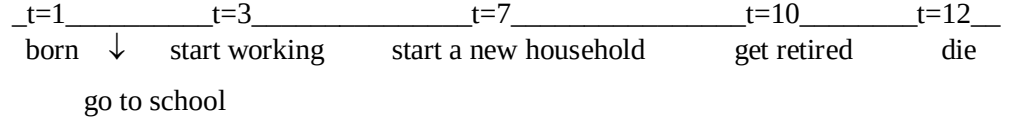
$$\pi(z', z) = [\pi_{i,j}], \quad i, j \in \{H, L\}$$

where $\pi_{i,j} = \Pr\{z' = j \mid z = i\}$, z' is the ability of the child while z is the ability level of his parent. The transition probabilities are consistent with the existence of a unique stationary measure of abilities $\lambda(z)$. There is no market that provides insurance against the risk of being endowed with low ability.

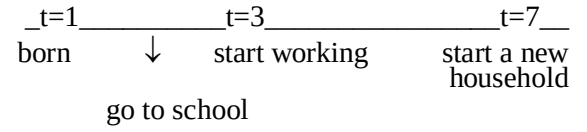
During the first two periods of his life the child goes to school where he acquires human capital. The household chooses the investment to be made in his education. The parent observes whether the child is of high or low ability before making the investment decision. There are borrowing constraints while the educational investment is being made. At the age of 3 in model time (18 in years), following entrance of the young into the labor market, the household faces no more borrowing constraints. At each period, an individual is endowed with one unit of labor, which he supplies inelastically to the firms

unless he is a student or retiree. The following diagram shows the flow of the lifetimes of two generations.

Generation i



Generation i+1



Human Capital

Individual i 's human capital, h_i , is determined by his innate ability, σ_i , and first and second period spending on education, e_1 , e_2 according to

$$h_z = h_0 + \sigma_z [e_1^\phi + (e_1 e_2)^\gamma] \quad z = h, l \quad (1.1)$$

where $\sigma_l < \sigma_h < 1$, $\phi, \gamma \in (0, 1)$, and h_0 stands for the minimum level of human capital one would have if no education is received. First and second period investments in education can be considered as spending on primary and secondary education, respectively.

There is little if any consensus on the form of human capital production functions.¹⁷ Equation (1) is based on three assumptions. First, investment in education in combination with innate ability produces human capital. A more able student

¹⁷ See Hanushek (1986) for a comprehensive discussion.

accumulates more human capital for the same level of education investment received. Second, primary and secondary schooling are complementary and early education is more productive. Finally, higher spending results in more human capital, holding everything else equal. The production function is increasing and concave in per student education spending.

The first and second assumptions are relatively innocuous. However, the last one, better known as the question of “does money matter”, is one of the most hotly debated issues in the current education literature, mostly, due to its policy implications. Since the publication of Coleman report in 1966, there have been claims that higher spending does not result in better student performance measured by standard achievement tests.¹⁸ Card and Krueger (1992) show that even though more money may fail to produce academic success at school, it gives rise to better job market outcomes. Students who graduate from the schools with higher per student spending earn higher wages in their adult lives. The other related controversy is called “selection bias”. It has been observed that individuals with more years of schooling earn significantly higher wages. Some consider this as a contribution of schooling to the student’s human capital. However, proponents of selection bias claim that high ability students get more schooling to signal their ability. Consequently, they earn higher wages not because of the skills they are taught in school, but because of their high ability which is valued more by the employers.

This paper will not attempt to solve the above controversies. The findings of most of the empirical studies carry some ambiguity since they have either serious data

¹⁸ Hanushek and Summers (1999).

limitations or econometric problems. However, I will argue that there is enough evidence supporting the claim that higher per student expenditure produces more human capital, everything else being equal.¹⁹ This should not be taken as a suggestion that investing more resources into the schools that fail for some other reasons will result in better performance of the students enrolled.

Preferences

Two-sided altruism is formulated following Laitner (1992).^{20,21} A household, composed of a parent of generation 0 and his child of generation 1, maximizes its dynasty's discounted sum of expected utility

$$E_0 \sum_{j=0}^{\infty} \beta^{jT} \left[\sum_{t=1}^T \beta^{t-1} \{u(c_{t,j}^p) + u(c_{t,j+1}^c)\} \right] \quad (1.2)$$

where j denotes generation, and superscripts p and c stand for parent and child, respectively. The age of the household which is equal to the age of its young member, is shown by t . For example, c_t^p denotes the consumption of a parent who is $T+t$ years old and lives with his t -year old child in a household formed t years ago. The period utility function $u(c)$ is of the constant relative-risk aversion class

¹⁹ See Burtless, ed. (1996) for an excellent discussion of the impact of higher spending. For a discussion of "selection bias" see Mayer and Peterson, eds. (1999). See Card (2000) for a discussion of econometric problems in such empirical studies.

²⁰ Fuster (1999) and Fuster, Imrohoroglu and Imrohoroglu (2000) use 2T-period OLG in studying social security. Nishiyama (2000) uses a similar model to study bequests and wealth distribution.

²¹ Parent and child care about each other's utility as if it is their own utility. This is an upper limit of two-sided altruism. Using this specification makes the solution of the model more tractable by elimination the possibility of strategic behavior. For example, if parent cares about his utility more he may consume more early in the life to extract resources from his child later in life. See Laitner (1993) for a discussion of this type of altruism.

$$u(c_t^p, c_t^c) = \frac{c_t^{1-\tau}}{1-\tau}$$

where τ is the coefficient of relative risk aversion.

The source of uncertainty is the talent level of future members of the same family line. Agents care about the well being of these future members of the dynasty but by assumption there is no market where they can buy insurance against the uncertainty of their type.

Technology

Competitive firms have access to the same constant-returns-to-scale production technology. They combine aggregate physical capital, K_t , with human capital stock, H_t , to produce the aggregate good, Y_t , each period according to the following Cobb-Douglas production function

$$Y_t = K_t^\alpha H_t^{1-\alpha}. \quad (1.3)$$

Physical capital stock depreciates at a constant rate $\delta \in (0,1)$. Factor prices, the rental rate of physical capital, r_t , and wage per unit of effective human capital, w_t , are equal to the marginal products of physical and human capital, respectively

$$r_t = \alpha K_t^{\alpha-1} H_t^{1-\alpha} - \delta \quad (1.4)$$

$$w_t = (1-\alpha) K_t^\alpha H_t^{-\alpha}. \quad (1.5)$$

Total wage of an individual is determined by equilibrium wage rate, his human capital, and age-efficiency units. The wages of the old and young member of the household are given by

$$w_t^p = w_t \varepsilon(t) h^p \quad (1.5')$$

$$w_t^c = w_t \varepsilon(t) h^c \quad (1.5'')$$

where $\varepsilon(t)$, $t = 3, \dots, 2T$ denotes age-efficiency units of a t -year old agent while h^p , and h^c stand for human capital of parent and child.

Government

The role of government is assumed to be very limited in this economy. It collects labor and capital income, and consumption taxes at the flat rates of τ_w , τ_r , and τ_c . Tax revenues are used to finance education subsidy at the rate of $s \in (0,1)$. The government's budget is balanced every period.

1.2.2 Optimization Problem of the Household

The household's objective is to maximize (2) subject to technological and budget constraints. The problem is divided into two parts and solved in two stages. First, the household takes the discounted sum of the expected utility of future members of its dynasty as given and maximizes utility from its own consumption over T -periods. Then, in the second stage, the well being of future generations is incorporated into the

optimization problem. There is an analytical solution for the former, whereas the latter is solved numerically.

First Stage

The household chooses the parent's consumption, c^p , the child's consumption, c^c , and asset holdings, a , over T periods to maximize

$$\sum_{t=1}^T \beta^{t-1} [u(c_t^p) + u(c_t^c)]. \quad (1.6)$$

In the first period, the level of parent's human capital, h^p , and the amount of the bequests inherited from the previous household in the same dynasty, a_0 , are known. The parent observes the child's ability type. The household targets the child's human capital, h^c , and makes the required first and second period investments in education.²² In addition to that, it targets the amount of bequest, a_T , to be left to the next household in the same family line. Then, it takes the pair of targeted physical bequest and human capital (a_T, h^c) , together with given equilibrium factor prices (r_t, w_t) and government policy variables $(\tau_r, \tau_w, \tau_c, s)$, and solves for the sequence of consumption and asset holdings $\{c_t^p, c_t^c\}_{t=1}^T$, $\{a_t\}_{t=1}^{T-1}$ to maximize (6) subject to budget constraints.

²² The levels of first and second period education expenditure required to achieve any target of human capital are found by solving the following problem

$$\begin{aligned} & \min (e_1 + e_2) \\ & \text{s.t. } h_z^c = h_0 + \sigma_z [e_1^\phi + (e_1 e_2)^\gamma], \quad z = h, l. \end{aligned}$$

The first stage problem expressed by (6) can be further divided into two sub-periods to exploit the fact that there are no borrowing constraints after the child leaves school at the end of the second period. Consider the optimization problem at $t = 3$. Suppose that first and second period optimal consumptions and savings have already been chosen, and the educational investments necessary to accumulate the targeted level of human capital have been made. The household has a_2 amount of assets and still aims to leave the targeted amount of bequest. Now, its problem is to choose $\{c_t^p, c_t^c\}_{t=3}^T$ and $\{a_t\}_{t=3}^{T-1}$ to maximize

$$\sum_{t=3}^T \beta^{t-3} [u(c_t^p) + u(c_t^c)]. \quad (1.7)$$

Since the household does not face budget constraints any more they can borrow to smooth consumption. The objective, (7), is maximized subject to the following budget constraint

$$\sum_{t=3}^T \frac{(1+\iota_c)}{R_t^{t-3}} (c_t^p + c_t^c) = (1-\iota_r) R_t a_2 - \frac{a_T}{R_t^3} + \sum_{t=3}^T \frac{(1-\iota_w)}{R_t^{t-3}} w_t [\varepsilon(T+t)h^p + \varepsilon(t)h^c]. \quad (1.8)$$

The constraint states that the present values of spending and income must be equalized over the period from $t = 3$ to $t = T$. FOCs are

$$c_{T+3}^p = c_3^c = \frac{1}{2F} \left[(1-\iota_r) R_t a_2 + \Omega - \frac{a_T}{R_t^{t-3}} \right] \quad (1.9)$$

$$c_{T+t}^p = c_t^c = \varphi^{(t-3)/\tau} c_3^c \quad t = 4, \dots, 6 \quad (1.10)$$

where

$$\varphi = \beta(1+r)$$

$$\Omega = \sum_{t=3}^T \frac{(1-\iota_w)}{R^{t-3}} w_t [\varepsilon(T+t)h^p + \varepsilon(t)h^c]$$

$$F = (1+\iota_c) \left[1 + \frac{\varphi^{1/\tau}}{R_t} + \frac{\varphi^{2/\tau}}{R_t^2} + \frac{\varphi^{3/\tau}}{R_t^3} \right].$$

The first order conditions (Equations 9-10) states that the amounts of consumption of parent and his offspring are equal to each other in every period. This results from the equal weights of parent's and child's consumption in the utility function. The household allocates its net sources (total income and assets minus bequest to be left) to consumption over the period of $t=3$ to $t=6$ and discount late consumption more.

Substituting equations for consumption (9, 10) into the objective function (7) gives the following indirect utility function

$$v(a_2, a_T, h^p, h^c) = \max \sum_{t=3}^T \beta^{t-3} [u(c_t^p(a_2, a_T, h^p, h^c)) + u(c_t^c(a_2, a_T, h^p, h^c))]. \quad (1.11)$$

Now, consider the problem of the household at $t = 1$, supposing that maximum utility over the period from $t = 3$ to $t = 6$ is given by equation (11) for any values of a_2 , h^p , and targeted variables (a_T, h^c) . The household maximizes

$$\sum_{t=1}^2 \beta^{t-1} (u(c_t^p) + u(c_t^c)) + v(a_2, a_T, h^p, h^c) \quad (1.12)$$

subject to

$$(1+\iota_c)[c_t^p + c_t^c] + a_t + (1-s)e_t = (1-\iota_r)R_t a_{t-1} + (1-\iota_w)w_t \varepsilon(T+t)h^p \quad t = 1, 2 \quad (1.13)$$

$$a_1, a_2 \geq 0. \quad (1.14)$$

$$a_1 = \frac{1 + \tau_c}{(1 + \iota_c)[(1 - \tau_r)R_t + \varphi^{1/\tau}]} \left\{ \varphi^{1/\tau} [(1 - \tau_r)R_t a_0 + (1 - \tau_w)w_t \varepsilon (T + 1)h^p - (1 - s)e_1] \right. \\ \left. - [(1 - \tau_w)w_t \varepsilon (T + 2)h^p + a_2 + (1 - s)e_2] \right\} \quad (1.15)$$

FOCs are

$$c_{T+1}^p = c_1^c = \frac{1}{2} [(1 - \iota_r)R_t a_0 + (1 - \iota_w)R_t w_t \varepsilon (T + 1)h^p - (1 - s)e_1 - (\varphi^{-1/\tau} a_2 / 1 + \varphi^{-1/\tau} (1 - \iota_r)R_t)] \quad (1.16)$$

$$c_{T+2}^p = c_2^c = \varphi^{1/\tau} c_1^c \quad (1.17)$$

Substituting the solutions of consumption (9, 10, 16, 17) into the objective function (6) gives the household's indirect utility in terms of initial variables (a_0, h^p) , targets (a_T, h^c) , and a_2 ,

$$U(a_0, a_2, a_T, h^p, h^c) = \max \left\{ \sum_{t=1}^2 \beta^{t-1} [u(c_t^p(a_0, a_2, a_T, h^p, h^c)) + u(c_t^c(a_0, a_2, a_T, h^p, h^c))] + \beta^2 v(a_2, a_T, h^p, h^c) \right\} \quad (1.18)$$

Initial conditions (a_0, h^p) are taken as given. The optimal levels of targets (a_T, h^c) are to be solved in the second stage. The value of a_2 is solved to maximize the indirect utility given by (18),

$$a_2 = N(D - JE) \quad (1.19)$$

where

$$N = \left[\frac{J(1-\iota_r)R}{F} + \frac{\varphi^{1/\tau}}{(1+\iota_c)[(1-\iota_r)R + \varphi^{1/\tau}]} \right]^{-1}$$

$$J = (B/A)^{-1/\tau}$$

$$A = \frac{\varphi + \beta\varphi^{1/\tau}}{(1+\iota_c)[(1-\iota_r)R + \varphi^{1/\tau}]}$$

$$B = \frac{\beta^2(1-\iota_r)R}{F} (1 + \beta\varphi^{(1-\tau)/\tau} + \beta^2\varphi^{2(1-\tau)/\tau} + \beta^3\varphi^{3(1-\tau)/\tau})$$

$$D = \frac{(1-\iota_r)R}{(1+\iota_c)[(1-\iota_r)R + \varphi^{1/\tau}]} \left\{ \begin{aligned} &\varphi^{1/\tau}[(1-\iota_r)Ra_0 + (1-\iota_w)w\varepsilon(T+1)h^p - (1-s)e_1] \\ &-(1-\iota_w)w\varepsilon(T+2)h^p - (1-s)e_2 \end{aligned} \right\}$$

$$+ \frac{1}{(1+\iota_c)} [(1-\iota_w)w\varepsilon(T+2)h^p - (1-s)e_2] - JE$$

$$E = \frac{1}{F} \left[\Omega - \frac{a_T}{R^3} \right].$$

Substituting the solution of a_2 back into (18) gives the household's T -period total indirect utility in terms of initial conditions, (a_0, h^p) , and target variables, (a_T, h^c)

$$U(a_0, a_T, h^p, h^c) = \max \sum_{t=1}^T \beta^{t-1} [u(c_t^p(a_0, a_T, h^p, h^c)) + u(c_t^c(a_0, a_T, h^p, h^c))]. \quad (1.20)$$

Second Stage

In this stage, the household is allowed to choose the values of the targeted variables (a_T, h^c) that are taken as given in the previous stage. Although the parent observes child's

ability before investing in his education, the types of future members of the dynasty are unknown. Educational investment thus child's future wage and bequests are chosen to maximize the dynasty's total expected utility. The following functional equation, with z denoting ability level, is solved by value function iteration

$$V_t(a_0, h^p, z) = \max \{ U(a_0, a_T, h^p, h^c, z) + \beta^T E_t V_{t+1}(a_0', h^{p'}, z') \}. \quad (1.21)$$

Decision Rules

Let the state of the household be $x = (a_0, h^p, z)$, $x \in X = A \times H \times Z$, where A denotes a finite grid on asset holdings and H represents a finite grid on human capital holdings while $Z \in \{H, L\}$ stands for ability levels. Let the future state of the same household be defined as $x' = (a_0', h^{p'}, z')$. The solution of the above functional equation (21) gives optimal decision rules for consumption, $\{c^c(x, t), c^p(x, t)\}_{t=1}^T$, and asset holdings, $\{a(x, t)\}_{t=1}^5$. The optimal amount of the bequest and the child's future wage are given by

$$a_0' = a_T(x) \quad (1.22)$$

$$h^{p'} = h^c(e_1, e_2; x). \quad (1.23)$$

Equation (22) states that the amount of bequest chosen by the current household is the initial asset holdings of the next household in the same family line. Equation (23) states that the targeted human capital chosen by the current household will be the parent's human capital in the next household.

1.2.3 Steady State Equilibrium

The steady state equilibrium is examined under different model specifications.

Definition: A steady state for given government policy variables $\{\iota_w, \iota_r, \iota_c, s\}$ is a collection of relative prices of labor and capital (w, r) , indirect utility functions $U(x; a_T, h^c)$, value functions $V(x)$, and decision rules $\{c^c(x, t), c^p(x, t)\}_{t=1}^T$, $\{a(x, t)\}_{t=1}^5$, $a_T(x)$, $h^c(e_1, e_2; x)$ such that

1. Given $\{\iota_w, \iota_r, \iota_c, s\}$, and (w, r) , decision rules solve the household optimization problem. $U(x; a_T, w^c)$ is the indirect utility function associated with the solution of (6) while $V(x)$ is the value function that solves optimization problem given by (2).

2. Markets are competitive

$$r = \alpha K^{\alpha-1} H^{1-\alpha} - \delta$$

$$w = (1 - \alpha) K^\alpha H^{-\alpha}$$

3. Markets clear and individual decisions and aggregate variables are consistent

$$K = \sum_{t=1}^T \sum_{x \in X} \lambda(x, t) a(x, t)$$

$$H = \sum_{t=3}^{10} \sum_{x \in X} \lambda(x, t) \varepsilon(t) h(x, t)$$

$$Y = \sum_{t=1}^T \sum_{x \in X} \lambda(x, t) [c^c(x, t) + c^p(x, t) + a(x, t) + e_1(x) + e_2(x)] + G + (1 - \delta)K$$

where $\lambda(x, t)$ is the measure of households that have state (x, t) .

4. The invariant distribution of $T+1$ year-old agents satisfy

$$\lambda_{j+1}(x') = \lambda_j(x) \Pi(z', z)$$

5. The government budget is balanced, that is, the total education subsidy is equal to the tax revenue collected from wage and capital income, and consumption expenditure.

$$s \left(\sum_{t=1}^2 \sum_{x \in X} \lambda(x, t) [e_1(x, t) + e_2(x, t)] \right) = \iota_w w_t H_t + \iota_r r_t K_t + \iota_c \left(\sum_{t=1}^T \sum_{x \in X} \lambda(x, t) [c^c(x, t) + c^p(x, t)] \right)$$

1.3 Calibration

The parameters used in the calibration of the benchmark economy are listed in Table 1. The parameter values are chosen to replicate some of the stylized facts of the U.S. economy.

Demographics and Preferences

Every agent lives $2T$ periods. A model period T is set equal to 6 years. Agents are born when they are 6 years old and die at the age of 78 in real time. Empirical studies report that coefficient of relative risk aversion is a number between 2 and 10. It is set equal to 2 in this paper. The annual discount factor is chosen to obtain a capital-output ratio close to 3.

Production and Asset Holdings

A non-uniform grid of 195 points is put on asset holdings. The lowest asset holding is set equal to zero because negative bequests are not allowed. The upper bound of asset holding is a large number and it is never binding. Capital's share of output is set equal to

Table 1. Parameters of Benchmark Model

<i>Demographics and Preferences</i>	
$2T = 12$ $\tau = 2$ $\beta = 0.99$	Lifetime (78 years) Coefficient of Relative Risk Aversion Annual Discount Factor of Utility
<i>Production</i>	
$\alpha = 0.3$ $\delta = 0.05$	Capital Share of GNP Annual Depreciation Rate
<i>Human Capital</i>	
$\lambda(H) = 0.28$ $\varphi = 0.5 \quad \gamma = 0.4$ $\sigma_l = 0.14$ $\sigma_h = 0.20$ $\Pi = \begin{bmatrix} 0.57 & 0.43 \\ 0.17 & 0.83 \end{bmatrix}$	Measure of High Ability Individuals Productivity of Education Spending Markov Process for Ability Transition
<i>Education Finance Policy</i>	
$\tau_w = 0.2$ $\tau_c = 0.3$ $\tau_R = 0.2$ $s = 0.545$	Labor Income Tax Rate Consumption Tax Rate Capital Income Tax Rate Rate of Subsidy

0.3. The annual depreciation rate is chosen to obtain a rate of return on capital close to the four percent long term U.S. annual interest rate.

Human Capital Production

A finite grid of human capital holdings is used. Its range is wide enough to accommodate sizeable earning disparities observed in the U.S. economy. The lowest level of human capital holdings can be accumulated without any educational investments. The parameters of the human capital production function are chosen to obtain a concave production function that makes first and second period educational spending complementary and the former more productive.

The calibration of the ability transition matrix has proved to be very crucial. Inheritance of ability between parents and their children has always been a very controversial topic. Therefore, I have tried to rely on more than one measure. A large sample of mothers from National Longitudinal Survey of Youth (NLSY79) and their children from the database of Children of the NLSY79 is used.

NLSY79 is designed to represent the entire population of American youth. It has 12,686 respondents coming from both civilian and military youth. In 1980, NLSY79 respondents (15-22 years old) were administered a battery of ten intelligence tests called Armed Forces Vocational and Aptitude Battery (ASVAB). Armed Forces Qualification Test (AFQT) scores are calculated using four tests of ASVAB; arithmetic reasoning, word knowledge, paragraph comprehension, and mathematics knowledge. AFQT has been used as a cognitive ability test.

Children of NLSY79 covers all the children of female respondents of NLSY79. The number of children in this survey has reached 6,417 in 2000. Since 1986, a number of cognitive, socio-emotional, and physiological assessments have been biennially administered to these children. The Peabody Picture Vocabulary Test (PPVT) is one of these cognitive tests. Both the AFQT and the PPVT have been subject to criticisms as cognitive ability tests, in particular, the AFQT is claimed to be an achievement test rather than an IQ test. There seems to be some truth to these arguments; for example, AFQT scores increase by age. However, for the purposes of this study, it does not make a big difference even if the correlation between mothers' AFQT and children's PPVT scores partly reflects direct transmission of human capital from mother to child in addition to innate ability. Since this study neither has a separate mechanism through which parents transmit their human capital to their children, nor does it try to distinguish between these two sorts of parental effects. However, to eliminate the effects of schooling as much as possible I use the PPVT scores of the children who are 3 to 6 years old.

The sample used in this study covers 4,107 NLSY79 mothers and their children. Age-adjusted percentile AFQT scores of mothers and PPVT scores of their children are used. PPVT scores are age-adjusted, but there are concerns regarding reliability of those of 3 year-olds. For this reason test scores for different age groups are tabulated separately. Table 2 shows correlations of mothers' AFQT and children's PPVT scores. Correlations vary across age groups.²³

²³ Simple correlations found here are not as high as those reported by Murry and Herneststein (1994). The difference is due to the fact that this paper uses a larger and more representative sample of mother and child test scores.

Table 2. Correlation of Mother's AFQT and Children's PPVT Scores

Child Age	Correlation
3 year-old	0.49
4 year-old	0.55
5 year-old	0.51
6 year-old	0.49

Source: NLSY79 and Children of NLSY79.

One other way of assessing the relation between mother and child aptitude test scores is to put them into quintiles and find the proportion of transition between these groups. This is done for the white respondents in Table 3.

Table 3. Mother's AFQT and Children's PPVT Scores

Mother AFQT Quintile	Child PPVT Score Quintile				
	1	2	3	4	5
1	0.74	0.14	0.06	0.05	0.02
2	0.40	0.26	0.16	0.10	0.08
3	0.32	0.25	0.16	0.16	0.12
4	0.22	0.19	0.20	0.20	0.19
5	0.13	0.16	0.17	0.26	0.28

Source: NLSY79 and Children of NLSY79

The first row shows the children of mothers who have the lowest 20 percent of AFQT scores. The first entry in this row indicates that 74 percent of these children have

scores falling into the lowest quintile of PPVT scores. A mere 2 percent of them have scores falling into the range of the top quintile of PPVT scores. On the other hand, this figure is 28 percent for the children whose mothers themselves are placed in the top quintile of AFQT scores.

Table 4. Mother-Child Ability

Child Mother	High	Low
	High	Low
High	0.46 (0.59)	0.54 (0.41)
Low	0.19 (0.24)	0.81 (0.76)

Source: NLSY79 and Children of NLSY79

In this paper, there are two ability types; high and low ability. For this reason, the sample is divided into high and low ability groups according to the test scores. The transition proportions will change depending upon the position of the cut-off point dividing these two groups. First, I assume that low ability individuals are the ones who account for the lowest 40 percent of aptitude test scores. Corresponding proportions between parents and children are shown in Table 4. Then, I assume that the lowest-scoring 60 percent of individuals are low ability. The proportions are reported in the same table in parentheses.

Regardless of which measure is used as a proxy for the relation between ability types of mothers and their children, one striking observation can be made; low ability mothers are significantly more likely to have low ability children. On the other hand,

high ability mothers tend to have high ability children, but this relation is not as strong as the previous one. In calibration of the benchmark model, the following transition matrix is used since it is very close to the proportions calculated above.²⁴ Furthermore, it is consistent with the findings of other studies and makes the results of this paper comparable to the findings of others.²⁵

$$\Pi = \begin{bmatrix} 0.57 & 0.43 \\ 0.17 & 0.83 \end{bmatrix}$$

Education Finance Policy

Tax and subsidy rates of the benchmark economy are chosen to replicate the U.S. education finance structure. In the school year of 1993-94, revenues raised from local sources paid 45.5 percent of total public education spending. The remaining 54.5 percent is paid by tax revenues collected at the state and federal level.

More specifically, income, and sales and indirect tax revenues accounted for 21.2, and 13.7 percent of total education expenditures, respectively. The remaining 19.6 percent is picked up by a revenue source called “other” which is mainly composed of user fees and miscellaneous revenue sources (Table 5).

This paper considers the portion of education expenditures paid by local revenue sources as private spending on education. In the benchmark model this rate is 45.5

²⁴ Notice the difference between Table 4 and the probability transition matrix. The former reports proportions of high and low ability children for each type of mothers, whereas the latter shows the probability of having high and low ability children for each type of mothers. The transition probability matrix implies that nearly 30 percent of agents are of high ability type.

²⁵ Currie and Thomas (1999), Fuster et. al. (2000).

percent. The remaining 54.5 percent is paid by education subsidies. The income and consumption tax rates in the benchmark model are chosen such that they account for their respective shares in total education spending in 1994. In this model there is no counterpart for the revenue sources grouped under the name of “other”. For this reason, the shares of income and consumption taxes are scaled up proportionately to account for this category. For example, income tax rate is set such that at the steady state equilibrium of this model income tax revenue pays 33.11 percent of total spending on education as shown in Table 5.

Table 5. Total Education Finance in 1994

Source	Share (%)	Adjusted Share (%)
Income tax	21.2	33.11
Sales and Indirect taxes	13.7	21.39
Local	45.5	45.5
Other	19.6	---

Source: U.S. Census Bureau

1.4 The Benchmark Model and Policy Experiments

In the benchmark model, agents choose the level of optimal investment to be made in their children’s education and thus human capital accumulation. They pay 45.5 percent of this amount out of their incomes and/or savings. The remaining 54.5 percent is paid by government subsidies which are financed by income and consumption taxes. In addition

to the benchmark model, four different policy experiments are carried out and the results reported in Table 6.

Table 6. Results of Policy Experiments

Model	Physical Capital Stock	Human Capital Stock	Output	Total Consumption	Investment in Human Capital	Interest Rate	Wage
Benchmark	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Private Finance	60.34	57.00	57.90	90.17	37.88	80.04	102.99
Subsidy (0.45)	90.23	80.74	79.66	96.32	82.63	96.07	101.27
Subsidy (0.65)	104.08	107.42	106.44	101.69	112.00	101.60	98.73
Equal-Spending	61.00	49.55	52.08	85.52	37.88	89.43	100.80

The first one of these experiments is a “private finance” model. This model sets all the tax and subsidy rates equal to zero in the benchmark economy and finds a new steady state. Agents choose the optimal amount of education investment and pay the entire cost out of their pockets. This is equivalent to a private school system. The next model decreases the subsidy rate to 0.45 in the benchmark economy while the third one increases this rate to 0.65. The last policy experiment is an equal-spending model. In this model, everybody receives the same amount of educational spending, which is fully subsidized. The fixed amount of spending is set equal to the average spending on education investment in the private finance model.

The steady state of the benchmark economy is set equal to 100.00. The steady states of other models are normalized accordingly. In the rest of this section, the steady

states of the benchmark and the private finance models are compared. Then, the findings are generalized to the results of other policy experiments.

Comparison of steady states of the benchmark and the private finance models reveals one striking result: the benchmark economy generates a higher stock of physical capital, despite the fact that capital income is taxed to pay a part of the cost of education subsidies. In the benchmark economy, taxation of capital income does not result in crowding out of steady state physical capital stock as it would in an environment where the rate of return on savings is given or fixed.

Two reasons account for this result. First, the model presented here uses a Cobb-Douglas production function with physical and human capital as factors of production. Subsidizing education increases total investment in human capital. As the stock of human capital increases, the ratio of physical to human capital goes down; this in turn leads to a higher marginal product and rate of return on physical capital. The higher rate of return gives rise to a larger stock of physical capital. This result still holds, even when capital income is taxed, so long as the tax rate is not high enough to completely eliminate the increase in the rate of return on physical capital resulting from accumulation of more human capital.

In a different environment, where the rate of return is fixed by assumption, subsidizing investment in human capital would increase human capital investment; however, the rate of return on investment would stay the same. If capital income is taxed to finance part of the subsidies, physical capital's rate of return (net of tax) would decrease, and this would crowd out part of the savings and physical capital accumulation.

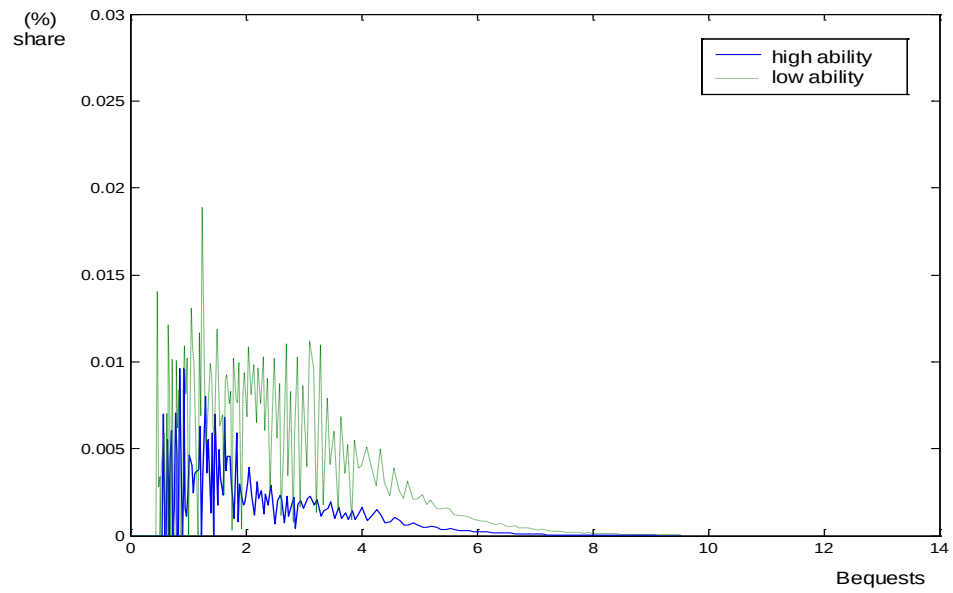


Figure 1. Distribution of Bequests in the Private Finance Model

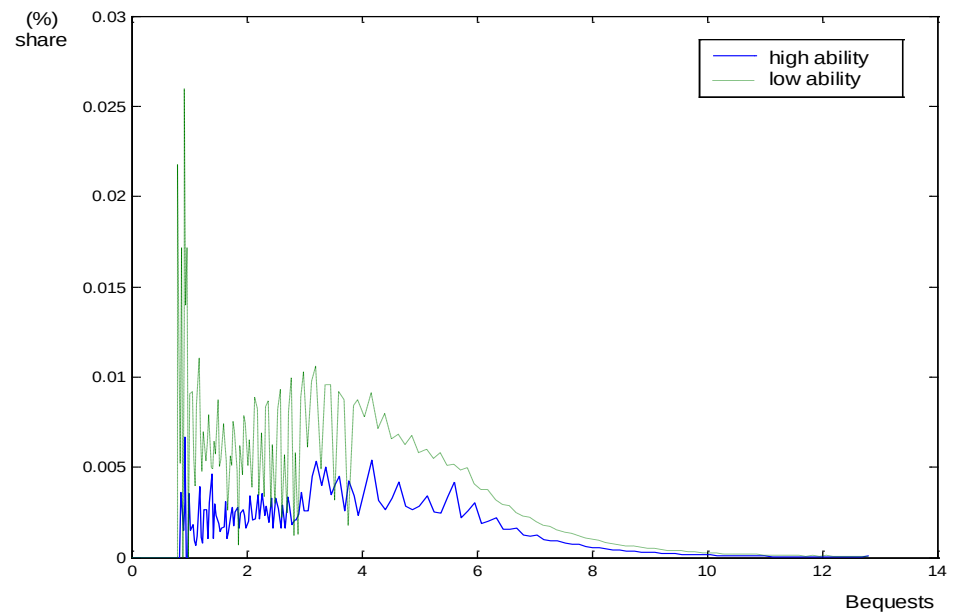


Figure 2. Distribution of Bequests in the Benchmark Model

The second factor leading to a higher physical capital stock in the benchmark economy is the existence of a bequest motive. In this model altruistic agents save in part to leave bequests so that future members of their dynasty can invest in human capital, especially if they are high ability type. The existence of a bequest motive makes sure that savings are not very easily crowded out by taxation of capital income as it would in a framework without a bequest motive.

Figures 1 and 2 show the distributions of bequests to be left for the next generation under the private finance system, and benchmark model, respectively. The horizontal axis denotes the level of bequest whereas the vertical axis denotes the percentage share of households in total population that leaves a certain level of bequests in high and low states. The benchmark model results in larger amount of bequests in both states, which in turn partly accounts for a larger capital stock.

The human capital stock is also larger in the benchmark model compared to the private finance model. In addition, total spending on human capital is much higher in the benchmark model. Some of the high ability agents, who are credit constrained in the private finance model, can receive more education investment in the benchmark model due to the education subsidies. This results in a larger stock of human capital in this framework. However, compared to the amount of human capital produced, the benchmark economy spends disproportionately more on human capital investment. That is, the private finance economy makes 37.88 percent of the benchmark economy's educational investment whereas it can produce as much as 57 percent of the benchmark economy's human capital stock. The reason for this is the following: under the private

finance model human capital investment goes mostly to the high ability individuals. But in the benchmark economy the existence of subsidy encourages low ability individuals to invest more in education, who require more resources to produce the same amount of human capital compared to a high ability individual.

Figures 3 and 4 show the distribution of human capital holdings of the young generation in the private finance economy and the benchmark model, respectively.

In the private finance model, some of the high ability individuals are credit constrained; therefore they can not invest more in human capital. In the benchmark economy, a higher rate of subsidy results in a significant rightward shift of the human capital distribution of low ability individuals. With the subsidies, a higher number of low ability individuals find it optimal to invest more in human capital. This is consistent with the finding of a higher amount of spending on education and a relatively smaller gain in human capital stock as discussed above.

The benchmark and the private finance models are further compared in Table 7. Expected utility is higher in the benchmark model. In addition, the spread of distribution of human capital holdings and earnings is smaller for this model. The benchmark model offers a somewhat higher expected utility with more distributional equity.

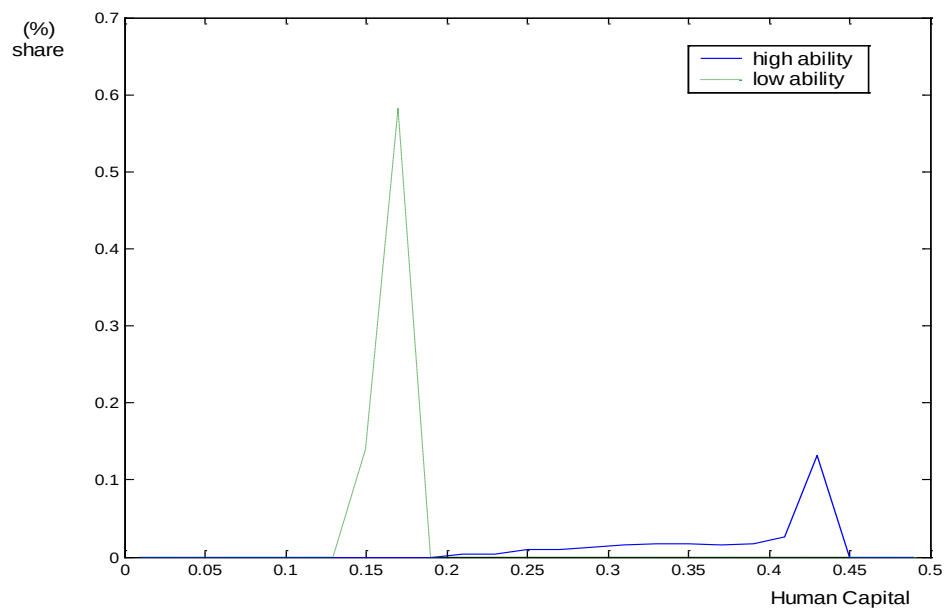


Figure 3. Distribution of Human Capital Holdings in the Private Finance Model

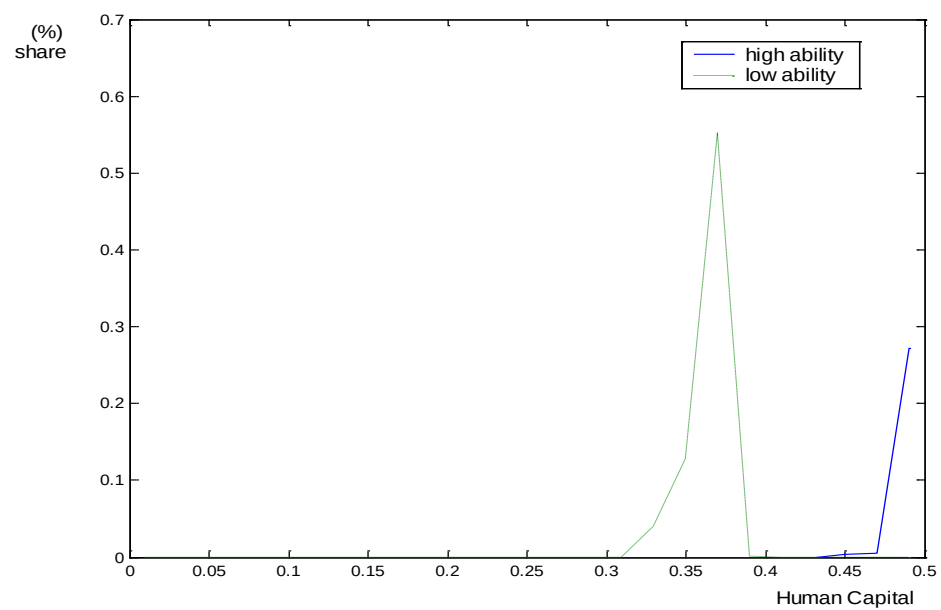


Figure 4. Distribution of Human Capital Holdings in the Benchmark Model

Table 7. Benchmark vs. Full-Private Finance Model

	Benchmark Model	Private Finance Model
Expected Utility		
High Ability	-39.0643	-54.7556
Low Ability	-43.3373	-61.2407
Highest Wage/Lowest Wage		
High Ability	1.1494	2.3684
Low Ability	1.2581	1.4615
Overall	1.2821	3.4615
Average Human Capital	0.3987	0.2281
Median Wage/Mean Wage	0.9280	0.7727
Variance of Wage distribution	0.0110	0.0033
% of Credit Constrained Households in Total population	3.00	11.05

The next two models, change the subsidy rate to 0.45 and to 0.65, and exhibit the same underlying workings with the benchmark model. The lower subsidy rate leads to physical and human capital stocks that are smaller compared to the benchmark economy, but larger compared to the private finance model. On the other hand, the model with the higher subsidy rate generates larger physical and human capital stocks compared to the benchmark economy, but the rates of change are smaller. Since the subsidy rate in the benchmark economy is already high, increasing this rate even further does not increase any of the capital stocks significantly.

Finally, the equal-spending model gives the worst results among all policy experiments. Although total investment in human capital is the same relative to private finance model, the equal-spending model produces a smaller human capital stock. A larger share of total investment spending goes to high ability individuals in the private finance model whereas under the equal-spending policy high and low ability individuals get the same amount of investment. Therefore, the total production of human capital is smaller in the equal-spending model for the same level of education investment.

1.4.1 No Bequest Case

This paper has argued above that some of the studies in the literature overestimate the benefits of a state funded education system by not allowing bequests. To illustrate this point further, a version of the benchmark model without a bequest motive is presented in this section. The basic structure and the parameters of the model is the same as in the benchmark model, but agents are not allowed to leave bequests. Production is carried out

by human capital alone, which earns the same efficiency wage given by the steady state of the benchmark model. Agents hold their savings in the form of a bond which pays the same rate of return that capital pays at the steady state of the benchmark model. Savings cannot be transferred to next generation as bequests. If savings are left unconsumed before death, the government confiscates and uses them for its own consumption which has no effects on the welfare of the rest of the population.

Two versions of the model are simulated. The first one, a private finance economy, is similar to the one described for the model with bequests. Agents choose the optimal amount of human capital investments and pay the full cost. The second one uses a combination of education subsidies and consumption taxes. It subsidizes education expenditures at the same rate as in the benchmark model and uses consumption tax revenues to finance subsidies. The steady states of the private finance models under both cases are set equal to 100.00. The steady states of policy models are normalized accordingly.

Notice, first, that under both versions of the no-bequest model, savings and the human capital stock are very low compared to the benchmark model. Second, in relative terms, subsidizing human capital investment makes a larger difference in the no-bequest case compared to the case with bequests. Education subsidies result in higher physical and human capital stocks, consumption, and expected utility in both cases. However, the rate of change is much higher in the no-bequests case. For example, education subsidies increase human capital stock from 100.00 to 157.88 if bequests are allowed. However,

the same rate of subsidy increases human capital stock from 100.00 to 267.13 if bequests are not allowed (Table 8).

Table 8. No Bequests vs. Bequests

Model	Physical Capital Stock	Human Capital Stock	Total Consumption	Investment in Human Capital	Expected Utility High Low	
<i>No Bequest</i>						
Private Finance	100.00	100.00	100.00	100.00	-100.00	-100.00
Subsidy-Taxation	267.13	269.14	216.08	952.90	-54.91	-58.63
<i>Bequest</i>						
Private Finance	100.00	100.00	100.00	100.00	-100.00	-100.00
Benchmark	157.88	175.43	110.90	263.99	-71.34	- 70.77

Education subsidies are more effective in increasing the human capital stock if no bequests are allowed because in this case, without receiving any bequests, everyone is credit constrained in the private finance model. High ability individuals can not afford to invest more than low ability individuals. Relaxation of the credit constraints by a combination of subsidy-tax policy makes a larger impact in these models compared to the models where the existence of bequests saves part of the population from being credit constrained (Figures 5 and 6).

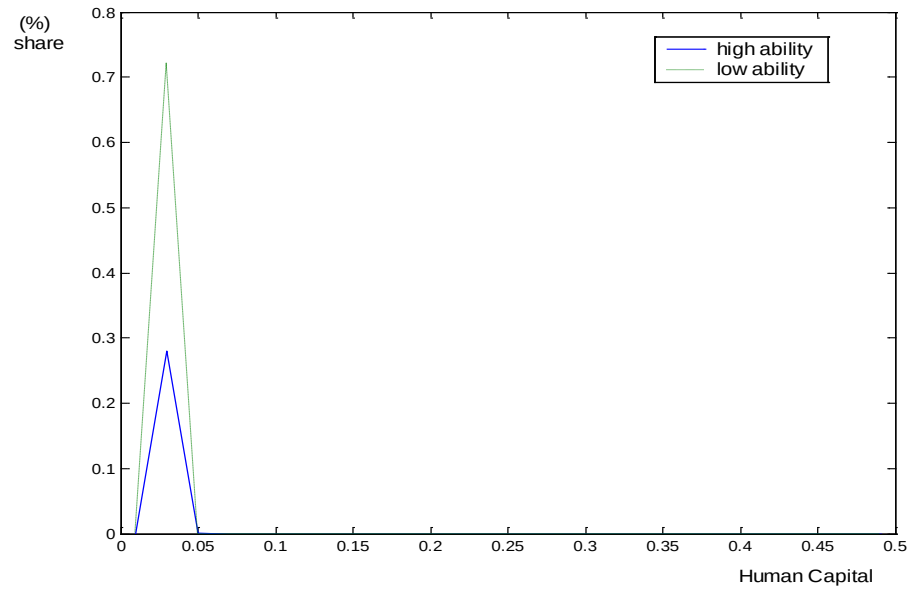


Figure 5. Distribution of Human Capital Holdings in the Private Finance Model

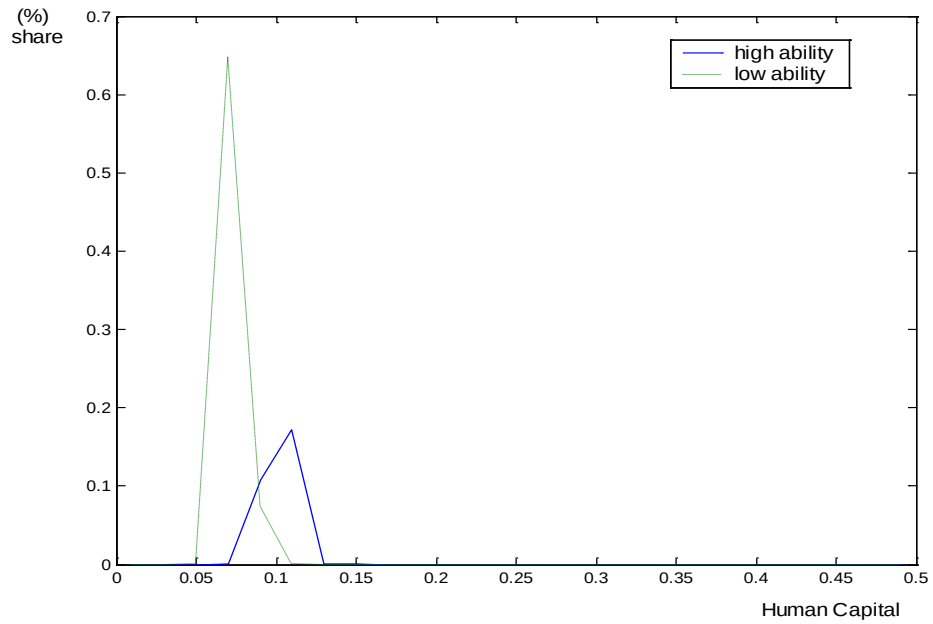


Figure 6. Distribution of Human Capital Holdings in the Subsidy/Tax Model

1.4.2 Sensitivity Analysis

Sensitivity analysis has been done for the parameters of the benchmark economy. An increase in the coefficient of relative risk aversion from 2 to 3 results in higher amounts of savings in all policy experiments. As this coefficient increases utility from the same amount of consumption declines.²⁶ As a result, future generations face the risk of obtaining further lower utility if they turn out to be low ability type individuals. To insure against this risk the current household saves more and leaves higher bequests to the next generation. Increasing the rate of depreciation to 0.1 leads to smaller physical and human capital stocks. Increasing the productivity of human capital investment by changing the parameters of the human capital production function (σ_l and σ_h) results in higher human capital stock. Increasing the difference between σ_l and σ_h (making human capital investment of the high ability individuals more productive) increases earnings inequality. The net change in aggregate human capital may be positive or negative.

Modified versions of Markov transition matrix are used to find out the response of steady state equilibria to changes in transition probabilities. This is done for both the benchmark and the private finance models. The transition matrices S_1 and S_2 keep the transition probabilities for low ability individuals the same, but S_1 increases the probability of having a high ability offspring for the high ability agents from 0.57 to 0.65, whereas S_2 decreases this probability to 0.52.

$$S_1 = \begin{bmatrix} 0.65 & 0.35 \\ 0.17 & 0.83 \end{bmatrix} \quad S_2 = \begin{bmatrix} 0.52 & 0.48 \\ 0.17 & 0.83 \end{bmatrix}$$

²⁶ For $c_t \leq 0.5$, which is the case in all the experiments.

On the other hand, S_3 and S_4 keep the transition probabilities the same for high ability individuals, but S_3 increases the probability of having a low ability offspring from 0.17 to 0.21 while S_4 decreases it to 0.13.

$$S_3 = \begin{bmatrix} 0.57 & 0.43 \\ 0.21 & 0.79 \end{bmatrix} \quad S_4 = \begin{bmatrix} 0.57 & 0.43 \\ 0.13 & 0.87 \end{bmatrix}$$

The benchmark and private finance models generate similar results. In all cases, except one, an increase in the probability of having a high ability offspring increases savings. However, an increase in the probability of having a low ability offspring decreases savings. In no case is the change in the steady state physical or human capital stock more than 10 percent.

The framework presented here has two limitations. First, for the sake of a more tractable solution of the model, the labor supply is assumed to be inelastic. This results in higher labor supply at the steady state equilibrium. If labor supply were assumed to be elastic, taxation of wage income would have resulted in a lower labor supply. However, the model offers a partial solution to this drawback. It allows agents to choose the amount of human capital that they accumulate. A higher tax on labor income affects total efficiency units to be supplied by decreasing human capital investment at the first place. Therefore, the model accounts for this kind of labor supply distortion of wage income taxation.

The other limitation of the model is the following. The share of credit constrained agents in the total population is smaller at the equilibrium. Being credit constrained is defined as not being able to make optimal investment in human capital accumulation.

This figure is around 11 percent in the private finance model and with a large subsidy to education spending it becomes about 3 percent in the benchmark economy. Aiyagari (1994) and Hugget (1993) argue that in infinite horizon models with borrowing constraints, it is usually the case that agents save so much that no one is credit constrained anymore. Laitner (1993) shows that if there is sufficient heterogeneity some agents will be credit constrained at the equilibrium despite the existence of precautionary savings. Laitner (1992) using a 2T-period OLG model generates a relatively large share of credit constrained agents. However, this limitation of the model strengthens the main findings of this paper. Since if more people are credit constrained in the real economy compared to the policy experiments considered here subsidizing education will lead to a higher amount of human capital accumulation in the real economy. This will increase the rate of return on capital more and increase the stock of physical capital in steady state.

1.5 Conclusions

Several education finance systems are considered to find out which one yields a more equal earnings distribution without generating large tax distortions. A 2T-period heterogeneous agent OLG model is used to assess distortionary costs of alternative systems of education finance. Agents, who are assumed to differ in the innate ability, accumulate human capital by investing in education. The model introduced two novel features; parents are allowed to leave bequests to their offspring, and rental rates of physical and human capital are determined by market clearing conditions in a closed economy.

It has been shown that a policy of partial subsidization of education expenditures generates higher earnings equality. More importantly, such a policy, funded by taxes on labor and capital income, and consumption, does not necessarily lead to a smaller steady state physical capital stock. This result is due to the new features introduced into the model. Education subsidies increase the stock of human capital. This decreases the physical to human capital ratio in a Cobb-Douglas production function, and therefore the rate of return on physical capital goes up. The higher rate of return leads to a larger physical capital stock at the steady state. Furthermore, agents in this model, save in part so that future members of their dynasty can invest in human capital. For this reason, savings, and thus the physical capital stock, do not decline as much as they would in a framework without a bequest motive in response to capital income taxation. It is also shown that the existence of a bequest motive has a significant impact on the outcomes of different education finance systems. If bequests are not allowed, education subsidies lead to relatively larger stocks of human and physical capital.

The model proposed here has not been very successful in generating a large enough proportion of credit constrained agents at the equilibrium. However, this does not weaken our findings because if more people are credit constrained in the real economy compared to the policy experiments considered here subsidizing education will lead to a higher amount of human capital accumulation and a higher rate of return on capital. This will increase the stock of physical capital in steady state.

Chapter 2

Persistence of Income and Wealth Inequality in the Presence of Technological Change

2.1 Introduction

Intergenerational economic inequality in the US, both in earnings and in wealth, was not believed to be persistent.²⁷ This belief, to a large extent, is based on a few studies that have found low estimates of intergenerational earnings and income correlations. For example, Behrman and Taubman (1985) argued that correlation of fathers and sons earnings is around 0.2 for the US data. However, a more recent and reliable literature shows that these estimates are biased downwards due to unrepresentative samples and measurement errors. The new findings indicate higher degrees of persistence. For instance, Solon (1992), and Zimmerman (1992) found estimates of intergenerational earnings and income correlations in the range of 0.4-0.5. Mulligan (1997) argued that the correlation coefficient is likely to be at least 0.5.²⁸

²⁷ In this paper, persistence of intergenerational inequality refers to existence of low (or lack of) upward mobility for the children of individuals who are poor in earnings and/or wealth. This study is concerned with the *origin independence* aspect of mobility. See Gary and Ok (1999) for a clarification of the terminology.

² There is no generally accepted cutoff point of father-son income correlation beyond which we can say that persistence is too high. But the following example from Solon (1992) may be illuminating. If the intergenerational income correlation is 0.2, a son whose father is placed at the fifth percentile has a 0.3 chance of falling into the bottom quintile, 0.37 chance of being above median, and 0.12 chance of reaching to the top quintile. On the other hand, if the correlation is 0.5, his chance of staying in the bottom quintile is 0.49, raising above median 0.17, and making it to the top quintile is only 0.03.

The existence of credit market imperfections has been used to provide an explanation for the persistence of inequality by a number of studies, including Aghion and Bulton (1992, 1997), Banerjee and Newman (1993), Galor and Zeira (1993), Piketty (1997), and Matsuyama (2001).²⁹ They have shown that if credit constraints exist the agents whose own resources are below a critical level cannot make the optimal investments which generate higher rate of returns or give them access to high-wage occupations. Instead, they take low-wage occupations or invest in low-return projects. As a result, they transfer lower levels of savings to the next period or leave smaller bequests to their offspring; this reproduces the same unfavorable initial conditions next time, therefore increases persistence of inequality.

Most of the studies argue that credit constraints create inefficiencies that can be corrected by policy intervention. However, in the long run, under certain conditions, the influence of unfavorable initial conditions diminishes. For example, Aghion and Bulton (1997) show that after the accumulation of the rich becomes large enough wealth starts to “trickle down”. Capital accumulation decreases the equilibrium interest rate, and enables the poor to borrow for the minimum investment requirement of better projects or occupations. Matsuyama (2001) also argues that interest rate is the transmission channel, which ultimately saves the poor from their misery. As the demand of the rich for savings of the poor increases, the interest rate goes up, increasing incomes of the initial poor and eventually enabling them to take the high-return projects. In Banerjee and Newman (1993), the interest rate is assumed to be constant, but the trickle down effect works

²⁹ Others used transmission of ability within families, local segregation, and self-fulfilling beliefs to account for persistent inequality (Piketty, 2000).

through wages; as the number of rich agents who want to employ the poor increases equilibrium wage goes up, as a result some of the poor wage-earners become self-employed or employers themselves.³⁰ However, empirical findings regarding changes in intergenerational mobility over time do not indicate an undisputed upward trend. In a recent survey, Piketty (2000, p.432) writes:

“Overall, the relative consensus at the end of the twentieth century seems to be that commonality and inertia are the main characteristics of intergenerational mobility: mobility rates just do not seem to vary very much”.

It cannot be argued with any certainty that sizeable trickle down effects have been taking place or the US economy is on such a trajectory to a steady state equilibrium. But, it is known there is not sufficient empirical support for the claim that persistence of intergenerational inequality is declining. Moreover, persistence has shown to be higher than what was previously believed. Therefore, this study holds that there is sufficient motivation for further research on causes and evolution of intergenerational mobility.

The paper introduces endogenous technological change as a new factor, which can generate higher persistence of intergenerational inequality, in combination with credit constraints by offsetting a part of trickle down effects or reversing them. Technological change is formulated as an endogenous process affecting earnings and wealth distribution, and persistence of inequality through the externalities it generates. This study differs from the previous studies in the way that it considers technology and technological change, but it is similar to them in modeling credit constraints.

³⁰ Another related literature studies the relation between income inequality and subsequent growth performance of economies. For a review see Perotti (1996). Main findings indicate that inequality has a negative effect on growth. Forbes (2000) challenges some of these findings.

A two-period overlapping generations framework is used where individuals choose to be unskilled or skilled workers. Skills are acquired by investing in human capital accumulation or education at the beginning of the first period of life, which requires payment of up-front costs in real resources in addition to commitment of one's own time. Agents have "joy-of-giving" bequest motive, and leave a fraction of their wealth as bequests to their offspring. There are credit constraints: for this reason, only the agents who inherit bequests above a critical level are able to borrow and make the optimal human capital investment. The critical level of bequest is decreasing in the equilibrium interest rate and increasing in the cost of human capital investment.

In any period t , there is only one vintage technology used by the skilled workers. Technological change is defined as the innovation and diffusion of a new vintage or generation of this technology. Technology advances in discrete steps or ladders. The innovation of next-vintage technology requires a minimum number of firms composed of skilled workers, operating in the research sector. The firm that discovers the next generation of technology first is entitled to earn monopoly profits next period.

Positive externalities to technological change have been pointed out by many studies before: technological progress makes future innovations possible by increasing society's stock of knowledge.³¹ In addition to these types of externalities, I will consider negative externalities. I will argue that technological change increases the cost of the minimum or optimal investment that is required to be a skilled worker in the model proposed here. More specifically, the up-front costs paid to receive further education

³¹ Helpman and Grossman (1991), Romer (1990).

increase as the level of technology advances. Negative externalities to technological change, to my knowledge, have not been proposed before in the study of income and wealth distribution. The next part of the paper will make the case for this type of externalities.³²

The model presented in this paper can generate a trickle-down effect similar to the ones proposed by previous studies if the cost of human capital investment is assumed to be constant. As technology advances the incomes, and therefore savings, increase. This leads to a lower equilibrium interest rate for the same cost of human capital investment. The lower equilibrium interest rate relaxes the credit constraints by decreasing the critical level of bequests for some agents whose parents were denied credit. Consequently, as the rich get richer, it becomes easier for the poor to borrow and invest in human capital, and eventually catch up with them, in line with earlier studies. As a result persistence of inequality declines.

However, the introduction of negative externalities from technological change in the form of an increasing cost to human capital investment changes this finding. There are two effects in play. First, incomes and savings are higher in the steady state, though in a smaller degree compared to the previous case since the innovation process stops at an earlier stage, and some agents move to lower steady state equilibriums where they earn and save less. As a whole, this higher level of total savings puts downward pressure on equilibrium interest rate and can generate some trickle-down effects.

³² For a similar intuition in study of growth and technological change see Papageorgiou (2000) which argues that as the technological gap between developed countries and developing countries widens it becomes more difficult for the latter to imitate or adopt.

The second effect works in the counter direction. The higher cost of human capital investment increases the critical level of the bequest agents need to inherit to be able to borrow in the credit markets. The net effect depends on the relative sizes of the increases in total savings and in the cost of human capital investment. It is possible to have the opposite of the trickle-down effect if the increases in the cost of human capital investment are large enough to offset any effects of higher savings on the equilibrium interest rate.

The rich have incentives to invest in new technologies. However, as technology advances the amount of investment the poor need to make to catch up with the rich increases. This process generates higher persistence of inequality. A number of extensions of the basic model are considered; they generate more realistic steady state distributions but do not affect the main findings.

The findings of this paper are important in the following sense. Some of the previous studies in the literature use the existence of credit constraints to explain the persistence of intergenerational inequality, and predict that, in the long run under certain conditions, persistence will decrease thanks to trickle-down effects. However, the lack of empirical findings showing declining persistence over time, and the recent findings indicating that higher persistence, does not lend much support to this prediction. This paper introduces endogenous technological change and demonstrates potential limitations of trickle-down effects in reducing persistence of inequality, within a relatively simple framework.

The paper is organized as follows. A case for negative externalities to technological change is made in the next part. The model is presented in the third part. Concluding remarks are stated in the last part.

2.2 Negative Externalities to Technological Change

I will offer three reasons for increasing cost of human capital investment as a result of technological change. First, the production of new technologies and education are both skill intensive processes. Technological change increases the demand for skills; as a result, the wages of skilled workers increase. Consequently, the cost of employing skills in the education sector goes up. Eicher (1996), among others, employs this intuition in his study of technological change and wage distribution.

Second, as technological change takes place at least a portion of the current skills become obsolete. Some of the Schumpeterian “creative destruction” type growth models use this intuition.³³ Workers whose skills are made obsolete by new technologies need to be retrained for these technologies by incurring additional costs. The last two decades have witnessed a higher pace of technological change accompanied by the highest number of expected occupation changes for the average employee at the start of his working life resulting in large retraining costs.

Finally, as production technologies become more advanced they require higher skills, which take more time and real resources to acquire. There seems to be ample evidence supporting this phenomenon in the economies that have undergone

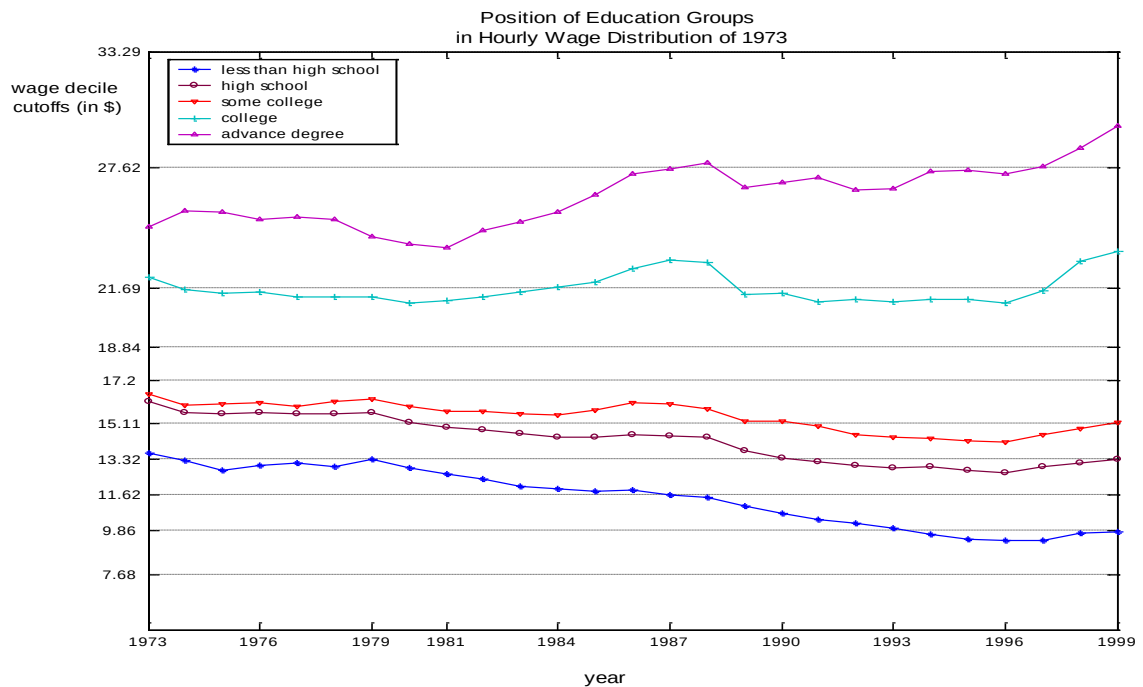
³³. For an example see Aghion and Howitt (1994).

technological change. For example, for a long period up until the early twentieth century, being literate was sufficient to be considered as a skilled employee. Similarly, when the mass production technologies were prevalent in the 1950s and 1960s it was possible for a high school dropout to become a skilled worker and earn a good wage. However, in the aftermath of the new technologies, especially during the last two decades, a skilled employee in the US, most of the time, is the one with a college degree.

The first two effects of technological change have already been suggested by others in the literature. For this reason, they do not require any further clarifications here. However, the last one has not been suggested by anyone before in my best knowledge, therefore it may need a little more convincing. I will offer some evidences below, which are not hard proof, but which are consistent with the claim raised above.

I posit that a person who wants to earn a certain real wage, say the average real wage in the 1990s had to stay in school longer compared to someone who was making the same real wage in the early 1970s. I will use Figure 7 to illustrate this point. For the period of 1973-1999, mean hourly male wages are classified according to highest education degree obtained by the wage earner. All the wages are in year 2000 dollars. The first curve, from the bottom of the figure, shows wages of individuals with less than a high school education. The second one shows the wages of high school graduates, the third, those of individuals with some college education, the next one, the wages of college graduates, and the last one, the earnings of individuals with post secondary degrees. The vertical axis shows hourly wage distribution in deciles in 1973, which is the first year in the dataset. I use the wage distribution in a single year to avoid dealing with

year-to-year changes in the shape of distribution. The cutoff points (or upper and lower limits) of the wage deciles -from the lowest 10 percent up to the 90 percent- are shown by dashed lines. The uppermost interval denotes the cutoff points of the second highest 5 percent of wages (from 90th to 95th percentiles). For example, in 1973, the hourly wage of a worker who was in the lowest 10 percent of the hourly wage distribution is below \$7.68. Similarly, the ones who are placed in the second lowest income percentile were making an hourly wage between \$7.68 and \$9.86. On the other hand, those placed in the second highest 5 percent were earning a wage between \$27.62 and \$33.29 for an hour.



Source: Bureau of Labor Statistics

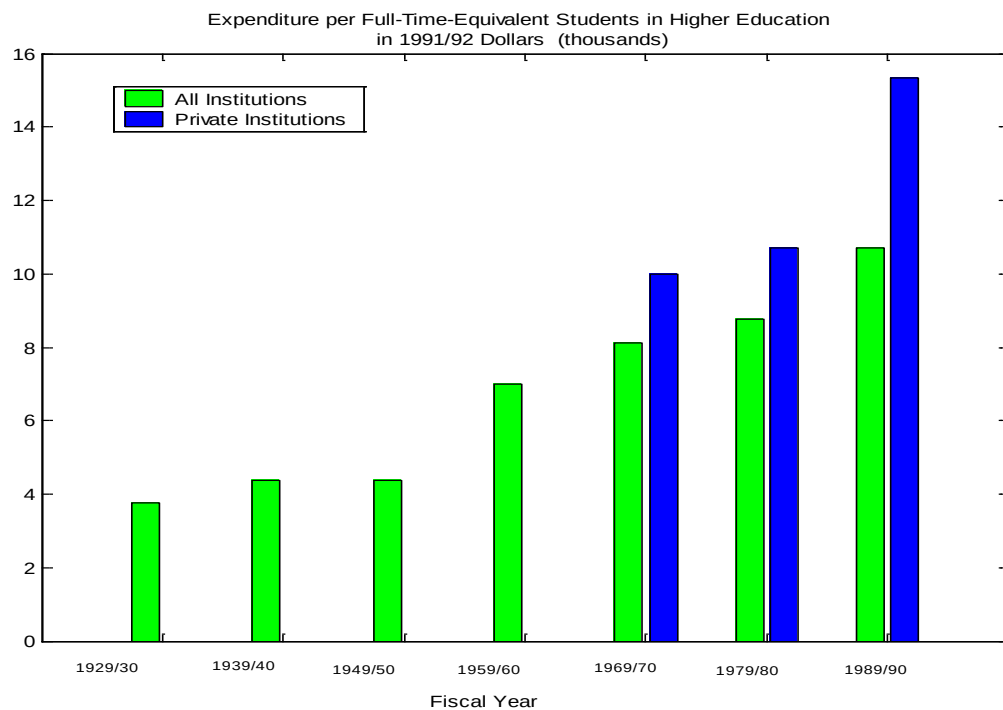
Figure 7. Position of Education Groups in Hourly Wage Distribution, 1973-1999

Let us trace the movement of wages of different education groups within the deciles of the overall wage distribution. In 1973, workers with education less than high school could earn enough to be placed in the lower end of 5th decile. By 1996, workers could be in this decile only if they had some college education. Similarly, from 1975 to 1987 it was possible for the workers with education less than high school to be placed in the 4th decile. But after 1990 it takes to a high school diploma to have the same position in the wage distribution. From 1980 to 1990 a high school graduate could earn enough to be in the 5th decile, but since 1990 to keep the same position a worker needs to have some college education.

One can conclude that to keep a certain position within a certain wage distribution, workers needed to have more education during the last three decades. This is consistent with the above claim, which states that as technology advances individuals have to invest more time and resources in their human capital accumulation to be a skilled worker.

Figure 8 can be viewed as more direct evidence in support of the claim raised above. It shows expenditure per full-time-equivalent student in higher education over the period of 1929-1990. All institutions refer to both public and private higher education institutions. After the fiscal year of 1969/1970 separate data is available for private colleges and universities. Cost of higher education has been increasing significantly since the fiscal year of 1949/1950. Clotfelter (1996) argues that the fastest growing expenditure item, especially for private college and universities, has been scholarships/grants offered to attract the best students. On the other hand, increasing faculty salaries especially due to

the pressure of the increasing wages of similar highly qualified individuals in other sectors of the economy is a contributing factor. In addition to that expenditures related to the technological revolution in computing and increasing cost of science laboratories and graduate programs have added to the cost of secondary education (Clotfelter, 1996).



Source: Clotfelter (1996), page 2.

Figure 8. Cost of Higher Education, 1929-1990

2.3 The Model

2.3.1 Demographics and Preferences

A two-period overlapping generations economy is considered. At any point in time, one old and one young generation, each composed of a continuum of T agents, coexist. The rate of population growth is zero. The old generation dies at the end of the second period and is replaced by a young generation composed of its offspring at the start of the next period. Agents are assumed to have “joy-of-giving” bequest motive, that is, they derive utility from the size of the bequests left rather than from the level of their offspring’s utility.

In the first period of their lives, young agents are endowed with one unit of time in addition to the bequests they inherit. At the beginning of the first period, they have to decide whether they will become unskilled or skilled workers. If they decide to become unskilled workers they start working right away and spend their one unit of time in the first period producing the one final good that the model economy has. On the other hand, if they decide to become skilled workers they have to invest in human capital which requires payment of upfront costs in real resources besides commitment of a fraction of $(1 - \theta)$ their one unit time at the beginning of the first period. Credit markets for human capital investment are imperfect due to enforceability problems. Therefore, at the equilibrium some agents who prefer to be skilled workers may not be able to make the required investment in human capital if they are credit constrained.

The unskilled workers do not make any other decisions until the second period. However, the skilled workers, after completing investment in human capital, have to decide if they will spend the remaining part (θ) of their youth working as skilled workers in the production of the final good, or as researchers in the technology sector trying to innovate the next generation of technology. If they choose the second option, two outcomes are possible: they become innovators if they succeed in discovering the next vintage technology, otherwise failed researchers.

In the second period of life, old agents are retired and allocate their savings between consumption and bequests. They die the end of the second period after consumption takes place. No utility is derived from leisure and agents are risk-neutral. Utility function is

$$u(c_{t+1}, b_{t+1}) = (1 - \beta) \log c_{t+1} + \beta \log b_{t+1} \quad (2.1)$$

where c_{t+1} and b_{t+1} stand for second period consumption and bequests, respectively.

2.3.2 Production

The economy has one final good which can be used either for consumption or investment purposes. Unskilled workers use no other inputs but their labor to produce the final good. The output of an unskilled worker is given by the following production function,

$$y_t^u = \mu. \quad (2.2)$$

On the other hand, skilled workers use θ fraction of their one unit of time with the latest vintage of skill-intensive technology, λ_t to produce the final good. Technology is not embodied in any kind of capital goods. It can be best considered as knowledge or technological know-how, for use of which each skilled worker pays a fee or rental price to the innovator. The output of a skilled worker net of any such payments is given by the following production function,

$$y_t^s = \theta \lambda_t. \quad (2.3)$$

Unskilled workers have no other option but to produce the final good, whereas skilled workers, instead of producing the final good, may choose to work in the “research” sector which generates the next vintage of technology, λ_{t+1} . When skilled workers choose to work in the research sector they allocate their time between research and final good production, and produce a smaller amount of final good, ψ which is assumed to be fixed over time. If they are successful in research they become innovators, and in addition to their first period income, ψ , earn π_t^m in monopoly profits, which is made up of payments from the next generation of the skilled workers for the use of the new technology. Determination of π_t^m is discussed below. In the equilibrium, the condition $\pi_t^m \geq \theta \lambda_t \geq \psi \geq \mu$ holds.

2.3.3 Technological Change

In any period t , there is only one vintage technology used by the skilled workers, λ_t . Technological change is defined as the innovation and diffusion of a new vintage or generation of this technology, λ_{t+1} . It takes place in consequent discrete steps or ladders and potentially can go on infinitely. There is no jump from one level of technology to a more advanced level which is more than one step ahead. For example, a more advanced technology, λ_{t+1} , cannot be discovered, unless all the prior technology ladders, λ_i $i = 1, \dots, t$, have been discovered and adapted. This process of technological change is based on the idea that advances in technology are built on previously accumulated knowledge and experience.

The next generation of technology, λ_{t+1} , is innovated in period t by the researchers who are members of the current young generation. The blueprints of new technology are carried to the next period; however, its diffusion is not automatic. It becomes the prevalent technology if and only if a significantly large part of skilled workers of next generation finds it in their best interest to adapt it. As soon as the new technology is adapted the previous vintage becomes obsolete.³⁴

Innovation of the next generation of technology requires “research” by firms or teams of skilled workers. There is one best technology, and research teams compete with each other to be the first one to discover it. Although only one firm discovers the new

³⁴ In real economies previous vintages do not become obsolete very quickly, and more than one vintage of technology are in use. This assumption is made for the sake simplicity and does not affect results of the paper.

technology first, research firms create knowledge and externalities for one another in the research process. As far as the entire economy is concerned there is no uncertainty involved in the process of technological change. The sufficient condition to attain the new vintage technology is the accumulation of a threshold level of knowledge which requires a minimum number of firms (N^*) operating in the research sector. As soon as this threshold is reached one of the firms discovers the new vintage technology with probability one. Each research firm is composed of a given number of skilled workers, n^* ³⁵. The process of generation of new technologies is characterized by the following expression,

$$\lambda_{t+1} = f(\lambda_t), \quad n \geq n^* \quad N \geq N^*. \quad (2.4)$$

Let $f(\cdot)$ be increasing and concave in the level of technology, which implies that as we move up in the technology ladder each additional innovation increases productivity at a declining rate, that is $f'(\cdot) \geq 0$ and $f''(\cdot) \leq 0$. Alternatively, it can be assumed that $f(\cdot)$ is increasing and linear, that is, every innovation in the ladder of the technology increases productivity by the same constant number. However, for the results of the paper this assumption is inconsequential since as long as the cost of education increases the process of innovation ends sooner regardless of the shape of $f(\cdot)$. Therefore, I will choose the former one.

³⁵ For a fixed proportion technology, n^* is given. For a concave production technology it is endogenously determined. This is not a realistic assumption but it is made for simplification and does not affect the results.

There is free entry to the research sector. The number of teams working in this sector, N_t , is determined endogenously. The researchers composing of the firms do not differ in ability, therefore each firm is equally likely to innovate with probability $1/N_t$. As N_t increases the positive externalities generated for each firm by others get larger. However, at the same time, for each firm, the probability of becoming the innovator declines.

New technologies are protected by patents; the successful research team is entitled to earn monopoly profits by collecting fees or rental payments from the users of their innovation next period. Each researcher of the innovator firm receives an endogenously determined profit share of π_t^m , where $\pi_t^m \geq \theta\lambda_t$.

2.3.4 Utility Maximization

At the beginning of the first period of life, members of the young generation receive non-negative amounts of bequests from their parents. They have two options to choose from. First, they can choose to work as unskilled workers. Alternatively, they can acquire skills by investing a certain amount of real resources, $e(\lambda_t)$, and a fraction of their time $(1 - \theta)$ into additional schooling at the beginning of first period and work as skilled workers during the remaining part of their youth (θ) .³⁶

³⁶ This paper does not have a separate education sector for the sake of simplicity. It is possible to model a more detailed education sector where part of the skilled labor is employed as educators. In such a model, increasing cost of education due to technological change can be derived as a result. As advances in technology makes the skilled workers more productive in production sector, wages of the skilled workers in the education sector will increase pushing the cost of education up. If one is not pleased by the lack of

Investment in human capital requires payment of a given amount of up-front cost, $e(\lambda_t)$. I assume that the cost of education or human capital investment is an increasing function of the level of technology for the reasons discussed in the second part of this paper. As technology advances the workers need increasingly complex skills to use the new technology, which may require additional investment of time and/or real resources in human capital accumulation. To simplify, I assume that only the amount of real resources required to be a skilled worker increases while the fraction of the first period time spent stays the same. In other words, $e'(\lambda_t) \geq 0$ whereas $\theta_t = \theta, \forall t$.³⁷ The cost may be assumed to increase at a constant, decreasing, or increasing rate. This assumption will not change the results. In Figure 5, below, $e''(\lambda_t) \geq 0$ is used.

Young agents can use the bequest that they inherit to finance the cost of human capital investment. If they do not inherit a sufficiently large bequest they may borrow in the credit markets. However, credit markets are imperfect due to enforcement problems, thus in the equilibrium some agents are credit constrained. Agents may borrow to invest in human capital and then default in repayment of their debt. The cost of defaulting is a given amount of real resources, D which is determined by the effectiveness of society's institutional structure in enforcing lending contracts, whereas no-default requires repayment of the funds borrowed with the accrued interests, $R_t[e(\lambda_t) - b_t]$. Lenders have to make sure that the cost of defaulting is greater than not defaulting at the

teachers in the model presented in this paper, s(he) can assume that some of the skilled workers work as teachers at the beginning of the second period before retiring.

³⁷ Alternatively, we can assume that the amount of time-spend increases and the cost per unit of time remains constant. This will not change the results because in this case also, total cost of human capital investment will increase.

equilibrium. Therefore, they will lend only to the agents whose inherited bequests are above a critical level, $b_t \geq \bar{b}_c = e(\lambda_t) - (D/R_t)$. The ones whose bequests are below this critical level become unskilled workers. As the cost of human capital investment increases the critical level of bequest goes up. On the other hand, an increase in cost of defaulting or a decline in the equilibrium interest rate lowers the amount of critical bequest.

As long as the productivity of a skilled worker is high enough compared to that of an unskilled worker, i.e., $\theta\lambda_t - \mu \geq R_t e(\lambda_t)$, the young agents are better off investing in human capital. However, those with bequests below the critical bequest level will not be able to do that and become unskilled workers. On the other hand, those who inherit sufficiently large bequests will invest in human capital and work as skilled production workers, or researchers in the technology sector. Some of the researchers will succeed in discovering the next generation of technology while the rest will become failed innovators.

All types of agents i.e. unskilled workers, skilled production workers, innovators, and failed researchers choose second period consumption and the amount of bequest that they will leave to their offspring to maximize the same utility function subject to their respective budget constraints,

$$u(c_{t+1}, b_{t+1}) = (1 - \beta) \log c_{t+1} + \beta \log b_{t+1}.$$

The following equation is the budget constraint of the agents who could not invest in human capital because their bequests are smaller than the critical level. They earn interest

income on their savings which is equal to bequests they received, and wage income as unskilled workers

$$c_{t+1} + b_{t+1} = R_t b_t + \mu \quad \text{if } b_t < \bar{b}_c. \quad (2.5)$$

Equation (5') shows the budget constraint of agents who are able to invest in human capital, and work as skilled workers in the production of final good. Their total income consists of interest income net of debt repayments and wage income,

$$c_{t+1} + b_{t+1} = R_t (b_t - e(\lambda_t)) + \theta \lambda_t. \quad (2.5')$$

The budget constraints of skilled workers employed in the research sector are given by the following two equations;

$$c_{t+1} + b_{t+1} = R_t (b_t - e(\lambda_t)) + \psi + \pi_t^m \quad (2.5'')$$

$$c_{t+1} + b_{t+1} = R_t (b_t - e(\lambda_t)) + \psi. \quad (2.5''')$$

Equation (5'') shows the budget constraint of innovators. The first term stands for interest income net of debt repayment while the second one shows the share of monopoly profit each researcher receives. Equation (5''') gives that of the skilled workers who work in research sector but fail to become innovators. The first term denotes interest income net of debt repayment while the second one shows income from their work in research sector.

The solution of the optimization problem shows that agents allocate a fixed share of their income, $(1 - \beta)$, to consumption and the remaining part (β) to bequests. Equations (6) show the bequest left by unskilled workers, skilled production workers, innovators, and failed researchers, respectively;

$$b_{t+1} = \beta\mu + \beta R_t b_t \quad \text{if } b_t < \bar{b}_c \quad (2.6)$$

$$b_{t+1} = \beta(\theta\lambda_t - R_t e(\lambda_t)) + \beta R_t b_t \quad (2.6')$$

$$b_{t+1} = \beta(\pi_t^m + \psi - R_t e(\lambda_t)) + \beta R_t b_t \quad (2.6'')$$

$$b_{t+1} = \beta(\psi - R_t e(\lambda_t)) + \beta R_t b_t . \quad (2.6''')$$

2.4 General Equilibrium

The credit market equilibrium condition states that the supply of savings is equal to the demand for savings at the market clearing interest rate. Let $G_t(b)$ denote distribution of bequests received at the beginning of time t ,

$$\int G_t(b) = \int_{\bar{b}_c} e(\lambda_t) G_t(b) \quad (2.7)$$

The left hand side of the expression denotes the supply of funds which is equal to the sum of bequests inherited (no first period consumption). The right hand side shows total demand for funds for human capital investment purposes. The labor market equilibrium condition states that sum of skilled and unskilled workers should be equal to the size of the young generation in every period,

$$H_t + L_t = T . \quad (2.8)$$

Skilled workers should be indifferent between working as a production worker or as a researcher. In other words, the income from working as a skilled production worker should be equal to the expected income from working as a researcher³⁸,

$$\theta\lambda_t = (1/N_t)(\psi + \pi_t^m/R_t) + (1 - (1/N_t))\psi. \quad (2.9)$$

The next condition expresses determination of π_t^m , the monopoly rents to be paid to each innovator. At the beginning of time $t+1$, the innovators from the previous generation and the current generation of skilled workers solve a bargaining game. It is assumed that one coalition of workers and a separate coalition of innovators play the game. Each coalition distributes the gains it obtains equally among its members.

The following equation shows total gains from the adaptation of the new vintage of technology assuming the skilled workers are employed only in the production sector³⁹

$$([\theta\lambda_{t+1}^g - e(\lambda_{t+1})] - [\theta\lambda_t^g - e(\lambda_t)])H_{t+1}, \quad (2.10)$$

where $\theta\lambda_{t+1}^g$ stands for the gross output of a skilled worker employing new vintage technology in the production of the final good. Recall that $\theta\lambda_{t+1}$ denotes the same output net of payments to the innovators for use of the technology.

The maximum payment that each of n innovators can extract from the skilled workers for use of the new technology is $(1/n)$ of the total gain. This constitutes the upper bound of what skilled workers would be willing to pay for use of the new technology. On the other hand, if the young workers refuse to pay a user fee, the innovators will keep their innovation but each one will make at most a wage equal to that

³⁸ This is a version of free entry condition into the research sector.

³⁹ Some of the skilled workers will be employed in the research sector. Since at the equilibrium expected income of a researcher is equal to that of a skilled production worker, we can make this assumption.

of a failed innovator, ψ . This constitutes the lower bound of the user fee that the innovators would accept.

$$\psi \leq \pi_t^m \leq ([\theta\lambda_{t+1}^g - e(\lambda_{t+1})] - [\theta\lambda_t^g - e(\lambda_t)]) \frac{H_{t+1}}{n} \quad (2.11)$$

I will assume that this bargaining game has an egalitarian solution, that is, total gains from the use of the new technology is equally divided between coalitions of innovators and skilled workers.⁴⁰

$$\pi_t^m = ([\theta\lambda_{t+1}^g - e(\lambda_{t+1})] - [\theta\lambda_t^g - e(\lambda_t)]) \frac{H_{t+1}}{2n} \quad (2.12)$$

Given an initial distribution of bequests $G_t(b)$, Equations (7), (8), (9), and (12) determine the market clearing interest rate, the share of skilled workers in total population, the number of research firms, and the monopoly profits each innovator receives.

2.4.3 Steady State Analysis

In this section, I will first show that a slightly modified version of the model outlined above can generate a “trickle down” effect similar to the ones proposed by the previous studies. Then, I will show that this effect may disappear with the introduction of increasing cost of human capital investment resulting from technological change.

⁴⁰ Instead of egalitarian solution to the bargaining game, utilitarian or Nash solution can be used. This choice will not affect the results of the paper. As technology advances total gains from new innovations decrease. Therefore, regardless of which bargaining solution used, the monopoly profits received by the innovators decline.

Instead of assuming that the cost of human capital investment increases as technology advances, suppose it stays constant, i.e. $e(\lambda_t) = e(\lambda)$, $\forall t$. Under this modified assumption, technological change may continue to take place until all the gains from adaptation of new vintages are depleted. In other words, the level of technology continues to advance until $f'(\lambda_t) = 0$. This is the point where $f'(\lambda_t)$ intersects the horizontal axis at λ^* in Figure 9. The highest vintage of technology that can be reached in this economy is λ^* , provided that the number of firms operating in the research sector continues to be above N^* as the gains from new vintages decline. If N_t falls below N^* at some point before λ^* is reached, the highest vintage adapted will be an earlier stage compared to this potential upper limit.

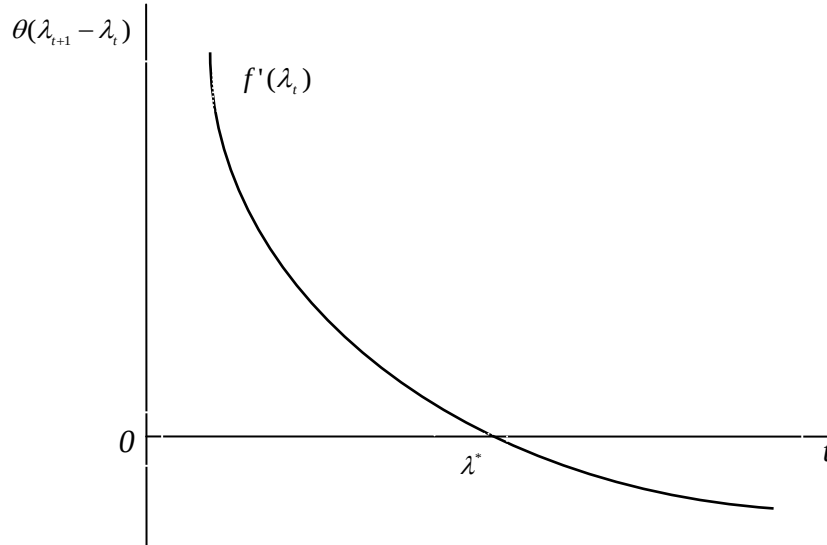


Figure 9. Technological Change

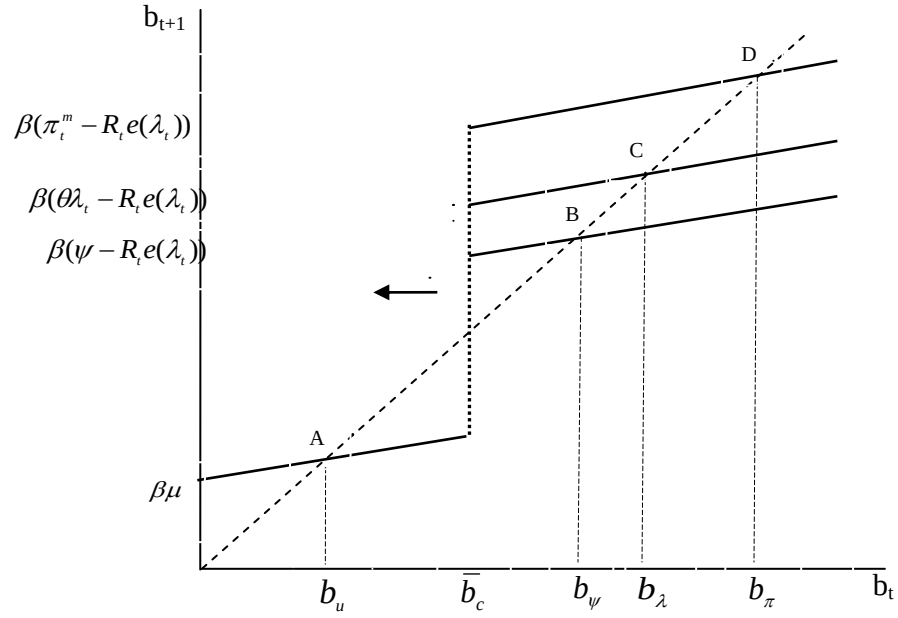


Figure 10. Steady State Equilibrium

Figure 10 illustrates the bequest decisions of agents from one period to the next one, expressed by Equations (6). The horizontal axis shows the amount of bequest inherited, b_t , while the vertical axis shows the amount of bequests to be left next period, b_{t+1} . Suppose that the level of critical bequest does not change for the moment. In the steady state, agents will converge to one of the four equilibriums; A, B, C or D. The first one is the low bequest equilibrium (b_u) of unskilled workers while the second one is the equilibrium for failed innovators (b_ψ). Equilibrium C and D are for the skilled production workers (b_λ), and innovators (b_π), respectively. Agents, who initially receive a bequest below b_u leave larger bequests until they reach b_u . On the other hand, agents, who inherit

a bequest above b_u but below the critical bequest level, $\bar{b}_c$, decrease their bequests until they reach b_u . The agents who receive a bequest above $\bar{b}_c$ become skilled workers and go to B, C or D at the steady state depending on their luck in each period. The levels of bequests remain the same at equilibriums A and B, while they increase at C and D as a result of technological change until the process of innovation stops at λ^* .

Above, it is assumed that the level of critical bequests stays the same to illustrate the differences between the four steady states. However, from the expression determining $\bar{b}_c$, it is clear that it will not remain constant; $\bar{b}_c = e(\lambda_t) - (D/R_t)$ even if $e(\lambda_t)$ and D (cost of default) are fixed. As the equilibrium interest rate R_t changes $\bar{b}_c$ will change; for example, a drop in R_t decreases the level of critical bequests, which in turn, makes it possible for some agents, who were denied credits before under a higher interest rate, to borrow and invest in human capital.

Recall that the equilibrium interest rate is determined by the following market clearing condition,

$$\int_{\bar{b}_c} G_t(b) = \int e(\lambda_t) G_t(b).$$

Depending upon the shape of initial distribution $G_t(b)$, total savings at the steady state, compared to the point where the economy starts, may go in either direction. For example, consider one extreme case, where initially all the agents inherit more than the highest bequest level, b_π at the steady state shown in Figure 4. In this case, no one is ever credit constrained and total savings are lower at the steady state compared to the starting point.

But, since no one is credit constrained the change in savings and in the interest rate does not affect anything. On the other extreme, consider another initial distribution where all the agents start with bequest levels, b_t , such that $b_u \leq b_t < \bar{b}_c$. In the steady state all the agents converge to equilibrium A; receiving and leaving the lowest steady state bequest, b_u . For this initial distribution, in the steady state, total savings is lower compared to its initial level. However, since every body is credit constrained in this case, the change in savings and in the interest does not have any effects.

The above extreme cases set aside, it can be shown that for the class of initial distributions with significantly large shares of agents starting with bequests above the critical level, total savings, and thus the total supply of credit, increase in the steady state. Notably, as technology advances the supply of credit increases thanks to higher incomes, whereas demand for credit stays the same at the going interest rate. This leads to declining equilibrium interest rates. As R_t goes down, $\bar{b}_c$ declines, and each time a smaller number of agents become credit constrained (the line denoting $\bar{b}_c$ in Figure 4 shifts to the left). This is the trickle-down effect taking place through the equilibrium interest rate. As the relatively rich agents get richer they supply higher amounts of savings to the credit markets, which in turn decreases the interest rate and makes it possible for the poor agents who were initially credit constrained to borrow and catch up with the rich. If the increase in savings and consequent decline in the interest rate is large enough, the measure of poor agents could significantly be lowered at the steady state. This implies a higher degree of upward mobility. Children of some of the unskilled

workers will be able to borrow, invest in human capital and become skilled workers. As a result persistence of inequality decreases.

Lemma 1: Let subscripts (0), and (*) denote initial state, and the steady state under the assumption of $e(\lambda_t) = e(\lambda)$, $t = 0, 1, \dots, \lambda^*$, respectively. Given the process of technological change, $f(\lambda_t)$, as the economy approaches to the steady state equilibrium with $f(\lambda^*)$, total supply of savings is higher compared to its initial level, $\int G_*(b) \geq \int G_0(b)$ if the initial distribution $G_0(b)$ has a sufficiently large measure of agents with $\bar{b}_c(0) \leq b_o \leq b_\psi$.

Proof: Agents with initial bequests $b_o : \bar{b}_c(0) \leq b_o \leq b_\psi$ increase their savings each period until λ^* is reached. Agents with initial bequests $b_o : 0 \leq b_o \leq b_\mu$ increase their savings until they reach b_u (or A), then stay and this equilibrium. The rest of population saves less as they approach their respective steady state equilibriums. If the measure of the first group is sufficiently large total savings increase each period as the incomes increase because of technological change.

Proposition 1: If $e(\lambda_t) = e(\lambda)$, $t = 0, 1, \dots, \lambda^*$ as technology advances the equilibrium interest rate, R_t , and the critical level of bequests, $\bar{b}_c$, decrease and generate trickle down effect.

Proof: Recall that R_t is determined by credit market equilibrium condition, Equation (7),

$$\int_{\bar{b}_c} G_t(b) = \int e(\lambda_t) G_t(b).$$

By assumption $e(\lambda_t) = e(\lambda)$ is constant. From the expression that determines critical level of bequests, $\bar{b}_c = e(\lambda_t) - (D/R_t)$ it is obvious that the only source of change in $\bar{b}_c$ is changes in R_t . For the same R_t , demand for credit (RHS of Equation (7)) does not change while supply of credit (LHS of Equation (7)) increases by Lemma 1. Therefore, R_t and $\bar{b}_c$ decline and create trickle down effects.

Now, let us consider the case where the cost of human capital investment increases with the advances in technology. Figure 5 shows the dynamics of technological change under this assumption. Innovations stop when the gains from adaptation of a new vintage are equal to the increase in the cost of human capital investment. This point is illustrated by the intersection of $f'(\lambda_t)$ and $e'(\lambda_t)$ at λ^{**} in Figure 11. The highest vintage of technology attainable at this steady state is λ^{**} , and $\lambda^{**} < \lambda^*$. Technological change comes to a halt at an earlier stage if it increases cost of acquiring skills. It may stop even before λ^{**} is reached if the number of firms in the research sector, N_t falls below N^* .

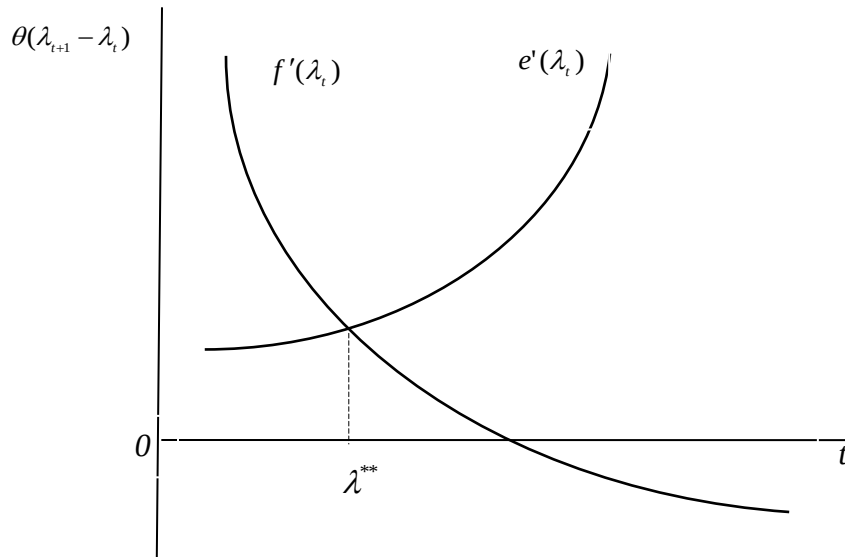


Figure 11. Technological Change with Increasing Cost of Human Capital Investment

Let us examine changes in the level of critical bequests, $\bar{b}_c = e(\lambda_t) - (D/R_t)$. There are two factors affecting the level of critical bequests: the cost of education, $e(\lambda_t)$, and the equilibrium interest rate, R_t . First, consider the effect of $e(\lambda_t)$ on $\bar{b}_c$ assuming that the equilibrium interest rate does not change. It is obvious that as the cost of human capital investment goes up due to technological change, the level of critical bequest increases. In Figure 12, as technology advances agents who are able to invest in human capital move to higher steady states, at the same time, the level of critical bequest which separates unskilled workers from the skilled workers shifts to the right.

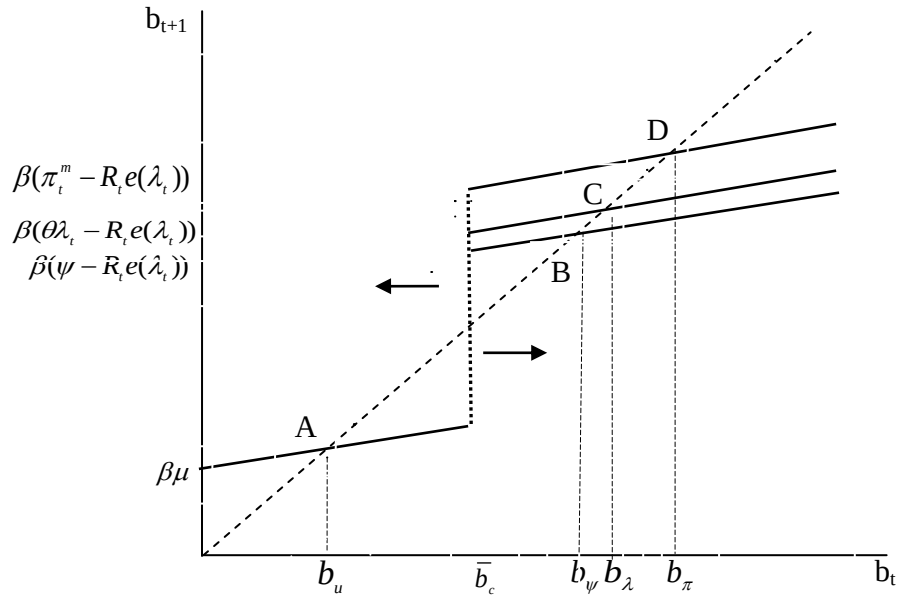


Figure 12. Steady State Equilibrium with Increasing Cost of Human Capital Investment

Next, let us consider the movement of the equilibrium interest rate assuming that $e(\lambda_t)$ stays the same. It can be shown that total supply of savings increases in the steady state if the economy has an initial distribution with significantly large shares of agents starting with bequests above the critical level. However, compared to the previous case (constant cost of human capital investment) the increase in savings, and therefore the decline in the interest rate, is smaller for two reasons. First, for the same initial distribution the innovation process stops at an earlier stage, at λ^{**} rather than λ^* as shown in Figure 5. Therefore, the highest income that can be obtained is smaller. Secondly, with every increase in the cost of human capital investment, some agents whose parents were skilled workers move to lower steady states where they earn and save less.

Although the increase in total savings at the steady state is smaller compared to the previous case there may be trickle down effect resulting from downward pressure on the interest rate. However, the increase in the cost of human capital investment acts as a counter effect. The net result depends on the relative strength of these two influences. For example, if advances in technology generate sizeable productivity gains, and therefore, significant increases in supply of savings, while increasing the cost of human capital investment slightly, the downward pressure on interest rates is larger and some trickle down effect occurs. Conversely, if the advances in technology do not result in a large increase in supply of credits while leading to significant increases in the cost of human capital investment, the opposite of trickle down effect is observed. As the rich agents invest in technological change they push some of the agents who are the poorest among

the rich, to lower steady states at the same time widen the investment gap that the poor has to overcome to catch up with them. The implications for persistence of inequality are not favorable. With increasing cost of human capital investment as a result of technological change the chances of children of low income parents to move upward in the distribution of income and wealth are lower and inequality is more persistent.

Proposition 2: *Let subscripts (0), (*), and (**) denote initial state, and steady states under the assumptions of $e(\lambda_t) = e(\lambda)$, and $e'(\lambda_t) \geq 0$, $t = 0, 1, \dots, \lambda^*$, respectively. For the same initial distributions considered in Proposition 1, if $e'(\lambda_t) \geq 0$, $t = 0, 1, \dots, \lambda^*$, then one of the following takes place in the steady state equilibrium:*

- i. *Partial trickle down effect, that is, $\bar{b}_c(*) \leq \bar{b}_c(**) \leq \bar{b}_c(0)$ if the increase in total savings is large enough to offset the effect of increases in $e(\lambda_t)$,*
- ii. *Reverse trickle down effect, that is, $\bar{b}_c(*) \leq \bar{b}_c(0) \leq \bar{b}_c(**)$, if increases in $e(\lambda_t)$ is sufficiently large to offset the effect of the increase in the supply of credits.*

Proof: From the expression that determines the level of critical bequest, $\bar{b}_c = e(\lambda_t) - (D/R_t)$ it is obvious that as $e(\lambda_t)$ increases as a result of further technological change, $\bar{b}_c$ increases for the same level of equilibrium interest R_t . Recall that R_t is determined by the credit market equilibrium condition,

$$\int G_t(b) = \int_{\bar{b}_c} e(\lambda_t) G_t(b).$$

The LHS of the above equation or the supply of credit increases by Proposition 1. For the same $\bar{b}_c$, the RHS of the above equation or demand for credit also increases. A simultaneous increase in both demand for and supply of credits may result in an increase or decrease in R_t depending upon the size of demand and supply shifts. If the increase in supply is higher, R_t , and therefore $\bar{b}_c(**)$ declines, leading to $\bar{b}_c(**) \leq \bar{b}_c(0)$. And, $\bar{b}_c(*) \leq \bar{b}_c(**)$ because the demand for credit does not increase under the assumption of $e(\lambda_t) = e(\lambda)$, $t = 0, 1, \dots, \lambda^*$. On the other hand, if the increase in demand for credit is

larger than the increase in supply of credit R_t increases and leads to further increase in $\bar{b}_c(**)$.

To summarize, if trickle-down effects take place, some of the poor are able to borrow and invest in human capital, and move upward in the distribution of income and wealth. In this case, inequality is less persistent. However, if the trickle-down effects are reversed or limited because of negative externalities to technological change, the poor have no or less opportunities for upward mobility. This results in higher persistence.

2.4.5 Extensions of the Basic Model

The basic model outlined in this paper can be extended in a number of different directions. First, it can be assumed that $f(\lambda_t)$ is linear rather than concave in the level of technology. If the cost of human capital investment does not increase with the level of technology, at the steady state, the economy will grow at a constant rate equal to the growth rate of technology. And, after some point in the future no agent will be credit constrained. Alternatively, if the cost of human capital investment increases with the level of technology a steady state similar to the one discussed above will be observed. At some point in the future, technological change will stop and the final effect on distribution will be determined by relative magnitudes of decreases in the interest rate and increases in the cost of human capital investment.

One other direction that the model could be extended is to use a different conceptualization of technological change. Throughout the paper I have assumed that

technological change is incremental. Another view of technological change claims that advances in technology occur not only in increments, but sometimes in big jumps called technological revolutions; for example, innovation of steam engines in the nineteenth century, or diffusion of new information technologies more recently. Although such overhauls have a wider spectrum of effects on economies than the paper aims to address, I will argue that regarding the major findings of the paper this assumption is inconsequential. Even if incremental changes in technology are replaced by technological revolutions, the people who would be in a position to take advantage of these significant changes are arguably the same ones in our model who can adapt and exploit the benefits of the new technologies.

Yet another line of extension of the basic model would be the consideration of multiple vintages of technology in use rather than only one vintage. For example, a “product-cycle” approach to technological change can be employed where the most recent vintage is used by the skilled workers, while the previous vintage is employed by the unskilled workers instead of being completely discarded as in the model presented above. Such an assumption would make the steady state distribution more realistic. However, as far as the main findings of this paper are concerned this assumption will not make a difference either.

A last direction of extension could be the incorporation of multiple ability types. In the model, I have considered only one ability type. Considering multiple ability types may result in a more realistic steady state distribution. For example, some of the agents who are born to poor parents may overcome the credit constraints by signaling to the

creditors that they are high ability types and eventually this may introduce a channel of upward mobility. However, this extension, too, will not affect the validity of the main arguments of this paper.

2.5 Concluding Remarks

A two-period overlapping generations model with endogenous technological change and credit constraints is used to study persistence of income and wealth inequality. Existence of credit constraints is used by others in the literature to study the same phenomenon. These studies conclude that, thanks to trickle-down effects, credit constraints will be less binding in the long run. As a result, the persistency of inequality is expected to decline. However, this finding does not seem to have strong empirical support. The recent empirical studies have found out that US earnings and income inequality is more persistent than what was previously believed.

This paper proposed a model to account for higher persistence of intergenerational income and wealth inequality. In addition to the credit constraints, endogenous technological change, accompanied by both positive and negative externalities, is introduced. Agents choose to become skilled or unskilled workers. Skills are acquired by investment of real resources and time at the beginning of first period of life. Technological change resulting from research activities carried out by firms composed of skilled workers, increases the cost of human capital investment.

High income agents have incentives to invest in new technologies; however this increases the investment gap that the poor need to close to catch up with the rich. It has

been demonstrated that if the increase in savings is not sufficiently large enough to offset the effect of increasing cost of human capital investment resulting from technological change trickle down effects are partially eliminated or reversed. It has been shown that if trickle-down effects are curtailed or reversed by the increasing cost of human capital investment, the persistence of inequality increases. This paper concludes that there are potential limitations of trickle down effects of the accumulation of the rich in reducing persistence of intergenerational inequality.

Chapter 3

International Trade and Wage Inequality in Developing Countries

3.1 Introduction

The workhorse of international trade theory, the Heckscher-Ohlin model, or more specifically, the Stolper-Samuelson theorem states that trade between skilled-labor-abundant developed countries and unskilled-labor-abundant developing economies will increase the relative wages of skilled workers in the former group of countries while lowering them in the latter.⁴¹ As a result, wage inequality between skilled and unskilled workers is expected to rise in developed countries and fall in developing economies.

In the 1980s and 1990s, a number of developing countries liberalized their international trade regimes. During the same period, the volume of trade increased considerably. Between 1985 and 1999, world exports grew at an annual rate of 10.04 percent while developing country exports increased 12.06 percent each year.

In contrast to the prediction of the Stolper-Samuelson theorem, preliminary evidence indicates that wage inequality has increased in some of the developing countries after they adopted more open trade regimes. Robbins (1996) studies a set of nine

⁴¹ The original version of the theorem considers trade between a labor- and a capital-abundant country.

developing countries and shows that the relative wages of skilled workers have increased after these countries opened up to trade with developed countries. Wood (1997) argues that the prediction of lower wage inequality in developing countries as a consequence of trade with developed countries was realized for the East Asian economies in the 1960s and 1970s. However, the same prediction seems to have failed elsewhere, especially for some of the Latin American countries which liberalized their trade regimes relatively more recently.^{42, 43}

A number of explanations have been offered to account for this increase in wage inequality in some of the developing countries. Skill-biased technological change resulting from trade with developed countries is the most commonly cited one among them. For example, Robbins (1996) concludes that trade with developed countries has led to skill-biased technological change in developing countries by generating resources for the importation of more machinery that embodies new skill-biased technologies. Similarly, Berman, Bound and Machin (1998, 2002) conclude that skill-biased technological change has been taking place in some of the middle-income developing countries. The reason for this, they claim, is the increasing volume of trade with developed countries. On the other hand, Wood (1997) claims that besides new skill-

⁴² It has been argued that the prediction of Stolper-Samuelson Theorem has been realized for the U.S.; increasing trade with unskilled-labor-abundant developing countries has caused higher wage inequality. On the other hand, skill-biased technological change has been nominated as another reason for increasing wage inequality. The size of relative impacts of international trade and technological change on wage inequality had been a point of controversy for some time, but a consensus seems to be reached recently. The impact of trade is not rejected but found to be small, whereas skill-biased technological change is shown to be the main cause of higher wage inequality (Acemoglu, 2002).

⁴³ See Goldin and Katz (1996) for U.S. wage inequality.

biased technologies, the entrance of large developing countries, like China, into the world trading system might have caused increasing wage inequality in other developing countries.^{44, 45}

This paper studies the same set of countries that are examined by Robbins (1996): Argentina, Chile, Colombia, Costa Rica, Malaysia, Mexico, the Philippines, and Uruguay.⁴⁶ The objective is to investigate whether international trade has played a role in increasing demand for skilled workers in these developing economies. Two potential effects of trade on demand for skilled labor are considered. First, a direct effect via exports: exports may become more skill intensive and increase demand for skilled workers. Second, an indirect effect via skill-biased technological change: trade may promote skill-biased technological change and increase demand for skilled labor. A particular version of the second effect is suggested by previous literature as discussed before, but it has not been empirically tested. This paper attempts to show if there is any empirical support for these two potential effects of trade on demand for skilled labor. In addition, it evaluates the claim raised by Wood (1997) and others stating that the entrance of cheap-labor-abundant large countries like China, into the world trading system has forced other developing countries to produce and export more skill-intensive goods, therefore led to higher demand for skilled labor.

⁴⁴ Davies (1996) proposes a theoretical model where inclusion of large unskilled-labor-abundant countries into the world trading system redefines comparative advantage of already-trading countries, and generates increasing wage inequality.

⁴⁵ Feenstra and Hanson (1996) offer a framework where inflow of capital from a capital-abundant country (the U.S.) to a labor abundant country (Mexico) increases wage inequality in both countries.

⁴⁶ Taiwan is excluded from this paper for lack of data.

This study is motivated by some questions that are left unanswered in the related literature. First, increasing wage inequality in developing countries, resulting from trade with developed countries, seems contradictory because the trade theory predicts that developing countries will produce more unskilled-labor-intensive commodities for exportation to developed countries, thereby increasing demand for unskilled labor. It is well known that exports from developing countries have increased considerably especially in the 1990s. However, it has not been shown whether the sectoral composition of developing-country exports and imports have remained the same after trade liberalization. For example, if they have begun producing and exporting relatively more skilled-labor-intensive goods, an increase in demand for skilled labor, and possibly higher wage inequality in these countries should not come as a surprise.

Second, the argument for skill-biased technological change as the reason behind increasing wage inequality in developing countries seems appealing, especially after a similar explanation has won the debate over causes of rising wage inequality in the U.S. This argument is partly based on previous research stating that developing countries acquire new technologies from the developed countries by importing capital goods from them (Helpman and Hoffmaister, 1997; Eaton and Kortum 2001). There are, however, a few problems with this claim. Producers in developing countries do not have incentives to adopt skill-biased technologies in an environment where skilled workers are scarce, unless these technologies increase productivity so much that they are adoptable for a large range of skill endowments and relative wages. In my best knowledge, no one has shown the existence of such large productivity gains yet. On the other hand, findings of

Acemoglu and Zilibotti (2001) suggest that even if those gains are large in developed countries, they may not be significant in developing countries since they obtain lower productivity compared to developed countries from the use of comparable technologies.

Third, Robins (1996) in line with the labor economics literature conducts a decomposition analysis of labor demand and supply and shows that higher wage inequality is caused by increasing demand for skilled workers despite the fact that the countries under examination had significant increases in supply of skilled labor during the same period. He, then, attributes the higher demand for skilled workers to skill-biased technological change which, he claims, has been caused by increasing trade with developed countries.

This paper takes a different approach. It does not repeat decomposition analysis of labor demand and supply. It starts with the findings of previous literature; higher wage inequality is caused by increasing demand for skilled labor. But rather than attributing the increased demand for skilled workers to trade or skill-biased technological change resulting from trade, it attempts to show if international trade with developed countries could have potentially increased demand for skilled workers directly by shifting exports to more skilled-labor intensive sectors, or indirectly by promoting skill-biased technological change. This is done by, first, documenting the changes in the trade patterns of the developing countries after they liberalized their trade regimes, and then assessing potential indicators of higher skill-intensity or skill-biased technological change, especially in high-growth export sectors. In addition to international trade statistics, wages and salaries, value added, and capital investment data are used.

The following conclusions have been reached. All of the above countries have experienced significant increases in their trade volumes, especially during the 1990s, regardless of how early or late they liberalized their trade regimes. As the volumes of trade increased the composition of exports and imports have also changed. The most important change in trade patterns has been the increased significance of a manufacturing industry called “Fabricated Metals, Machinery and Equipment”. The growth in trade volumes have been concentrated in a few sub-sectors within this industry; mainly, “Radio, Television, and Communication Equipment and Apparatus”, “Motor Vehicles”, and “Office, Computing and Accounting Machinery”.⁴⁷

More interestingly, these sectors have become the largest export and import sectors at the same time. However, this is not an example of intra-industry trade similar to trade patterns observed between developed countries. Instead, the developing countries import some parts and components of the final commodity to be produced by these sectors, then after carrying out some additional production tasks on them, they are re-exported. For this reason, large amounts of both exports and imports appear in the same industry. Examples of such trade had been observed before in case of some East Asian countries, especially for unskilled-labor-intensive production tasks. The new development seems to be the expansion of this type of trade to other developing countries, including the ones that are covered by this paper.⁴⁸

The answer to the question of whether international trade has increased demand for skilled labor in our sample of developing countries either by changing the

⁴⁷ Industries are grouped according to International Standard Industrial Classification (ISIC) system.

⁴⁸ UNCTAD (2001).

composition of exports (direct effect via exports), or by promoting skill-biased technological change (indirect effect via technological change) is a “qualified” no. The answer is “qualified” because the available data that can be used to assess skill-intensity of sectors is very limited. This paper does not refute the claim that trade has increased demand for skilled labor. But it concludes that available data does not support this claim. The extent of analysis carried out by this paper has been limited by the lack of reliable data for developing countries. Therefore, the findings should be taken as the first attempt in this direction rather than final results.

The composition of exports has changed as discussed above. This might have resulted in higher demand for skilled workers if the expanding sectors were relatively more skill intensive. For lack of better measures mean wages and valued added in these industries are used to assess relative skill-intensity of production processes compared to the rest of the manufacturing sectors. It is shown that high-growth export sectors do not pay higher wages or have higher value added per worker compared to the rest of the manufacturing industries.

For the sample of developing countries, the available data does not lend support to the claim that trade by itself has led to skill-biased technological change. Imports of machinery by all of the countries have increased, though a more careful aggregation indicates that this increase is not as significant as one would conclude from more broad measures which are used by previous studies. Moreover, industry level capital formation data suggests that a large part of the machinery imports are used to create production capacity in the high-growth export sectors. Instead of trade causing skill-biased

technological change it is shown that removal of high tariffs on imports has made it profitable for the producers in developed countries to relocate part of the production processes to the developing countries. In this way, these developing countries have become integrated into the global production networks in a small number of industries. It seems that part of the machinery imports have been made to create production capacity in these sectors. It is still possible to have skill-biased technological change in these industries if the imported machinery embodies skill-biased technologies. However, available data does not suggest that this has happened, at least in a significant degree. Average wages and the levels of value added in these sectors, most of the time, do not suggest high productivity or higher skill content in their production processes.

The answer to the question of whether China's entrance into the world trading system has increased competition for other developing countries is possibly yes for two reasons. First, China has the same rapidly growing export industry, "Fabricated Metal Products, Machinery and Equipment". Second, China serves the same export markets. The U.S. has been either the first or the second largest export market for all the other developing countries in the sample. China's exports to this market have started to increase around 1993. During the few years following this, the share of the U.S. in the exports of all the countries in our sample, except Mexico, has declined.

The findings of this paper are important in the following sense. Unlike previous studies, it presents a detailed analysis of changes in the trade patterns of a group of developing countries that have experienced increasing wage inequality after trade liberalization. It demonstrates that the major change in their trade patterns has been

caused by their integration into the global production networks of a small number of industries. This new development, in addition to shaping trade patterns, may influence choice of technologies or skill-intensity of production, thus demand for skilled labor, and wage inequality in these countries. Although data availability has limited the analysis that can be done in this direction, this paper argues this factor should be incorporated into the study of increasing wage inequality and technological change resulting from international trade in developing countries.

The rest of the paper is organized as follows. The next part presents background information about the set of countries covered in this paper, and describes the data used. The third part, first discusses broad trends in trade patterns during the post trade liberalization period, then, presents a detailed examination of changes in sectoral composition of exports and imports. This is followed by a discussion of foreign direct investment and machinery imports. The last part, analyzes the implications for demand for skilled labor and wage inequality.

3.2 The Sample of Countries and Data

The paper covers the sample of countries studied by Robbins (1996): Argentina, Chile, Colombia, Malaysia, Mexico, the Philippines, and Uruguay. Taiwan is excluded from this study for lack of data. All the countries in the sample, except Colombia and Malaysia, have undergone significant trade liberalization episodes during the last two decades.

Argentina has undergone two episodes of trade liberalization; first in 1976-1982, then, in 1989-1993. Chile started lowering barriers to international trade during the

period of 1975-1979, and speeded up the liberalization process after 1984. Colombia has not undergone trade regime liberalization but devaluated its currency in 1985-1986 significantly and doubled its exports as a result. Costa Rica adopted a more open trade regime in 1987. Malaysia has been following relatively liberal trade policies and had significant increases in its external trade volume, especially after 1987. Mexico started liberalizing its trade regime significantly in 1985-1987. Finally, the Philippines and Uruguay began to liberalize their trade regimes in 1991 and 1990, respectively.

International trade data in two different classification systems: International Standard Industrial Classification (ISIC) and Standard International Trade Classification (STIC) are used. ISIC data is provided by United Nations Industrial Development Organization (UNIDO) at four-digit industry level for the period of 1980-1999. It includes series of exports and imports, output, value added, number of employees, and wages and salaries. The data series for exports and imports are more or less complete; however the remaining ones have some missing points. Trade data in STIC is used especially for machinery imports and whenever a finer sector breakdown of trade statistics is needed. All of the data series are in current U.S. dollars.

3.3 Changes in Trade Patterns

This section of the paper describes how and why trade patterns of developing countries in the sample have changed following trade-liberalization policies. First, it outlines the general trends, and then presents a more detailed sector analysis. After that, it attempts to

discover the causes for these new developments and discusses the role of foreign direct investment and imports of capital goods in this process.

3.3.1 General Trends

The most obvious change following liberalization of trade policies has been the considerable increase in trade volumes of all the countries covered by this study. This increase has been relatively stronger, especially during the 1990s (Figure B1). The annual growth rates of exports during the post-trade liberalization period range from 8.43 percent for Colombia to 19.07 percent for Malaysia. Argentina's exports have risen at an annual rate of 10.69 percent since the start of its second episode of trade liberalization. Similarly, Chile's exports have expanded at an annual rate of 9.47 percent since 1984. The corresponding growth rates are 14.19, and 11.06 percent for Costa Rica and the Philippines. Uruguay's annual export growth rate, 15.67 percent, has become the second highest in the sample while Mexico's exports have increased at a rate of 11.94 percent annually since its trade liberalization in 1985.

Imports by the developing countries in the sample have increased at comparable rates to their exports. For some of the countries, the annual growth rates of exports during the post-trade liberalization period are smaller compared to the export growth rates they had enjoyed during the pre-trade liberalization period. This is partly due to the fact that, during the pre-trade liberalization period, the export levels were relatively small; for this reason the same absolute increase in exports had generated a much higher growth rate during this period compared the post liberalization period. Besides this, in Colombia's

and Chile's case, smaller export growth rates are partly caused by deterioration of terms of trade of their major export goods.

As the volume of trade has increased, composition of exports and imports at the board categories of agriculture, mining, and manufacturing has also changed. This change has been drastic for some of the countries in the sample while others experienced small to moderate shifts. Mexico and Costa Rica are the best examples in the former group while the Philippines and Uruguay belongs in the latter (Figure B2).

The share of agriculture in total exports has declined in all countries except Chile. Although this sector's share has been declining over time, it still accounts for a significant portion of total exports of Argentina, Colombia, Costa Rica, and Uruguay. Similarly, the share of mining in total exports has declined in the majority of countries except Argentina, Chile, and Colombia (Tables B1-8).

The upward trend of the share of manufacturing sector in total exports has continued for most of the countries except Chile, and Argentina after its second episode of trade liberalization. But the fall in the share of manufactured exports in total exports of Argentina in this period is small. On the other hand, the reason for the decline in Chile's case is the falling price of its major export commodity, which is covered by a sub-sector (non-ferrous metals) of aggregate manufacturing industries. Excluding this sub-sector, the share of manufactured exports in Chile has also increased.

Colombia has the lowest share of manufactured exports in total exports, 41.4 percent, whereas the Philippines has the highest share, 96.4 percent in the sample. Manufacturing has been the main export sector for Malaysia, the Philippines, and

Uruguay since the early 1970s. After the liberalization of trade regimes its share has surpassed a very high rate of 90 percent of total exports in these countries. This sector has made the sharpest percentage gain in Mexico's exports by rising from 33.3 in 1984, to 90.2 percent in 1999. It has registered another high percentage gain in Costa Rica's exports by rising from 33.3 to 66.2 percent during 1986-1998.

The major trend in imports has been the increasing amount and share of machinery imports (Figure B4). Industrial supplies have been the largest import category in the sample of countries (Figure B5). However, it has been surpassed by machinery imports in Malaysia, and more recently in the Philippines. Manufacture of chemicals has become another sector that has lost share in total imports in all the countries except Argentina.

3.3.2 Composition of Manufactured Exports and Imports

After having discussed the major trends in broad export and import categories, the next part presents a more detailed examination of the composition of manufactured exports and imports. This paper argues that the most important change in composition of manufactured exports and imports has been the increasing share of a manufacturing sector called "Fabricated Metal Products, Machinery and Equipment" or ISIC-38 according to International Standard Industrial Classification system (Figure B3). Apart from this, there have not been any significant changes in the international trade patterns except the trend of increasing share of manufactured goods in total exports at the expense of agricultural and mining sectors as discussed above.

The shares of nine two-digit manufacturing sectors in total exports during the pre- and post-liberalization periods are reported in Tables 11-18 in the appendix. To determine whether the sectoral composition of trade have changed significantly after the adoption of trade liberalization policies, correlations among these shares are calculated for each country; they are positive and very high. For example, the correlation is 0.97 for Argentina, and 0.93 for Chile. On the lower end of the spectrum, it is 0.68 for Costa Rica, and 0.76 for the Philippines. Mexico has the lowest correlation between its pre- and post-liberalization export shares, 0.4. However, the same correlation reaches about 0.94 if mining sector which exhibited the largest change is excluded. Similarly, correlation of Colombia's pre-and post-export shares is relatively low, 0.72, but it goes up significantly if the mining sector is excluded.

Although the expansion of "Fabricated Metal Products, Machinery and Equipment" industry (ISIC-38) has been the major source of change in the overall trade patterns of the sample countries, the degree of this change has varied greatly from one county to another. For example, Colombia has the lowest percentage rise in the export share of this sector, from 1.7 percent in 1984 to 5.9 percent in 1998. The other relatively less affected country is Chile. The share of this sector in Chile's exports rose to 10.4 percent from 0.7 percent after the first episode of trade liberalization in 1974 but since 1983 it has declined to just 4.7 percent. Argentina experienced a decline in the share of this sector in its total exports after its first trade liberalization episode but since the beginning of the second episode the share has risen to 17.3 from 7.1 percent. On the other hand, this sector's export share has registered more moderate increases in Costa

Rica, and Uruguay; from 3.8 to 29.8 percent in the former, and from 2.5 percent to 9.8 percent in the latter country during 1989-1998.

The Philippines had the largest percentage increase in the share of ISIC-38 in its total exports, from 15.5 percent in 1990 to 75.7 percent in 1998. Mexico has the second largest percentage increase in this sector's export share from 15.1 percent in 1984 to 65.7 percent in 1999. This is followed by Malaysia, with an increase in the corresponding export share from 26.6 to 63.7 percent during 1987-1998.

The more interesting phenomenon is that, in addition to increasing its export shares, ISIC-38 ("Fabricated Metal Products, Machinery and Equipment") has begun to account for larger shares of imports at the same time. However, this is not an example of intra-industry trade which has been widely observed among developed countries. Finer classifications of trade data (four-digit ISIC and up to six-digit SITC categories) are used to test whether the simultaneous nature of exports and imports in the same industry is robust. It is shown that simultaneous exports and imports do not disappear. Instead, they are heavily concentrated in a number of sub-sectors of ISIC-38.

The reason for this phenomenon is the following. In the industry of "Fabricated Metal Products, Machinery and Equipment" the final product, say a computer, television set, or a car is made up of a number of components and parts. It is possible to divide them according to their labor, capital, skill, or technology intensity and produce each of them in a different place where the most intensively used factor is the cheapest.⁴⁹ The

⁴⁹ This is simplification of more complex decisions of mainly transnational corporations. Although low factor cost is one of the most important criteria it is not the only one that determines these types of decisions.

production relocation can be done by parent company directly via foreign direct investment or indirectly by subcontracting the production of such goods to local producers in developing countries. It usually involves importation of the parts and components produced elsewhere, to the developing country. The developing country re-exports them after some additional production tasks are carried out. This is the reason for the simultaneous appearance of relatively large amounts of exports and imports in the same industry.

Examples of such production networks had been documented for some of the East Asian countries before, and they have shown to be spreading to other developing countries during the 1990s. This seems to be the case for the countries studied in this paper. Trade liberalization policies have increased the speed of this process by removing the cost of tariffs on the imports of parts and components by the developing countries. These countries have become a part of the global production network in a small number of industries; “Radio, Television, Communication Equipment and Apparatus” (ISIC-3832), “Motor Vehicles” (ISIC-3843), “Office, Computing and Accounting Machinery” (ISIC-3825), and “Electrical Apparatus and Supplies” (ISIC-3839).

The integration of the developing countries in our sample to production networks has been taking place via international trade in varying degrees for each of them. Mexico is the best example of this phenomenon. In 1999, its five largest manufactured exports and imports sectors are the same sub-sectors of “Fabricated Metals, Machinery and Equipment”. Some of them are the fastest growing exports and imports sectors (Table. 9).

Malaysia is the other country where sub-sectors of “Fabricated Metals, Machinery and Equipment” constitute the largest export and import sectors. The share of this sector in total exports has been increasing since the mid-1980s. Compared to other countries Malaysia’s exports and imports are more diversified within a larger number of sub-sectors of ISIC-38 rather than heavily concentrating only in a few industries.

In the Philippines’ case, the increasing share of ISIC-38 in manufactured exports and imports is a relatively recent phenomenon starting around the mid-1990s. However, the increase has been very sharp. In 1999, four out of the five largest exports and imports sectors are the sub-sectors of ISIC-38 (Table 10). Similarly, Costa Rica had a significant increase in the share of ISIC-38 in its exports and imports. “Electrical Apparatus and Supplies” (ISIC-3839) has a high share in its imports and exports.

As discussed above Argentina had a modest increase in the share of “Fabricated Metal Products, Machinery and Equipment” in its exports. A large part of this increase is accounted by only one sector, “Manufacture of Motor Vehicles” (Table 11).

Uruguay had a small increase in the share of ISIC-38 in its trade volumes. Only one sector, “Motor Vehicles” is among the top five exports and imports industries. Industries within “Food and Beverages” and “Textiles” have continued to be the largest export sectors despite the fact that some of them experienced falling shares in total exports (Table 12).

In Chile’s case, the share of “Motor Vehicles” in total imports has increased, but this sectors share in imports is still relatively small. “Non-ferrous Metals” despite its declining share is still the largest export sector of Chile (Table 13).

Table 9. Mexico-Major Manufactured Exports and Imports Industries

Exports				Imports			
Industry ISIC Code and Name	Share in Manufactured Exports (%)		Annual Growth Rate	Industry ISIC Code and Name	Share in Manufactured Imports (%)		Annual Growth Rate
	Pre	Post			Pre	Post	
3843-Motor vehicles	7.34	20.13	42.98	3832-Radio, tv. comn. equipmnt. & apparatus	9.81	14.48	32.08
3832-Radio, tv. comn. equipmnt. & apparatus	11.32	15.34	33.25	3843-Motor vehicles	7.33	10.26	31.39
3839-Electrical apparatus &supplies	4.29	8.35	38.17	3831-Electrical machinery equipment	5.82	6.42	28.29
3825-Office& computing machinery	2.60	7.74	44.14	3829-Machinery & equipment	6.49	5.81	25.66
3831-Electrical machinery &equipment	4.65	6.26	33.17	3839-Electrical apparatus and supplies	3.89	5.24	30.88

Source: UNIDO-Industrial Demand Supply Balance Database (Revision 2), 2002.

Table 10. Philippines-Major Manufactured Exports and Imports Industries

Exports				Imports			
Industry ISIC Code and Name	Share in Manufactured Exports (%)		Annual Growth Rate	Industry ISIC Code and Name	Share in Manufactured Imports (%)		Annual Growth Rate
	Pre	Post			Pre	Post	
3832-Radio, tv. comn. equipmnt. & apparatus	—	50.61	—	3832-Radio, tv. comn. equipmnt. & apparatus	—	33.57	—
3825-Office & computing machinery	—	15.95	—	3825-Office & computing machinery	—	10.33	—
3220-Wearing apparel	—	6.47	—	3824-Special industrial machinery & equipment	—	4.21	—
3831-Electrical machinery &equipment	—	2.86	—	3831-Electrical machinery & equipment	—	4.19	—
3839-Electrical apparatus and supplies	—	2.68	—	3511-Industrial chemicals	—	3.10	—

Source: UNIDO-Industrial Demand Supply Balance Database (Revision 2), 2002.

Table 11. Argentina-Major Manufactured Exports and Imports Industries

Exports				Imports			
Industry ISIC Code and Name	Share in Manufactured Exports (%)		Annual Growth Rate	Industry ISIC Code and Name	Share in Manufactured Imports (%)		Annual Growth Rate
	Pre	Post			Pre	Post	
3115-Vegetable & Animal oils, fats	34.41	26.25	7.27	3843-Motor vehicles	5.43	17.10	35.18
3843-Motor vehicles	2.41	17.49	34.38	3829-Machinery and equipment	7.82	7.82	20.52
3111-Slaughter. prep. preserving meat	10.11	4.96	2.64	3832-Radio, tv. comn. equipmnt. & apparatus	7.94	7.69	20.15
3710-Iron & Steel	9.70	4.79	4.79	3511-Industrial chemicals	16.07	6.79	10.58
3231-Leather	5.46	4.38	7.80	3825-Office & computing machinery	3.05	3.96	23.71

Source: UNIDO-Industrial Demand Supply Balance Database (Revision 2), 2002.

Table 12. Uruguay-Major Manufactured Exports and Imports Industries

Exports				Imports			
Industry ISIC Code And Name	Share in Manufactured Exports (%)		Annual Growth Rate	Industry ISIC Code and Name	Share in Manufactured Imports (%)		Annual Growth Rate
	Pre	Post			Pre	Post	
3111-Slaughter. prep. preserving meat	24.66	21.11	4.14	3843-Motor vehicles	11.23	14.28	15.59
3116-Grain mill products	6.27	11.15	12.04	3829-Machinery & equipment	7.20	5.99	8.51
3211-Textiles	18.16	9.72	-0.64	3832-Radio, tv. comn. equipmnt. & apparatus	7.20	4.87	8.51
3112-Dairy products	4.18	7.60	12.28	3511-Industrial chemicals	10.19	4.49	3.97
3231-Leather	8.15	7.43	4.79	3513- Plastics, Man-made fibers	8.92	4.36	5.05
3843- Motor vehicles	1.38	6.76	24.00	3824- Special industrial machinery & equipment	3.20	4.11	15.71

Source: UNIDO-Industrial Demand Supply Balance Database (Revision 2), 2002.

Table 13. Chile-Major Manufactured Exports and Imports Industries

Exports				Imports			
Industry ISIC Code And Name	Share in Manufactured Exports (%)		Annual Growth Rate	Industry ISIC Code and Name	Share in Manufactured Imports (%)		Annual Growth Rate
	Pre	Post			Pre	Post	
3720-Non-ferrous metals	64.19	47.88	11.60	3843-Motor vehicles	4.63	14.02	38.03
3411-Pulp, paper & paperboard	7.50	7.94	15.56	3829-Machinery & equipment.	7.29	9.77	27.19
3311-Wood mills	2.58	6.11	25.24	3824-Special industrial machinery & equipment.	4.00	7.28	31.16
3511-Industrial chemicals	3.07	5.29	21.33	3832-Radio, tv. comn. equipmnt. & apparatus	4.14	6.50	29.25
3115-Vegetable & Animal oils, fats	8.56	3.91	6.25	3511-Industrial Chemicals	7.90	4.35	16.37

Source: UNIDO-Industrial Demand Supply Balance Database (Revision 2), 2002.

Table 14. FDI Inflows as a Percentage of Gross Fixed Capital Formation

Country	1984-89	1990	1995	1998
Argentina	3.8	24.2	12.1	12.2
Chile	15.4	8.3	19.0	24.4
Colombia	8.5	7.5	6.4	24.3
Costa Rica	9.5	12.8	15.1	21.0
Malaysia	8.8	5.6	15.0	13.9
Mexico	7.8	23.8	20.6	13.2
Philippines	5.1	5.2	8.9	12.7
Uruguay	4.1	4.7	6.0	4.9
Developing Countries	2.8	3.2	7.7	13.8

Source: UNCTAD-World Investment Report (various issues).

3.3.3 Foreign Direct Investment

It is shown above that the international trade patterns of the countries studied in this paper evolved in a particular way because most of them have increasingly become part of the international production networks in a small number of industries. Inflow of foreign direct investment (FDI) is one of the channels through which the integration into these production networks can be made. This part of the paper discusses the role of FDI in this integration process for the countries in our sample.

A very large part of the FDI inflows take place among developed countries. For example, developing countries received only 21 percent of total FDI inflows in 1999. Moreover, the distribution of FDI among the host developing countries is very skewed. A large part of it is directed to East Asian economies, and increasingly more to China. The share of FDI inflows received by the countries in our sample has not been very high with the exception of Malaysia and more recently Mexico. However, FDI's share in gross fixed capital investments has exhibited an upward trend in most of the countries in the sample during the 1990s (Table 14).⁵⁰ Although, we do not have reliable data showing which industries received FDI inflows, evidence suggest that especially in the case of Mexico, and more recently, in Argentina, and Costa Rica the major receivers of FDI inflows are some of the sub-sectors of ISIC-38, most prominently, "Motor Vehicles".⁵¹

FDI has played a role in the integration of some of the countries in our sample into the international production networks in their high-growth manufactured export sectors. However, given the small size of FDI inflows, it cannot be argued that this role

⁵⁰ This is partly caused by the low levels of domestic capital investments.

⁵¹ Inter-American Development Bank (1996)

has been a major one for many of the countries, with the exception of Malaysia, and more recently Mexico.

3.3.4 Machinery Imports

As mentioned above machinery imports have been increasing in all of the countries in the sample and the share of machinery in total imports has exhibited an upward trend (Figure B4). This has led Robins (1996) and Berman and Machine (1998, 2000) to conclude that developing countries have been adopting skill-biased technologies because the new machinery imports embody these technologies. Thus, they argue, international trade by making importation of new machinery possible has resulted in adaptation of skill-biased technologies by developing countries.

Two objections can be raised against this claim. First, a portion of the total machinery imports are “parts”, not capital goods embodying new technologies. The share of parts has not been negligible for some of the countries. For example, they constitute nearly half of the machinery imports of Malaysia. Mexico and more recently Costa Rica began to have relatively large shares of “parts” in their total machinery imports. Therefore, the increase in machinery imports has not been as large as broad aggregations of machinery imports would suggest.

Second, the gross capital investment data for Malaysia, Mexico, and the Philippines (in four-digit ISIC classification) suggests that the fast growing export sectors of these countries, specifically ISIC-3832, and ISIC-3843 account for a considerable part of investments in capital formation. The change in export share of an industry and its

share in total capital investments are positively correlated. The correlation coefficients are 0.79 for Malaysia during 1993-1997, 0.36 for Mexico in 1984-1991, and 0.48 for the Philippines during 1990-1995. Although, it is not known which sectors import new machinery, it can be argued that a large portion of the machinery imports have been used by the high-growth export sectors to build capacity. This does not preclude the possibility that machinery imports by these industries directed towards skill-biased technologies but it provides some evidence against the claim that there has been an economy-wide shift to such technologies and new machinery imports resulted from such a trend.

This paper argues that trade by itself has not caused skill-biased technological change in the developing countries in our sample, by increasing machinery imports. Instead, the changes in trade patterns that are brought about by their integration into the international production networks in a few industries have resulted in increasing imports of capital goods which are required to create the capacity to produce and export. The imported capital goods have embodied technologies; whether these technologies have been skill-biased and caused increasing demand for skilled workers is the subject of the last section.

3.3.5 Effects of China's Exports

China's entrance into the world markets might have increased competition for other developing countries producing unskilled labor intensive export goods for two main reasons. First, China's increasingly large volumes of exports have been concentrated in the same industries as those of the countries in our sample. Second, its exports are

directed to the same markets. China's exports have been increasing at a faster rate than those of other developing countries. The composition of its exports has also changed: the share of manufacturing increased over time. Furthermore, within manufacturing sectors, its fastest growing sub-sector has become, ISIC-38 which is the fastest growing export sector of the countries in the sample (Figure B6). In addition, the U.S. has been either first or second largest export market for almost all the countries considered here. China's share in this market has increased at the expense of some of these countries (Figure B7).

3.3.6 Summary

The previous sections documented evolution of trade patterns of the developing countries studied in this paper after they have adopted more open trade regimes. It has been shown that the most important change in their trade patterns has been the increasing share of exports and imports in the same sub-sectors of "Fabricated Metals, Machinery and Equipment" industry. This has resulted from the integration of these countries into the international production networks of industries such as, "Radio, Television, and Communication Apparatus", "Motor Vehicles", "Office, Computing, and Accounting Machinery", and "Electrical Apparatus and Supplies". The sample of countries had different degrees of integration. In Mexico, Malaysia, Philippines, and Costa Rica, the increase in the share of ISIC-38 have been very significant. They are followed by Argentina, Chile, Uruguay and Colombia. Even in countries like Colombia and Chile where the share of ISIC-38 is relatively small, at least one sector, ISIC-3843 increased its shares in exports and imports. The role of FDI has shown to be limited in this integration

process for most of the countries, except Malaysia and Mexico. It has been demonstrated that imports of machinery has increased but part of this increase has been accounted by “parts” rather than capital equipments in some of the countries in our sample. In addition, the high-growth export sectors mentioned above seem to have used a large part of the machinery imports to build capacity. The implications for demand for skilled labor are discussed in the next section.

3.4 Demand for Skilled Labor

This section of the paper attempts to answer the question of whether international trade has contributed to increasing wage inequality between skilled and unskilled workers by increasing relative demand for skilled workers either by changing the composition of exports or by promoting skill-biased technological change.

The effect of trade on demand for skilled labor will be a function of the skill-intensity of the expanding sectors. Most of the sub-sectors of ISIC-38 are known to be relatively more unskilled labor intensive, especially the ones that had large export shares.⁵² This should not be surprising to anyone given the extent of relocation of these industries to labor abundant developing countries. The question, then, becomes how skilled-labor-intensive these sectors relative to the host country labor markets. An industry may be considered as relatively unskilled-labor-intensive in an average developed country labor market. However, the same industry can be considered as skilled-labor-intensive if the host country has a workforce composed of very low-skilled

⁵² Not all sub-sectors of ISIC-38 are labor intensive. Some of them are considered as high technology intensive.

workers. Relocation of such an industry to the developing country will increase the wage inequality between its skilled and unskilled workers.

To assess the degree of relative skill intensity of the high-growth-export sectors, the following statistics are calculated for Malaysia, Mexico, Chile, and the Philippines.⁵³ For each sector, mean wage, and mean value added (per worker) are calculated. For the aggregate manufacturing sector, the mean and median wage, and value added are also calculated. Then, industry level wage and value added statistics are compared to the statistics of aggregate manufacturing sector. For example, if the ratio of the mean wage in “Motor Vehicle” to manufacturing sector mean or median wage is greater than one, this would suggest that, on the average, this sector pays higher wages compared to the rest of the manufacturing industries. Similarly, if the ratio of the mean value added in “Motor Vehicles” industry to the aggregate manufacturing sector mean or median value added is greater than one, this would suggest that in this sector, on the average, the value added is higher compared to the rest of the manufacturing industries. In either case a higher wage and/or higher value added in a sector compared to the rest of the manufacturing sector is considered as an indicator of relative skill intensity of this particular sector.⁵⁴

The statistics that are used in this section are not the perfect indicators of skill-intensity of the sectors. There are a large number of factors that can affect the results and available data is not adequate to capture that. Therefore, the findings should be considered as first attempt in the right direction rather than not final conclusions.

⁵³ Data is not available for the other countries in the sample.

⁵⁴ Average wage for each industry is used. This is a limitation because this measure does not capture within sector wage changes.

For Mexico's high-growth-export sectors, the findings do not suggest a significant high skill intensity of production in these sectors, with the exception of "Motor Vehicles" and "Office and Computing Machinery" which report wage and value added ratios greater than one (Table 15). In case of low-growth-export sectors the pattern is very clear; they pay higher wages and have higher value added per worker. From these figures it can be concluded that the available data does not suggest that Mexico's high-growth-export sectors are high-skilled-labor intensive with one or two exceptions.

Malaysia's high- and low-growth-export sectors exhibit a clear pattern; the high-growth-export sectors do not pay higher wages and do not have higher value added compared to the rest of the manufacturing sector. On the other hand, low-growth-export sectors pay higher wages and have higher value added except the "Wood Mills" industry. Available data suggests that Malaysia's high-growth-export sectors are not significantly more skilled-labor-intensive compared to the rest of the manufacturing sector (Table 16).

In Chile's case, none of the high- or low-growth-export sectors are sub-sectors of "Fabricated Metals, Machinery and Equipment". Chile's high growth export sectors pay significantly low wages and have low value added per worker with only one exception, "Industrial Chemicals" industry. On the other hand, the low growth export sectors pay higher wages and have higher per worker value added. In Chile's case, it is certainly not possible to conclude that export sectors increase demand for skilled labor. The above ratios seem to be more consistent with the opposite statement, that is, high growth export sectors increase demand for less skilled and low paid workers (Table 17).

The Philippines presents an interesting and seemingly contradictory case. One of its high growth sectors pay higher wages and have higher valued added. On other hand, three out of five of its low-growth export sectors pay very low wages and have low value added (Table 18). The Philippines has the lowest average wages within our sample. The declining export shares of its very low wage sectors may be caused by China's entrance into its major export market, the U.S. In 1993, about 40 percent of Philippines' exports were directed to the U.S. markets. China has increased the share of US in its exports from slightly above 10 percent to nearly 20 percent. This coincides to the starting point of the downward trend of the U.S. share in the Philippines' exports. Although the Philippines is a low-wage country, the wages are not low enough to compete with China in low skill intensive sectors like "Wearing Apparel". It can be concluded that given the very large share of "Radio, Television, and Communication Equipment and Apparatus" industry (50.51 percent), it may increase demand for relatively skilled workers. In addition to that, the competition that its low-wage export sectors facing from China might have decreased demand for unskilled workers.

Table 15. Mexico-Selected High- and Low-growth Export Industries

Industry	Ratio of Mean Wage to Manufacturing Mean Wage	Ratio of Mean Wage to Manufacturing Median Wage	Ratio of Mean Value Added to Manufacturing Mean Value Added	Ratio of Mean Value Added to Manufacturing Median Value Added
Selected High-growth Export Industries				
3843-Motor vehicles	1.05	1.09	1.37	1.85
3825-Office & computing machinery	1.47	1.53	0.82	1.28
3832-Radio, tv. comm. equipmnt. & apparatus	0.78	0.81	0.54	0.73
3839-Electrical apparatus and supplies	1.04	1.08	0.69	0.93
3220-Wearing apparel	0.62	0.65	0.30	0.40
3829-Machinery & equipment	1.06	1.10	0.68	0.92
3831-Electrical machinery & equipment	0.95	0.99	0.81	1.10
Selected Low-growth Export Industries				
3720- Non-ferrous metals	1.13	1.17	1.82	2.45
3511- Industrial chemicals	1.47	1.53	2.31	3.12
3710- Iron & Steel	1.13	1.17	1.32	1.78

Source: United Nations-Industrial Statistics Database (4-digit ISIC), 2001.

Table 16. Malaysia-Selected High and Low-growth Export Industries

Industry	Ratio of Mean Wage to Manufacturing Mean Wage	Ratio of Mean Wage to Manufacturing Median Wage	Ratio of Mean Value Added to Manufacturing Mean Value Added	Ratio of Mean Value Added to Manufacturing Median Value Added
Selected High-growth Export Industries				
3832- Radio, tv. comn. equipmnt. & apparatus	0.84	1.00	0.61	0.98
3839- Electrical apparatus and supplies	0.92	1.09	0.66	1.06
Selected Low-growth Export Industries				
3115-Vegetable & animal oils, fats	2.30	2.73	1.04	1.68
3720-Non-ferros metals	1.14	1.35	0.75	1.22
3311-Wood mills	0.71	0.85	0.45	0.73
3530-Petroleum refineries	3.64	4.33	6.72	10.89

Source: United Nations-Industrial Statistics Database (4-digit ISIC), 2001.

Table 17. Chile-Selected High and Low-growth Export Industries

Industry	Ratio of Mean Wage to Manufacturing Mean Wage	Ratio of Mean Wage to Manufacturing Median Wage	Ratio of Mean Value Added to Manufacturing Mean Value Added	Ratio of Mean Value Added to Manufacturing Median Value Added
Selected High-growth Export Industries				
3311-Wood Mills	0.5	0.56	0.61	0.74
3132-Wines	0.67	0.75	0.85	1.04
3113- Canning & preserv. fruits, vegetables	0.43	0.48	0.38	0.46
3511- Industrial chemicals	1.52	1.70	2.01	2.44
3114- Processing & preserve. fish	0.40	0.44	0.30	0.37
Selected Low-growth Export Industries				
3720-Non-ferros metals	1.82	2.04	7.62	9.27
3115-Vegetable & animal oils, fats	1.20	1.34	1.5	1.82
3530-Petroleum refineries	2.11	2.36	12.66	15.40

Source: United Nations-Industrial Statistics Database (4-digit ISIC), 2001.

Table 18. Philippines-Selected High and Low-growth Export Industries

Industry	Ratio of Mean Wage to Manufacturing Mean Wage	Ratio of Mean Wage to Manufacturing Median Wage	Ratio of Mean Value Added to Manufacturing Mean Value Added	Ratio of Mean Value Added to Manufacturing Median Value Added
Selected High-growth Export Industries				
3832-Radio, tv. comn. equipmnt. & apparatus	1.07	1.22	1.14	1.77
3825-Office & computing machinery	0.7	0.8	0.41	0.64
Selected Low-growth Export Industries				
3115- Vegetable & Animal oils, fats	0.91	1.04	1.41	2.20
3720- Non-ferrous metals	1.20	1.37	1.09	1.70
3220- Wearing apparel	0.61	0.69	0.32	0.50
3311-Wood mills	0.19	0.21	0.38	0.59
3320-Furniture & fixtures	0.47	0.54	0.25	0.38

Source: United Nations-Industrial Statistics Database (4-digit ISIC), 2001.

The rest of this section presents additional correlation coefficients which are calculated to test whether the high-growth export sectors are relatively more skill intensive. For each four-digit industry, the change in its export shares (the difference between pre- and post-trade liberalization percentage shares in total exports) is calculated. Then, the correlation between these differences and the levels of pre- and post trade liberalization period wages are computed.

A negative correlation between changes in export shares and pre-trade liberalization wage levels indicates that the export shares of low-wage industries have increased more after trade liberalization. In other words, demand for low-skilled (low-wage) workers has increased with the expansion of exports. Similarly, a negative correlation between the change in export shares and the most recent industry wage levels shows that exports are concentrated more heavily in low wage industries, implying higher demand for low skilled workers. Similar correlations are calculated between changes in export shares and levels of valued added.

The largest correlations are found in Chile's case. The correlation coefficient between the changes in export shares and the wage levels in 1985 is -0.27. The same correlation is -0.36 for the wage levels in 1997. Corresponding correlations for value added are -0.50 and -0.35 for levels of value added in 1985 and 1997, respectively. These correlations suggest that Chile's exports have expanded more in low wage and low value added sectors. This implies higher demand for unskilled workers. Similar correlations are calculated for Malaysia, Mexico and the Philippines. They are all negative but small,

(in absolute value) less than -0.1 . Therefore, they do not suggest a concentration of export sectors in low wage low skill sectors.

3.5 Conclusions

The Stolper-Samuelson theorem predicts that trade between skilled-labor-abundant developed countries and unskilled-labor-abundant developing economies will decrease wage inequality between skilled and unskilled workers in developing economies. In contradiction to this prediction, some empirical evidence reported in the literature indicating that wage inequality between skilled and unskilled workers has increased in some of the developing countries after they adopted more open trade regimes during the last two decades. Skill-biased technological change resulting from trade with developed countries has been nominated as a cause for the increased inequality.

This paper has studied a group of such developing countries composed of Argentina, Chile, Colombia, Costa Rica, Malaysia, Mexico, the Philippines, and Uruguay to determine whether international trade has increased demand for skilled workers in these countries either directly by increasing skill-content of exports or by promoting skill-biased technological change. To do that the evolution of trade patterns of these countries after trade liberalization and a more detailed examination of their machinery imports are presented. It has been shown that the majority of developing countries in the sample have been in the process of integration into the international production networks of a small number of industries; mainly “Radio, Television, and Communication Equipment and Apparatus”, “Motor Vehicles”, and “Office, Computing and Accounting Machinery”.

This has been the reason behind the changes in their trade patterns following the trade liberalization policies. Imports of machinery have increased, but for some of the countries in the sample, the increase is not as large as broad measures of imports would suggest. In addition, it seems that the above mentioned high-growth export sectors have used a large part of the machinery imports to build capacity.

The implications for demand for skilled workers have been examined. For lack of better measures, mean wages and mean valued added are used as indicators of skill-intensity of different sectors. The data that is used in this paper do not lend strong support to the claim that trade increased demand for skilled labor directly or by promoting skill-biased technological change. This finding should be taken with caution because of the limitations of the available data. This paper do not refute the claim that trade increased the demand for skilled workers but it concludes that the limited amount of data that is available do not support this claim. Despite this shortcoming, the findings of this paper are important in the following sense. It has shown that the new development has been the integration of these countries into the global production networks of a small number of industries. This should be taken into account by future studies dealing with wage inequality and technological change in these countries.

Appendix A

Appendix to Chapter 1

A.1 Computation of Steady State Invariant Distribution of T+1 Year- Old Agents

Let the number of grid points in A , and W be m , and n , respectively. Define $A \times W$ as a $m \times n$ dimension array. Let $T(x', x)$ be the transition matrix of the state of $T+1$ -year old agents. It gives the probability that the state of next $T+1$ -year old agent is x' conditional on his parent having current state of x . The transition matrix is formed using the Markov process with ability distribution and decision rules as

$$T(i, j) = \Pr(z' = H \mid z = H)$$

$$\text{if } (a_0', h^p'; H) = A \times W(j) \text{ and } (a_0, h^p, H) = A \times W(i)$$

$$T(i, j) = 0 \quad \text{otherwise}$$

$$T(m \times n + i, j) = \Pr(z' = H \mid z = L)$$

$$\text{if } (a_0', h^p'; H) = A \times W(j) \text{ and } (a_0, h^p, L) = A \times W(i)$$

$$T(m \times n + i, j) = 0 \quad \text{otherwise}$$

$$T(i, j + m \times n) = \Pr(z' = L \mid z = H)$$

$$\text{if } (a_0', h^p'; L) = A \times W(j) \text{ and } (a_0, h^p, H) = A \times W(i)$$

$$T(i, j + m \times n) = 0 \quad \text{otherwise}$$

$$T(i + m \times n, j + m \times n) = \Pr(z' = L \mid z = L)$$

$$\text{if } (a_0', h^{p'}; L) = A \times W(j) \text{ and } (a_0, h^p, L) = A \times W(i)$$

$$T(i + m \times n, j + m \times n) = 0 \quad \text{otherwise} \quad i, j = 1, \dots, m \times n$$

Define $\lambda(x)$ as any initial distribution of one-year old agents. To find the invariant steady state distribution iterate on the following equation until convergence, that is, until $\|\lambda_{j+1} - \lambda_j\|$ is small enough.

$$\lambda_{j+1}(x') = \lambda_j(x) \sum_{x \in X = A \times W \times Z} T(x', x)$$

A.2 Computation of Steady State Equilibrium

1. Guess physical and human capital stocks, K_0 and H_0 .
2. Find corresponding competitive wage and rate of return on capital, w, r .
3. Solve optimization problem of the household given government policy, w and r to find decision rules.
4. Use decision rules with Markov process of ability distribution to solve for steady state invariant distribution of $T+1$ -year old agents.
5. Use invariant distribution and decision rules to compute physical and human capital stocks, K' and H' .
6. Compare K_0 and H_0 with K' and H' found in (5). If $\frac{K_0 - K'}{K_0}$ and $\frac{H_0 - H'}{H_0}$ are small enough stop. Otherwise update the guess for K_0 and H_0 go to step (2).

Appendix B

Appendix to Chapter 3

B.1 Tables and Figures

Table B1. Argentina-Exports by Industrial Origin

ISIC Code	Industry Definition	Percentage Share in Exports Pre and Post Trade Liberalization		
		Pre-L. (1975)	Pre-L. (1988)	Post-L. (1998)
1	Agriculture	47.1	26.6	24.1
2	Mining	0.4	0.5	8.0
3	Manufacturing	52.60	72.8	67.9
31	Food, Beverages and Tobacco	25.8	36.0	27.8
32	Textile, Wearing Apparel and Leather Industries	4.9	8.3	5.0
33	Wood and Wood Products, Including Furniture	0.0	0.0	0.2
34	Paper and Paper Products, Printing and Publishing	0.9	1.6	1.6
35	Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products	4.7	9.9	10.3
36	Non-Metallic Mineral Products	0.2	0.5	0.5
37	Basic Metal Industries	0.8	9.3	4.1
38	Fabricated Metal Products, Machinery and Equipment	15.1	7.1	17.3
39	Other Manufacturing Industries	0.1	0.1	1.1

Source: Untied Nations Trade Statistics Yearbooks (various issues).

Table B2. Chile Exports by Industrial Origin

ISIC Code	Industry Definition	Percentage Share in Exports Pre and Post Trade Liberalization		
		Pre-L. (1974)	Pre-L. (1983)	Post-L. (1998)
1	Agriculture	2.6	11.3	17.7
2	Mining	12.3	8.0	12.7
3	Manufacturing	85.2	80.7	69.6
31	Food, Beverages and Tobacco	2.5	11.2	12.6
32	Textile, Wearing Apparel and Leather Industries	0.0	0.0	1.4
33	Wood and Wood Products, Including Furniture	0.5	2.0	4.2
34	Paper and Paper Products, Printing and Publishing	4.5	5.8	7.1
35	Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products	2.7	9.7	6.6
36	Non-Metallic Mineral Products	0.0	0.0	0.3
37	Basic Metal Industries	74.3	41.4	30.7
38	Fabricated Metal Products, Machinery and Equipment	0.7	10.4	4.7
39	Other Manufacturing Industries	0.0	0.0	2.0

Source: United Nations Trade Statistics Yearbooks (various issues).

Table B3. Colombia-Exports by Industrial Origin

ISIC Code	Industry Definition	Percentage Share in Exports	
		(1984)	(1998)
1	Agriculture	63.5	29.9
2	Mining	1.9	28.7
3	Manufacturing	34.7	41.4
31	Food, Beverages and Tobacco	3.7	7.2
32	Textile, Wearing Apparel and Leather Industries	4.2	7.6
33	Wood and Wood Products, Including Furniture	0.2	0.2
34	Paper and Paper Products, Printing and Publishing	2.0	2.5
35	Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products	17.2	13.7
36	Non-Metallic Mineral Products	1.0	1.7
37	Basic Metal Industries	2.2	2.0
38	Fabricated Metal Products, Machinery and Equipment	1.7	5.9
39	Other Manufacturing Industries	2.4	0.6

Source: United Nations Trade Statistics Yearbooks (various issues).

Table B4. Costa Rica-Exports by Industrial Origin

ISIC Code	Industry Definition	Percentage Share in Exports Pre and Post Trade Liberalization	
		Pre-L. (1986)	Post-L. (1998)
1	Agriculture	65.5	33.7
2	Mining	0.0	0.1
3	Manufacturing	33.5	66.2
31	Food, Beverages and Tobacco	9.8	9.4
32	Textile, Wearing Apparel and Leather Industries	4.9	14.3
33	Wood and Wood Products, Including Furniture	0.5	0.8
34	Paper and Paper Products, Printing and Publishing	0.9	1.4
35	Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products	9.4	7.0
36	Non-Metallic Mineral Products	1.1	1.0
37	Basic Metal Industries	1.1	1.2
38	Fabricated Metal Products, Machinery and Equipment	3.8	29.8
39	Other Manufacturing Industries	1.9	1.4

Source: United Nations Trade Statistics Yearbooks (various issues).

Table B5. Malaysia-Exports by Industrial Origin

ISIC Code	Industry Definition	Percentage Share in Exports	
		(1986)	(1998)
1	Agriculture	20.4	2.7
2	Mining	21.5	5.4
3	Manufacturing	58.1	92.0
31	Food, Beverages and Tobacco	12.6	9.0
32	Textile, Wearing Apparel and Leather Industries	4.6	4.9
33	Wood and Wood Products, Including Furniture	5.2	3.1
34	Paper and Paper Products, Printing and Publishing	0.3	0.6
35	Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products	4.8	5.8
36	Non-Metallic Mineral Products	0.4	0.7
37	Basic Metal Industries	2.7	2.0
38	Fabricated Metal Products, Machinery and Equipment	26.6	63.7
39	Other Manufacturing Industries	0.9	2.1

Source: United Nations Trade Statistics Yearbooks (various issues).

Table B6. Mexico-Exports by Industrial Origin

ISIC Code	Industry Definition	Percentage Share in Exports Pre and Post Trade Liberalization	
		Pre-L. (1984)	Post-L. (1999)
1	Agriculture	7.5	3.9
2	Mining	59.2	5.9
3	Manufacturing	33.3	90.2
31	Food, Beverages and Tobacco	1.4	2.5
32	Textile, Wearing Apparel and Leather Industries	1.8	8.2
33	Wood and Wood Products, Including Furniture	0.3	0.4
34	Paper and Paper Products, Printing and Publishing	0.6	1.0
35	Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products	8.5	6.1
36	Non-Metallic Mineral Products	1.2	1.5
37	Basic Metal Industries	3.5	3.2
38	Fabricated Metal Products, Machinery and Equipment	15.1	65.7
39	Other Manufacturing Industries	0.8	1.7

Source: United Nations Trade Statistics Yearbooks (various issues).

Table B7. Philippines-Exports by Industrial Origin

ISIC Code	Industry Definition	Percentage Share in Exports Pre and Post Trade Liberalization	
		Pre-L. (1990)	Post-L. (1998)
1	Agriculture	8.8	2.9
2	Mining	4.9	0.7
3	Manufacturing	86.3	96.4
31	Food, Beverages and Tobacco	11.3	4.5
32	Textile, Wearing Apparel and Leather Industries	20.8	10.3
33	Wood and Wood Products, Including Furniture	2.6	0.5
34	Paper and Paper Products, Printing and Publishing	0.5	0.4
35	Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products	5.5	2.2
36	Non-Metallic Mineral Products	0.7	0.5
37	Basic Metal Industries	4.6	0.9
38	Fabricated Metal Products, Machinery and Equipment	15.5	75.7
39	Other Manufacturing Industries	34.9	1.4

Source: United Nations Trade Statistics Yearbooks (various issues).

Table B8. Uruguay-Exports by Industrial Origin

ISIC Code	Industry Definition	Percentage Share in Exports Pre and Post Trade Liberalization	
		Pre-L. (1989)	Post-L. (1998)
1	Agriculture	18.6	14.4
2	Mining	0.3	0.2
3	Manufacturing	81.1	85.4
31	Food, Beverages and Tobacco	28.3	39.0
32	Textile, Wearing Apparel and Leather Industries	37.4	21.9
33	Wood and Wood Products, Including Furniture	0.0	0.4
34	Paper and Paper Products, Printing and Publishing	0.7	2.5
35	Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products	9.5	8.7
36	Non-Metallic Mineral Products	1.3	1.5
37	Basic Metal Industries	0.8	1.1
38	Fabricated Metal Products, Machinery and Equipment	2.5	9.8
39	Other Manufacturing Industries	0.6	0.6

Source: Untied Nations Trade Statistics Yearbooks (various issues).

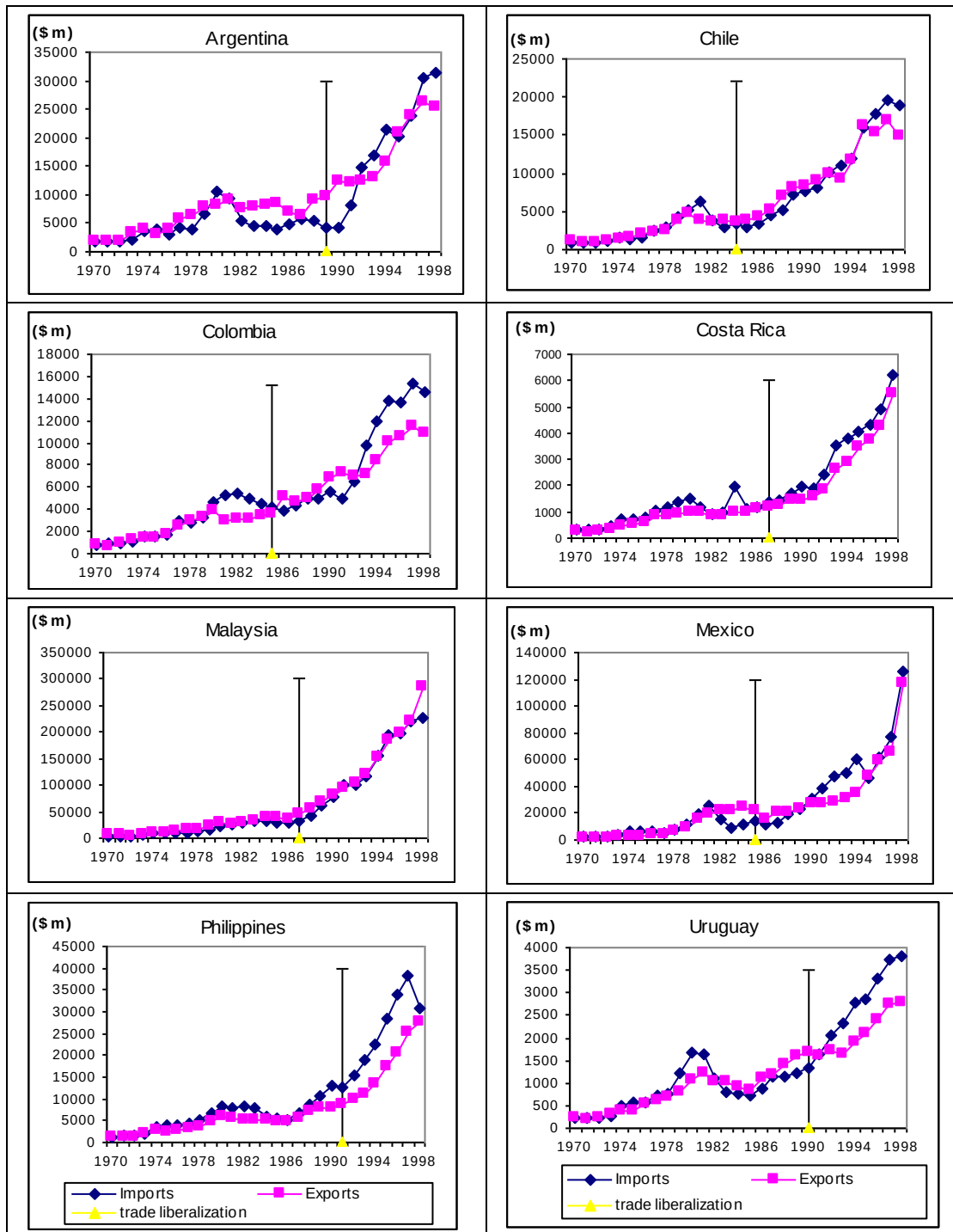


Figure B1. Exports and Import

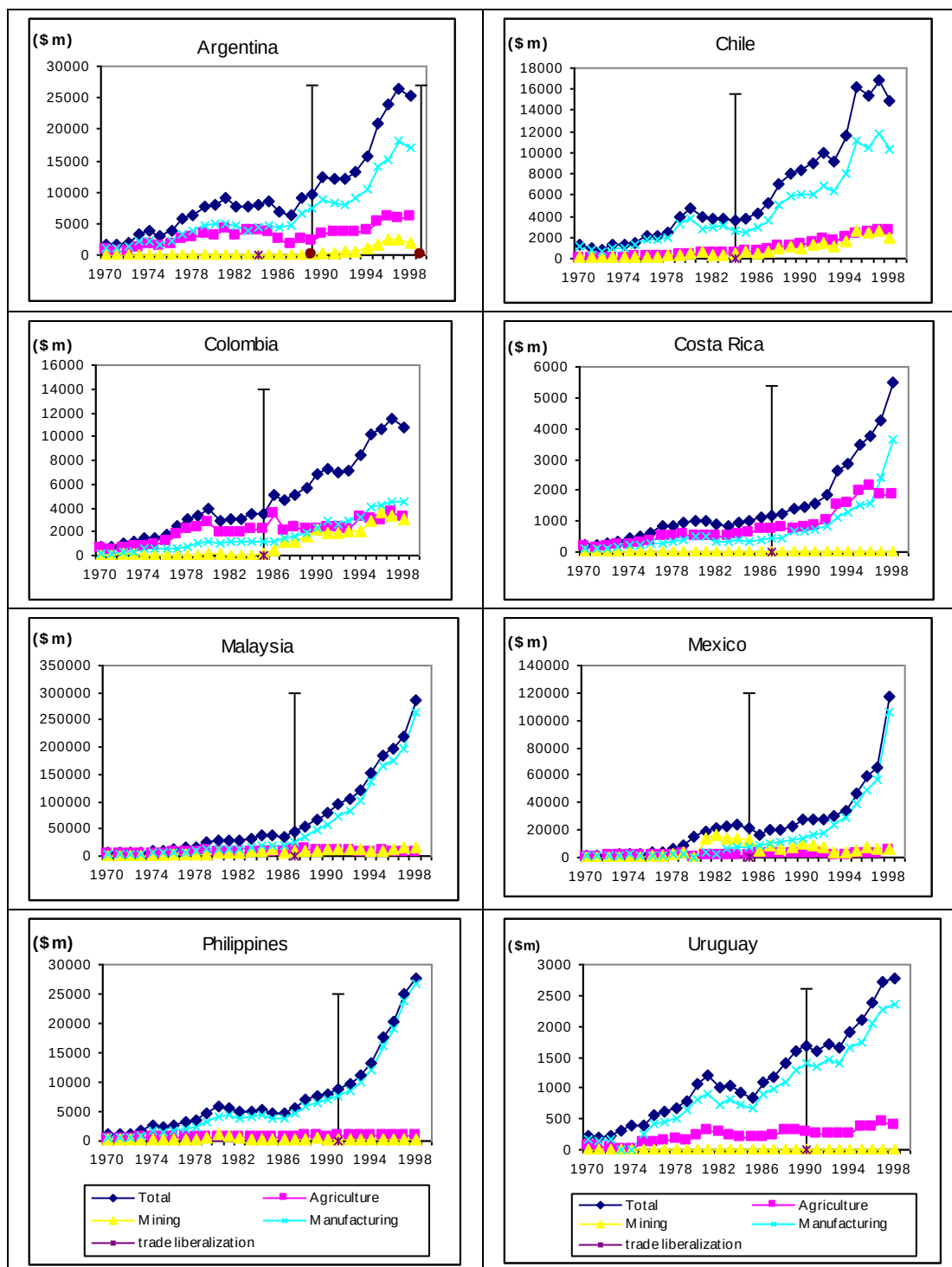


Figure B2. Composition of Exports-Agriculture, Mining, and Manufacturing

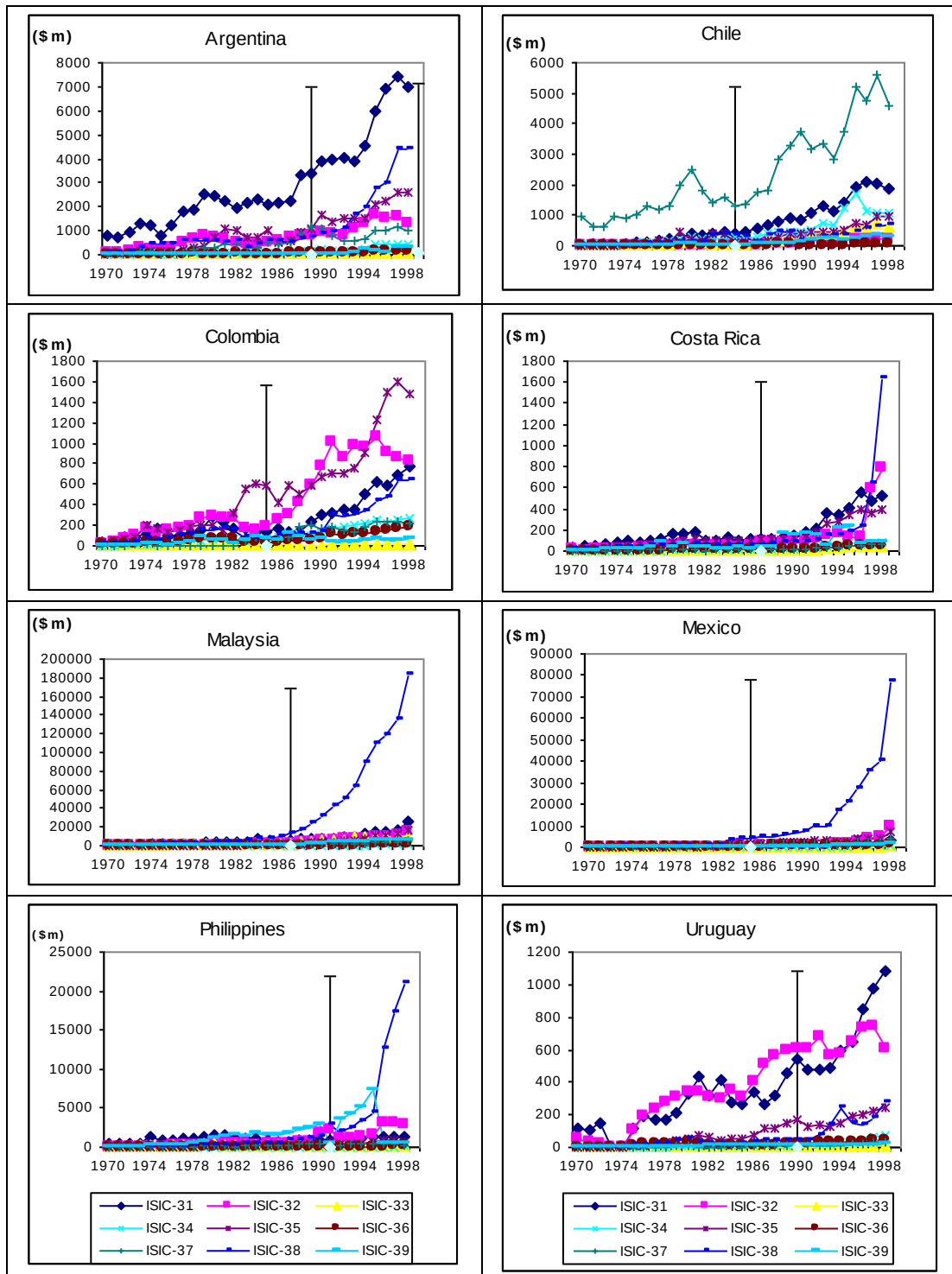


Figure B3. Composition of Manufactured Exports (2-Digit ISIC)

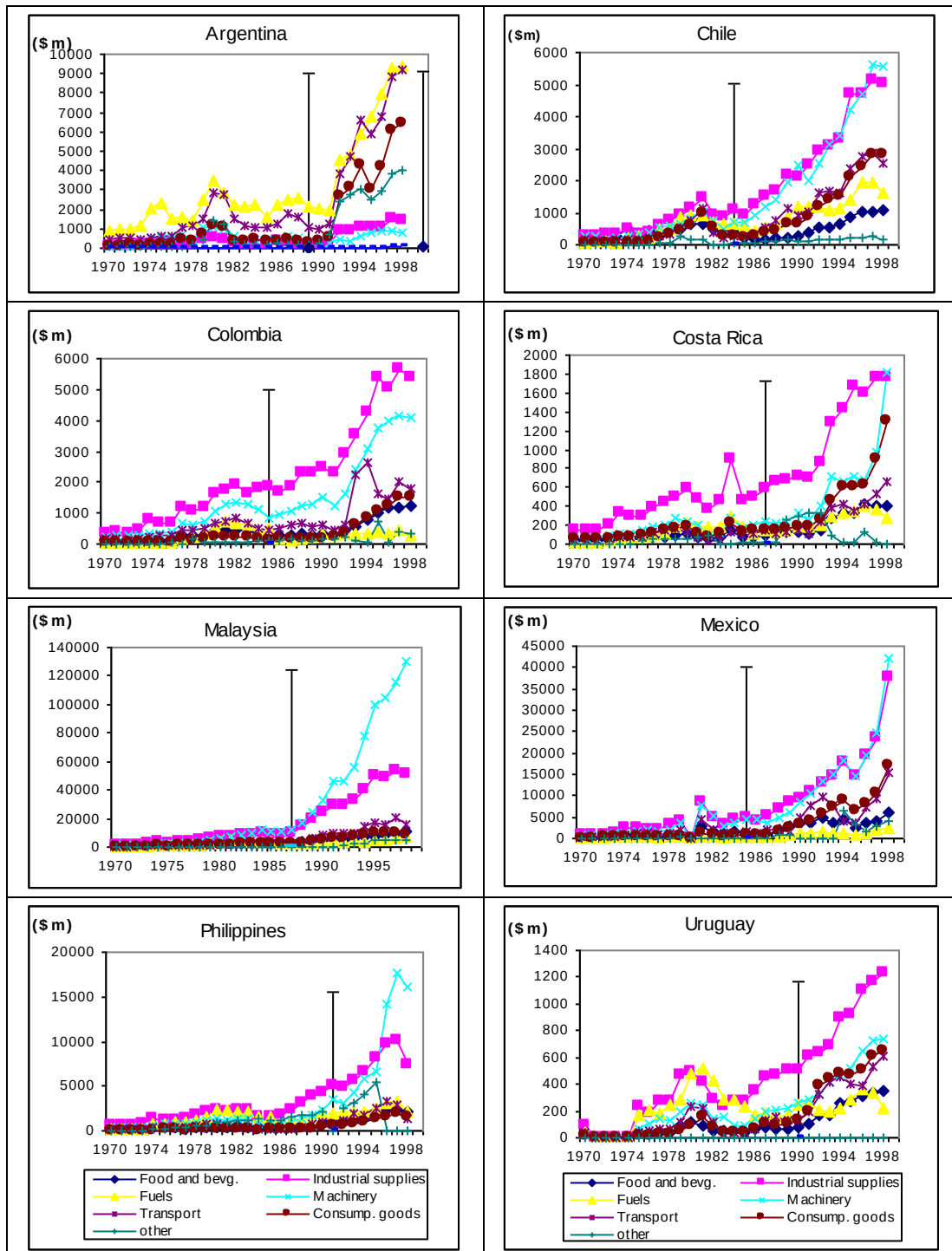


Figure B4. Imports in Broad Economic Categories

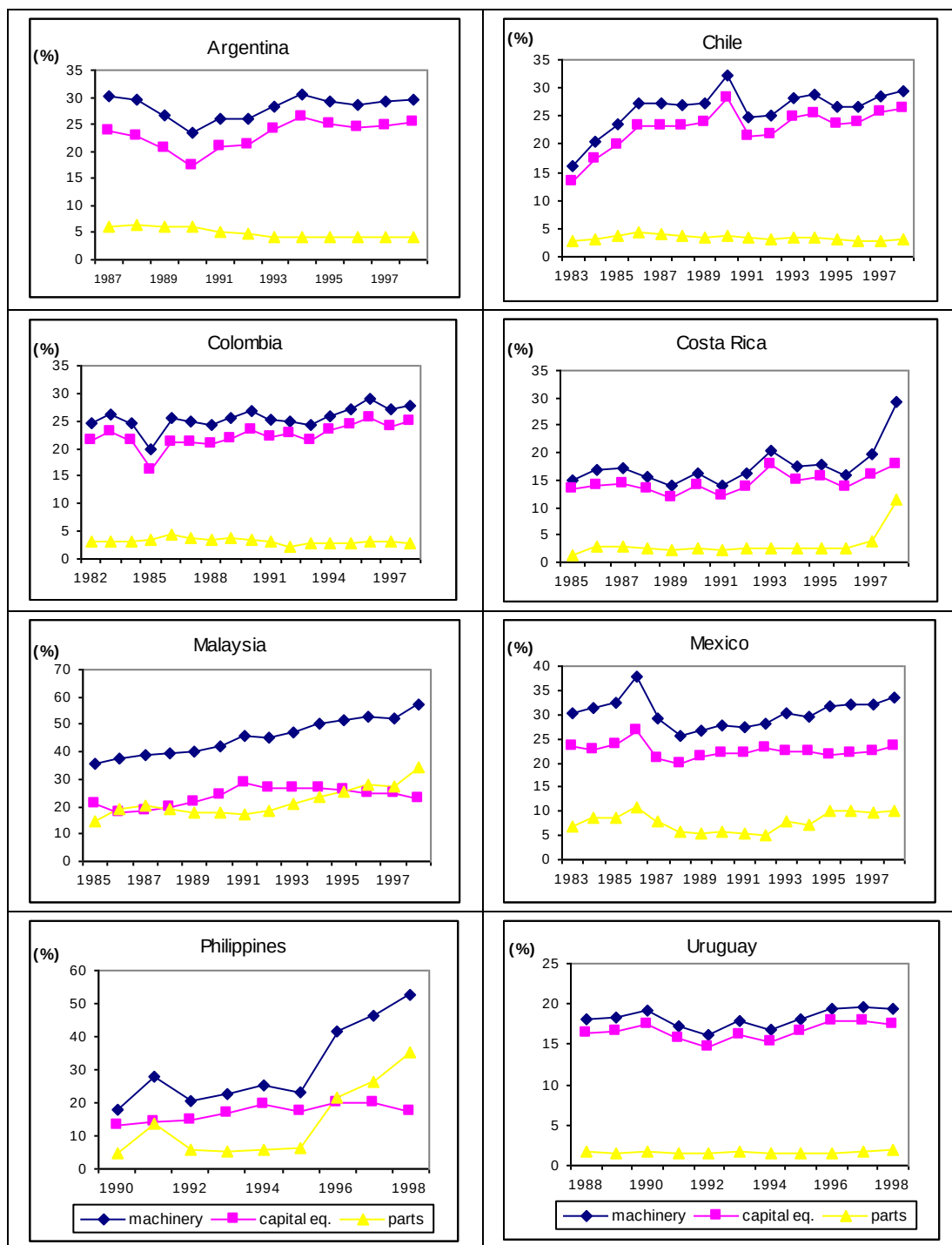


Figure B5. Composition of Machinery Imports

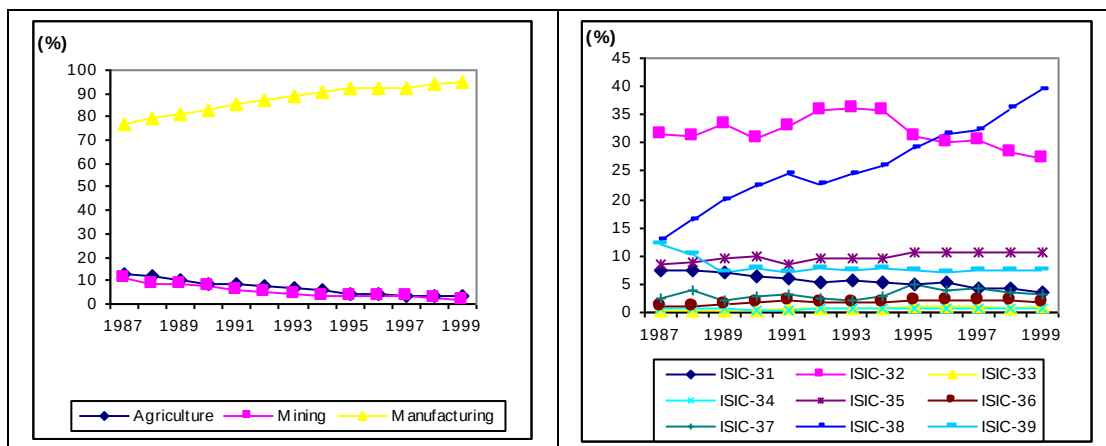


Figure B6. Composition of China's Exports

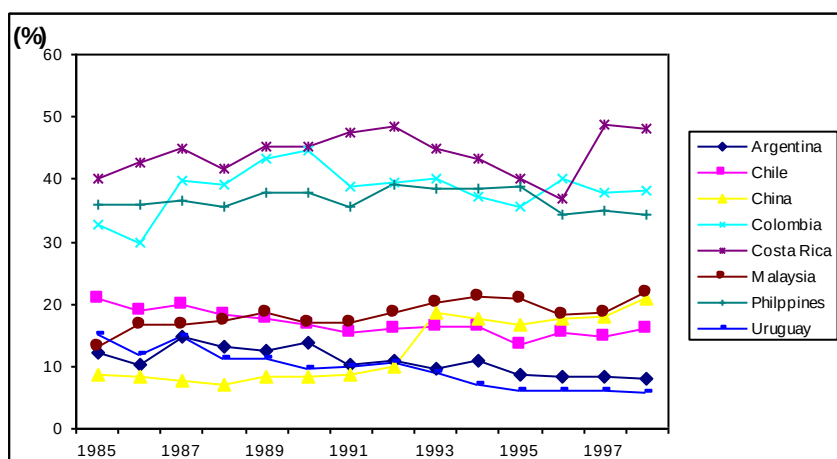


Figure B7. The U.S. Share in Exports of Countries in the Sample

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