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Foreign Direct Investment and Total Factor Productivity in the Mining Sector: the Case of Chile

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Abstract

This thesis investigates the impact of Foreign Direct Investment (FDI) on the Total Factor Productivity (TFP) in the Mining Sector of Chile. We use the Solow model and developed a Cobb-Douglas production function to estimate total output as a function of labor, capital and productivity. Hence, TFP is the portion of output that is not attributed to labor or capital and it is derived as the Solow 'residual'. We estimate the capital variable as a function of capital stock corrected for depreciation and utilization rate. We derive the labor variable as a function of hours worked corrected for quality (education premium). We find that FDI is positively correlated with TFP and it is statistically significant in most cases. The relation is more significant when the variations in the price of copper are included in the regression.

I. Chapter 1: Introduction

1) Background and subject overview

The neo-liberal model of growth applied throughout the world is the most wide-spread economic model mainly because results are substantial and tangible. Yet, there is no pre-conceived formula and every country has its own set of conditions that need to be accommodated. In the 1990s, Latin American countries started to liberalize foreign trade and investment that were to fuel growth and development. In Chile, the country had just returned to democracy after almost twenty years of dictatorship under the General Augusto Pinochet.

Chile implemented neo-liberal policies such as privatizations and other reforms even before two of the strongest advocates of neoliberalism Margaret Thatcher and Ronald Regan became Prime Minister of Great Britain (1979) and President of the United States (1981). One of the main reforms was trade openness and the flat tariff rate system. "In 1974 […] Chile started a profound process to reduce import tariffs. In 1979, a flat tariff of 10% (low for that time) was enacted for every import." (Büchi[1], 2006) Another major transformation was the privatization of weak state entreprises. "After [they] implemented a massive privatization plan that included more than 50000 new direct shareholders and several millions indirect (through pension funds) shareholders, these companies were managed by private entrepreneurs that carried out important expan-

[1] Hernan Büchi is a Chilean economist who was appointed Minister of Finance of Chile from 1985 to 1989

sion plans.” (Büchi, 2006) More importantly, Chile opened itself to foreign investment. The Foreign Investment Committee provisions were modified to accelerate the procedures for investment projects and tax breaks were offered to foreign investors. The question that arises from this observation is whether the massive inflows of monies positively contributed to the growth of the economy and to what extent.

Foreign investment in Chile grew rapidly. “Between 1974 and 2000, materialized foreign investment totaled US$ 52.4 billion. Of this amount, 83.4% entered the country after 1990. During the 1990s, FDI represented an annual average 6.4% of Chile’s GDP, rising to 8.3% between 1995 and 2000.”(Poniachik, 2002) Foreign investors were particularly attracted by Chile’s internal political stability, its sound economic policies and, more importantly, its abundance of quality minerals such as copper. About 34.1% of foreign investment that captures Chile goes directly to the mining sector, and more than half goes to copper. The annual investment in copper is about U.S. $ 4.4 billion. Copper accounts for about 1.5% of total employment and all the copper sector represents about 6% of GDP. Copper accounts for more than half of Chile´s total exports, and the sector has a meaningful state-owned participation despite Chile´s overall openness and market oriented economy. The copper production in volume of Chile over the last two decades has grown by about 150% (Fig.1).

Figure-1 Chile's refined copper production 1992-2011

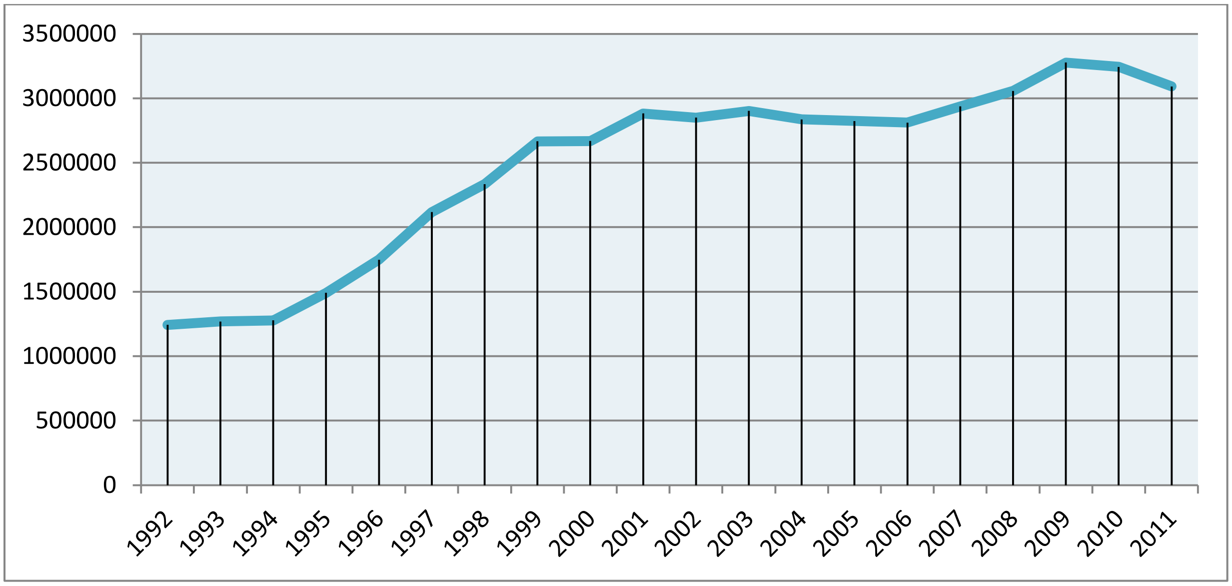
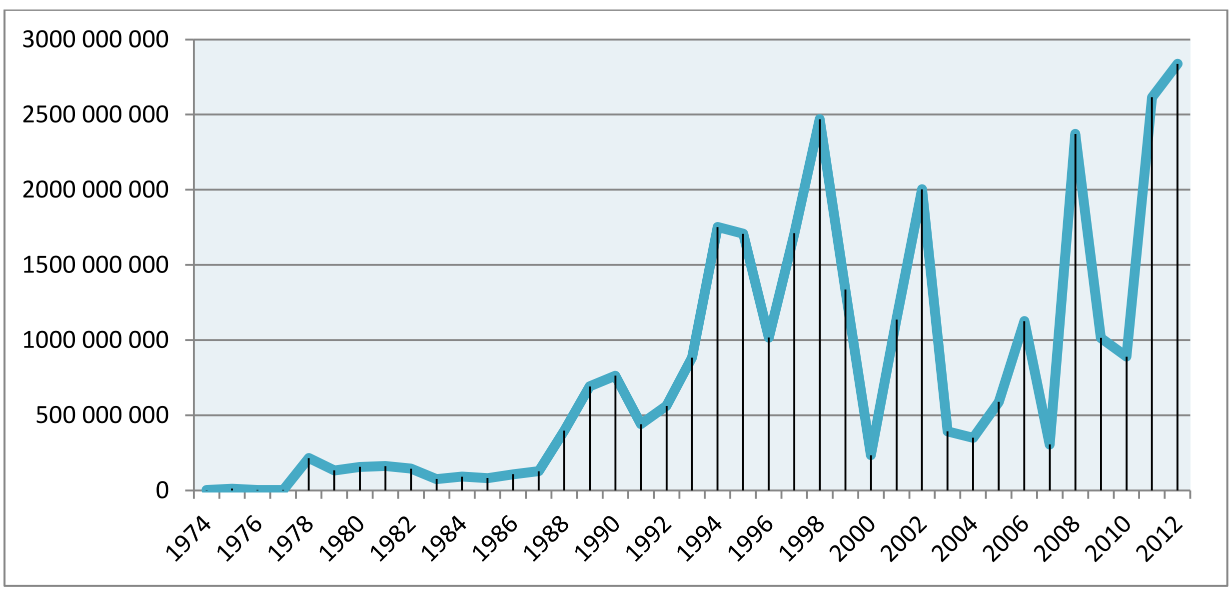
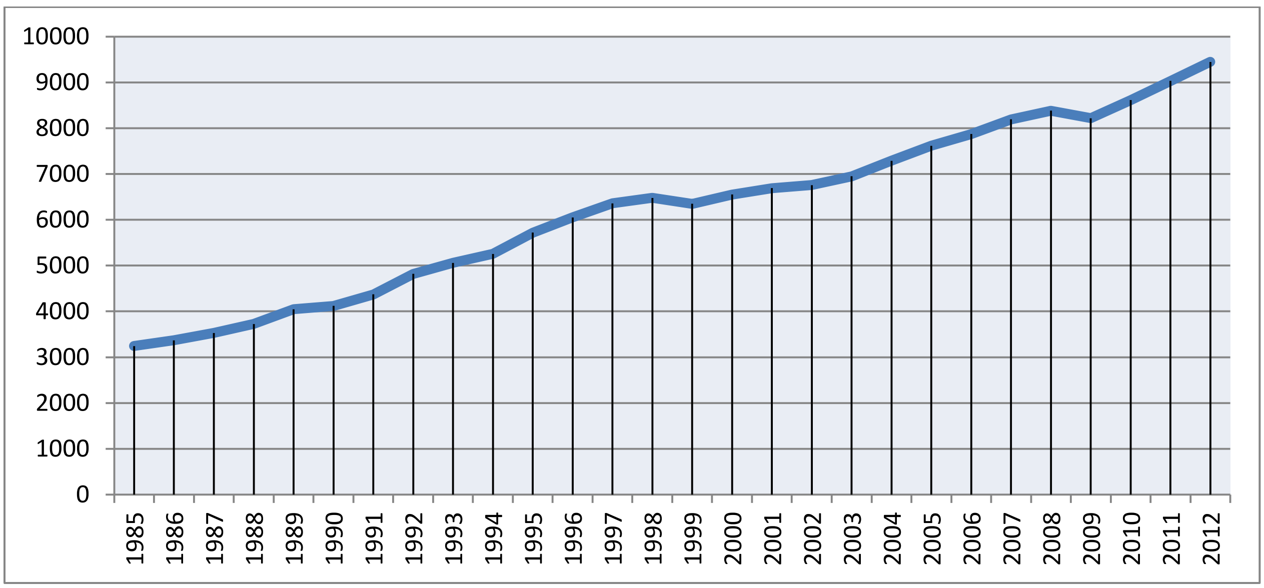


Figure 2 Materialized Foreign Investment 1974-2012



FDI in the mining sector has increased by over 900% in real terms since 1985 (Fig.2). This influx of monies certainly had a positive impact on the economy. During the same period, GDP per capita grew by about 191% (Fig.3). Although there is no certainty as to the extent to which FDI in the mining sector contributed to the economic growth, there is room to believe that it provided a boost to the economy because, admittedly, these investments notably expanded production capacity of the single most important export commodity.

Figure 3 GDP per capita (1985-2012)



Research on the macroeconomic effect of FDI on growth, however, has remained inconclusive thus far. Part of the reason is that scholars usually focus on FDI at the aggregate level without considering the differences across sectors. Indeed "the sectorial FDI structure in [Latin America] displays differences and the intensity of FDI (stock of FDI per employed) varies widely across sectors and over time."(Tondl & Fornero, 2008) FDI effects operate in three ways: a direct productivity within the host company, a horizontal productivity effect within the sector through pro-competitive effects and technological spillovers through backward and forward linkages. (Tondl & Fornero, 2008) Technology, in turn, is believed to be a key factor in a country/sector long-term growth. Since the macroeconomic effect of FDI is somewhat unclear, the purpose of this study is to understand the effect of FDI at the sector level. More specifically, the study investigates the effect of FDI on the Total Factor Productivity in the Chilean mining sector. In other words, how does FDI contribute to the efficiency/productivity of the mining sector in Chile and to what extent?

This study is relevant for several reasons. First, it will provide a framework for analyzing the impact of FDI on a sector's productivity gains. Therefore, it has policy implication as it is useful to target policies to a sector in order to enhance its growth if one knows how to channel economic resources efficiently. From a pragmatic perspective, foreign investment, if properly managed, can directly enhance welfare by improving the competitiveness of domestic industries, leading to higher national output. Examining the policy outcome can therefore help define the policy process, that is, the de-sign of strategies that may stimulate the best outcomes. In addition, this study will contribute to the literature on growth and development economics and shows how the openness of an economy impacts the productivity of its economic sectors. Economic openness in almost all developing countries is usually detrimental. In fact, with openness national firms have to compete with (often) better performing foreign firms. For openness to succeed, you must first put in place ports, roads and other building blocks for prosperity, and you need well-functioning bureaucracy to help build the foundation for a strong trade sector. All these factors are often lacking in developing countries. In addition, developing nations often face the Dutch disease which will hurt their exports in the long run. Surprisingly, economic openness worked in Chile enabling the country to gain competitive advantage in copper mining because Chile designed instruments to address the possibility of a Dutch disease and built a commodity stabilization reserve fund to hedge against price volatility. Building on the infrastructure – technological and of human capital – that had been promoted since the 1960s, Chile had managed to spur economic growth soon after it reconnected to the world market in the late 1970s. Academically, it is therefore a pertinent contribution.

2) Thesis statement

Total Factor Productivity (TFP) is the part of output that is not attributed to the use of capital and labor. In other words, TFP represents the efficiency with which the production inputs are utilized. The importance of TFP in economic growth is indisputable such that economists and policy makers prescribed policies that target the TFP in order to achieve durable economic growth. Scott L. Baier, Gerald P. Dwyer Jr. and Robert Tamura (2002) found that "over long periods of time, the growth of output per worker is associated with accumulation of physical and human capital and technological change." (Baier, Dwyer & Tamura, 2002) TFP reflects not just technology but also organizational innovations, improvements in the allocation of capital and labor, and returns to scale, for example. Technology and innovation constitute a big portion of TFP and FDI is said to positively contribute to such innovations by bringing in new technology, which results in knowledge spillovers and durable increase in the productivity. The purpose of this study is to examine the effect of FDI on TFP in the mining sector in Chile. This task will be accomplished by:

i. First elaborating a general theoretical model of TFP applicable at the sector level
ii. Estimating the TFP of the Chilean mining sector – using regression analysis - by deriving the 'Solow residual' from a production function relating output to production inputs such as capital and labor.
iii. Estimating the impact of FDI on TFP.

Throughout the analysis, the key hypothesis is that FDI, if properly invested, is positively correlated with TFP.

3) Research method

Research in social sciences such as Economics can take two forms. On the one hand, qualitative research uses theories, real case studies and social behaviors to support an argument. Quantitative research, on the other hand, uses models derived from mathematics usually supported by different statistical processes to establish relationship between variables and to support an argument.

This study relies more on the empirical analysis to show the link between TFP and FDI. A mathematical method is used to derive the productive inputs and the TFP and different regressions are conducted to determine the coefficients of the different variables. However, qualitative research in the form of literature review is used to support the theoretical foundation of the analysis.

4) Limitations of the research

A time series is a sequence of data points, measured typically at successive points in time spaced at uniform time intervals. Time series analysis comprises methods for analyzing data in order to extract meaningful statistics and other characteristics of the data. In order for time series analysis to provide the best and most meaningful results, however, a large number of data points are necessary. This study comprises data for at least 25 years, from 1985-2010. Therefore, the series is a sequence of 25 data points. Although it might be sufficient to determine meaningful coefficients and establish significant correlation claims, readers should be cautious in interpreting the results. If anything, the results of this study are significant only for the period studied and do not necessarily apply to other periods in the history of the Chilean mining sector. In fact, Chile underwent substantial changes in its economic policies over the past century. Going from a barter economy, an import-substitution model of development, to the implementation of neo-liberal economic strategies while going through several political jolts including socialist and military regimes, it is evident that those changes affected the economy in one way or another, and that data on these periods might prove to generate different results than this present study.

The data used in this study are retrieved from public sources including the Central Bank of Chile, the National Statistical Agency, various Chilean government institutions statistical database, and international sources. However, as in many developing countries, it is extremely difficult to gather data for some periods. In the study some data for some years were missing. We proceeded by different statistical methods including linear interpolation to fill in the blanks.

It is worth nothing that the TFP is not a variable that the Chilean Statistical agencies usually calculate. Therefore, before we proceed to the empirical analysis of the effect of FDI on TFP, the TFP needs to be estimated. The TFP is usually derived from a production function as a residual. The production function is the relationship between capital and labor and output. In this study, we also estimate these variables because they are also not calculated. These estimations are, therefore, based on several assumptions that may or may not need to be corrected.

5) Thesis organization

This study is organized as follows:

Chapter 2 is an extensive overview of the literature on TFP and the relationship with FDI. Economists have extensively argued over the sources of TFP increase. It is now indisputable that factors such as the introduction of new capital and higher human capital are contributing factors. However, the contribution of FDI on TFP variations and economic growth is also unclear. It is worth noting that very few scholars have investigated these topics at the sector level. Therefore, this work constitutes a contributing element to the literature.

Chapter 3 provides the theoretical models that support our empirical analysis. Here, two models are designed. The first model establishes the relationship between output, productive inputs and TFP. The second model relates TFP to FDI and other factors. Then, regressions are used to estimate the different coefficients needed for our analysis.

Chapter 4 provides a thorough description of the calculation methodology of some of the variables. These variables include the Effective Labor (EL), and the Capital Used (KU) variables. Finally, a time series analysis is used to test the relevance of the variable.

Chapter 5 concludes the study by providing policy recommendations to fortify the link between FDI and TFP and increase TFP more durably.

II. Chapter 2 –The Chilean Economy and Literature Review

1) Literature Review

> *"Today's policy literature is filled with extravagant claims about positive spillovers from FDI but the evidence is sobering" (Rodrik, 1999)*

The diffusion of technology is indisputably one of the major contributors to economic growth. The use of new technology, among other things, improves the efficiency with which the productive inputs are used. FDI certainly contributes to the diffusion of new technology. FDI "represents not simply a pure transfer of 'capital,' […] but the transfer of a 'package' in which capital, management, and new technology are all combined."(Findlay 1998) Essentially, FDI acts as a vehicle for knowledge transfer. This can occur through several channels. One is the imitation of foreign companies' technology by the local firms in the host country (Das, 1987; Wang & Blomstrom, 1992). Another one is the acquisition of knowledge by local workers when they are hired by FDI-firms because they receive training and gain new technology know-hows (Dasgupta, 2012; Fosfuri, Motta, & Røndee, 2001). Lastly, the competition with FDI-firms forces domestic firms to become more efficiency and increase productivity (Glass & Saggi, 1998).

Borensztein, De Gregorio, and Lee (1998) used a cross-country regressions framework to analyze the effect of FDI on economic growth and found that "FDI is an important vehicle for the transfer of technology, contributing relatively more to growth than domestic investment [but] FDI contributes to economic growth only when a sufficient absorptive capability of the advanced technologies is available in the host economy." (Borensztein, De Gregorio, and Lee, 1998) In other words, the intensity of the effect of FDI depends on the level of human capital and productivity that the host economy already had.

Findlay (1978) argues that FDI increases the rate of technical progress in the host country through a 'contagion' effect from the more advanced technology, management practices, etc. His theory is based on a two country-model where one country is the technology leader with more advanced technology and the second one a technology 'follower' which advances technologically by copying the technology of the leader. The wider the gap between the two countries the faster the follower will grow using the leader's technology.

Das (1987) assumes that technological transfer is costless and demonstrates that the presence of FDI-firms positively contributes to economic growth. Wang and Blomstrom (1992) relax the view that technological transfer is costless and show that the rate and modernity of technology transfer through multinationals is positively related to the learning investment of native firms (Wang & Blomstrom, 1992). This implies that firms need to devote a considerable amount of resources and efforts to learn the multinationals corporations (MNC) know-how. Otherwise, the MNC's new knowledge transferred will be used on outdated technology. In turn, the rate at which the new knowledge will affect productivity would be slower.

Fosfuri, Motta & Ronde (2001) constructed a model by which they argue that multinational enterprises can transfer advanced technology only after training domestic workers, especially domestic managers. Their idea is that these local trained managers could be hired by domestic firms and technological spillover might occur. In addition, “even when such spillovers do not take place, the host country welfare might improve because of the informational rent that trained managers receive by the MNE to prevent them from moving to a local firm.” (Fosturi, Motta & Ronde, 2001) Also, the authors found that “spillovers are the more likely to arise the more similar the technological levels of local firms and MNEs, and the lower the costs of training the local workforce.” (Fosturi, Motta & Ronde, 2001) This idea is similar to Borensztein, De Gregorio, and Lee (1998)’s that the effect of FDI on the TFP depends on the productivity that the firm already has.

Despite the abundance of evidence that suggest that FDI has a positive impact on productivity, other studies have reached mixed or inconclusive results (Rodrik, 1999; Contessi & Weinberger, 2009). Aitken and Harrison (1999) using firm-level panel data in the case of Venezuela, found that FDI has a crowding-out effect on domestic firms of the same industry. This challenges the idea of horizontal spillovers, that is, that domestic firms can benefit from FDI firms by acquiring some technological know-how (Fosturi, Motta & Ronde, 2001; Wang &Blomstrom, 1992). This usually occurs for MNCs, more productive and (often times) with better quality products, that seize a considerable portion of the market. In other words the crowding-out effect does not necessarily apply to the TFP of firms per se but more to the general output level and profit of domestic entities. Other studies have reported evidence that FDI actually "stimulates, or 'crowds in' domestic investment." (Borensztein, De Gregorio and Lee, 1998).

De la Porterie and Lichtenberg (2001) have investigated the presence of technological spillover of foreign new knowledge through channels such as FDI using OECD country level data and found an insignificant effect from FDI inflows (De la Porterie and Lichtenberg, 2001).

2) Overview of the Chilean Economy

In November 1970, Chile's Salvador Allende became the first Marxist-socialist president of a Latin American country to be democratically elected. Under his presidency, the Chilean government attempted to move the economy closer to socialism through populist measures that raised wages, fixed prices, expropriated and nationalized firms, and announced a comprehensive agrarian reform. These policies motivated a deterioration of the Chilean economy leading to a coup d'état in September 1973 by the General Augusto Pinochet. During the Pinochet's regime, under the ideological influence of the 'Chicago Boys'[2], the country adopted liberal economic programs which included privatizing state-owned companies, lowering taxes and tariffs, 'freeing' prices by eliminating government subsidies, and privatizing government social services such as health, edu-

[2] The Chicago Boys (c. 1970s) were a group of young male, mostly Chilean economists, the majority of whom trained at the Department of Economics of the University of Chicago under Milton Friedman and Arnold Harberger, or at its affiliate in the economics department at the Catholic University of Chile. "Chicago boys generally advocated widespread deregulation, privatization, and other free market policies for closely controlled economies. They rose to fame as leaders of the early reforms initiated in Chile during the rule of General Augusto Pinochet. Chicagoans were attacked partly because central planning and government controls were still advocated by economists in that region."(Becker, 1997)

cation and social security. However, contrary to neoliberal prescriptions, the regime retained the lucrative state owned mining company CODELCO which brings in about 30% of government income. Surprisingly, the policies promoted during the Pinochet's regime enabled the country to gain competitive advantage in copper mining, fisheries, and agro-industrial businesses. Building on the infrastructure – technological and of human capital – that had been promoted since the 1960s, Chile had managed to spur economic growth immediately after it was reconnected to the world market as soon as General Augusto Pinochet took office in 1973.

The Chilean economic reforms were strengthened after Patricio Aylwin took over from the military in 1990. Between 1990 and 2010, Chile's per capita incomes doubled thanks to exceptional economic growth averaging 5.5% a year (Fig. 3). The country became a dynamic participant in globalization and achieved an extraordinary expansion of infrastructure and public services as well as education coverage, housing, health care and social security.

The neoliberal model of development that advocates for more open markets makes countries exposed to international crisis and fluctuations. The Mexican crisis in 1994, the East Asian crisis in 1997, and the Brazilian and Russian crises in 1998 and their contagion effects slowed down economic activity in the world including Latin America. Annual GDP growth fell from an average of 3.6% (1991-97) to 1.3% (1998-2002) and to -.5% in 2003. In the same periods, Chile's GDP growth fell from 7.5% to 2.6%, to 1.8% in 2003, also partly due to tight monetary policy to keep the current account deficit in check. In addition to the East Asian crisis, Europe had just faced the breakdown of the Soviet Union and was restructuring its economy, the US underwent a recession, and Latin American economies were inflated. Much of the Chilean economy heavily relied on exports and international demand dramatically decreased. However, since 2000, Chile has enjoyed an annual GDP growth average of 3.9% and inflation was kept at an average of about 5%.

According to a recent World Bank assessment, Chile faces two key challenges. "The first is to enhance productivity [as] productivity growth and investment levels experienced a downward trend throughout the past decade."(World Bank, 2013) Tackling inequality is the second challenge that Chile faces. As mentioned above, Chile has one of the highest levels of inequality in the region even though the government managed to considerably reduce poverty (15% in 2009). "The average income of the richest 20% was 14.5 times that of the poorest 20% in 2009. Although Chile has actively invested in social protection programs, middle- and low-income households remain vulnerable to crises." (World Bank, 2013) The government established goals to achieve and plans to emphasize three strategic areas during 2010-2014: "Achieve greater competitiveness, including the modernization of the state; increase job creation and improve job quality; and promote investment. The government is also committed to strengthening social policies and protecting the environment."(World Bank, 2013) In other words, even though there is nothing alarming about the Chilean economic health, it still needs to address challenges namely moving up the value added ladder; that is Chile needs to further industrialize its economy and boost the manufacturing sector.

3) Chile and TFP

A country needs productivity growth to keep growing economically. Chile enjoyed high economic growth (5-7%) for over a decade thanks to economic reforms implemented during the 1980s and 1990s, aimed at liberalization and the creation of a real market economy. Chile's economic success "is associated with the application of sensible economic policies and the existence of a sound institutional environment."(Vergara[3], 2005) In the last twenty years, however, Chile has experienced an economic slowdown. "There were six consecutive years of modest average growth in Chile (about three percent on average per annum from 1998 to 2003). Although this is not as low as in other Latin American countries, it is quite a poor record when compared to the recent economic performance of Chile and has opened a debate on what must be done to return to a high-growth path."(Vergara, 2005) In fact, "if economic growth is viewed not as a linear process, but rather as one marked by sporadic productivity shocks that lead to high growth for a period before fading in convergence until the next productivity boost, then Chile would currently be in a phase in which the most recent productivity shock is contributing its last ammunition." (Beyer and Vergara, 2002) According to UNIDO estimates, TFP only grew on average by 1.1% between 1962 and 2000. The TFP growth in Chile is characterized by high volatility certainly due the business cycles. Usually, high TFP growth periods are correlated with high economic growth with some lagged effect. Yet, this is not true all the time. For instance, "average GDP growth in between 1966

[3] Rodrigo Vergara is a Chilean and Harvard University-educated economist and currently the Chairman of the Chilean Central Bank.

and 1970 was 5.4% and TFP grew 5.3%, on average, in the same period. From 1971 to 1975 both variables showed negative growth rates and only in two sub-periods in this sample do TFP and GDP growth rates diverge." (Beyer & Vergara, 2002) The data on Chile presents an incomprehensible downward sloping TFP trend. Table 2 show recent TFP growth estimates. In 2010, TFP decreased by 1.6%, and recovered by 1.3% in 2011. In 2012, the growth was estimated at .2% when GDP grew by 3% in the same period.

Table-1 Chile TFP Growth (UNIDO Data)[4]

1962 - 1965	-0.3
1966 - 1970	5.3
1971 - 1975	-1.0
1976 - 1980	5.3
1981 - 1985	-2.1
1986 - 1990	-1.1
1991 - 1995	1.9
1996 - 2000	0.3
1962 - 2000	1.1

[4] Vergara, 2005

Table 2 – Chile TFP Growth 1996 - 2012[5]

1996-2005	*2006-2010*	*2010*	*2011*	*2012*
-1.1	*-1.8*	*-1.6*	*1.3*	*0.2*

Some economists and policymakers have attributed the decline in productivity to the cyclical nature of TFP. The Solow model demonstrates that factor accumulation can drive economic growth but not permanently. If we assume that economic growth is succession of productivity shocks, then there will be periods when productivity is high and low. Others have attributed the decline to structural weaknesses. "Product market competition remains weak by OECD standards, as suggested by high price-cost margins."(Schwellnus[6], 2010) Furthermore, "existing framework conditions do not encourage entrepreneurial risk-taking and the reallocation of production to new and higher-productivity activities."(Schwellnus, 2010) Chile's innovation policies always favored basic public research over business innovation[7]. Therefore, "both rates of technological (product and process) and non-technological (marketing and organization) innovation in firms remain low and production remains concentrated in low-productivity activities." (Schwellnus, 2010) The lack of a specific R&D policy has been frequently mentioned as one of the weaknesses of the Chilean economy. Chile spends 0.5% of GDP on R&D compared with the world average of 1.3%. "Chile's expenditure in R&D is not on-

[5] Vergara, 2005
[6] The paper was originally produced for the 2009 OECD Economic Survey of Chile, published in January 2010 under the authority of Economic and Development Review Committee of the OECD.
[7] This trend has been reversed in the last five years with the development of projects promoted by CORFO, the Chilean government agency with the aim of developing innovation and entrepreneurship.

ly lower than the world average, but also below that of industrial countries and that of East Asian countries."(Vergara, 2005) Therefore, Chile would benefit if more resources were devoted to R&D.

However, physical capital is one of the strengths of the Chilean economy. "Fixed capital investment increased from less than 15% of GDP in the mid-eighties after the recession of 1982-83 to over 27% of GDP in the mid-nineties."(Vergara, 2005) However, as shown by the downward sloping trend of the TFP growth, the contribution of capital is not significant enough to reverse the trend.

As mentioned earlier, Chile social inequality is a problem. The GINI index[8] of the country has been over .5 for the last two decades. "Widespread income inequality can create social tensions that hamper productivity growth."(Vergara, 2005) In fact, income inequality is a leading factor of civil unrest and political instability. This, in turn, interrupts economic activities which hamper productivity growth. However, tackling income inequality is very difficult but the government, through development projects that promote entrepreneurship and innovation, attempts to improve the living conditions of people outside urban areas. The low female participation in the labor force is also a weakness of the country. As a matter of fact, "productivity gains from women's inclusion in the labor market come from the variety of ways women bring added value to their workplaces, including their high education levels and alternative labor practices. More broadly, equality of employment opportunities for men and women is associated

[8] The Gini index coefficient measures income inequality. A Gini coefficient of 0 expresses perfect equality (everyone has the same income). A Gini coefficient of 1 (or 100%) expresses maximal inequality (1 person has all income)

with poverty reduction and higher GDP levels."(IFC[9], 2013) The issue of female participation is further complicated as it is also a political issue.

4) Mining Sector and TFP

The mining industry has been the leading economic sector for the last eighty years. The 1990s marked the beginning of a boom in Chile's mining industry, especially in copper mining, principally due to FDI in the sector, and steady and high demand from China ("the China effect"). In this time period Chile had one of the fastest growing economies in the world and mining accounted for 8.5% of the GDP and 47% of exports.[10] Chile has become the copper mining capital of the world, producing over 1/3 of the global copper output. In 2005, the production value of both nonferrous and ferrous minerals was $24.4 billion; Copper ($19.6 billion), followed by molybdenum ($3.5 billion), gold ($566 million) and iron ore ($352 million).[11] Also, Chile's National Copper Corporation, Codelco, is the world's largest copper-producing company, refining 2,187 metric tons of fine copper in 2006 alone. Along with its status as the largest producer of copper, Codelco is also known to have the largest copper reserves in the world, numbering about 77 million metric tons and representing about 20% of total reserves worldwide.[12] According to the Foreign Investment Committee of Chile, mining is the largest recipient sector of FDI. This is not only due to the size and prestige of Chile's

[9] International Finance Corporation
[10] Source: Encyclopedia of the Nations
[11] Source: Swedish Trade Council
[12] Source: CODELCO

mining sector, but also to the legal environment surrounding the industry. The Chilean government strongly supports foreign investment in the sector and has modified its mining industry laws and regulations to create a favorable investment and business environment for foreigners[13].

The mining sector faces challenges that include the aging of the mines contributing to lower ore grades, deeper mines, and longer hauling distances. In addition, new projects will require an increase in the workforce in the future. Chile should therefore invest in training. The 'environmental awareness' is and will be a big problem in the future, especially for the energy generation projects.

Several studies have investigated the evolution of sectorial TFP. In the case of the mining industry, the difficulty resides in the estimation of the stock of capital. However, there is some evidence that the mining sector productivity has been declining for the past 7 years. A recent study by CORFO – the Chilean Development Agency – and the University Adolfo Ibanez reveals that the mining sector productivity has been growing at a rate below 0% since 2005. This realization is counter intuitive giving that the industry is the largest recipient of foreign investment. A possible explanation of this situation is that R&D is not heavily promoted in the mining sector. In addition, the aging of the Chilean mines resulted in the decrease of productivity. "Aging copper mines and geopolitical risk provide a "challenging" environment for global mining companies."(Craze & Woods, 2011) The remaining sections of this research will examine the impact of FDI on the mining sector.

[13] Source: The Chilean-American Chamber of Commerce - http://www.amchamchile.cl

Figure 4 Evolution of the TFP of the mining sector, 1985-2011

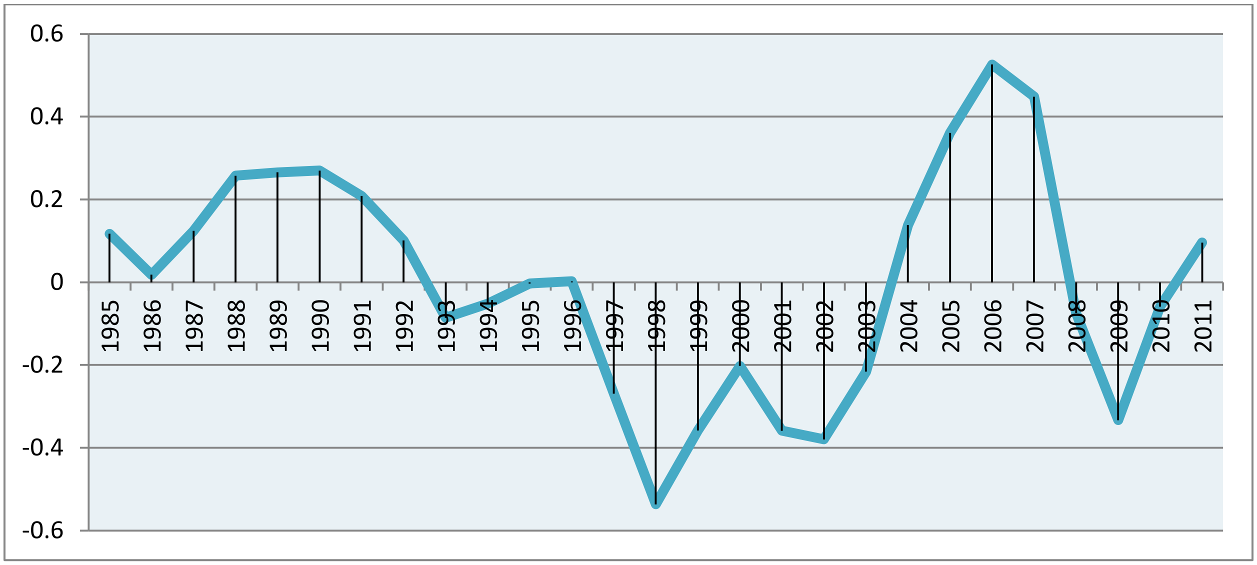
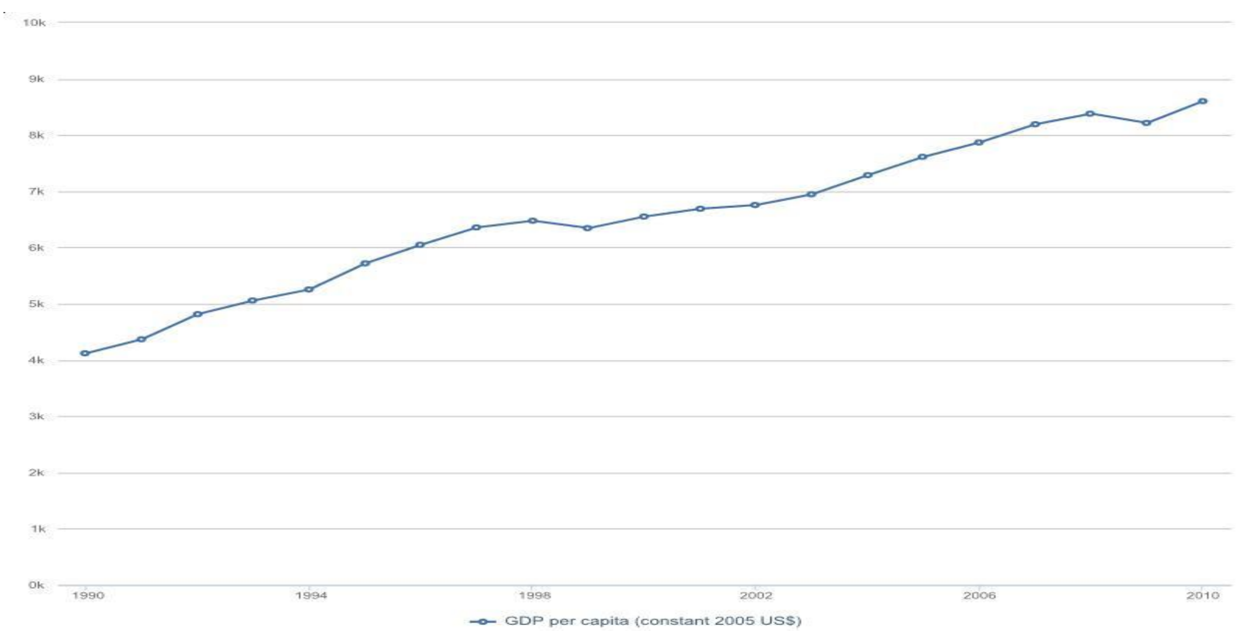


Figure 5 Per Capita GDP Growth 1990 - 2010



5) Conclusion

The Chilean economy had its golden era (1980s, 90s) but recent trends have shown that this era is coming to an end. Productivity growth is also declining. Experts suggest that new policies in promoting innovation and an increase in investment in R&D are necessary measures to bring about a new wave of productivity growth. Income inequalities as well as the low female participation in the labor force also contribute to the worsening of TFP growth. In the case of the mining sector, although it presents tremendous potential for growth, it faces several challenges including the aging of the mines and a need for more qualified labor. TFP at the sector level is also declining despite the fact that mining is the largest recipient of FDI. The lack of data – especially on capital stock – makes the calculation of the TFP at the mining sector very problematic. The remaining of this paper will consist of elaborating the theoretical models that capture the role of TFP in sectorial growth before we proceed to estimating the TFP and examining the contribution of FDI.

III. Chapter 3 - The theoretical model

Every day in the media there is always news pertaining to economic growth. The term commonly refers to the percentage rate of increase in real Gross Domestic Product (GDP). GDP is the market value of final goods and services produced and sold by a country in a given time period. It is an important factor to evaluate the economic state of a country: the higher the GDP of a country, the better its economic state. In other words, economic growth measures how much the market value of a country's production increased from the previous time period. Not surprisingly, policy makers and economists are very interested in economic growth because it directly impacts the living conditions of the people. As a matter of fact, an improvement in people's living conditions is usually measured by the per-capita income growth; which is a function of economic growth and population growth. Therefore a sustainable economic growth rate higher than a population growth rate will bring higher standards of living.

However, some countries have higher economic growth than others and it is unclear what the reasons for such differences are. Similarly, differences in country's incomes are very wide. With this in mind, Nobel-Prize-winning economist Robert Solow developed a model in 1956. The Solow model is simple because it focuses on a single dimension along which countries may differ from each other or along which a single country may change over time: namely, the amount of physical capital that each worker has to work with.

Since economic growth is directly related to the country's production, it is necessary to set up a production function. A production function is used in microeconomics to measure how the inputs that a firm uses are transformed into output. Inputs are also called factors of production. This same principle can be applied at the country level with output as the total GDP/income/production. .

1) The Solow growth model

The Solow model of economic growth is an attempt to explain the long run economic improvement of an economy. The Solow model is concerned with the long term growth and assumes that the economy is at full employment. Consequently short term variations in the economy do not affect the outcomes of the model because countries will eventually converge to their long term economic path. In order to illustrate the model, let's assume a production function with production as a function of labor and capital.

$$Y = A\ F\ (L, K) \qquad (1)$$

where A is technical efficiency or productivity, L and K are labor and capital inputs respectively. The Solow model can apply to any standard production function. However, for the sake of simplicity and concreteness, let's use the production function in the Cobb-Douglas form:

$$Y_t = A\ K_t^{\alpha}\ L_t^{1-\alpha}\ ,\ 0 < a < 1 \qquad (2),$$

where α and (1-α) are the shares of inputs.

Note that an increase in A will also increase Y, the total output, without an increase in any other input (K and L). For now we assume that the main factors of production are Labor and Capital.

Many economists refer to an increase in *A* as technological progress or total factor productivity. In other words, an improvement in technology will increase the total output with the same amount of inputs. Productivity is also positively affected by the skill level of workers because, as their skills increase, workers are able to produce better output. Also, studies on TFP show that an increase in foreign investment in a country would increase total factor productivity as the inputs provided by the investment will be technologically more advanced. Political stability and the level of competition also increase productivity. Natural calamities on the other side decrease productivity as they might lead to lesser outputs for the same inputs. These factors do not directly impact the productivity level, but rather affect the output level which in turn affects the TFP.

The model is based on two main assumptions that are worth keeping in mind.

First, the production function assumes a constant return to scale ($a + (1 - a) = 1$ and $a<1$) which means that if we multiply the inputs by some factor, the output will increase by the same factor.

$$F(zK, zL) = zF(K, L),$$

with z being the factor by which the inputs and the output increased and $z > 0$.

The second assumption is that there is decreasing marginal returns to factor accumulation. The marginal product of a particular input is the additional output produced when one unit of the input is used in production. The assumption signifies that when equal quantities of one variable factor are increased, while other factor inputs remain constant, a point is reached beyond which the addition of one more unit of the variable factor will result in a diminishing rate of return and the marginal physical product will fall. Let’s take the example of the marginal product of capital:

$$\frac{\partial Y}{\partial K} = \alpha A\, K_t^{\alpha-1}\, L_t^{1-\alpha}\,,$$

taking the second derivative of (Y/K), we obtain:

$$\frac{\partial 2Y}{\partial K} = \alpha(\alpha-1)A\, K_t^{\alpha-2}\, L_t^{1-\alpha} < 0 \text{ and } (\alpha-1) < 0$$

The derivative being negative, the equation shows that an extra unit of capital will raise the output. However, if capital is added without an increase in labor the increase in output with slow down. Let’s consider the example of a change in labor.

Let’s consider 10 people working in an assembling factory with 10 machines who are able to produce 10 assembled cell phones per day (100 phones in total every day). If the company hires 1 additional workers, 11 people will be working with 10 machines and produce 10 cell phones each as they are sharing the same machines (= 110 phones). In other words an additional worker produced an additional 10 phones per day: a 10% increase in the labor increase output by 10%. If we add 1 worker (a 9% increase) they will be able to produce 8 cell phones because they are sharing the same amount of capital.

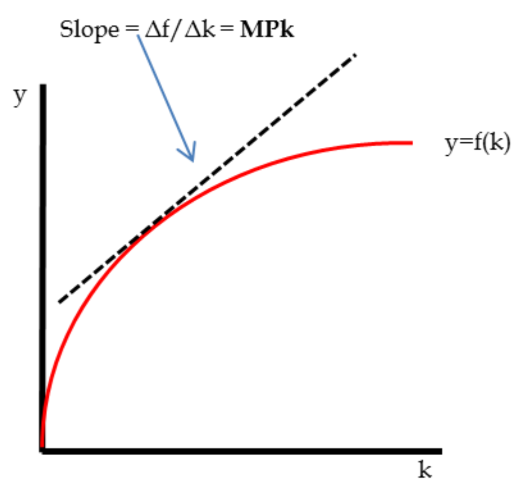
(96 phones, 12% decrease). In other words, the law of diminishing marginal productivity kicks in where it is inefficient to use additional labor because it will lead to a decrease in output.

It is best to write the Cobb-Douglas production function in per worker term because it eliminates the effect of labor growth and yields a more accurate measure of productivity. For that, we divide both sides of the equation by L (labor):

$$y = \frac{Y}{L} = \frac{F(K,L)}{L} = F\left(\frac{K}{L}, \frac{L}{L}\right) = A\left(\frac{K}{L}\right)^{a}\left(\frac{L}{L}\right)^{1-a} = Ak^{a} \qquad (3)$$

with y being output per worker, A remains factor of productivity and k, the amount of capital per worker. Keep in mind that the Solow model is an attempt to explain differences in income among countries. The model clearly demonstrates the importance of physical capital in explaining these differences.

Figure 6 Per-worker Production Function



This function is the relationship between aggregate output per worker and capital per worker determined by the constant-returns-to-scale production function. The slope of the per-worker production function is the marginal product of capital, MPk. MPk is the additional output resulting, ceteris paribus, from the use of an additional unit of capital. It equates to 1 divided by the incremental capital-output ratio. It is the partial derivative of the production function with respect to capital.

The marginal product of an input is the extra output produced when an additional unit of input is used. In our case, MPk is the increase in output per worker resulting from adding one more unit of capital. In order words, output per worker increases if an addition unit of capital per worker is used in production:

$$MPk = f\,(k + 1) - f\,(k)$$

To illustrate the role of capital in output let's consider the Cobb-Douglass function and let's assume that labor and productivity are constant and output is only a function of the stock of capital. In other words, let's assume that $y= f\,(k)$; change in capital stock is a function of investment and depreciation. Investment refers to the goods and services that are used in the production process rather than consumption. Depreciation is the wearing-out process of capital. When capital is used, it wears out because of the passage of time, weather etc. Since depreciation helps determine the quantity of capital that is not usable, the change in capital will be determined by the amount of investment less the depreciation.

$$\Delta K = I - D$$

if we make i and d the quantities of investment and depreciation per worker the equation becomes as follows:

$$\Delta k = i - d$$

$i = \gamma y$, assuming that a fraction γ of output is invested

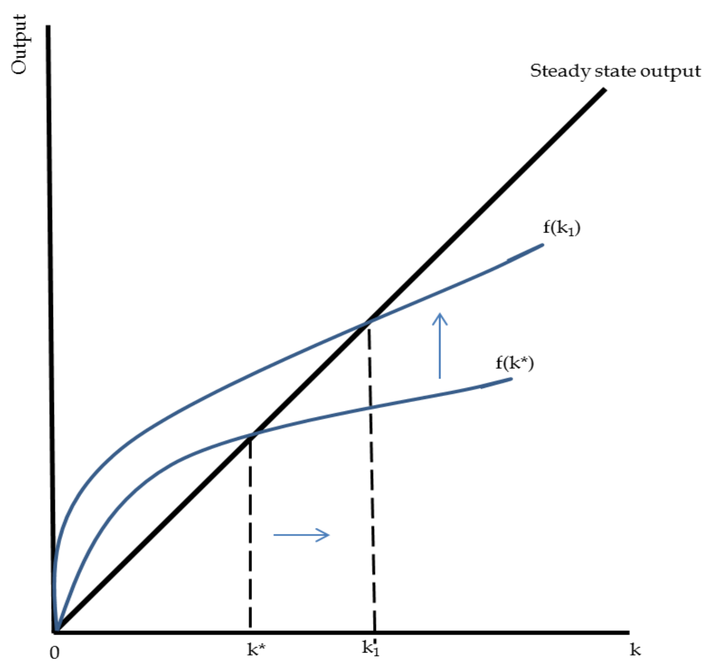
$d = \delta k$ assuming a fraction δ of the capital stock depreciate each period

Replacing the equation of investment and depreciation in the change of capital stock we get:

$$\Delta k = \gamma y - \delta k \qquad (4)$$

➔ $\Delta k = \gamma f(k) - \delta k$, since our initial assumption was that $y = f(k)$.

Figure 7- Investment and Capital

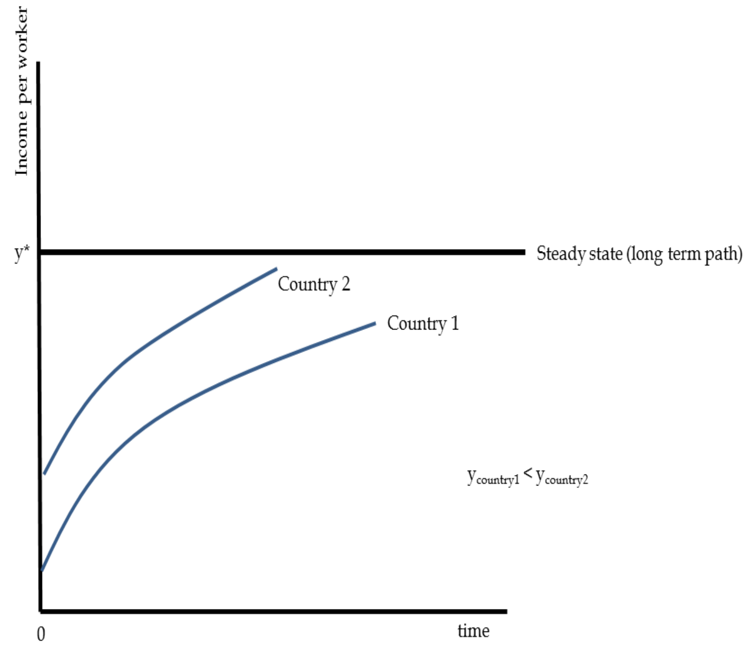


An increase in Investment leads to an increase the Capital from k* to k_1 increasing the output level from f(k*) to $f(k_1)$

This equation shows that as long as the level of investment $\gamma f(k)$ is larger than depreciation δk, the capital stock will increase and vice versa. Consequently if investment and depreciation are equal, the amount of capital stock will not change. This is called the steady-state. At a steady state, raising the rate of investment, γ, will raise the steady state level of output per worker and raising the rate of depreciation, δ, will lower the steady state level.

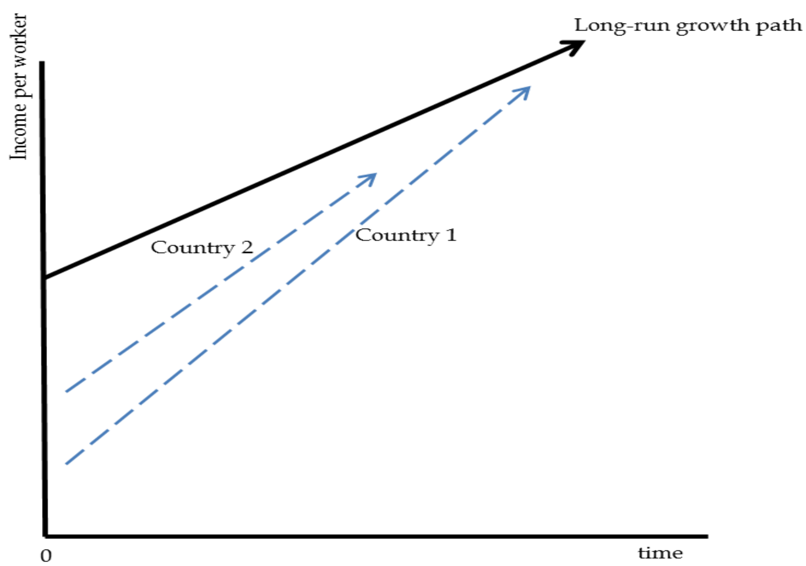
The Solow model presents a useful framework for understanding how a country can improve its level of production through the increase in capital. The convergence toward the steady state principle describes the process by which a country’s per worker output will grow or shrink from its initial level of output toward its steady state level determined by the investment rate. The hypothesis is that any given country can be viewed as converging to a balanced (steady) growth path and the distance from this balanced growth path will influence the economic growth rate of the country. Countries a long way below their steady-state path will show relatively fast growth, while countries a long way above their steady-state position will grow relatively slowly, and perhaps even see reductions in GDP per worker to reach the steady-state. More importantly the model tells us that in the short run, growth is possible through factor accumulation. However, the law of decreasing marginal product applies and in the long run growth can no longer be sustained through factor accumulation. This is when technology comes into play. As the effect of technological advancement is taken as exogenous, it is the only way to sustain growth in the long run.

Figure 8 - Long term growth path convergence



Two otherwise identical countries, one with lower income per worker ($y_{country1}$) than the other ($y_{country2}$), both converge in the long-run steady to the same level of income per worker

Figure 9 - Long-run growth path



The initially rich country and the initially poor country converge in the long run to the same long-run growth path, where aggregate output grows at a constant rate.

Productivity (expressed as A in the Cobb-Douglas production function) is the component of output that is not attributed to Labor and Capital. To understand the importance of productivity in output growth we can ask the following question: Why do some countries get less output from the same level of inputs as do other countries?

We demonstrated that a change in output is due to an increase in capital, when productivity and labor input remain constant. Now, let's make productivity a variable. The Cobb-Douglas production function in per worker terms is:

$$y = \frac{Y}{L} = \frac{F(K,L)}{L} = F\left(\frac{K}{L}, \frac{L}{L}\right) = A\left(\frac{K}{L}\right)^{a}\left(\frac{L}{L}\right)^{1-a} = Ak^{a} \qquad (3)$$

We can see that an increase in y is affected by two components now: Capital deepening and productivity. Similarly we can use the log principle to show the effect of productivity on the growth of output per worker.

$$log\ (Y_t) = log\ (A\ K_t^{\alpha}\ L_t^{1-\alpha}) \qquad (4)$$

$$= log\ (A_t) + log\ (K_t^{\alpha}) + log\ (L_t^{1-\alpha})$$

$$= log\ (A_t) + alog\ (K_t) + (1-\alpha)\ log\ (L_t) \qquad (5)$$

Now we can take the derivative of Y with respect to time, where the '.' denotes the derivatives

$$\frac{\dot{Y}t}{Yt} = \frac{\dot{A}t}{At} + a\frac{\dot{K}_t}{K_t} + (1-\alpha)\frac{\dot{L}_t}{L_t} \qquad (6)$$

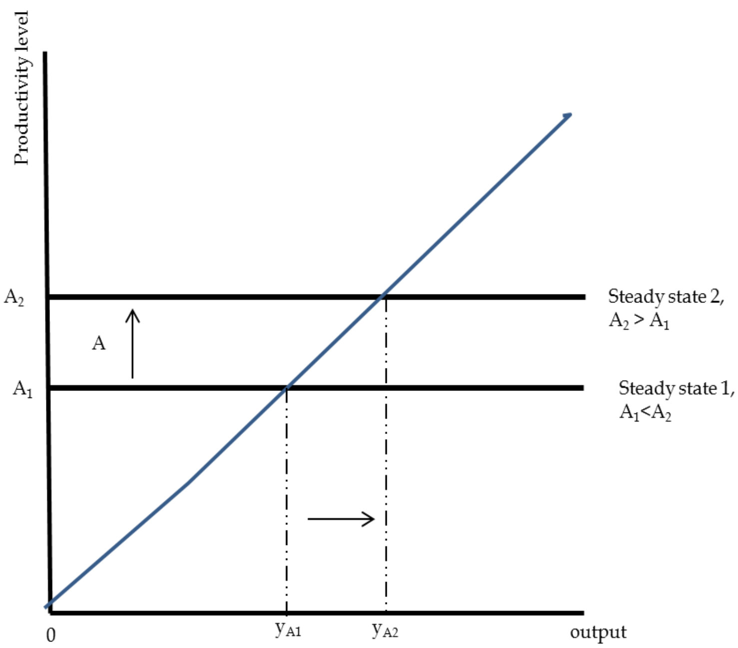
The growth rate of output in per worker terms is simply:

$$\frac{\dot{Y}t}{Yt} - \frac{\dot{L_t}}{L_t} = \frac{\dot{A}t}{At} + a\left(\frac{\dot{K_t}}{K_t} - \frac{\dot{L_t}}{L_t}\right) \quad (7)$$

where $\left(\frac{\dot{K_t}}{K_t} - \frac{\dot{L_t}}{L_t}\right)$ represent capital deepening.

What the equation (7) shows us is that the growth rate of output per worker is affected by capital deepening as we have shown before *and* the productivity growth.

Figure 10 - Increase in productivity



As the productivity A increases from A_1 to A_2, the steady state level of output increases and so does real output from y_{A1} to y_{A2}

2) Human Capital

Human capital refers to stock of competencies embodied in productive labor. Thus, it is an essential factor in output production. We can incorporate human capital in the

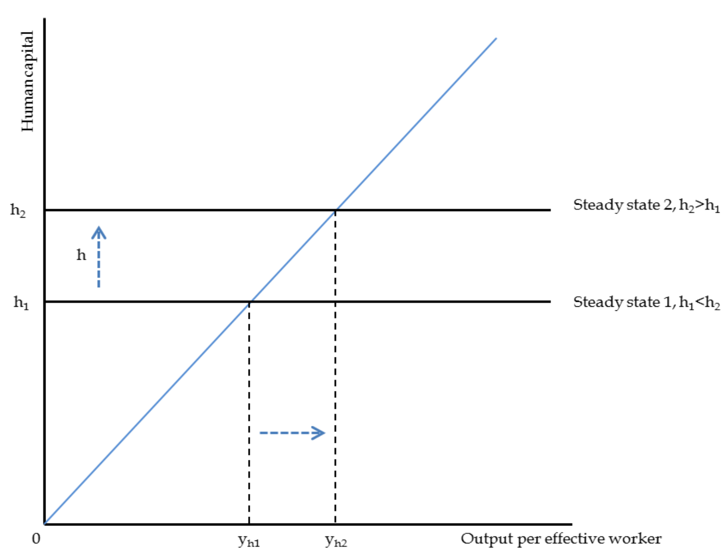
Solow model. Let's denote h, the human capital factor or the amount of labor input per worker. From (2) we can derive:

$$Y_t = A\, K_t^{\alpha}\, (hL)_t^{1-\alpha}$$

$$Y_t = h^{1-a} A K^{a} L^{1-a}$$

In the Solow model with human capital, economic growth can come from four sources, an increase in human capital, an increase in productivity, an increase in capital or an increase in labor. The approximate growth rate of output is the weighted average growth rates of h, A, K and L.

Figure 11 - Increase in Human Capital



An increase in human will lead to an increase in the output per effective worker.

3) How do we measure productivity?

Total Factor Productivity (TFP or A in the Cobb-Douglas production function) is also called the Solow residual because it is essentially what ‘is left over’ after having accounted for labor and capital in growth in. From (1):

$$Y_t = A\, K_t^{\alpha}\, L_t^{1-\alpha}$$

$$\therefore\ A = \frac{Yt}{K_t^{\alpha}\, L_t^{1-\alpha}}$$

To estimate the growth of productivity: From (6) we derive that:

$$\%\Delta Y_t = \%\Delta A_t + a\%\Delta K_t + (1-a)\ \%\Delta L_t \qquad (8)$$

In other words the percentage change in output is a function of the percentage changes of TFP, physical capital and labor. We can therefore mathematically derive the percentage change in TFP:

$$\%\Delta A_t = \%\Delta Y_t - (a\%\Delta K_t + (1-a)\ \%\Delta L_t) \qquad (9)$$

Note that $(a\%\Delta K_t + (1-a)\ \%\Delta L_t)$ is also the TFP because it encompasses the percentage change in capital and labor which is a measure of productivity. In other words, from (8) we can say that the percentage change in Y $(\%\Delta Y_t)$ is directly related to the change in TFP $(\%\Delta A_t)$

4) Econometric estimation

Since the TFP is the residual of the production function, it is found in the error term, ε, of the function.

$$lnY = \beta_0 + \beta_1 lnK + \beta_2\, lnL + \varepsilon$$

$$A = \varepsilon \text{ so,}$$

$$lnY = \beta_0 + \beta_1 lnK + \beta_2\, lnL + A,$$

where β_0 is a constant term, and β_1 and β_2 are the respective coefficients of capital stock and labor.

Ideally, according to the Solow model, A or the error term represents productivity. A change in productivity efficiency is directly related to technology. So through A we can derive the effect of technology on output.

However, the econometric estimation of the error term is far from ideal because in reality the error term may include a whole lot of other factors. As such, the model – thus, the result may suffer from several issues; one of them being the omitted variable bias.

5) Omitted variable bias

The omitted variable bias occurs when a model is created which incorrectly leaves out one or more important causal factors. The 'bias' is created when the model compensates for the missing factor by over- or underestimating the effect of one of the other factors. The bias can be derived mathematically.

Let the regression be as the following:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon$$

Now supposed X_2 is omitted from the equation, so we now have :

$$Y = \beta_0 + \beta_1 X_1 + \varepsilon^*$$

where $\varepsilon^* = \varepsilon + \beta_2 X_2$ as the omitted variable will now be included in the error term.

Now the estimator of β_1 *is:*

$$\widehat{\beta 1} = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sum(X-\bar{X})^2} = \frac{Cov(X,Y)}{Var(X)} .$$

Let's say $x = (X - \bar{X})$ and $y = (Y - \bar{Y})$.

The formula becomes:

$$\widehat{\beta 1} = \frac{\sum xy}{\sum x^2}$$

If the deviation form of the regression looks like the following*:*

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon^*;$$

plugging this into the last equation will give:

$$\widehat{\beta 1} = \frac{\sum x1(\beta 0 + \beta 1 x1 + \beta 2\, x2 + \varepsilon *)}{\sum x^2}$$

$$= \beta_1 + \beta_2 \frac{\sum x1x2}{\sum x1^2} + \frac{\sum x1\varepsilon *}{\sum x1^2}$$

If our estimator is unbiased we know that $E\,(\widehat{\beta 1}) = \beta_1$ now with the omitted variable

$$E(\widehat{\beta 1}) = \beta_1 + \beta_2\, E\,(\frac{\sum x1x2}{\sum x1^2})$$

where the bias = $\beta_2\, E\,(\frac{\sum x1x2}{\sum x1^2})$.

Clearly, if there is an omitted variable, the results from the regression will be misleading. Therefore, the TFP is sometimes overestimated because the error term includes some omitted variables. For instance, if a country moves its economic activities from agriculture to more productive sectors, aggregate TFP will increase – here we have an ambiguity between whether an increase in TFP leads to an increase in output or it is due to shifts in economic activities. Liberalization policies that increase competition also tend to have a positive impact on productivity. Also, an increase in demand also tends to increase the TFP because sales will have increased. Other factors that may influence TFP are frictions in financial markets, physical and human capital externalities, public expenditures or any other element that affect the aggregate productivity of the economy. In sum, the TFP calculated as the Solow residual poses a conceptual problem. Economists have focused on the share of technology in productivity in order to reduce the effect of this problem. That is, technological advancement has a much bigger impact on productivity than the other factors. The impact of technology is twofold. Technology is incorporated in capital for new capital contains new technology and also in the TFP. This should be taken into account when estimating the TFP, otherwise it will be overestimated. Furthermore there are lags in the processes of innovation, learning and implementation of technologies. Investment in new technologies today may have an impact in the future; therefore it cannot be factored in today's productivity because productivity will increase in the future.

In summary, the Solow residual is that part of output growth that cannot be attributed to the accumulation of capital and labor. There are a variety of factors that may contribute to output growth and hence the residual may be quite sizable.

6) Determinants of Total Factor Productivity

We developed the Cobb-Douglas production function to estimate total output as a function of labor, capital and productivity. Hence, TFP is the portion of output that is not attributed to labor or capital. We saw that in the short run, output can grow with capital deepening or factor accumulation. Overtime, however, output will reach its steady state where factor accumulation can no longer spur output growth. We then turned to the role of TFP to show that long term economic growth can be sustained by a growth in TFP.

We now turn to the components of productivity. Productivity is essentially composed of technology and efficiency. We can see how this is viable with an example: Imagine two farmers, with equal capital (a tractor each) with the same labor who produce the same output of wheat every year. Now suppose a technological breakthrough allows the tractor of farmer 1 to harvest twice the amount it harvested before (using an empowering fuel, for instance). Now farmer 1 produces twice the amount of output farmer 2 produces. However, they both still have the same labor and the same capital – the tractors stayed the same but one has a more powerful fuel. In this example, the fuel (technology) is the key to output growth. We can also imagine the two farmers with the same labor and capital but farmer 1 is working better or faster – this is efficiency – than farmer 2. In this case, farmer 1 would also end up producing more in a given period of time than farmer 2. Productivity is the effectiveness with which factors of production are converted into output and productivity growth stem from technological progress and efficiency improvement.

$$A = T * E,$$

where A is productivity, T, technology and E, efficiency.

An economy can technologically advance in two ways: either by creating new technology or imitating advanced technology from other countries. Creating new technologies requires investment in research which is the reason modern economies devote vast resources to research and development (R&D). Firms for instance, invest a lot in improving production processes in order to raise quality of the products or lower costs –this process is known as shop-floor R&D.

7) The role of technology

a) One country model

In order to examine the relationship between technology and growth, let's consider the example of one country.

Let's define the total labor force L, as being composed of the number of workers who are involved in producing output, L_Y and L_A the number of workers involved in creating new technologies:

$$L = L_Y + L_A \qquad (1)$$

Let's define γ_A as the fraction of the labor force engaging in R&D:

$$\gamma_A = \frac{L_A}{L}. \qquad (2)$$

Therefore the number of workers working in the production:

$$L_Y = L - L_A \qquad (3)$$

$$L_Y = (1 - \gamma_A)\, L \qquad (4)$$

We assume that labor is the only input in the production function and ignore the role of physical and human capital. Therefore total output is equal to labor involved in the production and productivity, A.

$$Y = AL_Y$$

From (4),

$$Y = A\,(1 - \gamma_A)\,L,$$

or in per-worker terms:

$$y = A\,(1 - \gamma_A) \qquad (5)$$

According to the equation, output per worker is higher when the productivity is higher and, for a given value of A, when a bigger fraction of the labor force is involved in the production. This means that output is higher when a smaller fraction of the labor force is involved in doing R&D, ceteris paribus. This conclusion seems paradoxical for more investment in R&D will improve productivity and hence spur higher output. However, note that when fewer people are involved in R&D, more output will be produced today – but will be lower in the future.

Let's now turn to productivity growth through technological progress. We assume that technological progress is a function of the labor involved in R&D; the growth rate of productivity $\hat{A}$ is equal:

$$\hat{A} = \frac{L_A}{\mu}, \; (6)$$

μ is the price of a new invention, measured in units of labor; it tells how much labor is required to achieve a given rate of productivity growth. The larger it is the more labor must be devoted to R&D to achieve a given rate of technological growth.

The equation can be rewritten as:

$$\hat{A} = \frac{L * \gamma_A}{\mu}$$

We assume that γ_A is constant and therefore from (5), we know that the level of output per worker, y, is proportional to the level of technology, A.

$$\hat{y} = \hat{A}$$

So,

$$\hat{y} = \hat{A} = \frac{L * \gamma_A}{\mu}$$

Growth will be higher if the cost of creating new technology, μ, is smaller.

Taking γ_A as a variable term, we see that an increase in γ_A also entails a decrease *(1- γ_A)*, the fraction of the labor force involved in the actual production. Consequently, output will fall.

In sum, investing more on R&D lowers output in the short run but raises the growth rate of output which will lead to an increase in output in the long term.

Thus, the bigger the labor force the larger the growth rate of technology because more people will be involved in R&D. Therefore, one can conclude that the most populous country should have a faster technological progress because they would have the highest labor force. However, no evidence verifies this conclusion. This is due to the fact that a country's level of technology depends on R&D done not only within that country's borders but also abroad.

b) Two-country model

Recall that technological progress can occur through two ways: creating new technology or imitating others'. Let's define two countries with the same level of labor but different levels of technology A_1 and A_2.

$$L_1 = L_2 = L,$$

$A_1 > A_2$, so that country1 is technologically more advanced than country2. Therefore country1 is the *technology leader* and country 2 is the *technology follower.*

From (5), output per worker for country 1, y_1, and country 2, y_2, is respectively:

$$y_1 = A_1\,(1 - \gamma_{A,\,1}),$$

$$y_2 = A_2\,(1 - \gamma_{A,\,2}),$$

$$\text{with } \gamma_{A,\,1} > \gamma_{A,\,2}.$$

For the technology leader the creation of new technology is:

$$\widehat{A_1} = \frac{\gamma_{A,1}}{\mu_i} L_1.$$

For the technology follower, technological progress is defined as:

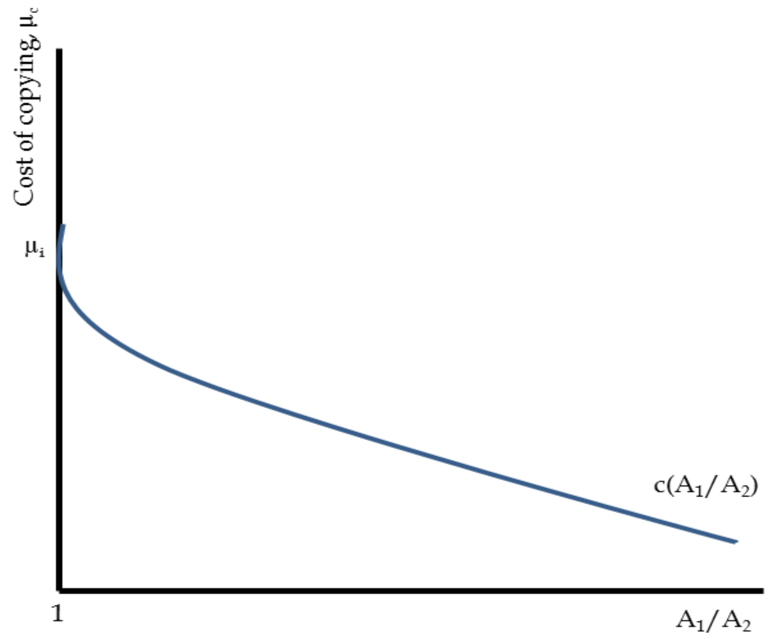
$$\widehat{A_2} = \frac{\gamma_{A,2}}{\mu_c} L_2.$$

i and μ_i stand for invention and cost of inventing respectively and μ_c is the cost of acquiring a new technology via copying. The assumption is that the cost of copying decreases as the technology gap between the follower and the leading country widens. As a matter of fact, a new technology is not easy to imitate because it is new, so the bigger the technological gap between the countries the easier for follower it is to copy.

μ_c is a function of the ratio of technology in country1 to technology in country 2 where the function that describes the relationship is denoted as *c ( ):*

$$\mu_c = c\left(\frac{A_1}{A_2}\right)$$

Figure 12 - Cost of copying for the follower country



We can see that μ_c decreases as the technological gap widens. In addition as the ratio A_1/A_2 increases to infinity, the cost of copying falls to 0 and as the same ratio approaches to 0 the cost of copying approaches the cost of inventing.

As $(A_1/A_2) = +\infty$, $\mu_c = 0$.

As $(A_1/A_2) = 1$, $\mu_c = \mu_i$.

If we now turn to look at the steady state of the model, we have to assume that at this state both countries will grow at the same rate.

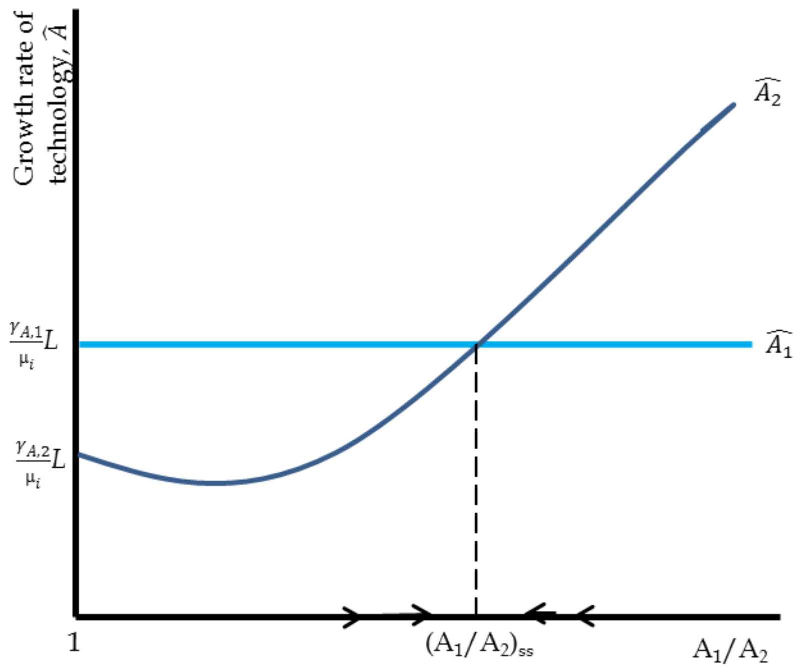
If the ratio is 1, technology would be growing faster in country 1 because it would have a higher γ_A (recall $\gamma_{A,1} > \gamma_{A,2}$). If the ratio is infinite, country2's cost of copying would be zero, so technology will grow faster in country 2.

$$\frac{\gamma_{A,1}}{\mu_i}L_1 = \widehat{A_1} = \widehat{A_2} = \frac{\gamma_{A,2}}{\mu_c}L_2$$

$$\text{Therefore, } \mu_c = \frac{\gamma_{A,2}}{\gamma_{A,1}}\mu_i$$

When μ_c is low, the follower can have the same level of productivity while keeping a low fraction of the labor force involved in R&D, γ_{A2}. So it will end up with higher production that country1. However, if μ_c is high, μ_c will be close to μ_i, and country2 should have the same γ_A and same level of technology A, in order to have the same level of output.

Figure 13 - Steady state in the Two-Country Model



c) Technological progress into the Solow Model

From the Cobb-Douglas production function:

$$Y = A\,K^{a}L^{1-a}$$

We assumed that A was constant, now we want A to change over time due to the effect of technology. Let's define a new variable $e = A^{1/(1-a)}$, a measure of the number of *effective workers* per actual worker. An increase in e and an increase in L have the same effect on output. (Weil, 2009)

$$e^{1-a} = A$$

$$Y = e^{1-a} K^{a} L^{1-a}$$

$$= K^{a} (e\, L)^{1-a}$$

Output per effective worker = $y = Y/eL$

Capital per effective worker = $k = K/eL$

Therefore production function: $y = k^{a}$

A the steady state, the growth rate of total output is a function of the growth rate of output per effective worker and the growth rate of effective worker per actual worker.

$$\hat{Y} = \hat{y} + \hat{e}$$

In the steady state $\hat{y}=0$. We can see that an increase in $\hat{e}$, that is an increase in the growth rate of technology, will lead to an increase in the total output.

d) Technology production function

A technology production function refers to a function that defines how some inputs are used in produce new technologies. Theoretically, the inputs include the labor and human capital and research capital such as research facilities, computers etc.

From (6), we know that the growth rate of technology is the ratio of the fraction of labor force involved in research and the cost of inventing.

$$\hat{A} = \frac{L_A}{\mu}$$

Here we assume a constant return to scale because an increase in L_A will increase $\widehat{A}$. However, the technology production function is characterized by a decreasing return to scale. Because technology is non rival in consumption, when a new technology is created, all other efforts to create the same technology goes to waste. As the level of technology rises, finding new discoveries becomes even harder. Therefore, as the effort devoted to R&D increases, the effectiveness of each new researchers falls. For technological progress to occur, the overall labor could grow, and assuming that the ratio of the labor force involved in R&D remains constant, the fraction involved in R&D will grow as well, increasing the rate of growth.

e) The role of Government

No economic activity can properly function without the intervention of the government. Government policy can impact productivity by maintaining the rule of law. By granting patents the government can make sure new technologies are not stolen from their creators which could reduce the incentive to do research. The government can provide funding for research increasing L_A or research capital which in turn will increase technological progress. In other words, the government can provide an environment in which R&D can flourish.

Other economic activities such as education, health, infrastructure, imports, institutions, openness, competition, financial development, geographical predicaments and absorptive capacity have a positive influence on productivity. Investment in human capital is necessary. Because technological progress is also embodied in the human capital that students acquire through education, it is also embodied in factor accumulation. A country with a high rate of investment will utilize new capital that already embodies new technologies. This means that the singled-out effect of technology on productivity and growth is extremely difficult to estimate.

8) Conclusion

The Solow model provides a useful framework to estimate productivity and to understand its impact. Productivity refers to the part of output that is not attributed to labor and capital. The model reveals that productivity is directly affected by technological progress, R&D activities, and human capital.

IV. Chapter 4 - Methodology & Data

The main objective of this paper is to estimate the contribution of Foreign Direct Investment to the Total Factor Productivity (TFP) of the mining sector in Chile. We estimate the following relationship:

$TFP_t = TFP_{t-1} + FDI_{t-1} + TECH_{t-1} + OTHER_t + \varepsilon,$

where TFP_{t-1} represents the lagged dependent variable and FDI_{t-1} represents the lagged FDI. We use the lagged TFP as an explanatory variable as there are reasons to believe that the level of productivity of certain period is directly affected by the level of productivity of the previous period. The lagged TFP is often necessary for the regression model to be able to predict the future as it helps predict what will happen in period t based on knowledge of what happened up to period t-1. We use the lagged FDI to allow for the effect of any change FDI materialization structure to show up in firm performance. This also diminishes simultaneity and endogeneity issues. However, this idea is based on the assumption that the lagged independent variables are exogenous to the error term in the time period they are being applied.

$TECH_t$ refers to imported machinery which is a proxy for new technology. Imported machinery is different from FDI in the sense that FDI include investment in technology, R&D, the cost of the relocating new labor etc. Imported machinery refers to equipment that is used to replace old ones, and so there is reason to believe that it is used in the same year in the production.

OTHERS$_t$ represents some macroeconomic variables such as inflation (lagged), international price of copper, unemployment rate and GDP.

Since the TFP is not observable the first step would be to estimate it.

In order to estimate the Total Factor Productivity of the mining sector in Chile, we use the Cobb-Douglas production function, where the variable A captures the part of production that is not attributed to labor and capital which, by definition, is the Total Factor Productivity (TFP).

$$Y_t = A\, K_t^{\alpha}\, L_t^{1-\alpha}\ ,\ 0 < a < 1.$$

The main advantage in using this production function is that all the variables are observable, except the TFP itself. However, it is necessary to note that A not only captures the variations in productivity but also encapsulates the errors in the specification of the model. As mentioned, A is the residual in the econometrics analysis, so it is easy to see how other factors may be captured by A, such as management style, international factors, etc. However, it is assumed that with a proper estimation of labor and capital input, the A will accurately measure the efficiency with which these inputs are used.

1) Output

TFP is the component of production that is not attributed to labor and capital inputs. In order to estimate production we use Value Added (VA). VA is defined as "the difference between gross output (at basic prices) and intermediate consumption (at purchasers' prices."(OECD, 2009) VA represents the shares of the labor and capital used in the production process. Although VA and variables such as gross output (GDP) are correlated, the use of the former as an appropriate measure of output in productivity estimates is preferred to the use of the latter.

VA is a better measure of output for many reasons. "One of the major advantages of value added is that it avoids problems inherent in the measurement of output which is a gross concept - gross in the sense that it counts the output of all production units". (OECD, 2009) VA measures "the value that a resident unit adds to that of the resident units that supply its inputs."(OECD, 2009) Also, the use of VA is practical because it is measured in real pesos which render it easier to aggregate different outputs. In addition, VA is easy to calculate because it derives directly from the organization's (industry, sector, national level) statement of income and it is applicable to both manufacturing and service industries. In fact, "value added is calculated in the same way for both the manufacturing and services industries. Unlike physical indicators, value added can measure the output of service industries which is often intangible." (Spring Singapore, 2011) In addition, VA reflects the productivity of the organization as value added growth implies a more efficient use of the factors of production, ceteris paribus.

In our analysis we use VA as provided by the National Accounts of the Central Bank of Chile. The National Accounts compiled by the Central Bank not only report the GDP, but also the value added for thirteen sectors of the economy including the Mining Sector. However, the National Accounts report the VA in current terms. All prices have been converted to constant terms (2010=100). Data on VA are available for the years 1985-2012.

2) Labor input

Productivity studies in the literature have used different measures to estimate the input of labor in productivity depending upon the availability of the data. Most studies have used the *number of worked hours.* "'Hours actually worked' by all persons engaged is the conceptually preferred measure of unadjusted labour input (L) for estimating productivity." (Arnaud, Dupont, Koh, & Schreyer, 2011) In addition, conceptually, labour income and labour shares should reflect the compensation paid to labour from a producer's point of view."(OECD, 2013) In other words, the quantity of labour inputs in production should be expressed in total worked hours and its cost should be the compensation to employees. Alternatively – due to lack of data, for instance – number of employees can also be used as a proxy for labor input. However, none of the aforementioned measures capture the difference in the quality of labour. The measure assumes that the contribution of each worker to the production is exactly the same across the labor force. However, in reality, one worked hour by one employee does not always equate one worked hour by another one. There may be differences in skills, education, health and professional experience that lead to large differences in the contribution of different types of labour. Because of this, "a differentiation of labour input by type of skills is particularly desirable if one wants to capture the effects of a changing quality of labour on the growth of output and productivity." (OECD, 2011) Our present analysis addresses this issue.

In the literature, a few studies have been conducted on the TFP of Chile but they seldom look at the specifics of the TFP of the Chilean mining sector. Fuentes, Larrain & Schmidt-Hebbel (2004) have used *number of employees* as a primary measure for labor input. They adjusted the variable with i) average worked hours of the economy, ii) quality of the labor measured by the average years of schooling of the workers and iii) a labor quality index developed by Jorgenson and Griliches (1967). This measure classifies workers into groups by educational level and weighted by the relative wage, under the assumption that wage differentials accurately reflect differences in worker productivity. The advantage of this index over the school setting is that it reflects the average changes in productivity validated by the market. Vergara and Rivero (2006) adjusted the number of employed with education levels and Vergara and Fuentes (2004) only used number of employees without adjusting.

In our analysis we take a similar yet different approach to estimate the contribution of labor in production processes. We construct an effective labor (EL) variable, which is the amount of worked hours weighted by the relative wage and the number of workers in each category of professional attainment. The methodology to construct EL was first developed by economists from CORFO and the Universidad Adolfo Ibáñez of Chile. The quality adjustment is related to productivity differences between workers with different levels of human capital. In order to capture the quality of labor, we assume that the difference in wage of a worker with a formal education with respect to an uneducated worker corresponds to an "education premium". In other words, an (formally) educated worker will earn more than a non-educated worker because he is better educated hence more productive. Therefore, we estimate EL at the national level to be:

$$EL = H \times N \times \Sigma\,(N_I/N) \times (W_I/W_0)$$

$$= H \times N \times \Sigma\Omega_I$$

$$= H \times N \times \Omega$$

Where H is the number of hours worked, N the number of employees, W_I the average salary of the economy and the W_0, the average salary of workers with no formal education and Ω is the adjustment for quality at the national level and the national education premium.

However, in order to carry our analysis, we also need to adjust the quality of the labor force at the sectorial level (Ω_s).

$$\Omega_s = \Omega \times W_s/W,$$

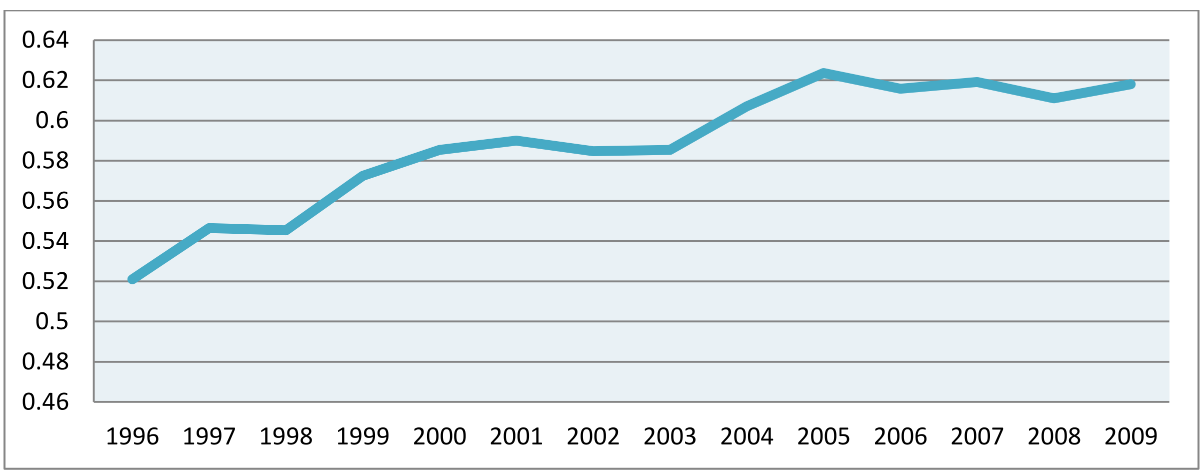
where W_s is the average wage in the sector and W the average wage of the economy.

The average working hours for Chile is estimated at 2047 hours a year[14]. The Instituto Nacional de Estadisticas (INE[15]), the Chilean Statistical agency, reports the number of worked hours by economic sector since 2010 with the mining sector averaging 50 hours

[14] This is estimated by the OECD Better Life Index at http://www.oecdbetterlifeindex.org/countries/chile/
[15] http://www.ine.cl/

a week (or 2500 hours/year, 50 x 52, minus 2 paid vacation weeks). Since we do not have data for the years prior to 2010, we use the national average of as a proxy for the number of worked hours for the mining sector. Data on worked hours for the mining sector do not significantly differ from the data on national average for the year's post-2010. The data on wages and number of workers of the mining sector are available in INE database[16]. The INE classifies the workers in eight different categories: Executives, Professionals, Technicians, Administrative Personnel, Protection and Service personnel, qualified workers, machine operators, non-qualified workers. Due to the fact that there is no clear distinction between the last five categories (except for non-qualified workers), to avoid double counting we only estimate education premium ($\boldsymbol{\Omega}$ and $\boldsymbol{\Omega_s}$) based on the data on executives, professionals, technicians and non-qualified workers (with no formal education).

Figure 14 - Aggregate Education Premium (Ω), 1996-2009



[16] For the years that are not covered by INE's Data, the data is linearly interpolated

Figure 15 – Mining Sector Education Premium (Ω_S), 1996-2009

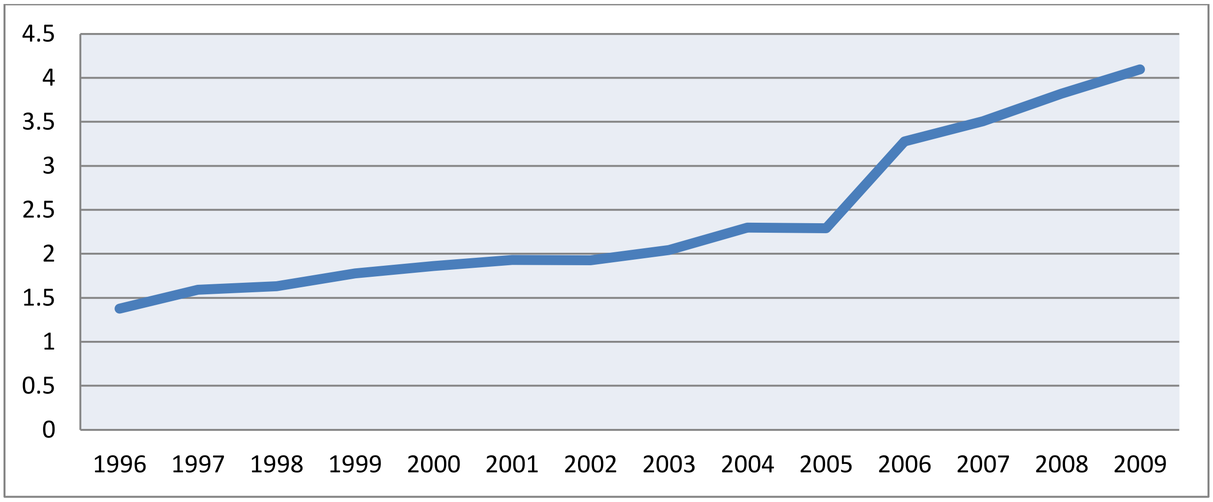


Figure 16 – Mining Sector Labor (H × N), 1985 - 2011

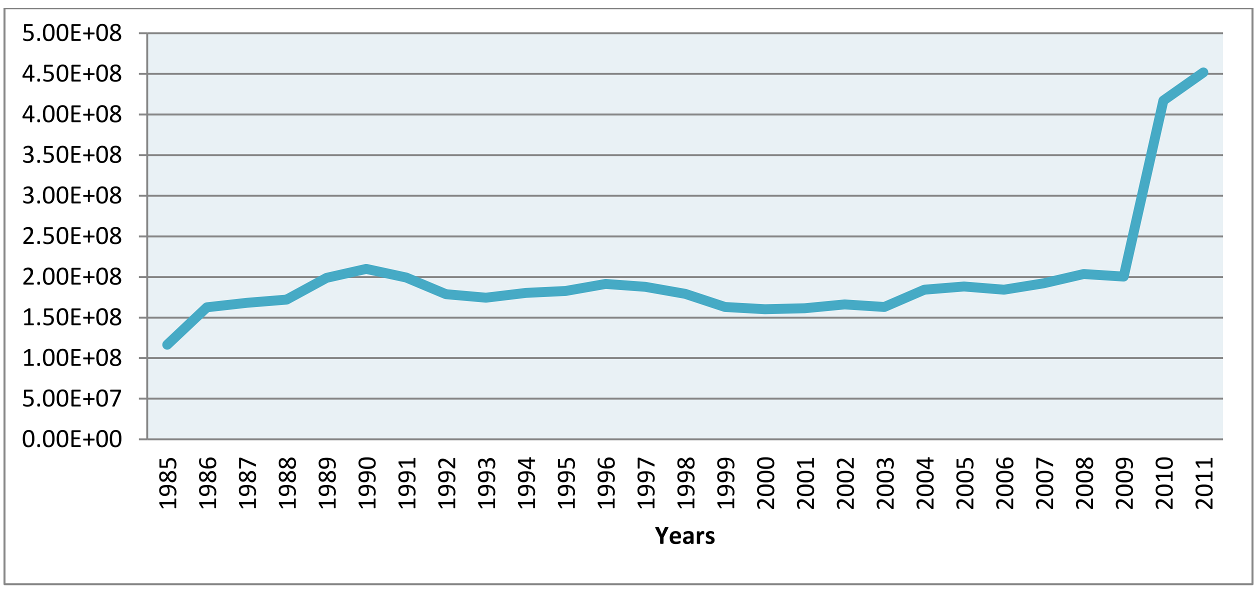
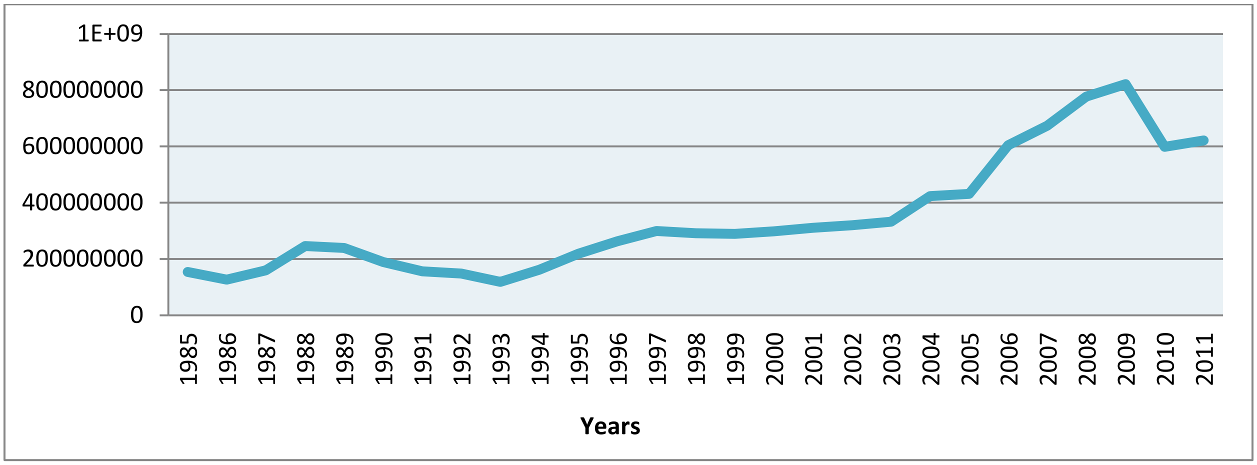


Figure 17 – Mining Sector Effective Labor (Adjusted for education), 1985-2011



3) Capital Input

The contribution of capital input in the production process is essential because whereas labor is the human touch in the production, capital is the tools to produce. However, the conceptual estimation of capital proves to be problematic. Most TFP studies at the aggregate level use the gross capital stock as the capital input, which is "the total value of capital assets at what they would have cost to purchase, as new, in the current year or in a base year."(Blades & Meyer-zu-Schlochtern, 1997). Other studies, Kendrick (1961), Christensen & Jorgenson (1969) have use the net capital stock which refers to assets valued at the prices at which they could be bought in their present state instead of "as new" prices. It is argued that net capital stock *present state* captures "the reduced efficiency of older assets due to higher repair costs or growing obsolescence." Other authors have agreed that there is indeed some loss of efficiency as assets age and that the [gross capital stock] requires some downward adjustment if it is to serve as the capital input for TFP studies."(Blades & Meyer-zu-Schlochtern, 1997) However, the full amount of depreciation is generally agreed to overstate the loss of efficiency.

The U.S. Bureau of Labor Statistics (BLS) applies an explicit age-efficiency function which reduces the value of the stock by the presumed loss of efficiency due to aging. The age-efficiency relationship is represented by the function[17]:

$$S_t = (L-t) / (L-\beta_t)$$

where S_t is the relative efficiency of a t year old asset, L is the service life, and t is the age of the asset. With values of β between 0 and 1, S_t lies on curve that is concave to the origin implying an increasing loss of efficiency as the asset ages.

At the firm or sector level, the capital stock variable used to calculate productivity is the replacement value of the equipment and machinery at market rates that is, the cost of the equipment used in the year's production if it were to be sold in the market. This provides a true measure of how much capital the firm is using. However, in many countries, this value cannot be estimated either because there is no tangible market for used equipment or managers cannot properly estimate it. In this case, the net book value of equipment can be used. Book value and gross value are accounting terms and are

[17] See Trends in Multifactor Productivity, 1948-81, U.S Department of Labor, Bureau of Labor Statistics, Bulletin 2178, September 1983 (pp. 41-45).

obtained by applying a depreciation rate to the initial acquiring cost of the equipment. Wherever possible, however, replacement value should be used.

It is argued that a stock variable is not appropriate to explain changes in economic flows and that capital consumption may be a better measure of capital input. One problem in using the gross or net capital stock in productivity estimates is that they are stock variables in a model where the dependent variable and other independent variable are flow variables. In $Y = f(L,K)$, Y (value added) and L(labor input) are flows of output and inputs during a single accounting period whereas K is a stock of asset used over several accounting periods. This is one of the reasons why capital consumption has been perceived as a viable alternative measure of capital input. "Annual capital consumption valued at a common replacement cost may be taken to represent an initial proxy estimate for the real annual capital factor input value of assets with differing lifetimes and vintages."(Ward, 1976) However, using capital consumption can also pose some issues. As Blades & Meyer-zu-Schlochtern (1997) mentioned: "Several countries use geometric rather than straight-line consumption; the former will give more weight to the services rendered by an asset during the early part of its service life, while straight-line depreciation gives equal weight to each year' s contribution which seems more appropriate for present purposes." In addition, conceptually capital assumption is also included in output and variations in capital assumption have no accounting implications on the dependent variable.

In our analysis, we use the net capital stock as estimated by the Central Bank of Chile. The net capital stock is estimated using the following relation:

$$\boldsymbol{K_{i,j}^{t}} = \boldsymbol{I_{i,j}^{t}} \Big/ (\boldsymbol{\delta_{i,j}^{t}} + \boldsymbol{\theta_{i,j}})$$

Where $I_{i,j}^{t}$ is the investment in asset i in sector j; $\delta_{i,j}^{t}$ is the depreciation rate of asset i in sector j; $\theta_{i,j}$ is the average growth rate of the capital stock in sector j.

The growth rate of value added by sector is used as a proxy for the average growth rate of the capital stock[18]. The depreciation rate is derived from the service life estimated in the study from which the depreciation rate of each asset is estimated for each economic sector. To ensure that the sum of the sectorial capital stock is equal to the total found by asset type, it is assumed that the estimates by asset type are valid, since longer investment series are considered. Thus, sector-level estimates are adjusted by asset type from the series estimated using the Perpetual Inventory Method[19] (PIM). The data available in the Central Bank compiled National Accounts cover the years 1996-2010. For the years before we use the PIM without differentiating by type of capital.

Furthermore, there is a need to estimate how much of this capital is actually used in the production process. For this reason, we derive a capital utilization rate. Unfortunately, the Central Bank does not calculate capital consumption. An alternative would be to use unemployment rate or energy consumption. We decide on the latter since labor and capital can be substituted throughout the economic cycle.

The relationship between the fluctuations in energy consumption, capital stock and capital utilization is defined as follows:

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[18] It is assumed that the capital-output ratio is constant, so that the growth rate of capital and value added is the same

[19] At the aggregate level, capital stocks by types of assets are estimated under the Perpetual Inventory Method

$$\mathbf{ln(EC) = \boldsymbol{\alpha} + \beta \times ln(K \times UT)}$$

where EC is energy consumption, K capital stock and UT corresponds to fluctuations in energy consumption that are not explained by changes in the capital stock (the residual). Therefore, capital utilization (UT) is derived from the following equation:

$$\frac{\ln(EC)}{\beta} - \alpha = \ln(K \times UT)$$

$$e^{\left(\frac{\ln(EC)}{\beta} - \alpha\right)} = K \times UT$$

$$UT = \frac{e^{\left(\frac{\ln(EC)}{\beta} - \alpha\right)}}{K}$$

Data on sectorial energy consumption are retrieved from the *Balancias Energeticos* of the National Commission of Energy of Chile[20].

[20] http://www.cne.cl/

Figure 18 – Capital stock Mining Sector 1984-2011

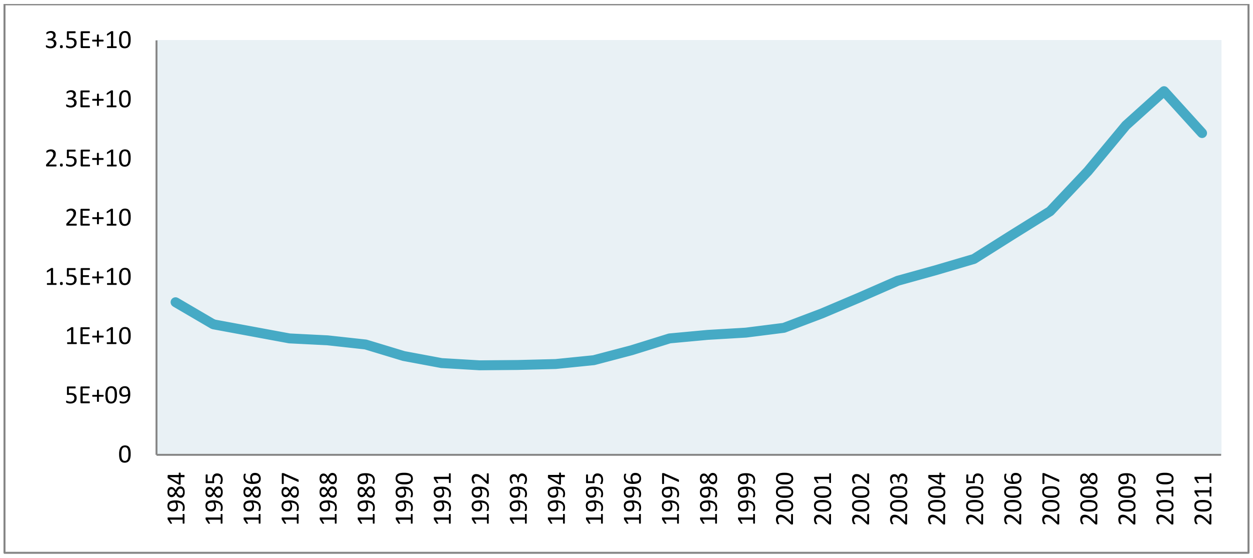
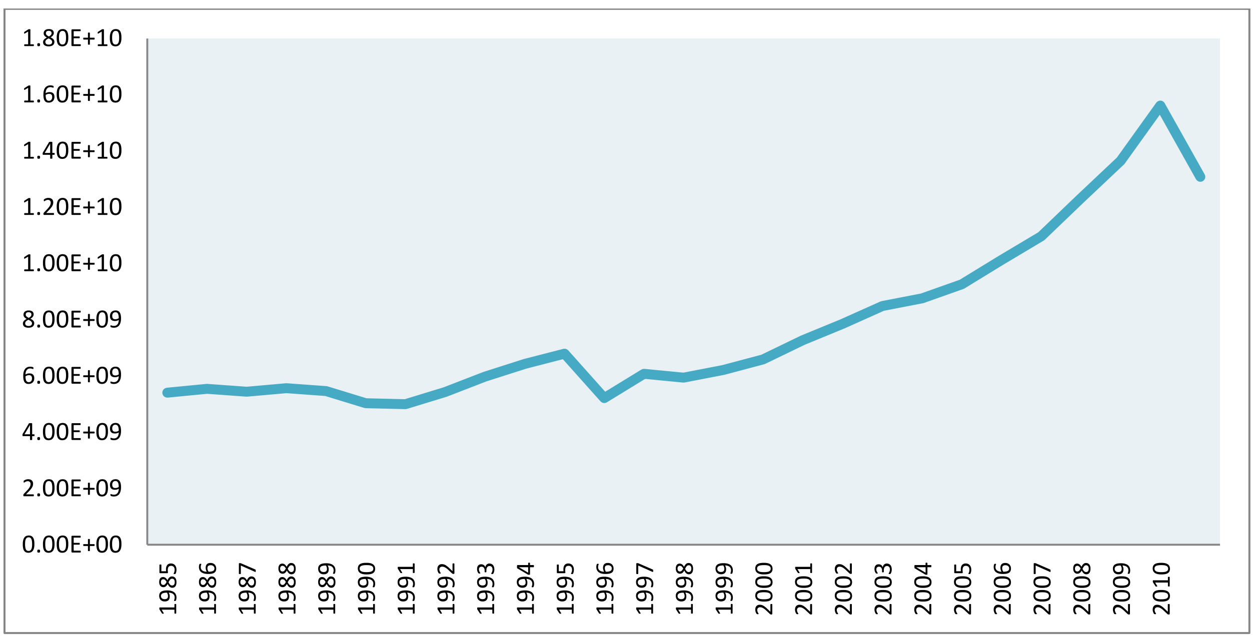


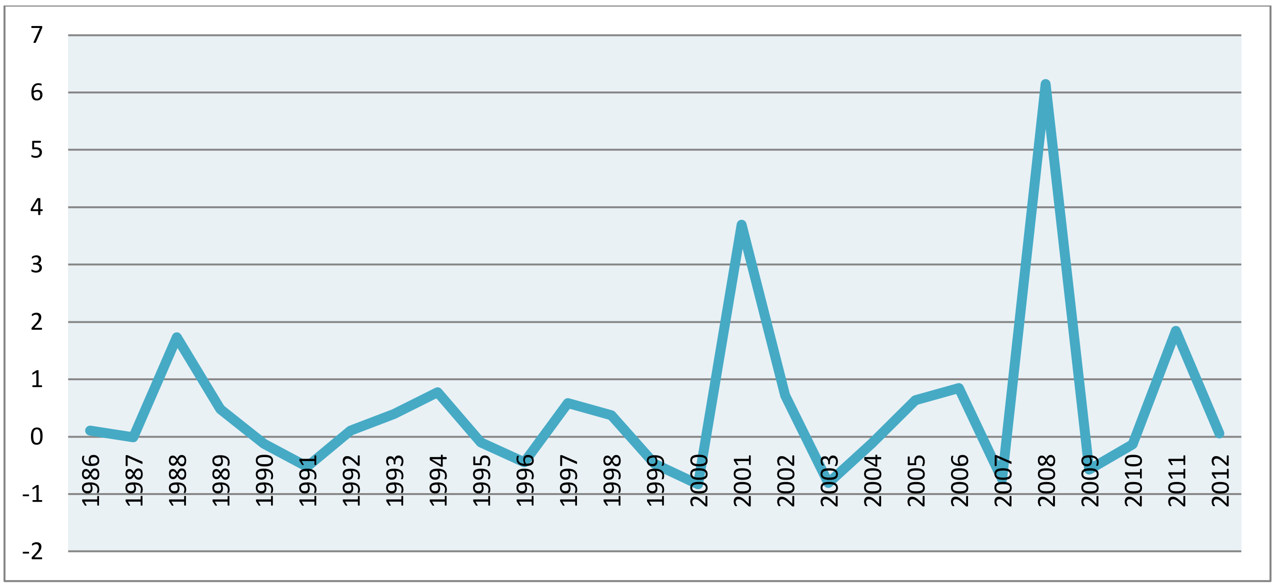
Figure 19 – Capital Stock adjusted for utilization, 1985-2010



4) Foreign Direct Investment

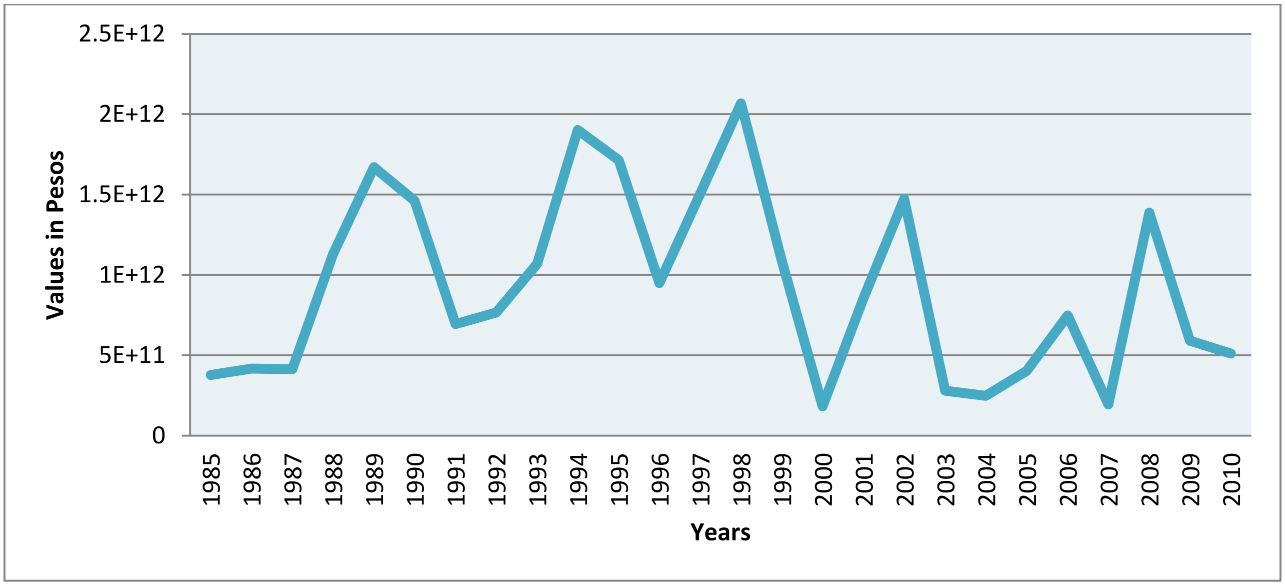
Foreign Investment data by sector are available on the Foreign Investment Committee database. We use the values of *Materialized Investment.* Materialized investments include amounts authorized each year and in all forms accepted under the Foreign Investment Statute D.L.600[21].

Figure 20 – Mining Sector - FDI Growth 1986-2012



[21] Decree Law (DL) 600 is a mechanism for the entry of capital into Chile since 1974.Under this regime, whose use is optional, foreign investors bringing capital, physical goods or other forms of investment into Chile may ask to sign a foreign investment contract with the State of Chile

Figure 21 FDI Inflows - Mining Sector, 1985 - 2010



5) Results

a) TFP Estimation

In order to retrieve the residual (TFP) we need to run the first regression using the Value Added (VA, output/dependent variable) with Capital Utilized (KU/independent variable) and Effective Labor (EL/independent variable). Table 1 summarizes the results. A 1% increase in Capital Used leads to a 1.086% increase in Value added. A 1% increase in EL leads to a .637% increase in VA. We use the log value of the variables because the variables exhibit growth that is approximately exponential meaning that the series grows by a certain percentage and the logarithm is therefore approximately linear. Also, the standard deviation, that is the average deviation from the mean, is proportional to its level and therefore, the standard deviation of the log of the variables will be approximately constant, allowing for more stationarity.

The estimations are all statistically significant at 1% level with an R-squared of .90. As expected, we find that Capital and Labor are positively correlated with output. The residual (TFP) is then regressed with foreign investment (FDI).

Table 3- Regression Results of Cobb-Douglas Production Function

	Value Added (log)	Value Added (log) (robust Std. Err.)
CAPITAL USED (log)	1.086	1.086
	(3.08)***	(3.86)***
EFFECTIVE LABOR (log)	0.637	0.637
	(3.01)***	(3.69)***
Constant	-7.800	-7.800
	(1.64)	(1.99)*
R^2	0.87	0.87
N	27	27

* p<0.1; ** p<0.05; *** p<0.01

b) Effect of FDI on TFP

- **Hypothesis**

We run the regression with TFP as the dependent variable. FDI and other variables such as imported machinery (as a proxy for transfer of technology), inflation, international copper price, unemployment rate, and GDP are included in the regressions. Our based model is therefore:

$$TFP_t = TFP_{t-1} + FDI_{t-1} + TECH_{t-1} + INF_t + COPPRICE_t + UNEMP_t + GDP_t + \varepsilon,$$

where INF_t is the inflation rate, $COPPRICE_t$ the international price of copper and $UNEMP_t$ the unemployment rate.

In addition we also run other regressions that are modified versions of the base model to test to the significance of some variables. Regression (2) does not include the price of copper. Regression (3) does not include GDP and regression (4) excludes GDP and the price of copper.

We expect FDI to have a positive sign and to be statistically significant. FDI provides new technology and technological know-how that positively contribute to the TFP. This is especially relevant in the case of the mining sector for it is capital and technology intensive. We used the lagged (one year) variable to allow for the absorptive capacity of firms which is a "firm's ability to recognize the value of new information, assimilate it, and apply it to commercial ends." (Cohen & Levinthal, 1990) In order words firms need time to effectively put the new information and capital to use.

We include the lagged TFP to account for the absorptive capacity of the firms lagged TFP should be positively correlated with the TFP as a higher level of productivity will lead to even higher level of productivity in the next period, ceteris paribus.

We also include imported machinery in the regression. The variable is used as a proxy for the transfer of new technology. We expect the sign to be positive as according to our model specification, new technology is said to improve productivity. This variable is also lagged (one year).

Inflation is included in the regression. While inflation may affect the accumulation of labour and capital it is most likely that its major effect will be to impede the efficiency of their organization – hence lowering productivity. "When prices are changing frequently, firms may find it more difficult to distinguish an increase in the relative scarcity of their inputs from an across-the-board increase in prices."(Bulman & Simon, 2003) As a result, firms may redirect resources destined to R&D and "organizational and managerial improvements, towards making basic decisions about optimal input allocations and the price of outputs."(Bulman & Simon, 2003) Consequently, we expect inflation to be negatively correlated with TFP.

We include unemployment and GDP to account for the business cycles. Booms and busts are usually correlated with the fall and the rise of the unemployment rate and an increase and decrease of GDP, respectively. Business cycles impact the profitability of the firm and hence correlate with productivity. Therefore, we expect unemployment to have a negative sign and GDP to have a positive relation with TFP.

Copper price is included in the regression. Copper represents more than 60% of mining revenues. Since most of the copper is exported, international price of copper is a significant determinant of the mining revenues in general. We introduce copper price in real terms. We expect its sign to be positive because an increase of international price level will drive up profits for firms which will contribute to an increase in productivity through investment in better technology, more and better labor etc.

Table 4 summarizes the results of the regressions.

Table 4- Regression Results: TFP and FDI

	TFP (1)	TFP (2)	TFP (3)	TFP (4)
TFP_{t-1}	0.910	0.552	1.049	1.146
	(4.37)***	(2.12)*	(9.27)***	(5.92)***
FDI_{t-1} (log)	0.092	0.035	0.105	0.067
	(2.43)*	(0.78)	(3.14)**	(1.04)
Machine $Imported_{t-1}$ (log)	-0.120	-0.197	-0.100	-0.139
	(3.38)**	(4.48)***	(4.14)***	(3.62)**
$Inflation_{t-1}$ (log)	-0.127	-0.115	-0.145	-0.226
	(2.50)*	(1.78)	(3.47)**	(5.16)***
Copper Price	0.458		0.530	
	(4.48)***		(5.46)***	
Unemployment	2.683	0.333	3.570	4.396
	(1.41)	(2.99)**	(2.07)	(1.66)
GDP (log)	0.085	0.502		
	(0.80)	(0.22)		
Constant	-2.170	-4.105	-1.220	0.511
	(1.48)	(2.35)*	(1.49)	(0.34)
R^2	0.90	0.83	0.90	0.73
N	25	25	25	25

* p<0.05; ** p<0.01; *** p<0.001

- **Discussion**

Multicolinearity

We test for multicolinearity within the sample data. Multicollinearity is a statistical phenomenon in which two or more predictor variables in a regression are highly correlated, meaning that one can be linearly predicted from the others with a non-trivial degree of accuracy. Even though multicolinearity does not reduce the reliability of the model as a whole, it affects calculations regarding individual predictors. Recall that our base model is:

$TFP_t = TFP_{t-1} + FDI_{t-1} + TECH_{t-1} + INF_t + COPPRICE_t + UNEMP_t + GDP_t + \varepsilon,$

where INF_t is the inflation rate, $COPPRICE_t$ the international price of copper and $UNEMP_t$ the unemployment rate.

To test for multicolinearity, we use the **VIF** command after the regression in STATA. **VIF** stands for Variance Inflation Factor. As a rule of thumb, a variable whose VIF values are greater than 10 may merit further investigation. Tolerance, defined as **1/VIF**, is used by many researchers to check on the degree of collinearity. A tolerance value lower than 0.1 is comparable to a VIF of 10. It means that the variable could be considered as a linear combination of other independent variables.

After finding the VIF for the base model (regression (1)), we also run the VIF test for the other regressions which are modified version of the base model. Regression (2) does not include the price of copper. Regression (3) does not include GDP and regression (4) excludes GDP and the price of copper.

We find that GDP in the base model has a large VIF (14.71) and a very low tolerance (1/VIF = .07) which may indicate that it might be linearly correlated with one or more independent variables. Other variations of the base model divulge acceptable VIFs and tolerances.

Table summarizes the results of the VIF tests conducted.

Table 5 Tests for Multicolinearity

Variables	VIF (1)	1/VIF (1)	VIF (2)	1/VIF (2)	VIF (3)	1/VIF (3)	VIF(4)	1/VIF (4)
GDP	14.71	0.067960	8.06	0.124107				
Imported Machines (lag)	8.63	0.115818	5.67	0.176466	4.84	0.206408	4.53	0.220610
TFP (lag)	8.15	0.122682	6.24	0.160306	2.76	0.361901	2.71	0.369653
Inflation (lag)	6.41	0.156037	6.38	0.156854	5.13	0.195114	4.51	0.221611
unemployment	3.47	0.288530	3.18	0.314647	2.58	0.387383	2.56	0.389935
Copper Price	2.44	0.410096			1.34	0.748911		
FDI (lag)	2.16	0.462217	1.82	0.548267	1.82	0.550091	1.75	0.570185
Mean VIF	6.57		5.22		3.08		3.21	

- ***Interpretation of the results***

For some variables we used the log variables. Statistically, if your variables are skewed then a measure such as correlation or regression can be influenced a lot by one or a few cases at the high end on one or both variables (outliers, leverage points, influential points). Taking the log can help this by reducing or eliminating skewness. In theory it also good to log transform your data to help with some model assumptions. For instance, in regression analysis it is assumed that the residuals have constant variance. When your variable is not log transformed this assumption is often violated. We used the log of some variables when the data appears to be skewed.

Figure 22 - Histogram FDI vs. log (FDI)

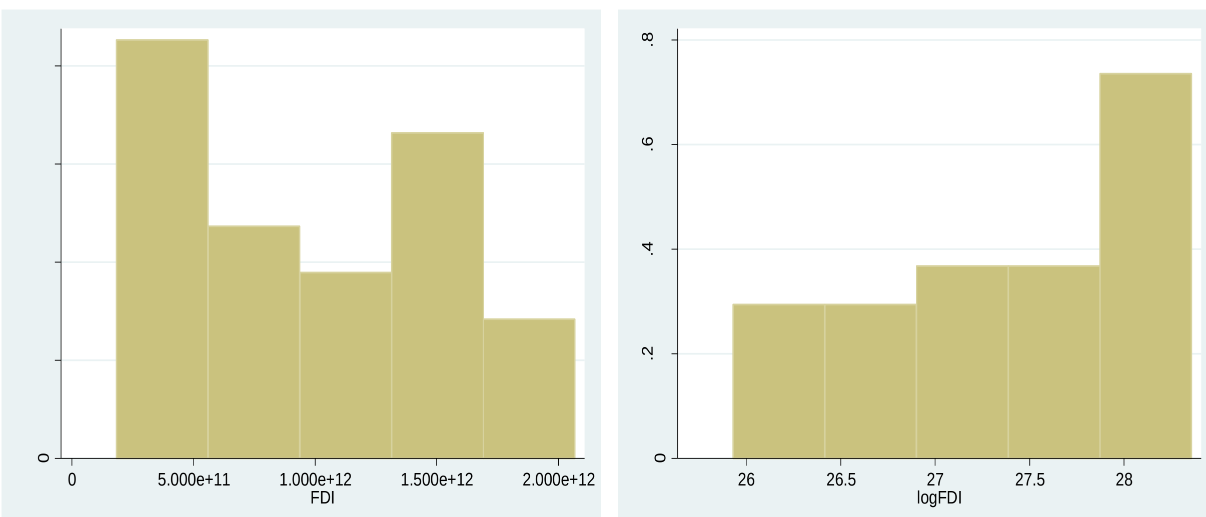


Figure 23 - Histogram: Imported Machines vs log (Imported Machines)

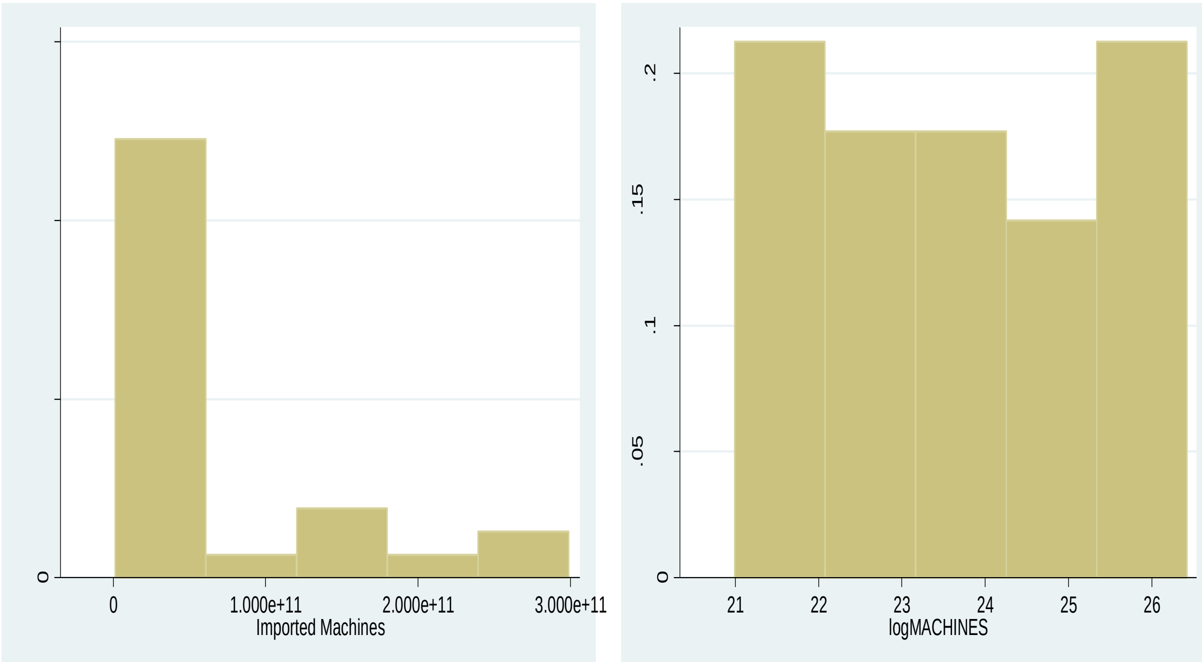
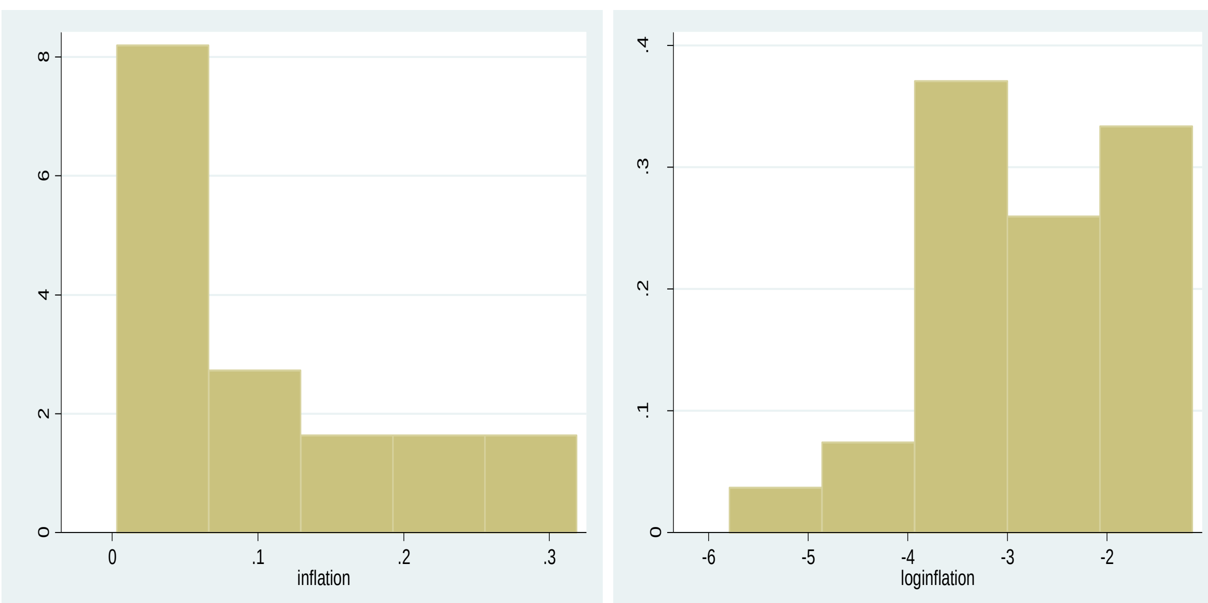


Figure 24 - Histogram: inflation vs log (inflation)



As expected the results indicate a positive sign for FDI in all regressions. In our base model a 1% increase in FDI will lead to a .092 unit increase in TFP or a 9.2% change. The result is statistically significant at 5% level. In other words, we find that FDI positively contributes to an increase in productivity. However, in regression (2) and (4), FDI is not statistically significant, which might indicate that the price of copper is a contributing factor to the effect of FDI.

The lagged TFP is a contributing factor to productivity (year t) and it is statistically significant in all regressions. This is not a surprising outcome. In our base model, an increase in 1 unit of TFP_{t-1} will lead to .9 unit increase in $TFP_{t.}$ As mentioned in the literature, this is a behavior that is quite expected because the level of productivity that a firm already has will determine its absorptive capacity of new technology. In other words, a firm ability to efficiency use new knowledge and technology is based on the level of productivity it already has. For instance, it must already have efficient labor and capital.

Imported machinery (used as a proxy for technology transfer) is negatively correlated with the productivity in the four regressions. The results indicate that a 1% increase in the value of imported machinery will lead to a 0.12 unit decrease in TFP. This is somewhat unexpected because we foresaw a positive correlation between TFP and technology transfer. However, it is also not a surprising outcome. In fact, for imported machines (for lack of sufficient data) we use the value of the machines rather than the quality or the equipment of the number. In other words, we estimated it using prices. Consequently, as prices of the machines increase, this will lead to higher acquisition cost for firms hence lower profitability and lower productivity.

The inflation variable included in the analysis yield a negative correlation with TFP in all regressions. In other words, inflation is negatively linked to TFP. According to the results, a 1% increase in inflation will decrease the TFP by .127 units. The well-known development economist, Vernon Ruttan sums up really well the relationship between inflation and productivity:

> "Inflation leads to inefficiency, because it makes market prices a less efficient system for coordinating economic activity. Its impact is particularly corrosive on the functioning of capital markets. It contributes to a decline in the rate of savings and to the distortion of investment patterns. A consequence of inflation which appears to have been overlooked is the erosion of the capacity of public sector institutions to provide the services needed to enhance productivity in the private sector." (Ruttan, 1979)

This is an expected result as inflation leads to economic uncertainty and firms may devote their resources previously reserved for R&D (hence TFP) to optimize their profitability and output.

The international price of copper is positively correlated with TFP. We included the price of copper because copper bring approximately 15% of the GDP. More importantly, copper represents about 90% of mining gross output. In other words, it is the main driver of the mining sector. Our results indicate that a one dollar increase in the price of copper will lead to .458 units increase in TFP. In other words, the higher the price of copper, the higher the productivity. Intuitively this makes sense, the higher the copper price, the higher the revenues which will result in the increase of the value added. In addition, one can argue that a higher price of copper will generate revenues that will be used to purchase new equipment and new technology.

According to our results, unemployment rate is positively correlated with the TFP but it is only significant in regression (2). This is a somewhat an intriguing finding because we expect unemployment rate to follow the busyness cycles – rise when the economy is declining and fall when the economy is growing – hence an inverse relationship with the TFP. However, in the case of Chile, unemployment rate does not follow the business cycles (Fig.12). Unemployment also appears not to be correlated with TFP (Fig. 13). This might also explain why the estimates are not statistically significant.

We find that GDP is positively correlated with TFP which is what was expected. A 1% increase in GDP leads to 0.085 increase in TFP. However, the results are not statistically significant at the lowest level of significance we tried (5%; std. error: .80)

Figure 25 - GDP Growth and Unemployment Rate (1985 – 2010)

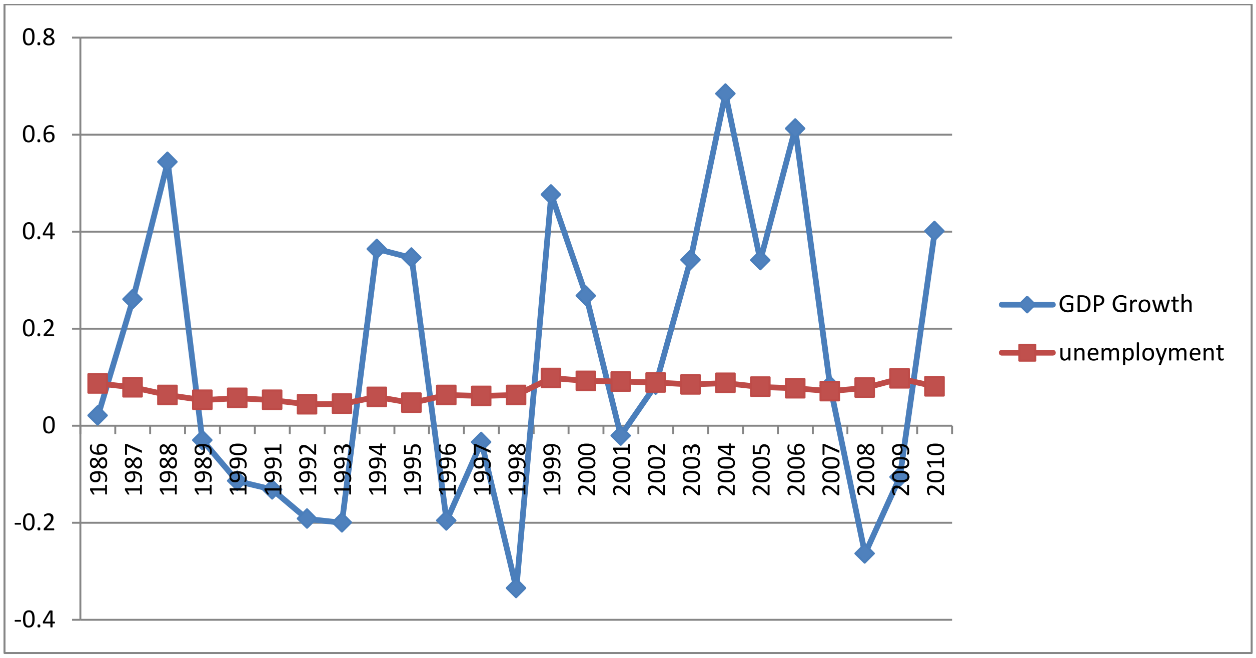


Figure 26 - TFP and Unemployment rate (1985-2010)

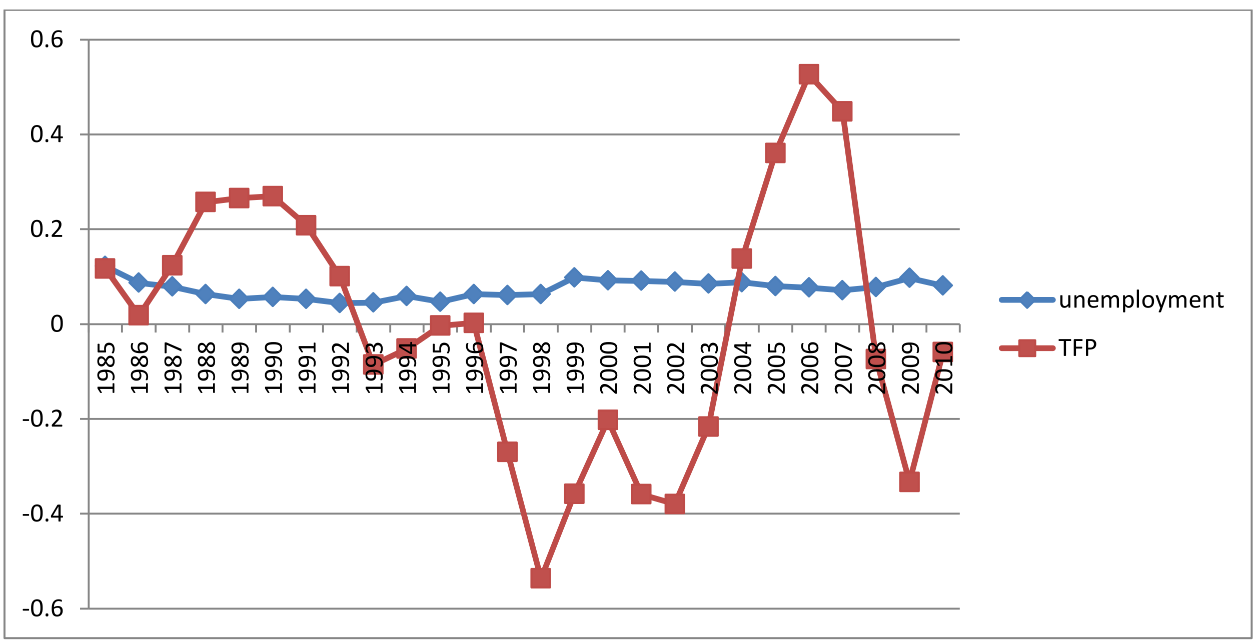
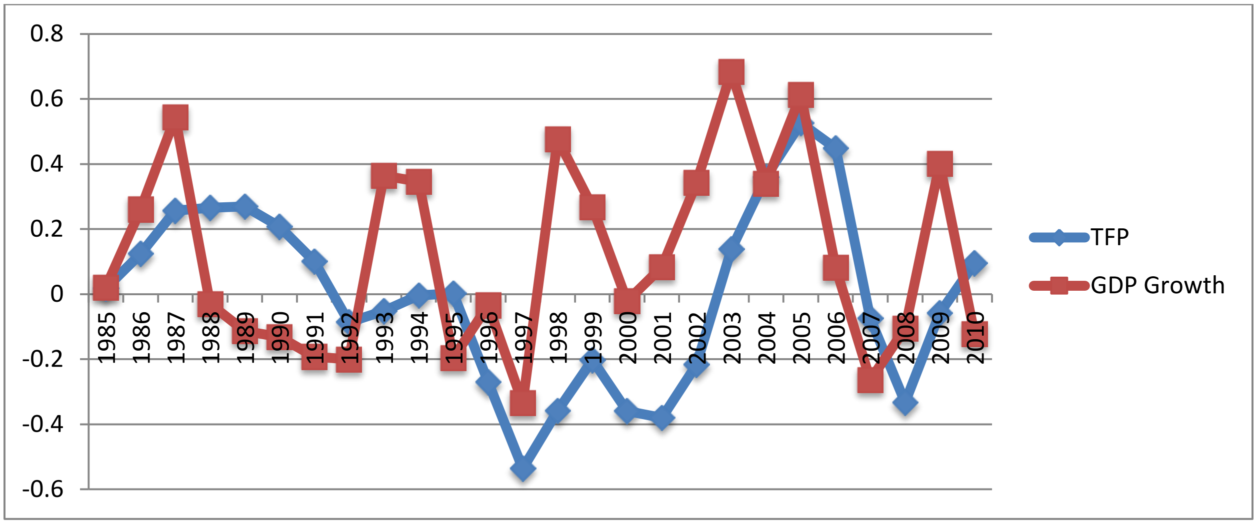


Figure 27 - TFP and GDP Growth (1985-2010)



V. Chapter 5 – Policy Recommendation and Conclusions

1) Policy Recommendations

Our results indicate that FDI has a positive contribution to TFP, in the case of the mining sector in Chile. Theoretically, policies that promote foreign investment should lead to higher FDI hence higher productivity. In general, a good business climate, good policies of integration, a stable currency, and sound macroeconomic policies, are contributing factors to FDI inflows. Also as "it is clear that regulatory stability and the overall business and political environment of the country are also very important for FDI" (Vergara, 2005) Chile should make sure property rights are respected and the rule of law maintained. In the case of the mining sector, FDI is a vehicle of new knowledge, machineries and new technology.

2) Human Capital

One factor that clearly contributes to TFP is the quality of human capital. However, "the quality of education in Chile is below the standards of countries with a similar per capita income."(Vergara, 2005) Chile could improve its productivity if it ameliorates its educational system. Some studies have found that "the average productivity growth might increase between 0.5 and 1 percentage points per year, whilst more optimistic estimates project an impact as great as two percentage points annually." (Vergara, 2005) In addition, the government should invest some resources in vocational training, especially in the field of mining that requires heavy technical school. It should provide scholarships for mining students to go abroad and get some experience in countries where the mining sector is developed. These students should come back with some expertise which will improve labor productivity.

3) R&D investment

According to our model of TFP in Chapter 3, one of the major contributing factors of TFP is R&D. The bigger the investment in R&D, the more likely R&D will find innovative tools and the higher the impact on TFP. One of the major problems in Chile is the relatively low level of investment in R&D by the private sector. In addition, "an excessive share of the R&D expenditure is devoted to basic rather than applied science." (Vergara, 2005) One way to solve this issue is for the government to boost investment in R&D in the more productive and profitable sectors such as mining. Another approach would be to provide tax incentives R&D expenditures for companies. To this effect, "Chile's current R&D law, enacted in 2008, encourages private investment in R&D by providing a tax credit of 35% for expenditures on R&D contracts with pre-certified third party R&D centers. However, since its creation, this incentive has been used sparingly due to its many restrictions." (Von Igel, 2012) As of 2012, Chile had improved its R&D law which tripled the amount of tax credit available to each company to $1.2 million per annum. Additionally, businesses "will now be able to claim the tax incentive for "in-house" R&D projects in addition to those developed externally." (Von Igel, 2012) All of these reforms will surely increase R&D activities in Chile, which will affect the productivity in the long run.

4) For Future Research

In our study, we have focused on the macroeconomic variables to test their impact on TFP. However, some economists have focused on the integration of the economy and its impact on TFP. According to this stream, the more integrated a country is in the world economy the better it is for economic growth. Since our research do not touch on this aspect, it will be interesting to include 'integration' variables in future studies. Integration includes variables such as foreign trade, foreign investment, capital movements and other related issues. "The effect on productivity is related to the enhancement of competition, access to more and better products and services, the increase in investment, upgrading of technologies, access to a larger market and the reduction of the capital cost of investment."(Vergara, 2005) Policy of integration can be said to have a bigger impact on economic growth which in turn affect productivity change. Trade liberalization and the opening of the capital movements are essential to the integration into the world economy but policies regarding the two should be implemented with caution as "some evidence suggests that the sequencing is important and, in line with this, the initial phase should be the removal of trade restrictions and then the liberalization of the capital account."(Vergara, 2005) Chile progressively liberalized its trade and capital movement starting in 1970s. Today, Chile should continue to sign more free trade agreements. Also, as "it is clear that regulatory stability and the overall business and political environment of the country are also very important for FDI" (Vergara, 2005), Chile should make sure property rights are respected and the rule of law maintained. In the case of the mining sector, FDI is a vehicle of new knowledge, machineries and new technology. In sum, we have yet to analyze the effect of business and political environment and world integration on TFP.

In addition, it is necessary to test for the stationarity of the data. Many economic series exhibit trending behavior or non-stationarity in the mean. In order to insure that the TFP is stationary, we need to test whether or not TFP contains a unit root. If the TFP contains a unit root, then the series contain a stochastic trend and any shock will have a permanent and long-term effect that needs to be accounted for in our analysis. If a series has a unit root, it is non-stationary, so the mean and variance are changing over time. The Dickey-Fuller test is often used to test for stationarity. The Dicker-Fuller test or Augmented Dickey-Fuller tests that a variable follows a unit-root process. The null hypothesis is that the variable contains a unit root, and the alternative is that the variable was generated by a stationary process. In order for a model to be stationary, all of the variables must be stationary, not just the dependent variable. There are two cases of interest. The first one is that all variables are stationary. In this case, we can use ordinary regression techniques. The second case is that none of the variables are stationary, but they are integrated of the same order. *Integrated of the same order* refers to the number of times that you must differentiate the variables before they become stationary. So, if we have two variables, neither of which is stationary, but both of which becomes stationary when we take the first difference of each variable, then we would say that both variables are integrated of order 1.

If all of the variables in a regression equation are integrated of the same order, and if the error term in the model is stationary, then we can also use ordinary regression analysis. This condition is known as co-integration. However, our sample size is not large enough to conduct such advanced techniques but it should be incorporated in future research with larger sample of data.

5) Conclusion

According to the Solow model, economies can grow in the short run through factor accumulation. However, long term growth stems from the growth of productivity which directly derives from technological improvement. Since the 1970s, Chile engaged in the liberalization of its economy. After a halt of the political stability during the dictatorship of General Augusto Pinochet from 1973 to 1989, Chile fully reconnected to the world market and democracy. This return to democracy was applauded by international observers and trade and foreign direct investment increased radically.

This study applies the Solow growth model to the mining sector in Chile. The mining sector in Chile is one of the pillars of Chilean economy and copper exports alone stand for more than one third of government income. Chile accounts for almost a third of the world copper production. Our hypothesis was that the 'Solow residual' or Total Factor Productivity can be targeted to increase sectorial growth. We suggested that Foreign Direct Investment (FDI) is a contributing factor to TFP. In fact, we found that FDI contributes to TFP; a 1% increase in FDI will lead to a .09 unit in TFP the year after. However, we also found that new technology (proxied by the import of new machinery) is negatively correlated with TFP and international copper price is positively correlated with TFP. Inflation is negatively correlated with TFP. In order to improve productivity, the government should take several measures. This includes an improvement of the educational system especially of the training in mining and the continuation of its trade policies with freer trade agreements. In addition, expenditures in R&D should increase, and Chile has already taken steps to solving this issue by providing tax incentives to companies who engage in R&D. Future studies may assess the impact of economic stability, the respect of property rights and sound macroeconomic policies as factors that attract FDI and lead to an increase in productivity in the long run, not only at the national level, but also at the sectorial level including mining.

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VII. Appendix

Descriptive Statistics

Variables	Observations	Mean	Standard Deviation	Min	Max
Capital Used	27	22.71082	.3421037	4.99e+09	1.56e+10
Effective Labor	27	19.49471	.5713499	1.19e+08	8.21e+08
FDI	28	27.38262	.7246539	25.92978	28.3579
GDP	27	22.41316	.7972006	21.44662	23.79808
Inflation	29	-2.771853	1.103015	-5.791997	-1.14334
Int'l Copper Price	27	.0683247	.2377839	-.25489	.748363
Machines Imported	26	23.68323	1.695622	20.99059	26.42364
TFP	27	-1.88e-09	.2709044	-.5366352	.5261453
Unemployment	26	.0742308	.0198339	.04	.12
Value Added	28	29.32645	.7824159	2.17e+12	2.16e+13

Variables and sources

Variables	Sources
Capital Used	Data used to estimate to the Capital Stock are retrived from The National Accounts of the Chilean Central Bank. Data on energy consumption are retrieved from the *Balancias Energeticos* of the Chilean National Commission of Energy
Effective Labor	Data used to estimate EL are retrieved from the Instituto Nacional de Estadisticas (INE)
FDI	Chilean Foreign Investment Committee database
GDP	National Accounts of Chile's Central Bank
Inflation	National Accounts of Chile's Central Bank
Int'l Copper Price	Chilean Commission of Copper
Machines Imported	National Accounts of Chile's Central Bank
TFP	Derived econometrically
Unemployment	Instituto Nacional de Estadisticas (INE)
Value Added	National Accounts of the Central Bank of Chile

Table 6- Regression Production function

```
. reg logVA logKU logEL, robust

Linear regression                                      Number of obs =      27
                                                       F(  2,    24) =  101.28
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.8744
                                                       Root MSE      =  .28197
```

logVA	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
logKU	1.086479	.2815348	3.86	0.001	.5054193	1.667538
logEL	.6365662	.1724658	3.69	0.001	.2806144	.992518
_cons	-7.800128	3.920948	-1.99	0.058	-15.89257	.2923123

Table 7 - Regression TFP

```
. reg TFP L.TFP L.logFDI L.logMACHINES L.loginflation COPPERPRICE logPIB unemployment, robust

Linear regression                                      Number of obs =      25
                                                       F(  7,    17) =   63.89
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9011
                                                       Root MSE      =  .10469
```

TFP	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
TFP L1.	.9097839	.2079531	4.37	0.000	.4710411	1.348527
logFDI L1.	.0920924	.037836	2.43	0.026	.0122655	.1719193
logMACHINES L1.	-.1202339	.0355403	-3.38	0.004	-.1952175	-.0452504
loginflation L1.	-.1272871	.0508517	-2.50	0.023	-.2345748	-.0199995
COPPERPRICE	.458467	.1023037	4.48	0.000	.2426251	.6743088
logPIB	.0852789	.1060605	0.80	0.432	-.1384892	.309047
unemployment	2.682663	1.906714	1.41	0.177	-1.340152	6.705478
_cons	-2.170252	1.468293	-1.48	0.158	-5.268079	.9275742

Figure 28 Chile Economic Sectors

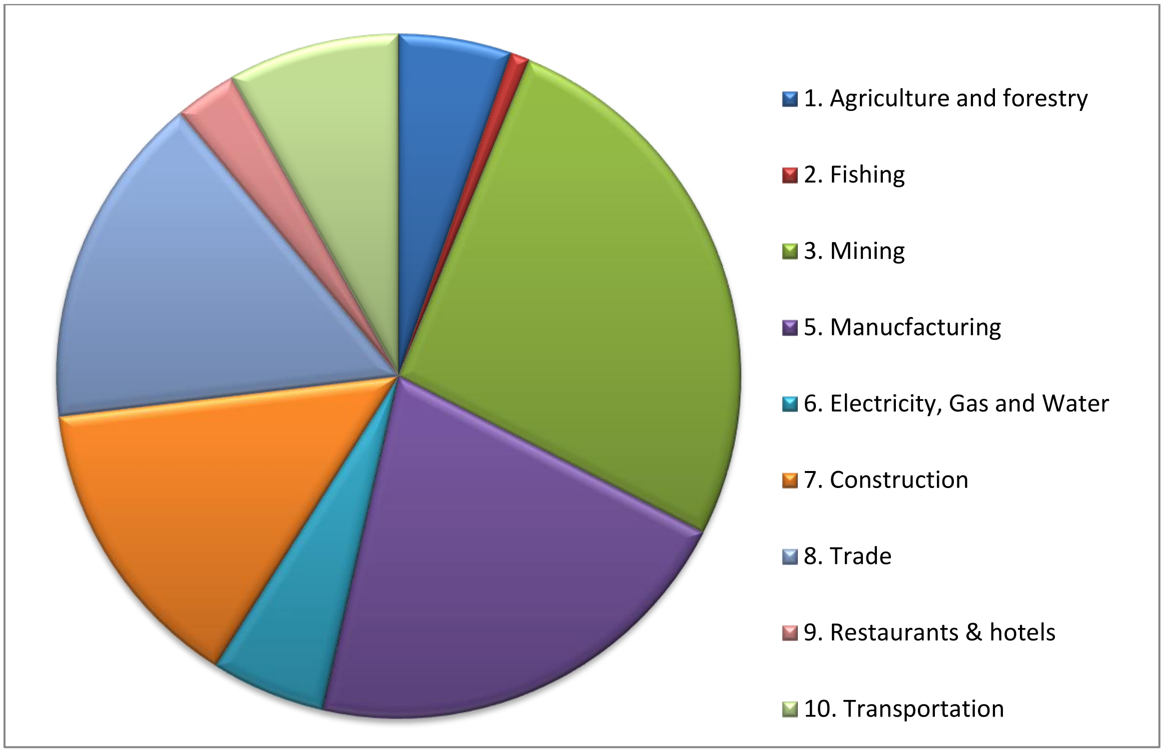


Figure 29 Copper Mining vs Other Mining

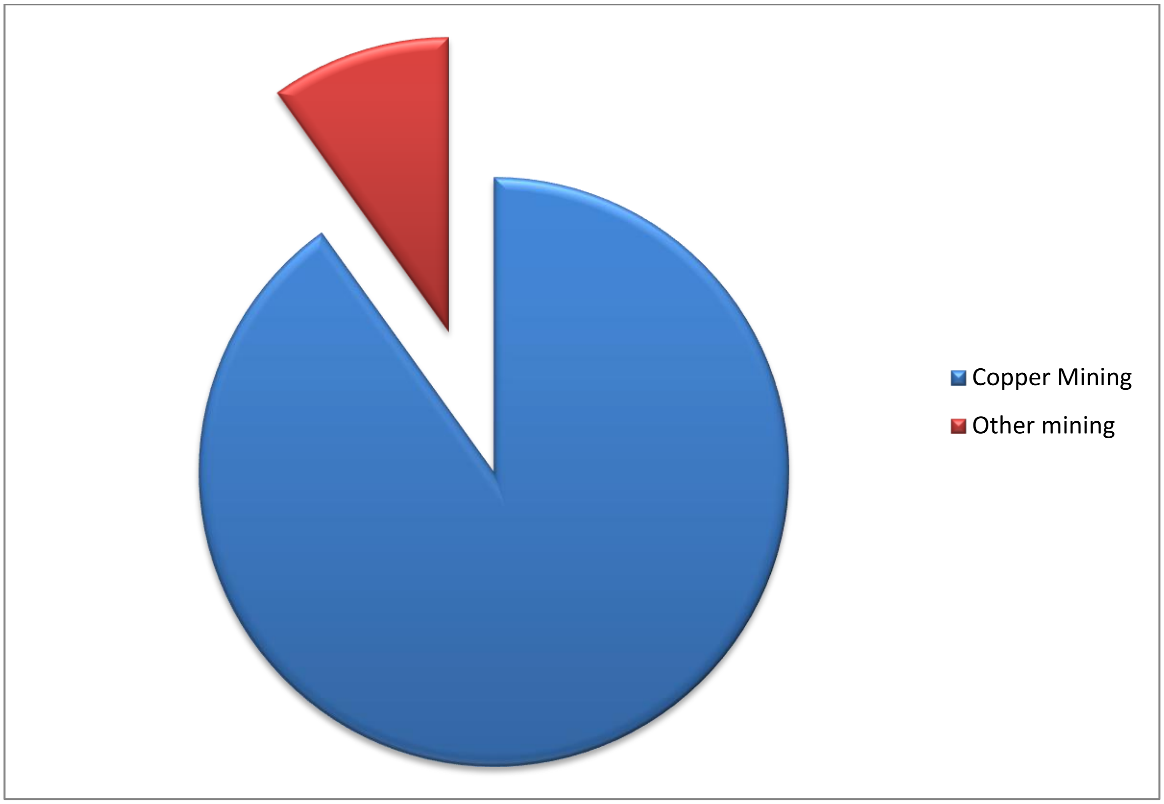
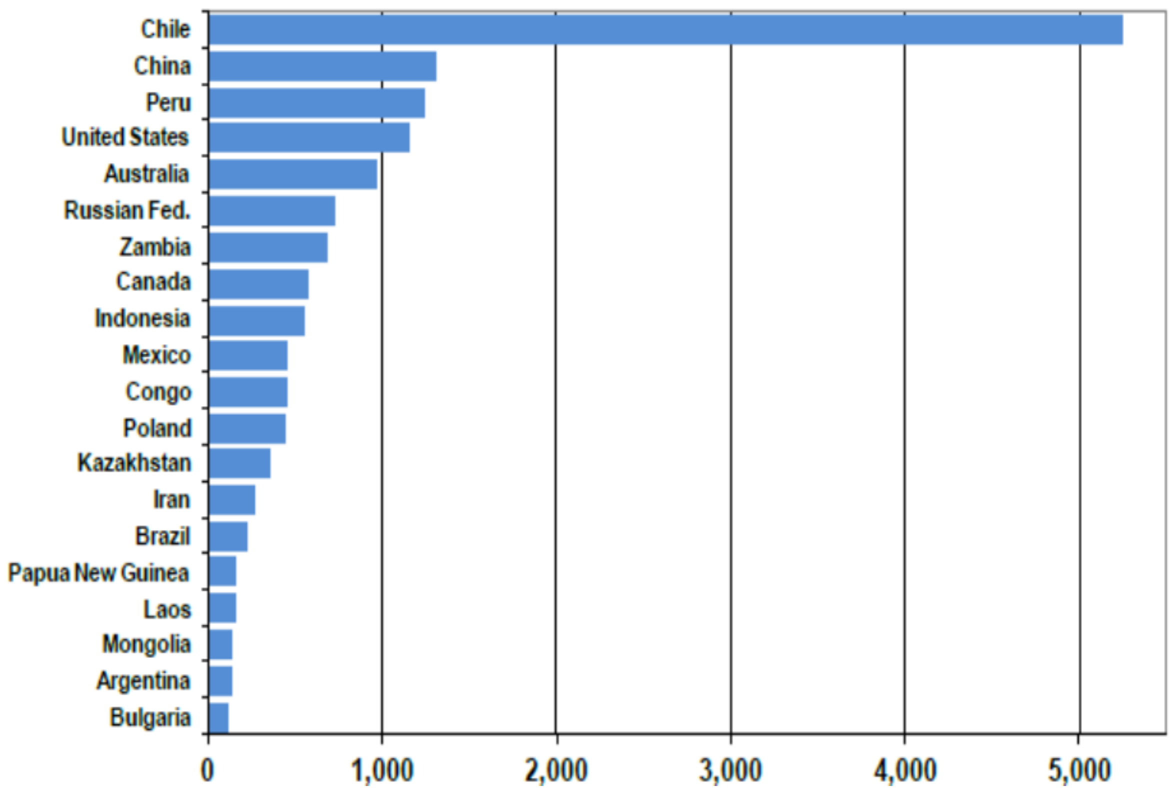


Figure 30 Copper Mine Production by Country: Top 20 countries in 2012. Chile accounted for over one-third of world copper mine production in 2012 with mine output of over 5.4 million tons copper.[22]



[22] Source: Interrnational Copper Study Group

Figure 31 - Geographical Location of Chile