China's Semiconductor Industrial Policy and Income

A Case Study at the Provincial Level

by

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Abstract

When government directs the economy, how does human welfare fare? This research narrows the scope of this question to explore the relationship between industrial policy and human development indicators through the context of China's semiconductor industry and average income from employment from 1999-2019. While both the literature on industrial policy and China's State Council's guidelines suggest that the driving force behind semiconductor policy is the pursuit of economic growth, results suggest that the policies, as executed, bear limited significance to income increases over time. However, analysis does provide some key insights into the effectiveness of policy variations: 1) "national guidelines" accompanied by state investment vehicles are more effective than the just the publication of the former and 2) investment into historical Chinese industrial geographic clusters correlates to higher income increases as compared to new "upstart" semiconductor provinces.

Keywords: semiconductor industrial policy, industrial policy and income, industrial policy and human development, China industrial policy, China semiconductors

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Introduction

In the past decade, the economic academia has experienced a reinvigoration of interest in industrial policy. Indeed, the rise of East Asia's Tigers, most notably China (ranging from 6-14% annual GDP growth since 1999 in contrast to the US' GDP growth ranging from -3% to 5%), is difficult to miss (Chang & Andreoni, 2020). Although economists still heavily debate the "how" of industrial policy execution (Wade, 2009), *The Economist* jests that at least the field is in consensus that "one industry has been a big unintended beneficiary" of Chinese industrial policy: "the academic study of industrial policy." In short, China has utilized industrial policy extensively for the purpose of economic growth, which makes it a good industrial policy case study (*The Economist*, 2020).

This paper intends to contribute to the academia of industrial policy by studying the existing literature gap concerning industrial policy and its interactions with human development indicators by focusing specifically on average income from employment – a noted "aspect that has been neglected so far" (Barbieri et al., 2019). The particular nation selected for study is China and the particular industry selected is the semiconductor [also known as the integrated circuits ("IC") and microchips] industry.

Given the industry's position as a key point of contention during the US-China Trade War that began in 2018 and a national security issue [in that it is crucial to the functioning of any electric device (Semiconductor Industry Association, 2021)], semiconductors are considered well-documented compared to other product "outputs" China's National Bureau of Statistics provides public statistics for. Since 1956, China's State Council (the central governing committee of China) has listed semiconductor research and industry advancement as a national priority. A variety of industrial policy tools, varying from VAT tax breaks, R&D subsidies, to designated national champions strategies have been employed at the level of the central government and is clearly written in legislation. There are also noticeable periods in which China's State Council's semiconductor industrial policy has evolved, namely from: 1956-1990, 1991-2004, 2005-2013, and 2014-Present (VerWey, 2019). These periods will be further discussed in the *Background & Theory* section.

Furthermore, the development of the industry has been studied in the United States extensively and has been deemed a particularly effective "economic boon" to the economies it participates in (Jackson, 2020). Following this logic, studying the semiconductor industry is again more instructive compared to other industries subject to Chinese industrial policy for analysis of average income levels.

There is another important motivation behind this research. Global demographics are changing. 70% of Millennials considered company values when making a consumer decision, compared to 51% of all online US adults (Lai, 2018). In the future, Millennials and Generation Z will become the architects of our institutions and will demand research related to the improvement of the human condition.

For the empirical strategy, a two-step approach was used. First, analysis was run to verify two core assumptions that would fuel the second – the ultimate analysis of China's semiconductor industrial policy and average annual income from employment.

The first core assumption was to determine if income and semiconductor output in China's provinces, taking into account control variables, were significant from 1999-2019. Results suggest a strong correlation.

The second core assumption was that semiconductor industrial policy was significant to semiconductor output. At the national level of policy, a synthetic province analysis was used. For regional levels of policy, a DID (difference-in-difference) analysis was performed on semiconductor output with treatment reflecting years of national significance for semiconductor industrial policy. Although the literature provides an abundance of semiconductor industrial policy research and analysis reflecting the success [measured simply in that China was able to manufacture 6% of the semiconductors it used in 2020 (Sheng, 2021) versus having zero capability a little over five decades ago], analysis that pinned specific policy periods to semiconductor output was not found. To ensure the robustness of the treatment periods used later in research for income levels, this paper thus provides the first DID analysis of China's semiconductor output and policy to the author's best knowledge.

The core analysis used both a synthetic province analysis (again, at the national level of policy) and DID analysis (at the national and regional levels of policy) to determine average income from employment. Previous DID analysis available in the literature on China's industries has been performed on household income and other income datasets to analyze healthcare and housing policies (Cao, 2015).

Regressions of both assumptions and final analysis were necessary because to the knowledge of the author, similar analysis had not yet been conducted as of yet in the literature. All represent the first of their kind regarding the semiconductor and income question in literature.

The analysis intends to contribute towards informing some of the most debated questions in the current circle of industrial policy academia:

- What industrial policy tools make sense for what industries? Why?
- What sectors make sense for what countries to subsidize? Why?
- How should countries promote competition and innovation? (Stiglitz et al., 2013).

While the insights of this paper can be used to inform the discourse, the author considers it necessary for the study to be broadened beyond the Chinese semiconductor industry before any insights intended to inform real world decisions is practically applied to any industry and country. No industry is exactly similar to the semiconductor industry and no country is identical to China… both are very unique, as discussed later under *Background and Theory*. Instead, the key motivating factor behind this discussion is to gain traction for the importance of the idea and enlarge the circle of scholarly debate around industrial policy's effect on human development indicators. Human development itself is well-studied in the literature (ex. Lai's 2013 principal component analysis of human development indicators in China). Where the difficulty (and correspondingly, the gap in literature) lies is determining the magnitude of effect of the many factors (ranging from policy to macroeconomic events) that affect the development of the human condition. The research question proposed in this paper deals solely with average income per capita level from employment. Other human development indicators, such as income inequality, wealth inequality, and adult literacy rates, remain to be explored. The success and sustainability of policy, especially in the high tech sector, relies as heavily on the development of human capital as it does on technological advancement. Neither should the scope of policy considerations be limited to "industrial policy"; it would be informative to evaluate the effectiveness of mechanisms such as patent policy or R&D contests as well. By developing this body of research, leaders of industry and government alike can make more informed decisions regarding high-tech industries that promise to be not only nation-changing, but world-changing. Examples of such use cases include quantum mechanics, artificial intelligence, robotics, and genetic research.

Literature Review

An Introduction to Semiconductors

Semiconductors, also commonly referred to as integrated circuits ("IC) or microchips, are crucial to the functioning of any electric device (Yinung, 2015). In 2019, the global semiconductor industry market size stood at USD $513.08B and is expected to grow at a 4.7% CAGR (Fortune, 2020). Barriers to entry for the industry are notoriously high given: 1) the immense cost of factories capable of manufacturing advanced semiconductors (high economies of scale) [costs can reach USD $12B for a single fabrication plant (Shih, 2020)], and 2) Moore's Law which translates into significant first-mover and learning curve advantages.

As a result, two main business models have become popular. First are behemoth firms that produce their semiconductors from start to finish. These are known as Integrated Device Manufacturers or IDMs. Second are firms that focus on specific sections of the value chain. The value chain is broken into three general sections: design; manufacturing; and assembly, test and packaging. In industry lingo, these activities are more commonly known as: fabless, foundries and ATP. China desires to promote all activity types with their semiconductor industrial policy to create a self-sufficient domestic supply chain (VerWey, 2019).

The US Semiconductor Industry and History as Economic Boon

Given the prevalence and demand of electronics, the semiconductor industry has gained government support globally as an economic boon and key issue of national security/defense. There exists extensive study of this phenomena in the US semiconductor industry. Research shows that in 2020, every $1 the US federal government invested in the semiconductor industry represented a $16.50 increase to US GDP (SIA, 2020). Although the study did not further break down how national income was distributed at the individual or household level, The US Bureau of Labor Statistics estimates that the semiconductor industry adds jobs three times faster than the rest of the US economy, has an employment multiplier figure of 4.89 jobs to a US manufacturing average of 2.91, and commands average salaries $22,000 greater than the US average employee income (Toohey, 2016).

Of note, the US is the birthplace of the semiconductor industry. In its nascent stage, the US semiconductor industry was supported by the US defense R&D budget. In the 60s and 70s, private capital poured in, resulting in the market landscape largely driven by market forces today (Platzer & Sargent, 2016). This contrasts greatly with China's semiconductor industry, which has been nurtured almost purely through government coordination and industrial policy (Ezell, 2021).

An Introduction to Industrial Policy

The Carnegie Endowment for International Peace defines industrial policy as: "[A] government intervention in a specific sector which is designed to boost the growth prospects of that sector and to promote development of the wider economy." (Dadash, 2020).

Today, four economic realities of the 21st century have not only revived the discourse around industrial policy, but focused it on the question of execution. The first reality is the rise of East Asia's Tigers (ex. Japan, South Korea, and China). Second, the unprecedented government intervention during the 2008 financial crisis through "emergency use of industrial-policy tools leads to demands for more" (*The Economist*, 2010). Third, globalization, particularly in "supply chain, financialization and new imperialism" has caused countries to question the distribution and balance of their economies (Chang & Andreoni, 2020). Finally, “the weak state of the world economy” increases government pressure to reduce unemployment and stimulate growth (*The Economist*, 2010).

On the question of execution, a current key point of contention is how governments can boost domestic innovation and productivity. A 2019 report by the Center for Strategic & International Studies notes that in the US, while “[s]ome orthodox economists dismiss calls for more active federal intervention in the economy as “wasteful industrial policy,” exceptional innovations such as GPS, supercomputing and satellites have been the result of sizeable military procurement and R&D budgets (Gerstel & Goodman, 2020). In the context of China’s semiconductor industrial policy, the debate is especially pronounced given the significant investment as mentioned prior necessary for China to play “catch-up”... and the existing probability that it never can. That said, a study published in the *American Economics Journal: Macroeconomics* showed that in China’s manufacturing industries, “subsidies and tax breaks as instruments of industrial policy improve firm performance in competitive sectors while loans and tariffs do not.” (Aghion et al., 2015). In short, an understanding and following of general industrial policy involving its design and governance is imperative to the global semiconductor industry at-large given the involvement of governments and the strong influences of globalization on the industry.

On that note, the idea of differentiating between “horizontal” and “vertical” industrial policy is gaining prominence as an attempt to break down industrial policy. The International Institute for Sustainable Development defined the two in its 2019 *Global Economic Governance Through the Lens of Inequality and Sustainable Development* as: “The former traditionally referred to policies such as those involving science and innovation, which are meant to facilitate industry growth and are relatively uncontroversial. The latter can involve tariffs on specific inputs, subsidies to particular sectors and concessional loans." In simpler terms, vertical industrial policy is usually targeted at specific firms/narrow sectors while horizontal industrial policy is targeted towards "broad sectors by improving their business environments." (Loayza, 2017). Although there are circumstances where the line of distinction between the two are quite blurred, in the case of China's semiconductor industrial policy, the majority of policy is vertical. Guidelines for semiconductor development written by the central government clearly targets semiconductor innovation rather than general innovation.

Geographic industrial clustering is an industrial policy tool that features prominently in China. The concept of clusters was first introduced in 1990 by Michael Porter in his book, *The Competitiveness of Nations*. In more recent years, Porter and fellow luminaries have solidified the definition of clusters: "Clusters are geographic concentrations of industries related by knowledge, skills, inputs, demand, and/or other linkages." (Delgado et al., 2014). The concept is important to this study because China has traditionally utilized geographic industrial clustering heavily in every sectoral policy, semiconductors included. Although it is recognized in the literature that clusters as an economic organization principle is "mostly [a] positive development" (Donahue et al., 2018), there are negatives as well. For instance, while Porter argues in a 2003 paper that clusters produce higher firm-level income and employment gains for the individual, a body of research has found exceptions to this relation. A comprehensive study of technology-based clusters in the Appalachian region of the United States found that: "clustering is associated with new business formation for selected technology industries but not with employment growth." (Feser et al., 2008).

The Relationship between Industrial Policy and Income

An important assumption to solidify before even embarking on impending analysis is to ascertain that industrial policy actually affects average income from employment levels. The literature suggests that not only can industrial policy affect average income, increasing average income should be a motivating factor to implement industrial policy. Industrial policy tools, varying from tariffs to IP regulations, have all proven to be "drivers [that] can increase labour productivity, economic development and social welfare." (Kolesnik, 2016). In the determination of each of these factors, income levels are an important input. (Stone, 2017).

For more specific direction, this study will refer to the research of Robert Wade, who has written extensively on the topic of how industrial policy can be utilized to help developing countries move into the higher income brackets typical of more developed countries. A discussion of this will be provided in the *Theoretical Framework* section below.

China's Semiconductor Industrial Policy

Historically, China's semiconductor industrial policy can be broken down into four time periods.

The first time period begins in 1956, when the first transistor was created in a Chinese state-sponsored laboratory. The time period, which lasted till 1990, was characterized by state-led innovation (for instance, R&D was carried out solely at university labs like Tsinghua funded by the central government) and the emergence of the Yangtze River Delta cluster. The second time period, from 1990-2002, was characterized by two central government projects (Project 908 and 909) that were the first serious attempts to create a domestic IDM. By 2002, both projects had been abandoned in favor of joint ventures with foreign firms such as Siemens and Intel (VerWey, 2019).

A more in depth overview of the last two time periods, which is the focus of this research, is provided below.

- 3rd Period: 2005 - 2014

Focus: Rise of SMIC, Foreign Acquisition & Capitalizing on Growing Domestic Market

The suspension of Project 909 was accompanied by the rise of the Semiconductor Manufacturing International Corporation (SMIC) in Beijing. A foundry company, SMIC successfully leveraged "a five-year tax holiday (and another five-year tax break at 50 percent of standard rates), tariff exemptions [on inputs], reduced value-added tax rates[, and] partnerships with foreign firms" to produce semiconductors only two years behind international leaders. Today, it is among the five largest foundry companies in the world (Lee, 2021). Encouraged by this success, China began pouring resources into acquisitions of foreign semiconductor companies and reverse engineering.

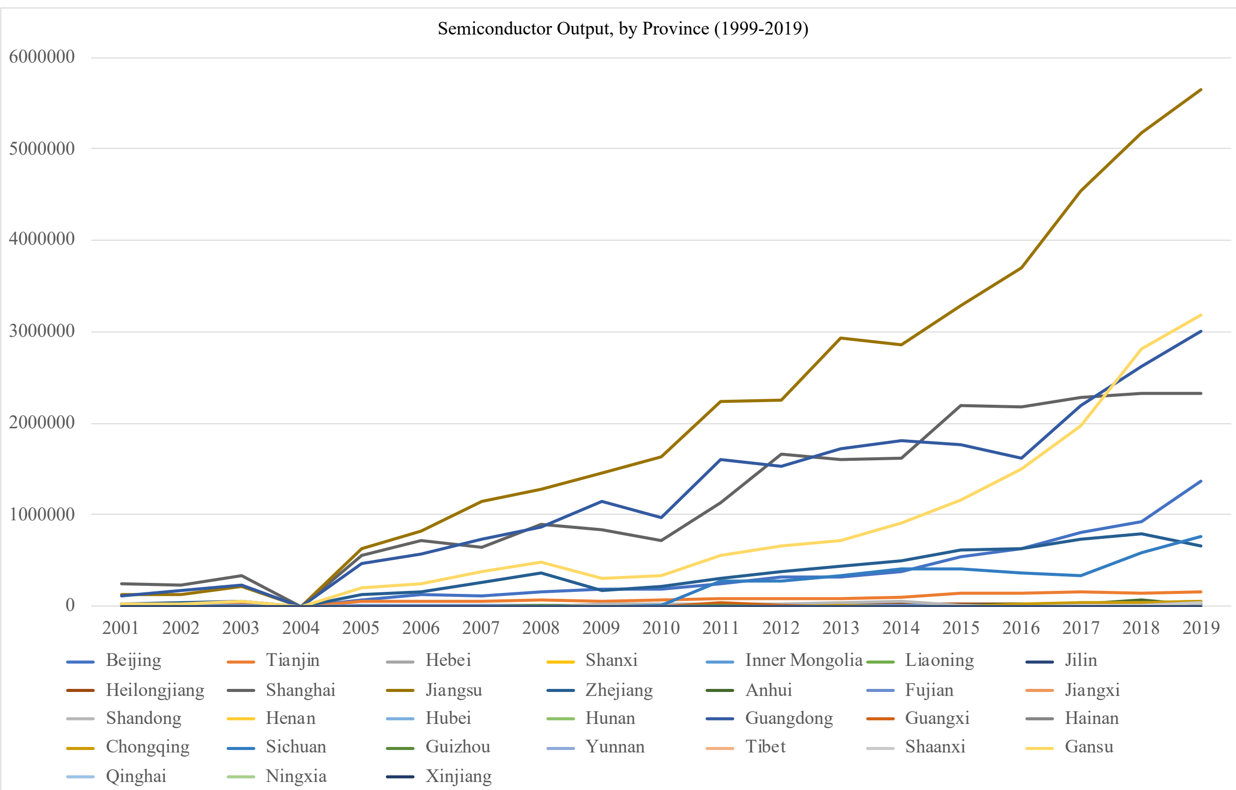
Also of note is the 2005 investment vehicle that the State Council raised specifically to stimulate semiconductor production in Western provinces (which are considered less developed than their Eastern counterparts). Funds are allocated for both R&D and production purposes (PwC, 2005).

- 4th Period: 2014 — Present

Focus: State-led Creation of Closed-loop Manufacturing Ecosystem

2014 marked a renewed effort on behalf of the central government to achieve semiconductor self-sufficiency. One notable exogenous event that spurred this desire was the Trade War waged between the Trump and Xi administrations. After the Trump administration blacklisted a series of Chinese semiconductor companies (whether by banning US investment, prevention of acquisition of US companies or urging allies to cease buying), Chinese semiconductor producer ZTE nearly went bankrupt. This spurred China's central government to list semiconductor technological and production "self-sufficiency" as a first priority in a new set of national guidelines published in 2015 called *Made in China 2025* (Cheng, 2018). In 2019, semiconductors represented China's greatest import at $160B and an export of $20B. (Horwitz, 2018). This discrepancy due to semiconductors is China's greatest trade deficit, greater than even the Chinese oil trade deficit. (Wübbeke et al., 2016). *Figure 1* provides an illustration of semiconductor output by province form 1999, the earliest year China's National Bureau of Statistics provides statistics for.

Figure 1: Semiconductor Output, by Province (1999-2019)



During the present period, China has been incorporating the lessons it has learned from previous time periods to produce very detailed national guidelines on how to produce a closed-loop manufacturing ecosystem. The capital amounts dedicated towards achieving these goals are unprecedented, with USD $200B expected to be invested in the next decade. Three national plans now govern China's semiconductor industrial policy: 1) "The Guidelines to Promote a National Integrated Circuit Industry," 2) "Made in China 2025," and 3) "The Made in China 2025 Technical Area Roadmap" (VerWey, 2019).

Semiconductors have become the foremost state priority, especially after the Trump administration used semiconductors as political leverage, as noted earlier, during the Trade War. The urgency felt by China's central government is reflected in policy. The Semiconductor Industry Association summarizes: "Some of these policies have the potential to: (1) force the creation of market demand for China's indigenous semiconductor products; (2) gradually restrict or block market access for foreign semiconductor products as competing domestic products emerge; (3) force the transfer of technology; and (4) grow non-market based domestic capacity, thereby disrupting the fabric of the global semiconductor value chain" (Goodrich, 2017).

In contrast to the body of current industrial policy research that has de-emphasized the selection of "national champions" (Bianchi et al., 2006), the concept is taking center stage in China's semiconductor policy. The main fault of the previous fragmentation of the industry (and previous policy) was the inability of domestic manufacturers to build up the capability to absorb technology spill-overs. As such, China is now focused on investing in national champions along each key step of the semiconductor supply chain (Orr et al., 2014). Although there is no official publication that details which companies have been designated national champions, a quick cross-reference of company leader backgrounds and revenue (given the unique business environment in China where business success is almost predicated upon strong government support) gives reason to suspect certain firms have been designated national champions. A quick overview is given of these firms:

· *Tsinghua Unigroup*

Tsinghua Unigroup, once an affiliate of Tsinghua University (where China's first experiments with semiconductors began) is hailed as the "national champion of champions." A state-owned enterprise (SOE), it is seen as China's response to the likes of Intel and China's greatest hope for a semiconductor company with an IDM business model. Largely the product of merger and acquisition sprees, it has a presence along the entire semiconductor supply chain. Notable domestic acquisitions include XMC, Speadtrum and RDA. Internationally, its attempted acquisitions of Micron Technologies and Powertech Mediateck were blocked by foreign governments in an attempt to prevent the transfer of valuable technology (Feng et al., 2018).

· *SMIC*

SMIC is China's national champion in foundry (chip manufacturing).

· *HiSilicon*

HiSilicon is a subsidiary of Huawei and China's chip design national champion. (*The Economist*, 2016).

However, perhaps what is most unprecedented about China's semiconductor industrial policy in 2014 is the capital influx into the industry. First, a national semiconductor investment fund was created. Local provinces followed in the footsteps of the state government and created their own investment vehicles as well. More details about these vehicles are provided below in the *Direct Subsidies* section. Second, the central government created a new domestic stock exchange platform focused on “hi-tech national champions” known as STAR. Semiconductor companies represented 17% of the newly-formed STAR exchange (Sheng, 2021).

In regards to specific industrial policy tools, this study will focus on the usage of direct subsidies (specifically investment vehicles) and geographic industrial clustering. It should be noted, however, that foreign M&A and joint ventures with a focus on technology transfer are prominent tools in China’s industrial policy toolbox as well.

Geographic Industrial Clustering

Four semiconductor clusters lead the industry in China. Broadly, they are the: Yangtze River Delta, Pearl River Delta, Beijing-Tianjin Bohai Sea region and Central-Western region.

The Yangtze River Delta represents not only the forefront and birthplace of semiconductor technology in China (with a focus on the midstream and downstream sections of the semiconductor supply chain), but the regions lead in revenue generation as well. In 2015, annual revenue reached 179.2B RMB (Trendforce, 2016).

The Pearl River Delta is home to China’s equivalent of Silicon Valley – Shenzhen which is located in Guangdong province. Annual revenue from the region’s semiconductor industrial cluster reached 68.8B RMB in 2015. The region is also home to HiSense, a semiconductor national champion and subsidiary of Huawei (Trendforce, 2016).

The Beijing-Tianjin Bohai Sea region is home to China’s two leading designated national champions: SMIC and Tsinghua Unigroup. Revenue from the cluster reached 62.5B RMB in 2015 (Trendforce, 2016).

Finally, the Hubei and Gansu provinces are the heart of the Central-Western region’s semiconductor production. Hubei, a newer entrant, has developed into China’s domestic NAND flash (computer storage medium and type of semiconductor (Grupp et al., 2012)) epicenter. Annual revenue in the region reached 50.5B RMB in 2015. (Trendforce, 2016). IC development in Wuhan's High-Tech Zone solidified around 2008 with XMC's entry. (Xie et al., 2018).

Direct Subsidies

Direct subsidies primarily take the form of industry-specific tax breaks and investment vehicles. The latter will be the focus of this study.

Over the next decade, China's plans to invest over $200B USD into the semiconductor industry. At all levels of the government (ex. city, provincial, national), investment funds/vehicles specifically targeting semiconductor development have been established. The most notable fund is the aptly named National Integrated Circuit Investment Fund ("NICIF") created in 2014 under the "National IC Plan" (formally the "Guidelines to Promote National Integrated Circuit Industry"). $21B and $29B were raised for the NICIF in 2014 and 2019 respectively (Kubota, 2019). Research into the sources of the NICIF's capital reveals significant participation from SOEs and financial institutions. (VerWey, 2019).

Below the state, many provincial and local governments have their own semiconductor-specific funds as well. For instance, Suzhou, a prefecture, recently established a 10B RMB semiconductor fund. (Ku, 2020). *Figure 2* shows a breakdown of provinces with provincial funds and fund sizes. It is expected that these funds have invested similarly to the national fund, often in the same national champions. The key difference lies in the fact that the provincial funds specifically target semiconductor production within the province, as opposed to investments between provinces and with multiple provinces.

Figure 2: Provincial Semiconductor Fund Sizes (2014 Regional Policy)

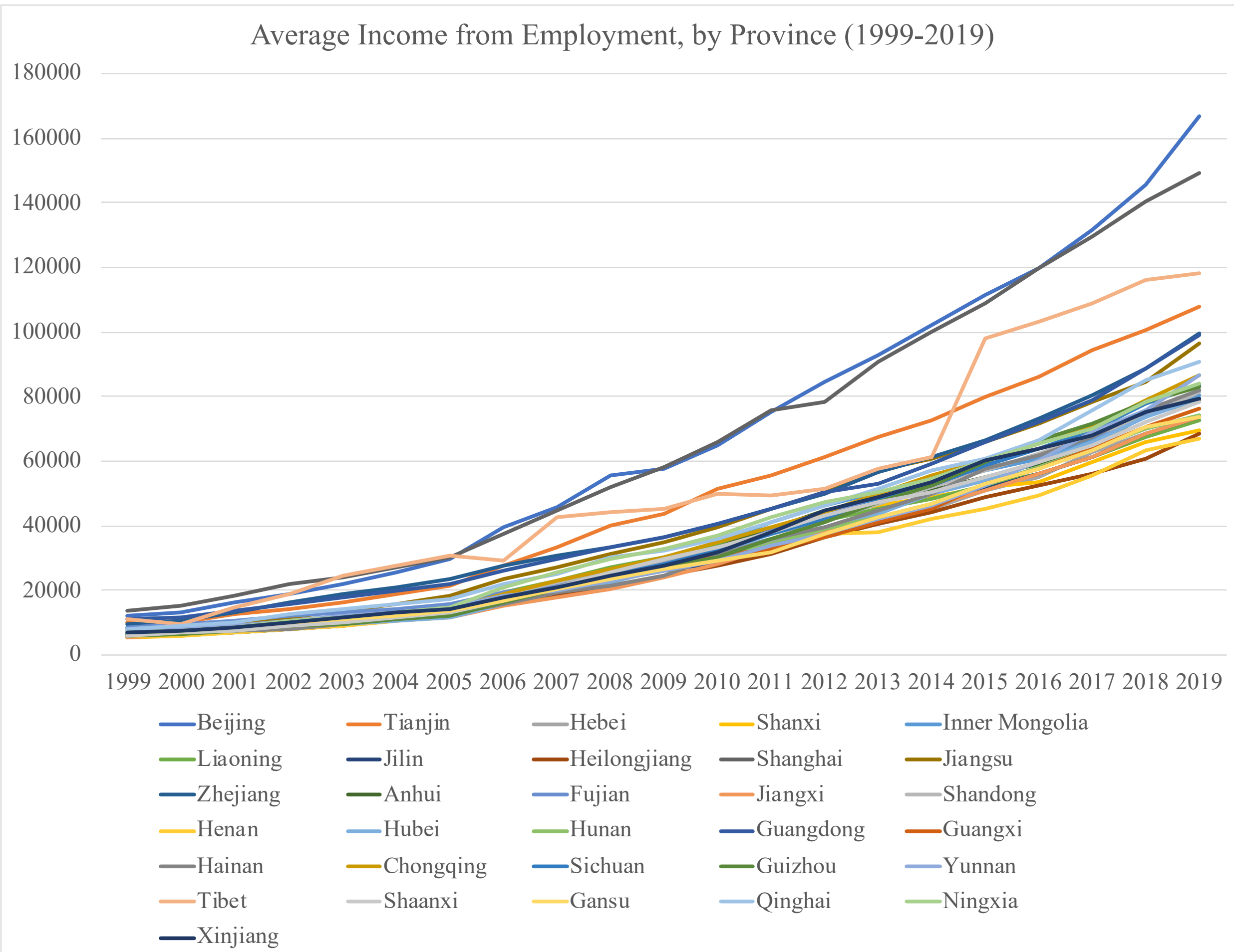
Provincial Semiconductor Fund Sizes (2014)	
Province	*RMB in billions*
Chongqing	50
Fujian	50
Shanghai	50
Beijing	32
Anhui	30
Hubei	30
Shaanxi	30
Jiangsu	20
Guangdong	15
Sichuan	12
Liaoning	10
Hunan	5
Shandong	3
Tianjin	0.2

Human Development and Income in China

The United Nations Development Program notes: "China's Human Development Index (HDI) has increased from 0.410 in 1978 to 0.752 in 2017, and China is the only country that has leapt from the low human development group to the high human development group since HDI was measured globally by the United Nations Development Programme for the first time in 1990." Since then, 740M people have been lifted out of poverty (UNDP, 2019). China's GDP enjoys some of the highest growth rates in the world (currently ~6%, 90.04 Trillion RMB in 2018 (The World Bank, 2021)) and consumption in both rural and urban areas has increased substantially. The reforms that have made this transformation possible began as primarily economic in nature. Most notably, after the "Reform and Opening Up" under the administration of Deng Xiaoping, China's fiscal system "changed from a 'each eats his own meal' (a system of dividing revenue and expenditure between the central and local governments) to a 'tax-sharing system.'" After economic growth was achieved, the state government began focusing on equitable contributions of the nation's wealth. This has led to an overall increase in income across the nation (UNDP, 2019). It is also important to differentiate between intensive and extensive growth (Wilczynski, 1972). The population of China, due to the One-Child policy, has remained at a ~0.4% growth rate since the 2000s (The World Bank, 2020). The country has also not annexed additional territory. Thus, most of its economic growth can be attributed to the intensive variety.

An illustration of provincial income from employment by year is provided in *Figure 3*.

Figure 3: Average Annual Income from Employment, by Province (1999-2019)



Theoretical Framework

China has been focused on economic growth, with the government using the tools of industrial policy extensively to achieve this goal. In theory, this should translate into higher levels of income from employment as citizens become better off with economic expansion. To establish this connection, three insights from theory were borrowed. First, the proliferation of the semiconductor industry leads to increased income (at least in the US where market forces dominate). Second, China's semiconductor industrial policy is well-designed, as defined by research of various case studies in literature. Finally, successful economic growth is accompanied by income growth. The first criteria has been discussed previously. The second will be discussed through the research of Robert Wade, an economist at the London School of Economics and Political Science and receiver of the Leontief Prize in Economics. The third will be discussed through the work of Jacob Mincer, a father of modern labor economics.

Industrial Policy and Economic Growth

In his 2012 article titled "Industrial Policy in Response to the Middle-income Trap and the Third Wave of the Digital Revolution," Wade discusses how "sectorally-target industrial policy can help to speed a middle-income country through the 'glass ceiling' and into the high-income segment." Although Wade discusses income at the level of the state instead of per capita, the tie between economic growth and a state moving from middle-income to high-income still holds. Wade conducts case studies of commonly accepted "successful" instances of industrial policy (ex. Japan's electronics industry, Korea's steel and semiconductor industry) and argues architectural components such as R&D investment and investing beyond comparative advantage spurs economic growth (Wade, 2019). Given Wade's guidelines, it would seem that China's semiconductor industrial policy is well-designed. The literature consensus is also that China's industrial policy in general, has helped spur the nation's economic growth. This in itself could be a definition of success.

Mincer's Income/Wage Model

Considering that the "Mincer earnings function is a cornerstone of a large literature in empirical economics" (Heckman et al., 2003), Mincer's 1958 human capital earnings model [derived from the principles of compensating differences and shown below as Model (*1*)] serves as the guiding framework in this paper to discuss earnings.

1. $\ln[w(s,x)] = \propto_0 + \rho_s s + \beta_0 x + \beta_1 x^2 + \varepsilon$

- s = schooling level
- x = work experience
- $w(s,x)$ = wage at schooling level *s* and work experience *x*
- s = rate of return to schooling

Two adjustments to Mincer's model are made given the context of this paper. First, average income will be thought to have the same determining drivers as the average wage depicted by Mincer. It will also be assumed that work experience and age exhibit similar characteristics and are substitutable.

Although an empirical analysis could not be found to verify whether these substitutions ensure the model remains significant, two studies found in the literature suggest these inputs are highly correlated. First, the Institute of Medicine (US) Committee on the Long-Run Macroeconomic Effects of the Aging U.S. Population published a report in 2012 noting: "As the workforce ages, it becomes more experienced." In other words, age and work experience are directly related. Second, Mincer developed a model for income determination in 1994 (Su & Heshmati, 2013), shown in Model (*2*) below:

$$2. \qquad \ln(INC_i) = X_i\beta + \varepsilon_i$$

- $\ln(INC_i)$ = natural logarithm of the annual income for observation i
- X_i= a vector of individual characteristics including a measure of education, age, occupation, gender, marital status, child status, and household size

Both education and age are inputs to individual income in this model.

Unfortunately, given the limited availability of public data regarding the other vector variables of Mincer's 1994 model, it was determined that Mincer's 1958 model would be more robust.

Hypotheses

Upon completion of a literature review, the theory would suggest the following hypotheses:

1. Semiconductor industrial policy in China should have a significant positive impact on human capital earnings, as represented by annual average income from employment by province.
2. 2014 semiconductor policy was the most extensive in scope; it should be most significant to income.

Methodology

Data

The data used for the purpose of this study was scraped from 2 sources. From both sources, the data ranged from 1999-2019, represents year-end numbers, and was measured by province, unless otherwise stated.

- National Bureau of Statistics China Statistical Yearbooks 1999-2019
    - Semiconductor output in 10,000 units
- China National Database Stats Center
    - Average income from employment, in yuan (1999-2002)
    - Total population
    - Number of people with at least a college degree
    - Number of people between the ages of 15-64 (sampling fraction of 0.820%)
- EPS China
    - Average income from employment, in yuan (2003-2019)

Of the 31 provinces in China, 7 provinces have never produced any semiconductors from 1999-2019. Based on 2019 regional GDP figures, the 24 Chinese provinces that have produced semiconductors represent ~94% of national GDP and ~92% of the national population. (National Bureau of Statistics China, 2020).

A total of 3,912 instances of data were collected.

The demographic data originates from an annual national sample survey of population. 2010 was the sole exception; census data was used that year instead.

Statistical Model & Variables

As noted earlier, some preliminary analysis is necessary to affirm the assumptions that underlie the ultimate topic of study: the relationship between China's semiconductor industrial policy and income.

Semiconductor Models

The first assumption is that semiconductor policy enacted in specific time periods has actually been significant to semiconductor output (as opposed to semiconductor output just growing consistently year by year). In short, if it is discovered that differences in semiconductor policy have no effect on overall semiconductor output, it would be dubious to take the next step and relate semiconductor policy time periods to income levels.

Two empirical methods were used to study the differing (or absorbing) effects of national policy versus specific regional policy.

A synthetic graphical analysis (where synthetic provinces were created to approximate the circumstance of provinces without policy enacted) was used to study national level policy in both 2005 and 2014.

To study regional policies, a difference-in-difference analysis ("DID") was determined suitable for the analysis because it allows a simple comparison between average income from employment and provinces that were treated and not treated. In 2005, the regional policy that deployed investment funds to Western semiconductor provinces was studied. In 2014, the regional policy of where local provinces raised their own semiconductor investment funds in conjunction to the national fund was studied.

Given the lack of data below the provincial level, it was determined that Chinese provinces that had no semiconductor output over the time period of 1999-2019 (and thus were not subject to semiconductor industrial policy) to be the most suitable counterfactuals. All Chinese provinces ultimately report to the central government and State Council, which is responsible for setting the guidelines and directing the bulk of China's industrial policy ambitions.

Semiconductor Synthetic Analysis

To create the synthetic provinces if 2005 policy did not occur, a CAGR was calculated using annual average provincial semiconductor output from 2001-2004. For the synthetic provinces if 2014 policy did not occur, a CAGR was calculated using the time range from 2001-2013.

Besides semiconductor output, these calculations were performed on the control variables of education, age and population as well. Look to the appendix for an output of the control variables; in all synthetic cases, the control variables to do not vary substantially from reality.

Semiconductor DID Analysis

The base model is defined in (*3*) and its variations are discussed below:

3. $$S_i = \alpha_0 + [\beta_1 T_1 + \gamma_1 D_1 + \alpha_1 (T_1 \cdot D_1)]$$

Average provincial semiconductor output in year *i* is represented by S_i. T_i, and D_i are dummy variables. T_i is equal to 1 when provinces record an output of semiconductors in any year within the year range of the policy being analyzed. Otherwise, it is equal to 0. D_i is equal to

1 inclusive of the year the policy was enacted and afterwards. For the years before, D_i is equal to 0.

A total of 16 model variations were analyzed. Variations can be split into two main categories:

- Control variables
- Treatment periods, T_i

Control Variables

Control variables were considered as an attempt to eliminate provincial demographic differences. Considerations were also made for the quality and availability of data. Education, age and population were selected. Model (*4*) represents the base Model (*3*) with the addition of the control variable variation.

4. $S_i = \alpha_0 + [\beta_1 T_1 + \gamma_1 D_1 + \alpha_1 (T_1 \cdot D_1)] + \alpha_2 education_2 + \alpha_3 age_3 + \alpha_4 population_4 + \alpha_5 recession2002_5 + \alpha_6 recessionGFC_6 + \varepsilon_i$

education is defined as the percentage of a province's total population that holds at least a college degree.

age is defined as the percentage of a province's total population that is aged between 15-64. This age range is typically considered the "workforce" proxy when studying Chinese labor economics (World Economic Forum).

population is defined as the total population in a province.

r*ecessiondotcom* is a dummy variable to account for the Dotcom bubble. It is 1 for 2001 and 2002, and 0 from 2003-2019.

recessionGFC is a dummy variable to account for the Great Financial Crisis. It is 1 for 2007-2009, and 0 from 2001-2006 and 2010-2019.

Treatment periods, T_i

Treatment periods were determined based on an evaluation of literature and general research. The evaluation suggested that the consensus is that from 1999 to 2019, there are two significant periods of semiconductor policy changes, with 2005 and 2014 being pivotal years. Furthermore, considering the high upfront costs and time it takes to spur semiconductor production (McKinsey, 2011), it would be appropriate to consider the data for lag in policy. To account for all these possibilities, each of these time periods were first analyzed in isolation as a single treatment to the data. Model (*3*) was then analyzed through iterations with T_i representing different post treatments (inclusive of policy implementation year) of 2005, 2006, 2014 and 2015.

However, the reality of China's semiconductor industrial policy from 2001-2019 is that it was separated into two general periods. To understand the true impact of individual policy periods without diluting the analysis with the impact of later policy periods, a variation on the simple DID model given in Model (*3*) was introduced. Model (*5*) accounts for two treatment periods. Model (*6*) represents the addition of the control variable variation noted in the previous section.

5. $S_i = \alpha_0 + [\beta_1 T_1 + \gamma_1 D_1 + \alpha_1 (T_1 \cdot D_1)] + [\beta_2 T_2 + \gamma_2 D_2 + \alpha_2 (T_2 \cdot D_2)] + \varepsilon_i$

6. $S_i = \alpha_0 + [\beta_1 T_1 + \gamma_1 D_1 + \alpha_1 (T_1 \cdot D_1)] + [\beta_2 T_2 + \gamma_2 D_2 + \alpha_2 (T_2 \cdot D_2)] +$
$\alpha_3 education_3 + \alpha_4 age_4 + \alpha_5 population_5 + \alpha_6 recession2002_6 + \alpha_7 recessionGFC_7 + \varepsilon_i$

Using the same reasoning described earlier regarding the controversy surrounding the true beginning of the first policy period and lag periods, the following model variations on time period were studied (T_1, T_2): (2005-2013, 2014-2019); (2006-2014, 2015-2019).

Income OLS Model

The second assumption is less of an assumption rather than a motivating factor. To test whether average provincial semiconductor output produced over 1999-2019 was even correlated with average provincial income from employment, a simple ordinary least squares ("OLS") regression was used. Income was the dependent variable and semiconductor output was the independent variable. Models (*7*) and (*8*) represent magnitudes/levels. Models (*9*) and (*10*) measures changes (delta) in variables. Models (*8*) and (*10*) represent variations with the addition of control variables.

7. $Y_i = a_0 + \beta_1 semiconductor_1 + \varepsilon_i$

8. $Y_i = a_0 + \beta_1 semiconductor_1 + \beta_2 education_2 + \beta_3 age_3 + \beta_4 population_4 + \beta_5 recessiondotcom_5 + \beta_6 recessionGFC_6 + \varepsilon_i$

9. $\Delta Y_i = a_0 + \beta_1 \Delta semiconductor_1 + \varepsilon_i$

10. $\Delta Y_i = a_0 + \beta_1 \Delta semiconductor_1 + \beta_2 \Delta education_2 + \beta_3 \Delta age_3 + \beta_4 \Delta population_4 + \beta_5 \Delta recessiondotcom_5 + \beta_6 \Delta recessionGFC_6 + \varepsilon_i$

Income Models

Income Synthetic Analysis

Similar logic was followed here to create the synthetic provinces as earlier in the semiconductor output analysis to study national policy. The only difference is the calculation of CAGR. 2005 synthetic provinces were projected from a 1999-2004 CAGR and 2014 synthetic provinces were projected from a 1999-2013 CAGR.

Income DID Models

In addition to the DID model variations studying semiconductor output, the DID models studying income introduce one more variation: the scope of policy (regional or national). Since China's semiconductor industrial policy at the national scope is applied to every province, every province in China should technically be considered "treated." However, practically, that leaves little room for analytical insight. Thus, for the purpose of this study, semiconductor output was used as a proxy to determine whether a province had experienced the effects of policy when studying the effects of national policy. The logic is that if funds were distributed specifically for semiconductor production, it would only be logical that those provinces that produced semiconductors received funds.

To study the regional policies (the 2005 Western province investment vehicle and 2014 provincial funds), the same approach was used as with the earlier semiconductor DID models.

The approach taken to analyze semiconductor industrial policy in China at the provincial level with average income from employment is informed by the previous two models.

11. $Y_i = \alpha_0 + [\beta_1 T_1 + \gamma_1 D_1 + \alpha_1 (T_1 \cdot D_1)] + \varepsilon_i$

12. $Y_i = \alpha_0 + [\beta_1 T_1 + \gamma_1 D_1 + \alpha_1 (T_1 \cdot D_1)] + \alpha_2 education_2 + \alpha_3 age_3 + \alpha_4 population_4 + \alpha_5 recession2002_5 + \alpha_6 recessionGFC_6 + \varepsilon_i$

13. $Y_i = \alpha_0 + [\beta_1 T_1 + \gamma_1 D_1 + \alpha_1 (T_1 \cdot D_1)] + [\beta_2 T_2 + \gamma_2 D_2 + \alpha_2 (T_2 \cdot D_2)] + \varepsilon_i$

14. $Y_i = \alpha_0 + [\beta_1 T_1 + \gamma_1 D_1 + \alpha_1 (T_1 \cdot D_1)] + [\beta_2 T_2 + \gamma_2 D_2 + \alpha_2 (T_2 \cdot D_2)] + \alpha_3 education_3 + \alpha_4 age_4 + \alpha_5 population_5 + \alpha_6 recession2002_6 + \alpha_7 recessionGFC_7 + \varepsilon_i$

Model (*11*) is the base DID equation where average income from employment is the dependent variable. Model (*11*) and (*12*) represent a single treatment period while Model (*13*) and (*14*) adjust for two treatment periods. Model (*12*) and (*14*) are the variations with the inclusion of control variables. In the exact fashion to Models (*3-6*), Models (*11-14*) were analyzed for varying treatment periods and datasets. Refer to the *Semiconductor DID Models* section above for the reasoning behind these model variations, designated treatment periods, and datasets.

A key difference in concept between the *Semiconductor DID Models* and the *Income DID Model* is in the selection of control variables. While the control variables for both are the same, the intent behind the inclusion of education, age and population here is due to theory in the literature that these factors are determinants of income (refer to Mincer's model discussed under *Theoretical Framework*) as opposed to controlling for provincial differences.

Below, a summary of the variables is provided:

Table 1: Summary Statistics of Key Variables, 1999-2019

Table 1. **Summary Statistics of Key Variables, 1999-2019**

Year	1999			2019		
	All provinces	*Treated provinces*	*Control provinces*	*All provinces*	*Treated provinces*	*Control provinces*
2005 - National Medium- and Long-Term Science and Technology Development Plan Outline (National)						
Number of provinces	*31*	*8*	*23*	*31*	*8*	*23*
Number of observations	*651*	*168*	*483*	*651*	*168*	*483*
Average Income from Employment *(in thousands)*	7.52	8.04	6.80	87.65	92.21	81.34
std dev	*2.10*	*2.36*	*1.49*	*22.15*	*26.35*	*12.96*
Education	0.03	0.04	0.03	0.15	0.16	0.12
std dev	*0.03*	*0.04*	*0.01*	*0.08*	*0.10*	*0.03*
Age	0.68	0.69	0.67	0.71	0.71	0.71
std dev	*0.03*	*0.03*	*0.03*	*0.04*	*0.04*	*0.03*
Population *(in millions)*	39.77	46.40	30.59	45.29	53.15	34.40
std dev	*25.83*	*24.08*	*26.25*	*29.12*	*28.17*	*27.84*
2014 - Guidelines for the Development and Promotion of the Integrated Circuit Industry (National)						
Number of provinces	*31*	*14*	*17*	*31*	*14*	*17*
Number of observations	*651*	*294*	*357*	*651*	*294*	*357*
Average Income from Employment *(in thousands)*	7.52	7.79	6.89	87.65	90.10	82.51
std dev	*2.10*	*2.29*	*1.50*	*22.15*	*24.98*	*14.30*
Education	0.03	0.03	0.03	0.15	0.16	0.13
std dev	*0.03*	*0.03*	*0.01*	*0.08*	*0.09*	*0.03*
Age	0.68	0.69	0.68	0.71	0.71	0.71
std dev	*0.03*	*0.03*	*0.03*	*0.04*	*0.04*	*0.03*
Population *(in millions)*	39.77	45.76	32.50	45.29	52.73	29.65
std dev	*25.83*	*22.60*	*23.39*	*29.12*	*26.68*	*29.06*
2005 - Western Province Semiconductor Investment Fund Policy (Provincial)						
Number of provinces	*31*	*18*	*13*	*31*	*18*	*13*
Number of observations	*651*	*378*	*273*	*651*	*378*	*273*
Average Income from Employment *(in thousands)*	7.52	6.54	7.86	87.65	80.67	90.08
std dev	*2.10*	*0.56*	*2.34*	*22.15*	*5.09*	*25.23*
Education	0.03	0.02	0.04	0.15	0.12	0.16
std dev	*0.03*	*0.01*	*0.03*	*0.08*	*0.02*	*0.09*
Age	0.68	0.68	0.68	0.71	0.70	0.72
std dev	*0.03*	*0.01*	*0.01*	*0.04*	*0.03*	*0.04*
Population *(in millions)*	39.77	47.35	37.13	45.29	49.19	43.93
std dev	*25.83*	*20.40*	*27.37*	*29.12*	*20.04*	*31.96*
2014 - Provincial Investment Vehicles Policy (Provincial)						
Number of provinces	*31*	*21*	*10*	*31*	*21*	*10*
Number of observations	*651*	*441*	*210*	*651*	*441*	*210*
Average Income from Employment *(in thousands)*	7.52	8.28	6.89	87.65	95.48	81.21
std dev	*2.10*	*2.51*	*1.50*	*22.15*	*28.49*	*12.74*
Education	0.03	0.04	0.03	0.15	0.18	0.12
std dev	*0.03*	*0.04*	*0.01*	*0.08*	*0.10*	*0.03*
Age	0.68	0.69	0.68	0.71	0.72	0.71
std dev	*0.03*	*0.03*	*0.03*	*0.04*	*0.04*	*0.03*
Population *(in millions)*	39.77	48.59	32.50	45.29	56.23	36.28
std dev	*25.83*	*26.71*	*23.39*	*29.12*	*30.74*	*25.14*

Notes:
Education = % of population (in province) with a college degree by province per year
Age = % of population (in province) that are working age (15-64) by province per year
Population = # of people 15-64 per province by year

Specific Regional Policy Descriptions
2005 - End of national VAT tax subsidy for domestic semiconductor firms after WTO dispute, new state-level investment vehicle targeting Western province tech raised
2014 - Local provinces formed provincial semiconductor-specific funds

Results

Below are the key insights of this study on the topic of China's semiconductor industrial policy and its relation to average annual income from employment.

- **Semiconductor industrial policy has not been significant on average income from employment levels in China.**
- In some cases, data shows a negative correlation (not significant, but large magnitude) between semiconductor industrial policy and income.
- Synthetic graphical analysis shows income has been increasing in growth rates significantly in 2005 and 2014 – suggests that there are other factors more determinant than semiconductor industrial policy.
- 2014 (national and regional) policy was the most significant to semiconductor output, but that significance was lost on income.
- 2014 local provincial investment vehicles in existing geographic cluster seem to have a more positive impact/correlation on income compared to the 2005 western province development IC investment vehicle.

In this section, figures and tables are organized according to their purpose/argument. A more in-depth discussion is provided in the *Discussion* section.

Assumption 1: Semiconductor output and average income from employment are positively correlated.

Table 2: Determinants of Income and ΔIncome

Table 2. **Determinants of Income and Δ Income**

Model #		A	B	C	D
Dependent variables		*Income*	*Income*	*Δ Income*	*Δ Income*
Independent variables					
(1)	Semiconductor	0 ***	0.01 ***	0.01 ***	0.01 ***
	std error	*0*	*0.00*	*0.00*	*0.00*
(2)	Education[1]		3.02 ***		0.52
	std error		*0.13*		*0.31*
(3)	Age[1]		-2.00 ***		-0.01
	std error		*0.22*		*0.42*
(4)	Population		0.01		35.02
	std error		*0.26*		*21.06*
(5)	Recession (dotcom)		-22.85 ***		
	std error		*2.25*		
(6)	Recession (GFC)		-8.53 ***		
	std error		*1.86*		
	Intercept[2]	37.03 ***	159.90 ***	2.17 ***	1.33 *
	std error	*1.09*	*15.56*	*0.32*	*0.52*

Notes:
Timeframe: 1999-2019
Dataset: All 31 provinces of China
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Semiconductor = # of semiconductors produced per year by province
Education = % of population (in province) with a college degree by province per year
Age = % of population (in province) that are working age (15-64) by province per year
Population = # of people per province by year

Model Descriptions:
A income ~ semiconductors
B income ~ semiconductors educaton + age + population + recessiondotcom + recessionGFC
C incomedelta ~ semidelta
D incomedelta ~ semidelta + educatondelta + agedelta + populationdelta

[1] in 100,000
[2] in 1,000

Assumption 2: Semiconductor industrial policy in China is significant to semiconductor output.

Figure 4: Synthetic Analysis of Annual Average Provincial Semiconductor Output

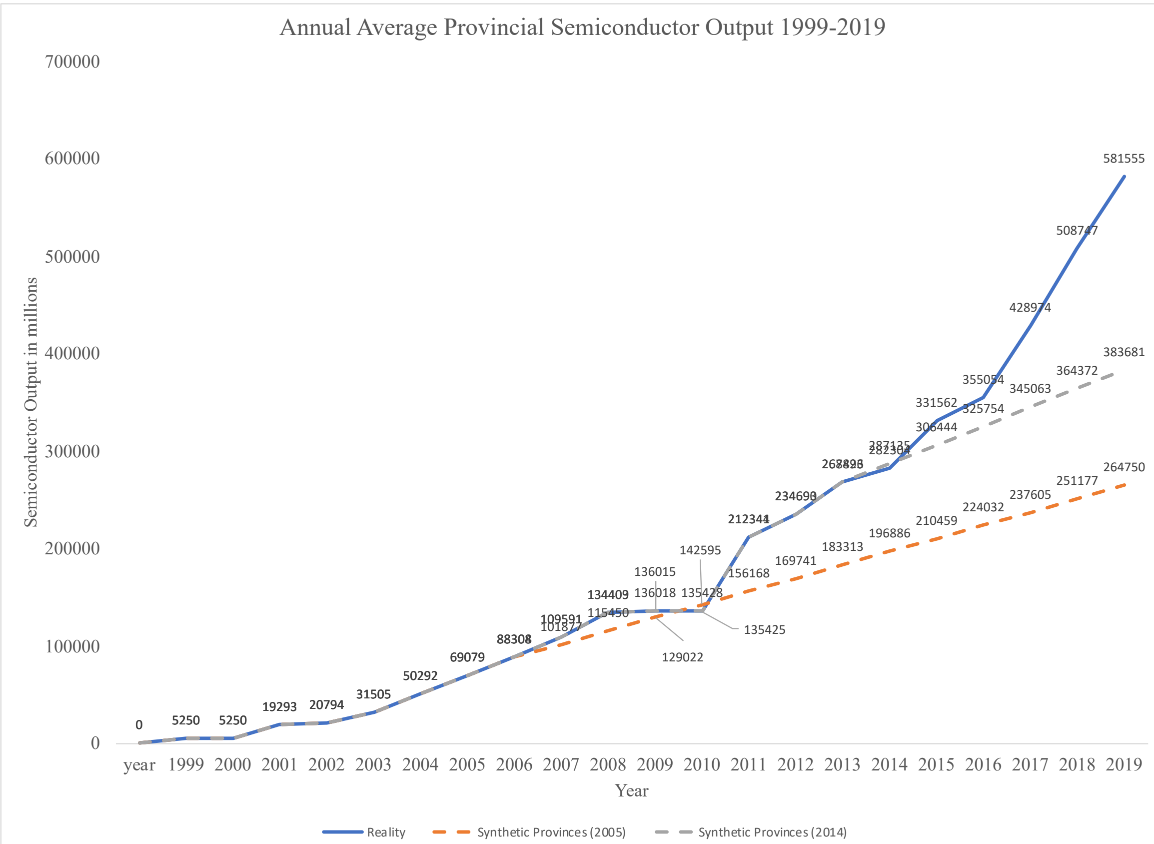


Figure 5: Synthetic Analysis CAGR Statistics (Semiconductor Output)

Annual Average Provincial Semiconductor Output

Statistic		Reality	2005 Synthetic	2014 Synthetic
	1999	5250	5250	5250
	2005	69079	69079	69079
	2014	282304	196886	287135
	2019	581555	264750	383681
CAGR (1999-2019)		**60%**	**48%**	**54%**
CAGR (2005-2019)		**16%**	**10%**	**13%**
CAGR (2014-2019)		**16%**	**6%**	**6%**

Table 3: Impact of Regional Semiconductor Policy on Semiconductor Output with a Single Treatment Period (DID)

Table 3. **Impact of Regional Semiconductor Policy on Semiconductor Output with a Single Treatment Period (DID)**

Treatment Year	2005	2006	2014	2015
DID estimator[1]				
Model				
(1)	-0.94	-0.94	3.82 ***	3.92 ***
	1.44	*1.33*	*1.05*	*1.11*
(2)	-0.49	-0.51	3.19 **	3.32 **
	1.32	*1.22*	*1.02*	*1.07*

Notes:
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Model Descriptions
1 semiconductors ~ treat + period + treatperiod
2 semiconductors ~ treat + period + treatperiod + education + age + population + recessiondotcom + recessionGFC
Education = % of population (in province) with a college degree by province per year
Age = % of population (in province) that are working age (15-64) by province per year
Population = # of people per province by year
Specific Regional Policy Descriptions
2005 - End of national VAT tax subsidy for domestic semiconductor firms after WTO dispute, new state-level investment vehicle targeting Western province tech raised
2014 - Local provinces formed provincial semiconductor-specific funds

Table 4: Impact of Regional Semiconductor Policy on Semiconductor Output with a Double Treatment Period (DID)

Table 4. **Impact of Regional Semiconductor Policy on Semiconductor Output with a Double Treatment Period (DID)**

Treatment period 1	2005-2013	2006-2014
Treatment period 2	2014-2019	2015-2019
DID estimator[1]		
Model (1)		
Treat period 1	0.33	0.04
st error	*1.11*	*1.11*
Treat period 2	3.86 ***	3.93 ***
st error	*1.05*	*1.11*
Model (2)		
Treat period 1	0.37	0.12
st error	*1.08*	*1.07*
Treat period 2	3.25 **	3.34 **
st error	*1.03*	*1.08*

Notes:

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Model Descriptions

1 semiconductors ~ treat1 + period1 + treatperiod1 + treat2 + period2 + treatperiod2

2 semiconductors ~ treat1 + period1 + treatperiod1 + treat2 + period2 + treatperiod2 + education + age + population + recessiondotcom + recessionGFC

Education = % of population (in province) with a college degree by province per year

Age = % of population (in province) that are working age (15-64) by province per year

Population = # of people per province by year

Specific Regional Policy Descriptions

2005 - End of national VAT tax subsidy for domestic semiconductor firms after WTO dispute, new state-level investment vehic targeting Western province tech raised

2014 - Local provinces formed provincial semiconductor-specific funds

Income Analysis

Figure 6: Synthetic Analysis of Annual Average Provincial Income from Employment

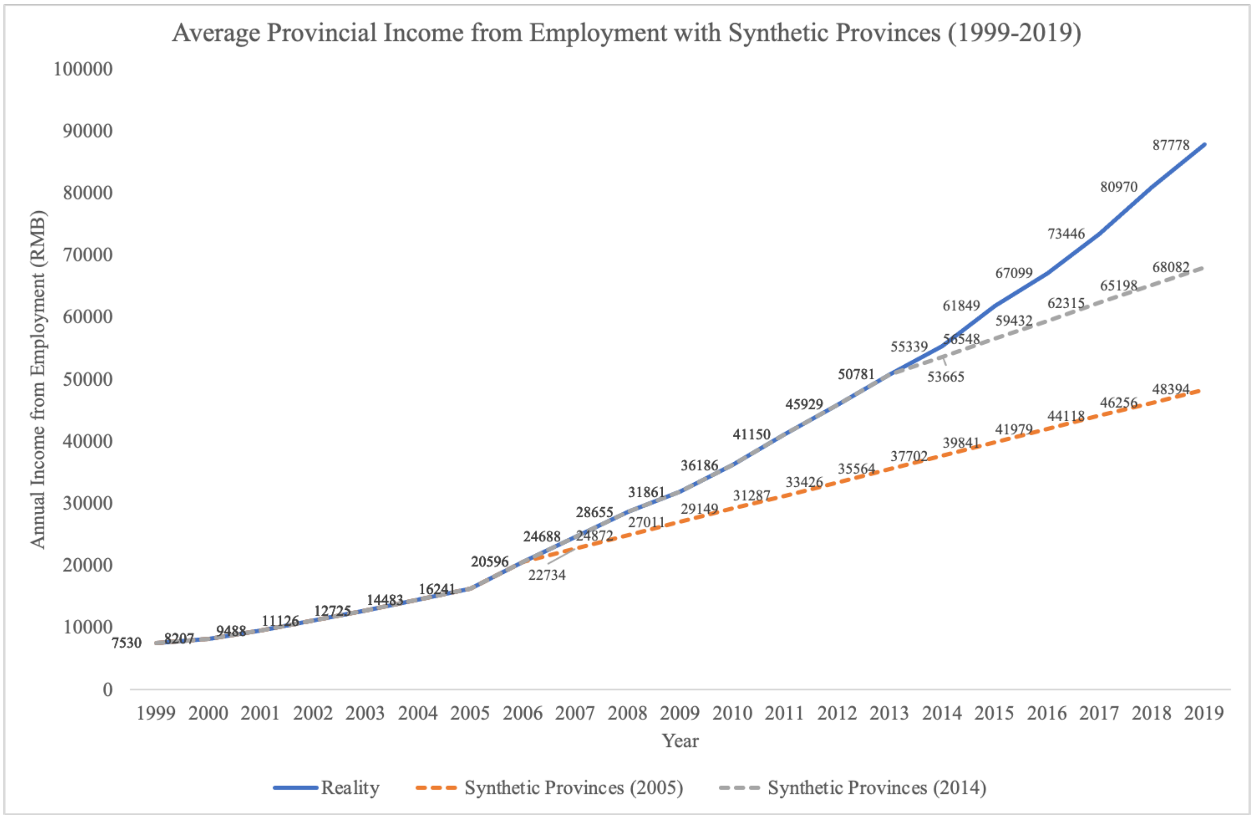


Figure 7: Synthetic Analysis CAGR Statistics (Income)

Annual Average Provincial Income from Employment

Statistic		Reality	2005 Synthetic	2014 Synthetic
	1999	7530	7530	7530
	2005	16241	16241	16241
	2014	55339	37702	53665
	2019	87778	48394	68082
CAGR (1999-2019)		**13%**	**10%**	**12%**
CAGR (2005-2019)		**13%**	**8%**	**11%**
CAGR (2014-2019)		**10%**	**5%**	**5%**

Figure 8: Preliminary DID Analysis of Average Income from Employment (2014 National Policy)

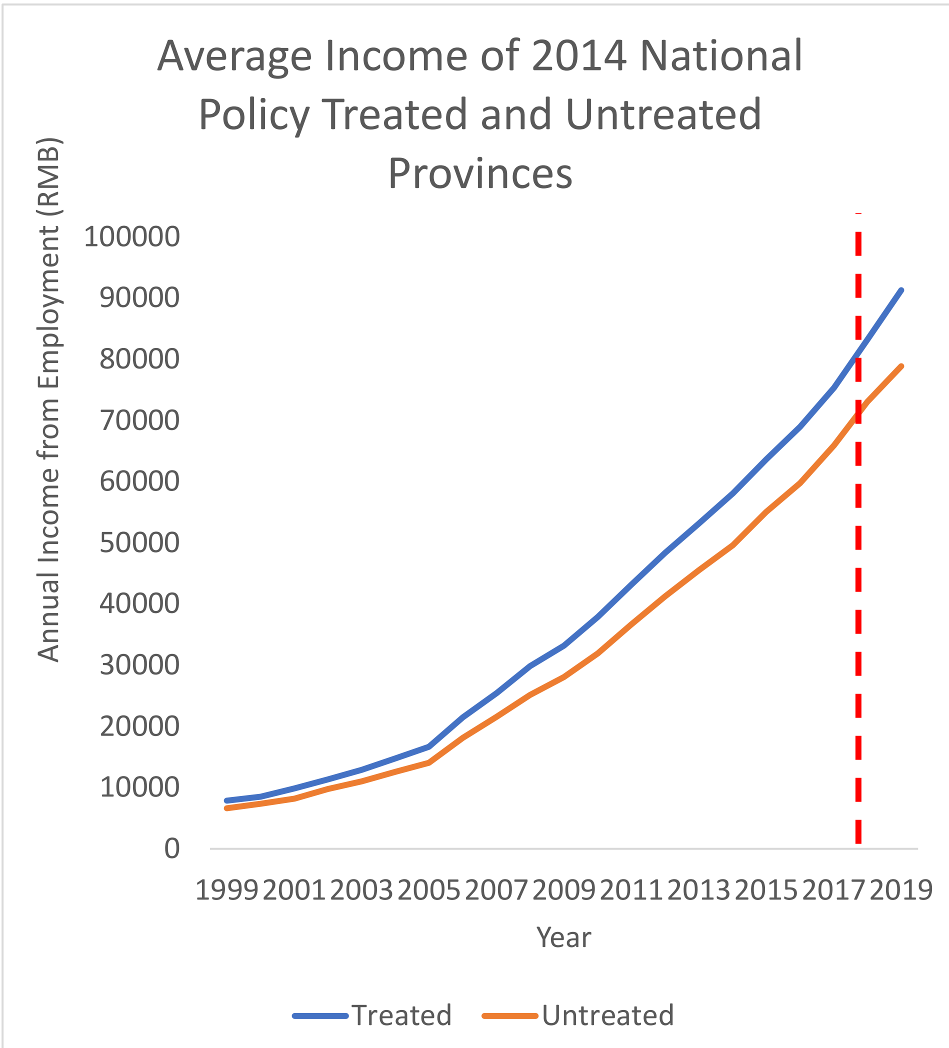


Table 5: Impact of National and Regional Semiconductor Policy on Average Annual Income from Employment with a Single Treatment Period (DID)

DID estimator of National and Regional Semiconductor Industrial Policy on Annual Income from Employment w/ Single Treatment Period

Treatment Year	2005		2006		2014		2015	
Policy	*National*	*Regional*	*National*	*Regional*	*National*	*Regional*	*National*	*Regional*
Model								
(1)	-0.76	-3.56	-0.66	-3.28	-0.36	1.31	0.80	1.08
st error	*6.66*	*2.74*	*5.70*	*2.38*	*4.50*	*2.16*	*3.89*	*2.38*
(2)	-2.87	-1.92	-2.91	-1.78	2.09	1.96	2.88	1.88
st error	*2.43*	*2.42*	*2.09*	*2.08*	*2.05*	*1.89*	*2.28*	*2.10*

Notes:
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Model Descriptions
1 income ~ treat + period + treatperiod
2 income ~ treat + period + treatperiod + education + age + population + recessiondotcom + recessionGFC
Education = % of population (in province) with a college degree by province per year
Age = % of population (in province) that are working age (15-64) by province per year
Population = # of people per province by year

Table 6: Impact of National and Regional Semiconductor Policy on Average Annual Income from Employment with a Double Treatment Period (DID)

DID estimator of National and Regional Semiconductor Industrial Policy on Annual Income from Employment w/ Double Treatment Period

Treatment period 1	2005-2013		2006-2014	
Treatment period 2	2014-2019		2015-2019	
Policy Scope	*National*	*Regional*	*National*	*Regional*
Treat period 1	-1.16	-0.99	-1.28	-1.30
st error	*1.70*	*1.73*	*1.55*	*1.60*
Treat period 2	1.32	2.68	2.06	3.09
st error	*1.94*	*1.64*	*1.86*	*1.61*

Notes:
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Model Description
income ~ treat1 + period1 + treatperiod1 + treat2 + period2 + treatperiod2 + education + age + population

Education = % of population (in province) with a college degree by province per year
Age = % of population (in province) that are working age (15-64) by province per year
Population = # of people per province by year

Discussion

Assumption 1

According to the OLS regression of both annual average income from employment levels and change in those levels, semiconductor output is significant with or without control variables. In the models with control variables, the signs of control variables coefficients align with what is expected as informed by Mincer's models. Education, or a more highly educated population positively impacts income. Age is negative here, but this can be due to a supply and demand effect of labor. For instance, if the percentage of the population that is able-bodied has grown but the number of jobs has not kept up in pace, income levels would deflate. The lack of specific age data regarding the aging of the population is a limitation of this study.

The recession variable coefficients are both negative, which matches the nature of an economic recession.

Of note, semiconductor output is the only significant variable in the delta income model. This brings even more motivation to the study as delta is more robust of a test (taking into account direction and magnitude as opposed to just magnitude for income levels). A graphic illustration of *Table 2* is provided in the appendix.

Assumption 2

Semiconductor industrial policy in China is significant to semiconductor output.

The synthetic graph shows that the highest CAGRs achieved are all in reality (60%) versus the CAGRs of the synthetic provinces (48% for pre-2005 policy and 54% for pre-2014 policy). In other words, in both 2005 and 2014, semiconductor output experienced an inflection point, accelerating growth above its run rate. Of note, 2014 and 2005 seem to have had a similar degree of impact on semiconductor output. The difference between 1999-2019 CAGRs is 6% between both reality and 2014 synthetic provinces, and 2014 synthetic provinces and 2005 synthetic provinces. The 2005-2019 CAGRs show an even difference of 3% between the above sets as well.

DID regressions, as represented by *Table 3* and *4*, show similar effects. 2014 seems to be the most impact year. However, because the methodology of a DID allows to control for semiconductor policy, it is possible to correlate/attribute this significance more specifically to semiconductor industrial policy than with the previous synthetic analysis. Furthermore, we see the regression suggests a lag period in policy (2015 is as significant as 2014), which makes sense given the heavy capex and initial costs of ramping up semiconductor production. While the coefficients of the DID estimator for 2014 and 2015 range from 3-4, the 2015 DID estimator is always greater than the 2014 DID, suggesting 2015 is more impactful to semiconductor output determination. However, all 2015 standard errors are also greater than all 2014 standard errors, suggesting greater volatility in impact as well. Put in context, this could be due to the fact that the funds raised by local provinces in 2014 vary widely in size – from 200M to 50B RMB. The difference in fund size probably has some relation to overall impact of semiconductor output, and that difference would become more obvious over time.

However, perhaps what is most intriguing about the regression is the negative coefficient for 2005 and 2006 regional policy when a single treatment period is used. Notably, the coefficient becomes positive with a double treatment period. While a double treatment period is more reflective of reality, any negative impact of semiconductor industrial policy on semiconductor output is still surprising. One possible explanation is that 2005 was the peak of a semiconductor cycle. As a capex intensive industry, semiconductor cycles are driven by inventory buildup and global GDP stagnation. Cycles generally range 5-10 years, and the next major semiconductor dip was during the Great Financial Crisis, which was accounted for with a dummy variable (Regions, 2019). Another explanation is that the Western provinces had a volatile experience with semiconductor production. The double treatment period would suggest that funds drove positive production from 2005-2013 and the negative coefficient of the single treatment period suggests that growth stagnated after 2013.

All in all, overall semiconductor output in China as depicted in the graph of output has never experienced negative growth (except for a stagnation period during the Great Financial Crisis). Given that the industry is largely directed and controlled by the State Council, this itself suggests that industrial policy has been successful to some degree in growing the industry.

Income Analysis

Semiconductor industrial policy has not been significant on average income from employment levels in China.

The synthetic province analysis graph shows similar trends to the previous synthetic province analysis of semiconductor output. As before, the CAGRs for reality were higher than the 2005 and 2014 synthetic provinces. However, with income, the 1% difference between reality and the 2014 synthetic provinces' CAGR and the 2% difference between the 2014 synthetic provinces' and 2005 synthetic provinces' CAGR suggests that whatever occurred in 2005 had a greater impact on income growth rate than 2014 did. However, both the synthetic and DID analysis of semiconductor policy to output would suggest that the opposite should be observed in income. There are a few reasons why this could be. It is important first though, to consider income in context. As Mincer's models inform us, there are many determinants of income and each of those determinants (ex. education) is influenced by its own set of determinants. Pinpointing income causality to semiconductor policy would be inaccurate in this synthetic province analysis. The only viable conclusion that can be determined is that the conglomerated effects of 2005 led to an increase in income growth higher than those of 2014. This is evident in overall national GDP growth in those years as well. GDP in 2005 grew by 11.4% versus 7.6% in 2014 (The World Bank, 2021). The early 2000s represented the peak of China's economic growth as the country underwent economic reform and benefited from global trade tailwinds after its inclusion into the World Trade Organization in December 2001 (UNDP, 2019). Another explanation originates from Wade's case studies of successful industrial policy. Wade notes that often, successful industrial policy results from investing beyond a developing country's comparative advantages. For instance, pre-1980, South Korea did not have a steel industry to speak of. However, the government directed investments into growing the industry, and now the country has a thriving steel industry. The investments in 2005 were targeted at semiconductor provinces that were considerably less developed than their Eastern, coastal counterparts. However, as discussed later, a DID regression on income seems to suggest the exact opposite. Given that a DID regression allows for more control for semiconductor policy specificity, it should be inferred that most of impacts to income being observed are from macro-level events whose effects far outweigh singular instances of semiconductor policy in 2005 and 2014.

The DID regressions show a lack of significance between semiconductor industrial policy and average annual income from employment.

Before entering into a discussion of the DID results, it is instructive to establish some of the necessary assumptions that make DID a solid methodology. First, parallel trends. Although treated and untreated provinces, as shown in the below figure, are not completely parallel pre and post-2014, a gradual divergence can be observed. Interestingly, treated and untreated provinces, as defined by 2014 policy, seem to have been affected by policy in 2005 quite significantly. This can be seen by the inflection point found in 2005 that both the treated and untreated province trendlines depict. A possible explanation for this phenomena is cause for further research.

Another assumption of DID is that intervention is unrelated to outcome at baseline. However, when studying national policy DID, semiconductor output was used as a proxy for provinces considered treated or control. Since there was no way to trace the funds distributed at the national level of policy or pinpoint what national guidelines were used in which provinces, the next-best alternative was to make the assumption that if the goal of semiconductor industrial policy is to increase semiconductor output, then those provinces with semiconductor output should be the "receivers" of semiconductor policy. Regional policy DID, however, does fully fulfill this assumption.

In short, the results of the DID in this study do not appropriately fulfill all the requirements in order to assume causality. Instead, given the steps used to remedy these shortcoming, whether by using two different empirical methods or varying the design of the DID models, this paper seeks to establish a strong correlation which may in the future, with the appropriate data, suggest a causation effect.

The first intriguing point to the regressions is the negative DID estimator coefficient for both national and regional policy in 2005 and 2006. National policy in both years is defined by semiconductor output, while regional policy is defined as Western provinces that received funds from the 2005 semiconductor investment vehicle. Recessions are ruled out given that their effects should have been negated by the presence of dummy variables for the dot-com bubble and the 2008 Great Financial Crisis. Earlier DID analysis of semiconductor output showed positive coefficients for the DID estimator for 2005 and 2006, even at albeit smaller magnitudes. Furthermore, national policy, in the case of 2005 and 2006 and accounting for control variables, seems to have a less negative impact (~ -1.9) as compared to regional 2005 and 2006 policy (~ -2.9). Meanwhile, 2014 and 2015 have the opposite effect, where regional policy (1.31 and 1.08) is more positively impactful to income as compared to national policy (-0.36 and 0.8). There are a few possible explanations for why all this is happening.

First, for 2004 and 2005, it is possible that the regional policy, which was targeted at underdeveloped Western provinces, consisted of more investments in R&D investment rather than production investment. However, R&D investment does not naturally translate into depressed levels of income – instead, it would help explain the insignificance of impact. A more probable explanation is the fact that China's labor force was experiencing a massive oversupply in unskilled labor (Hsu, 2015). Considering that most of the R&D surrounding the semiconductor industry is located in the East and the West is home to semiconductor manufacturing, low-paying factory jobs may have dropped in salary, with other manufacturing industries following suit.

Second, for 2014 and 2015, regional policy was defined as provincial investment vehicles. The provinces that raised funds tended to be the top semiconductor producers. These regions have not only historically been considered semiconductor geographic clusters (ex. Shanghai, Wuxi and Suzhou) but they are some of the highest income provinces in China. In contrast to the underdeveloped provinces targeted in 2004 and 2005, the data suggests that semiconductor industrial policy has greater effects on income in provinces that are already comparatively high-tech and wealthy. It is possible that only in such provinces is there the talent (top universities and their graduates are attracted to these areas) and existing infrastructure to truly absorb the spillover effects of a booming semiconductor industry and continue to organically sustain the industry profitably. These considerations help explain the different in coefficient magnitude between the regional and national policy scopes.

Also noteworthy is that while the difference in coefficients is approximately one turn (~1.0) between regional and national policy in 2004, 2005 and 2015, the difference is only ~.1 in 2014. One explanation is the existence of a lag period. Earlier in the semiconductor DID, a lag period was noted. It is logical to assume that if the lag period appears in the semiconductor output DID, an even longer lag period would appear in the income DID given that the logical progression of a spillover effect is: 1) policy is enacted, 2) products are produced, and 3) as more products are produced, the industrial cluster grows and the state of human welfare should change as a result. Over time, step 2 and step 3 form a virtuous (or vicious) cycle, but this would also complicate the analysis in a way which the current methods would not suffice. It could be a potential direction for further research.

Additionally, regional policy during 2014 and 2015 experiences a higher coefficient than during the single treatment period. The may suggest the existence of a compounding effect, where the existence of 2005 policy helped enable even greater success for 2014 policy. One possible explanation is the strategy China has taken with their industrial policy in the current period. The focus is on experimental trial-and-error, where the central government serves as the conduit of information. In other words, previous errors are internalized and applied in successive policy to more success.

The last point the author would like to address is the lack of significance between income and semiconductor industrial policy. A few explanations come to mind. First, 2014 was a pivotal year for China's industrial policy. The current leader of the Communist Party in China, President Xi JinPing, transitioned into power after President Hu JinTao in late 2013. Xi promised reform and continued economic growth, leading to a flurry of not only industrial policy targeting 10+ "key sectors," but economic and foreign policy reform legislation as well in 2014. (Look to the appendix for a list of some of these policies). It would be remiss to assume that semiconductor industrial policy would eclipse the effects of the sum of the other policies. However, at the same time, it should also be noted that even among all the industrial policy enacted in 2014, semiconductor industrial policy took center stage. Xi emphasized the importance of becoming domestically self-sustaining. The domestic semiconductor industry received the formation of a national investment vehicle and a significant share of the STAR stock exchange.

Another possible explanation for lack of significance, especially among the provinces that raised semiconductor investment vehicles in 2014 is that the funds were a transferal of funds from one hi-tech sector to another, resulting in an indistinguishable difference to income levels.

Finally, as a check for model quality, the control variable coefficients were all positive/negative in alignment to the original OLS model. A screenshot of a sample regression output from R can be found in the appendix.

Conclusion

Limitations

- The accuracy of the data used in this study is of concern because the majority was sourced from a Chinese government institution. In the literature, there are many accuracy critiques of China's publicly available data (ex. the widely speculated inflation of China's reported GDP). (Chen et al., 2019). However, given the lack of an alternative, and that there should be no egregious deviations, the author choose to stick with the current data source.
- As mentioned earlier, China is a prolific in regards to industrial policy. Furthermore, it is a massive country with a massive population [accounting for 17.9% of the world's population (WorldBank, 2020)]. Thus, it is difficult to establish causality. How does one go about distilling through the flurry of policy? Of exogenous factors? The various, complex interplay of policies? Without more precise data and knowledge of the exact nature of regulation, it is difficult to deem causality.
- Another simplification made in this research is assuming in DIDs with double treatment periods and even in synthetic analysis that the funds and correlated policies ended precisely in the year in which the treatment period ended. This is probably not representative of reality. Furthermore, there is no public data regarding the exact disbursement of funds.

Future Research

There are many avenues worthy of further research to expand the literature on the relationship between industrial policy and human development. A more comprehensive study consisting of several industries and other human development indicators could provide insight into the commonalities of industries or specific industrial policy tools that are more adept at promoting certain indicators. The same can be done by studying one industry but various countries. Although there is difficulty in that direction in that countries themselves vary substantially from how their governments operate to the maturity of their industries, a potential workaround could be a study of the EU generally or the states of the US.

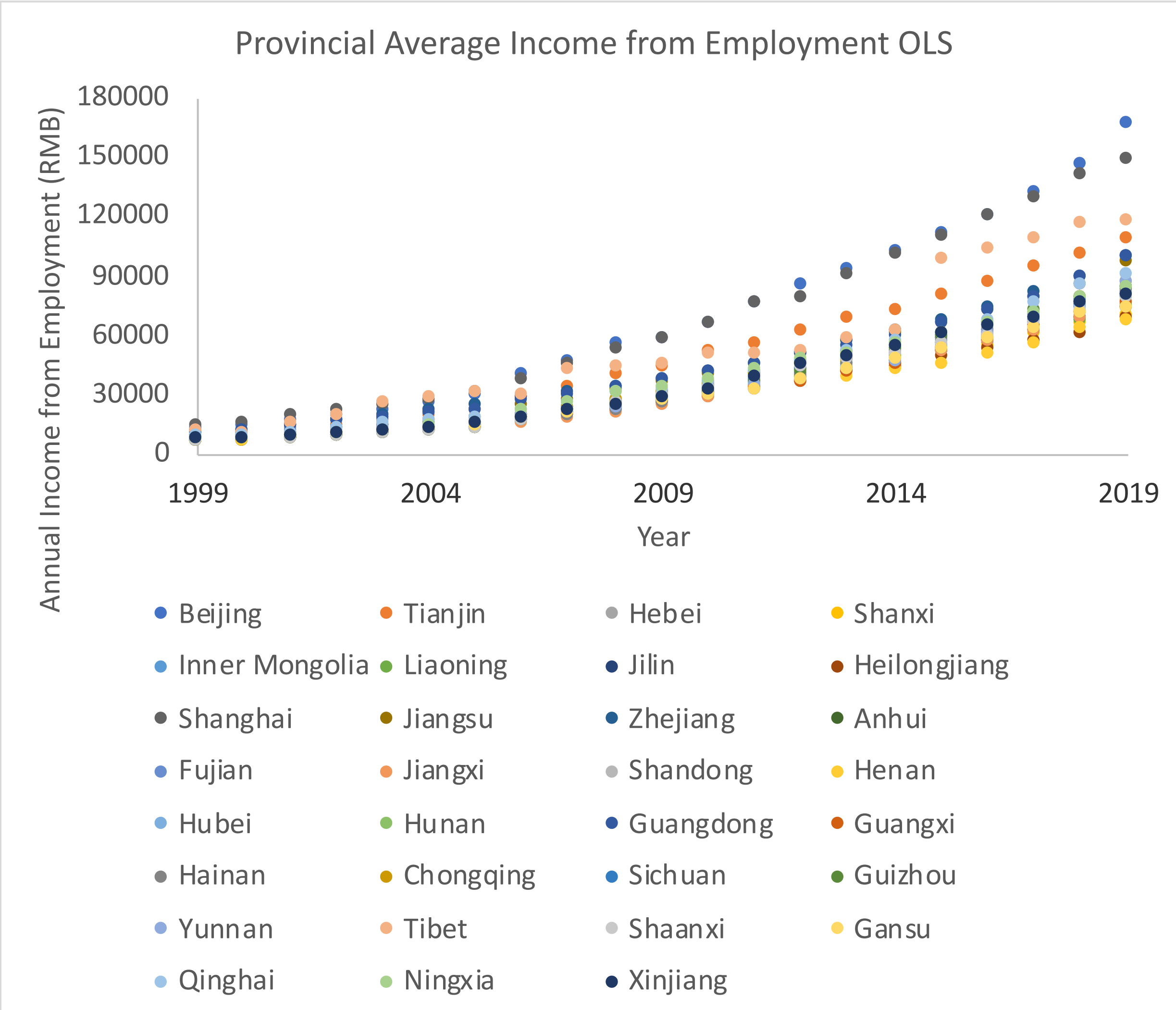
Appendix

Appendix A: Synthetic Province Control Variable Output

Synthetic Province Control Variable Output

Control Variable	Year	Reality	Synthetic Provinces (2005)	Synthetic Provinces (2014)
education	1999	3%	3%	3%
	2005	6%	6%	6%
	2014	12%	12%	12%
	2019	15%	15%	15%
age	1999	68%	68%	68%
	2005	72%	72%	72%
	2014	74%	78%	75%
	2019	71%	81%	77%
population	1999	3979	3979	3979
	2005	4151	4151	4151
	2014	4400	4452	4403
	2019	4532	4629	4537

Appendix B: Average Provincial Income from Employment



Appendix C: Sample R Regression Output

```
Call:
lm(formula = income ~ treat3 + period3 + treatperiod3 + treat4 +
    period4 + treatperiod4 + education + age + population + recessiondotcom +
    recessionGFC, data = firstrial)

Residuals:
   Min     1Q Median     3Q    Max
-33267  -4417   -168   3951  53679

Coefficients:
                  Estimate Std. Error t value Pr(>|t|)
(Intercept)      5.581e+04  1.004e+04   5.557 4.03e-08 ***
treat3          -1.276e+03  1.253e+03  -1.018    0.309
period3          2.390e+04  1.294e+03  18.474  < 2e-16 ***
treatperiod3    -1.077e+03  1.820e+03  -0.592    0.554
treat4           7.197e+01  1.081e+03   0.067    0.947
period4          4.651e+04  1.575e+03  29.521  < 2e-16 ***
treatperiod4     1.395e+03  1.886e+03   0.740    0.460
education        1.871e+05  1.009e+04  18.547  < 2e-16 ***
age             -7.470e+04  1.456e+04  -5.132 3.81e-07 ***
population      -1.279e-01  1.709e-01  -0.748    0.455
recessiondotcom -7.680e+02  1.500e+03  -0.512    0.609
recessionGFC    -9.536e+03  1.283e+03  -7.430 3.49e-13 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 9980 on 639 degrees of freedom
  (21 observations deleted due to missingness)
Multiple R-s( Adjusted R-squared:  0.8683
F-statistic: 390.5 on 11 and 639 DF,  p-value: < 2.2e-16
```

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