THREE ESSAYS IN INTERNATIONAL ECONOMICS

by

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ABSTRACT

The first paper presents an inter-temporal job search model and argues that both emigration and return of Chinese may be strategically planned as an optimal life-cycle residential location sequence. Particularly, it offers an explanation for two interesting phenomena in the context of Chinese immigration: (1) a substantial increase in both emigrants and returnees; (2) Returnees exhibit varying levels of educational degrees. The model attributes these phenomena to three facts: (1) China has a “dual” labor market with a higher paying modern sector; (2) the benefits of globalization accrue mainly to modern sector workers and; (3) the “information revolution” in US attracts China’s most productive intellectuals.

Keywords: Inter-temporal Job Search; Brain Circulation; Migration

The second and the third papers study the impact of trade variety on regional productivity for China and Canada respectively.

The second paper studies the effects of Chinese provincial export variety growth on its technological improvement by applying a monopolistic competition model with endogenous technology. The panel data covers all 31 executive districts of mainland China from 1998 to 2005. The results show that export variety significantly affect productivity growth: it accounts for 44.1% of cross-province TFP differences and 36.6% of within-province TFP growth; a 10% increase in the export variety of all exporting
industries leads to a 1.4% productivity increase in China (as a weighted province average).

By adding import variety in the empirical model used in the second paper, the third paper consolidates the effects of both import and export variety growth on Canadian productivity. Using balanced provincial data from 1988 to 2006, I find that export variety and import variety respectively account for 10.41% and 1.57% of the variation in Canadian provincial productivity differences, and the net trade variety related effects account for 7.06%. Furthermore, the export and import variety respectively account for 9.92% and 6.95% of within-province productivity growth, and their total effects can account for 17.31%. Evaluated at the sample mean, a 10% increase in all trade varieties leads to a 0.90% increase in Canadian productivity, in which the export variety's contribution is 0.57% and the import variety's is 0.33%.

Keywords: Export Variety; Import Variety; Price Index; Total Factor Productivity
DEDICATION

To my parents, Liuying and Ju; my brother, Fei; and my wife, Min.
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CHAPTER 1
A MODEL OF CHINESE BRAIN DRAIN AND CIRCULATION
1 Introduction

Globalization tends to increase not only the mobility of goods, services, technology and capital but also that of labour throughout the world. Under the process of globalization, it is interesting to observe that immigration, especially of the highly educated and highly skilled, exhibits two interesting phenomenon. First of all, unidirectional movement from developing countries to developed ones is no longer a dominant theme. The increasing presence of return migrants to their home countries clearly suggests the significance of brain circulation. (see, e.g. Johnson and Regets, 1998) Secondly, since immigration to the major desired destinations, such as the US, are not directly accessible for many developing countries¹, more and more immigration nowadays involves at least three parties: developing countries as the sending countries (e.g. China, India), the entrepôt countries (e.g. Canada, western European Countries, Israel), and the rest of the world (mainly USA) (see, e.g. Saxenian, 2005).

Traditional discussions of the immigration of skilled workers mainly focused on the loss of human capital and public investments in education and training (see, e.g. Bhagwati and Wilson, 1989), that is, the loss from brain drain. Though the issue of brain circulation has been noticed (Dawson, 2007) and discussed (Schmitt and Soubeyran, 2006), it is usually limited under a two-country or bilateral framework. On the other hand, though the phenomenon of multi-country brain drain/gain and circulation has been addressed (see DeVoretz and Ma, 2002), there is no explicit model to study the issues of the decision making strategy of the immigrants, the final distribution of them (within the three parties), and the impact of such migration to entrepôt countries.

¹ For example, citizens of China and India are not qualified to attend the US “Green Card Lottery” immigration plan.
In this paper, I present an inter-temporal job search model to explain the multi-country brain drain/gain and circulation phenomenon. Particularly, this case study looks at the outflow of skilled/well-educated migrants from China to Canada (as an entrepôt) and then to the US, as well as the return to China during the process. Such a case study is chosen for apparent reasons. First, skilled immigrants (as distinguished from family immigrants, refugees, and illegal immigrants) are considered as the major source of brain drain, and their immigration motives are usually driven by economic concerns. Second, China is one of the largest sources of migrants, and Canada is a good entrepôt representative from which the US job market can be easily accessed. This access is not only geographically, as it shares more than 6400 km of its border with the US, but also economically, given NAFTA, and culturally given English is spoken in both countries. (Harris, 2004)

Since the number of immigrants is very small compared to the host countries’ population, I treat the host countries’ labour market conditions as exogenous to immigrants; thus, I ignore the scale economy effect of team work (Miyagiwa, 1991). Given talent is exogenous, I also ignore the human capital formation issues aroused by migration (Stark and Wang, 2002). Furthermore, by assuming perfect information on immigrants, I rule out the problem of asymmetric information (Kwok & Leland, 1982). The basic idea of this paper relates to Borjas and Bratsberg (1996, BB hereafter); I argue that both emigration and return may have been strategically planned as an optimal life-cycle residential location sequence. However, my model differs from BB in two aspects. First of all, rather than using the reduced forms of wage distributions at home and in the US, this model provides a micro foundation of talent-dependent wage distribution.
Loosely speaking, this model is a generalization of BB’s model. Secondly, rather than bilateral brain circulation as BB, this model deals with three-country brain circulation, in which new issues about the intervention of the entrepôt country can be studied. Finally, the perfect information assumption rules out the inclusion of returnees whose initial migration decisions were based on erroneous information. Even though such poor decisions exist in reality, they do not account for the more and more significant trend of brain circulation.

Before proceeding to the model, let’s begin with presenting some Chinese migration stylized facts. In particular, Chinese migration exhibits two interesting features over the past 10 years:

(1) China is experiencing a substantial simultaneous increase in both emigrants and returnees.

![Figure 1.1 Studying Abroad v.s. Coming Home](image_url)

Source: Service Center for Returning Intellectuals, Department of Education (2006)
Figure 1.1 shows the number of Chinese students pursuing foreign academic degrees has jumped dramatically since 2000, while the number of returnees with foreign degrees, though relatively small, has increased drastically over the past few years. From approximately only 6,000 returnees per year in 1995, the number had soared to almost 40,000 in 2005. According to David Zweig, Director of the Center on China's Transnational Relations at the Hong Kong University of Science and Technology, China sees the largest population of overseas returnees. With the advancement of the Chinese economy and education system, he believes an increasing number of people will continue to go abroad and then return.

(2) Chinese brain circulation exhibits a sharply opposite pattern in terms of the different level of academic degrees obtained. Shao (2006) points out a very interesting phenomenon that though more and more Chinese intellectuals in recent years choose to return home, their educational backgrounds vary. Figure 1.2 shows the fraction of returnees with Master's degrees increased from 49.6% in 2001 to 91.0% in 2005 while the holders of PhD degrees decreased substantially from 35.7% in 2001 to 9.0% in 2005.

These stylized facts raise two important questions:

1. Why is China experiencing a substantial increase in both emigrants and returnees?

2. Why does Chinese brain circulation exhibit a sharply opposite pattern in terms of academic degrees?

---

2 There is no official report on China’s annual number of immigrants and returnees. However, studying overseas and pursuing recognized degrees is a usual way to immigrate (i.e. as skilled workers) to the targeted countries, so I deem such students as an important source of potential Chinese emigrants.

3 Mr. Shao is the incumbent associate director of the Service Center for Returning Intellectuals, Department of Education, P.R. China.
To reveal the essence behind these questions, I consider two key components with the model: (1) As a developing country, China has a so-called dual, or segmented, labour market (Lewis, 1979). The traditional labour market offers very low wages, while the modern labour market offers competitive wages due to globalization; (2) People are heterogeneous and immigrants with more talented have a greater probability of finding a good job.

This paper is organized as follows. In the next section, the model and general assumptions are laid out and general results are derived. Section 3 analyzes the special case in which multi-country brain circulation exists. The comparative static of the results as well as their implications are also discussed. The conclusion and extension are discussed in section 4.
2 The Model

Suppose there is a three-country world. CN is a populated, developing country, and a traditional source of immigrants. CA is a developed country that imposes no restrictions on immigration and will equip immigrants from CN with general human capital (i.e. English). US is another developed country with a more developed economy than CA, but only accepts immigrants with general human capital (i.e. only from CA) and later equips those immigrants with specific human capital (i.e. various high technology trainings). Furthermore, CN has dual labour markets that can only offer three types or ladders of wages, \( w_1 < w_2 < w_3 \). The traditional labour market (in general, the non-traded sector) can only offer \( w_1 \) while the modern labour market (in general, the domestic trade sector or multinational enterprises) can offer \( w_2 \) to those with general human capital and \( w_3 \) to those with specific human capital. However, on each ladder, there is no wage differentiation. In addition, there is no voluntary unemployment in CN. Compared to CN, both CA and US have continuous wage distributions \( F_{CA}(w) \) and \( F_{US}(w) \) \( (w \in [0, H]) \) because of their highly developed labour markets with various levels of jobs. However, \( F_{US} \) is first order stochastic dominant (f.o.s.d.) over \( F_{CA} \) to capture the fact that US’s economy is more developed than that of CA’s. Workers in these two countries draw wages randomly. Once they accept a job offer, they will remain with the company forever.

---

4 Canada has a so called “point system” to select qualified skilled immigrants. However, the criteria are quite low so that most Chinese workers with college degrees can pass. I do, however, implicitly include such criteria into the immigration and adaptation cost, such that by self-selection those who find emigration profitable already meet the criteria (i.e. the criteria are not binding).

5 The assumption of three uniform wages is based on a twofold fact. On the one hand, the Chinese labour market, though developing rapidly, is still premature with too much noise on labour quality such that employers are only willing to pay the expected wages (i.e. it is pooling wage equilibria). On the other hand, the labour supply in China is huge; thus, the wage schedule on skill is fairly inelastic (i.e. skill premium is pretty low).
and on-job search is prohibitive. Thus, workers would not quit unless they leave for another labour market in another country.

Thus, we can depict the possible directions of CN's immigration by Figure 1.3 shown below (the dotted arrows show the infeasible (CN to US) and unfavorable (US to CA) directions respectively).

![Figure 1.3 Immigration Direction Triangle](image)

Source: DeVoretz and Ma, 2002

In each country, everyone knows his or her talent (1) which is endowed by nature and indexed between 0~1 (0 stands for the lowest talent) with the same distribution. Thus, the traditional "Brain Drain" can be defined by a monotonic negative change in the national average talent ("Brain Gain" vice versa); and "Brain Circulation" can then be defined as any fluctuation in the national average talent caused by an outflow and subsequent return to the average talent or beyond. Moreover, I normalize the living costs

---

6 Brain drain is typically defined as the emigration of skilled/educated labourers. Since ceteris paribus, skill/education should be a function of talent. That is, more talented people acquire higher skill/education. Thus the definition of brain drain/gain and circulation in this paper is comparable to the typical definition.
in all countries to be zero. Given people are risk neutral, the cause or motivation to immigrate owes to the difference in the expected lifetime income between countries.

In addition, I assume perfect information. That is, immigrants know the wage distributions and the immigration policies of CA and US, as well as the competitive home wage offers \( w_2 \) and \( w_3 \). Furthermore, immigration is costly. The learning and adaptation cost \( C_{CA}(I) \) and \( C_{US}(I) \) is monotonically decreasing on the talent level. That is, the smarter the individual, the easier to adapt new requirement in immigration countries.

**Figure 1.4 Immigration Decision Making Tree**

[Diagram of immigration decision making process with stages and decision points labeled: Citizen of CN, Stay in CN, Move to CA, Stage 1, Return to CN, Ascension to Citizenship (CA), Stage 2.1, Stay in CA, Move to US, Stage 2.2, Return to CN, Ascension to Citizenship (US), Stage 3, CN, CA, US]

Source: DeVoretz and Pivnenko, 2006
However, I argue that due to costly $C_{CA}(I)$ and $C_{US}(I)$ and that the financial markets of CN and CA are not available (since CN’s financial market is premature and immigrants do not have credits in CA), only a small fraction of people at each talent level can migrate if their initial wealth can cover the immigration and adaptation costs. Thus, all the countries’ labour market structures remain unaffected during the immigration process, that is, they are exogenous to immigrants. A 3-stage decision-making process is illustrated by Figure 1.4.

**Stage 1. Immigration strategies in CN**

In stage 1, people in CN will make a decision on whether or not to emigrate to B based on the lifetime income they can earn from each alternative respectively. If they choose to stay then everyone, no matter how smart they are, will be offered only $w_1$ in each period. Given the discounted factor $\beta$, the lifetime income value, assuming infinite life, for all that never emigrate is given by,

$$V_{CN}(w_1) = \frac{w_1}{1 - \beta}$$

However, if one chooses to emigrate to B, she will be unemployed at least in the 1st period in order to accumulate the essential general human capital, which costs her $C_{CA}(I)$ (assumed to be monotonically decreasing on $I$). After the 2nd period, she can return to CN and get a wage offer $w_2$. Alternatively, she can ascend to citizenship in CA. By doing so, she can either choose to join CA’s labour market or move forward to US. If joining CA’s job market, she would draw a job randomly with wage $w$ and assume $w$
follows the cdf $F_{CA}(w, I)$ with the property of $\frac{\partial F_{CA}(w, I)}{\partial I} < 0$, that is, $F_{CA}(w, I)$ is f.o.s.d. over $F_{CA}(w, I)$ if $I_2 > I_1$. This property captures the fact that smarter/more capable people have a higher probability of obtaining a high wage job. Also note that $F_{CA}(0, I_2) = 0$ and $F_{CA}(H, I_2) = 1$ since the wage ranges from 0~H. The same situation applies to the US labour market except that the wage distribution $F_{US}(w, I)$ is assumed to be f.o.s.d. over $F_{CA}(w, I_2)$.

Therefore, the expected value of emigrating to CA, that is, the value of CA’s “Green Card”, $E(V_{CA}^{\text{inmi}}(I))$, is given by,

$$E(V_{CA}^{\text{inmi}}(I)) = \max \left\{ \beta V_{CN}(w_2), \frac{\beta w_{ca}(I)}{1 - \beta}, \beta E V_{US}^{\text{inmi}}(I) \right\} - C_{CA}(I) \tag{2}$$

where $w_{ca}$ is the reservation wage given by McCall’s Job Search Model (See Appendix 1).

Equation (2) means the value of CA’s “Green Card” according to a type I citizen of CN depends on the maximum gain on the following three values: the value of returning home $V_{CN}(w_2)$; the (expected) value of staying in CA’s labour market forever $\frac{\beta w_{ca}(I)}{1 - \beta}$; and the discounted (expected) value of moving forward to US $\beta E V_{US}^{\text{inmi}}(I)$, that is, the discounted value of US’s “Green Card” respectively.

Obviously, the decision on whether or not to emigrate from CN is based on comparing the value of staying in CN with the value of emigrating to CA. If we equate eq (1) with each of the terms in eq (2) (including the cost term $C_{CA}(I)$), we could find
\( I_{11}, I_{12}, I_{13} \) respectively. And we can tell that \( I^*_t = \min \{ I_{11}, I_{12}, I_{13} \} \) would be the equilibrium type of person who is indifferent to either staying or emigrating. Therefore, the first result is as follows.

**Result 1:** No one in CN would be motivated to emigrate if \( w_i \) is relatively high enough such that \( I^*_t > 1 \), and thus there is no brain drain. Such examples could be found in many gulf countries. On the contrary, all the people in CN would be motivated to emigrate if \( w_i \) is relatively low such that \( I^*_t < 0 \). This is the case in many sub-Saharan countries, and thus there would be a complete brain drain. In a moderate case where \( 0 \leq I^*_t \leq 1 \), the fraction of the population with higher levels of talent \( 1 \geq I \geq I^*_t \) would be motivated to emigrate, and thus there is a partial brain drain, such as in China and India.

**Stage 2. Immigration strategies in CA**

From the last section, we know that if there are no physical and/or political barriers between CN and CA, the population with talent \( I \in [I^*_t, 1] \) will move to CA.

Given the fact that immigration and adaptation is costly, it is natural to assume \( I \geq E(I) \).

Now let us turn to the decision-making strategy of this immigrant group in CA.

**Stage 2.1 Return Home or Ascend to Citizenship of CA**

After immigration, the group of immigrants with \( I \geq I^*_t \) in the 1\(^{st}\) period is unemployed (thus no income at all) but equipped with the general human capital with a cost \( C_{Cf}(I) \). And at the beginning of the 2\(^{nd}\) period, they are facing three alternatives: (i) going back to CN right away and obtaining a permanent wage \( w_2 \) (\( \geq w_i \)); Or after

\[\text{To facilitate the discussion later, I assume } I^*_t \geq E(I) \text{ as in the moderate case.}\]
obtaining citizenship in CA, (ii) drawing wage offers from CA’s labour market; (iii)
moving forward to US.

Like the decision-making problem in the first stage, the immigrants now base
their decisions on the expected values of these three choices. Apparently, if an immigrant
chooses to return CN, the value facing her, $V_{CN}(w_2)$, is given by,

$$V_{CN}(w_2) = \frac{w_2}{1 - \beta};$$  \hspace{1cm} (3)

Otherwise, his expected value of ascending to citizenship (or the value of CA’s
passport), $E(V_{CA}^{cit}(I))$, is given by,

$$E(V_{CA}^{cit}(I)) = \max \{ \frac{w_{CA}(I)}{1 - \beta}, E(V_{US}^{imm}(I)) \}$$ \hspace{1cm} (4)

Equate eq(3) with the two terms in eq(4), we can find $I_{2,11}$ and $I_{2,12}$ respectively.
Furthermore, $I_{2,1}^{*} = \min \{ I_{2,11}, I_{2,12} \}$ would be the lower bound of the talent people who
would choose to ascend to citizenship of CA. However, $I_{2,1}^{*}$ may not fall into the range
of $[I_{1,*}, 1]$. For example, if $w_2$ is high enough to make $I_{2,1}^{*} > 1$, then all the immigrants
would like to return to CN immediately after obtaining valuable general human capital
such as English. On the contrary, if $w_2$ is not attractive such that $I_{2,1}^{*} < I_{1,*}$, then none of the
immigrants would like to return home. For example, it is very unlikely for immigrants
from countries with developing economies, such as Cambodia to return home
immediately instead of ascending to citizenship of the U.S. or Canada. Thus, my 2\textsuperscript{nd}
result regarding stage 2.1 is ready to draw,
Result 2.1: If $I'_{2.1} > 1$, then all immigrants would choose to return home immediately. If $I'_{2.1} < I'_1$, then all of them would like to ascend to citizenship of CA in order to work there or move on to US. If the moderate condition $I'_1 \leq I'_{2.1} \leq 1$ holds, then all of those immigrants with talent $I \geq I'_{2.1}$ will feel confident in finding a satisfying job in CA or US later and choosing to ascend to citizenship of CA. However, for those with talent $I'_1 \leq I < I'_{2.1}$, they will return home as “disappointed immigrants” since there fails to be any promising prospects if they choose to stay. Given these factors, CN experiences brain circulation and CA has a lesser brain gain since I assume $I'_1 \geq E(I)$.

Stage 2.2 Stay forever in CA vs. Move Forward to US

After ascension to citizenship, the remaining immigrants in CA having gained general human capital can now access US's labour market as well. Since it is assumed that US's economy is flourishing more than CA's, I assume the wage distribution $F_{US}(w)$ in US is f.o.s.d. over $F_{CA}(w)$ in CA for any type of $I$. That is, for immigrants with any type $I$, it is more likely that they will find a better job offer in US. However, the decision of working in US bears a learning cost $C_{US}(I)$, which is monotonically decreasing on $I$ like $C_{CA}(I)$. Finally, note that after equipped with the specific human capital gained in US market, the immigrants can also obtain permanent wage offers, $w_3$, if choosing to return to CN.

As analyzed in stage 2.1, the expected value of working in CA is

---

8 A recent report from the Department of Human Resource and Skills Development of Canada (2006) shows that about 5%-10% of new immigrants choose to return to their home country within 2 years after landing in Canada. The main reason is believed to be relatively worse job opportunities offered in Canada than in their home countries.
\[
E(V_{\text{CA}}(w, I)) = \frac{w_{\text{ca}}(I)}{1 - \beta}
\] (5)

While the expected value of obtaining a US green card, that is, the value of moving
forward to US, \(E(V_{\text{US}}^{\text{imm}}(I))\), is given by,
\[
E(V_{\text{US}}^{\text{imm}}(I)) = \max \left\{ \beta \frac{w_{\text{us}}(I)}{1 - \beta}, \beta V_{\text{CN}}(w_j) \right\} - C_{\text{US}}(I)
\] (6)

where \(V_{\text{CN}}(w_j) = \frac{w_j}{1 - \beta}\).

When equating eq(5) and the two terms in eq(6) (including the cost term \(C_{\text{US}}(I)\)),
we can derive two talent levels \(I_{2.21}\) and \(I_{2.22}\) respectively. \(I_{2.2}^* = \min \{I_{2.21}, I_{2.22}\}\) represents
the lower bound of the talented people who would choose to emigrate once more from
CA to US. Nevertheless, there is no guarantee that \(I_{2.2}^*\) would fall into the range
of \([I_{2.1}, 1]\). Let us think about two extreme cases excluding the indirect attraction
generated by \(w_j\) (i.e. \(w_j\) is only marginally higher than \(w_2\)). In one case, if CA and US’s
economies are close to each other, \(I_{2.2}^*\) could be even less than \(I_{2.1}^*\), for the additional
gain from US labour market is rather negligible. Recall during the early 1980s when the
Canadian economy was close to that of the United States’, the amount of emigration to
the United States was fairly small. However, in the other case, if US’s economy is much
better than that of CA’s, \(I_{2.2}^*\) could be even bigger than unity. In this case, all the
immigrants of CA would treat CA only as a “springboard” to move on to their
destination, US. We could imagine what would happen if the United States treats the
Mexicans as equally as they does Canadians? Apparently, most of the immigrants who
initially migrate to Mexico would choose to immigrate to the United States eventually. Thus, result 2.2 is outlined as follows.

**Result 2.2:** If $I_{2,2}^* > 1$, that is, if neither US’s economy nor $w_3$ is attractive, then all the immigrants of CA would choose to stay. On the contrary, if $I_{2,2}^* < I_{2,1}^*$, that is, if either US’s economy or $w_3$ is tremendously attractive, then all of the immigrants would move forward to US. Otherwise, in a moderate case where $I_{2,1}^* \leq I_{2,2}^* \leq 1$, the immigrants with talent level $I_{2,1}^* \leq I < I_{2,2}^*$ would stay in CA forever, while those with $I_{2,2}^* \leq I \leq 1$ would move forward to US for a higher expected value from US or from CN (given the higher wage $w_3$ if they acquire specific human capital from US).

**Stage 3. Immigration strategies in US**

In the moderate case, the immigrants with talent level $I_{2,1}^* \leq I_{2,2}^* \leq 1$ will immigrate to US. During their periods in US, they have to stay unemployed in order to accumulate necessary specific human capital, such as computer skills. After the 1st period, they are capable of joining the US labour market or applying for a permanent wage, $w_3$, from their home.

Just as in the former stages, immigrants’ choice about staying in US or returning to CN after the 1st period of learning depends on the comparison of value between these two choices.

The value of returning CN is given by,

$$V_{CN}(w_3) = \frac{w_3}{1 - \beta}$$ (7)
While the value of working in US is given by,

\[
E(V_{US}(I)) = \frac{w_u(I)}{1-\beta}
\]  

(8)

Therefore, the lower bound of the talent, \( I^*_1 \), is given by equating eq(7) and (8). Of course, we should be cautious again for \( I^*_1 \) may fall outside of the range \([I^*_{22}, 1]\). For example, \( w_3 \) could be too low to attract any immigrants to return CN, or it could be high enough such that all the immigrants in US would like to return. Hence, result 3 is explained as follows,

**Result 3:** If \( I^*_3 > 1 \), then all of the immigrants to US would choose to return home eventually. If \( I^*_3 < I^*_{22} \), then all of the immigrants would rather to stay in US than return to CN. However given the moderate case where \( I^*_{22} \leq I^*_3 \leq 1 \), the immigrants with the talent level \( I^*_{22} \leq I < I^*_3 \) would choose to return to CN, while the rest of the immigrants with \( I^*_3 \leq I \leq 1 \) would choose to work in US.

### 3 Solutions and Implications

In this section, I illustrate, under the following four assumptions for the moderate situations where multi-country brain circulation exists (i.e. \( I^*_{i} < I^*_{i+1} < I^*_{22} < I^*_3 < 1 \)), the solutions for these threshold levels of talent. These assumptions are straightforward though they appear complex. Basically, I need three characteristics on CN’s ladder wages: (a) wage ceiling where \( w_3 \) can’t be higher than the expected wage offered to the most talented immigrant in US; (b) wage floor where \( w_2 \) should be higher than the
expected wage offered to the least talented immigrant in CA; and (c) sufficient ladder wage difference where the three wages should be sufficiently different so that temporary emigration for acquiring human capital is beneficial. In addition, I need the characteristic of enough high skill premiums in host countries. That is, rate of return to skill in US should be much higher than CA; whereas, it is zero in CN. I then discuss the implications of these results.

3.1 Solutions—Backward Induction

From the analysis in stage 3, we know that $I_3^*$ is determined by eq(7) and eq(8)

$$V_{CN}(w_3) = \frac{w_3}{1-\beta} = E(V_{US}(I)) = \frac{w_{us}(I)}{1-\beta}$$

Therefore,

$$I_3^* = \frac{w_{us}(I_3)}{w_3} \text{ with } \frac{dI_3^*}{dw_3} > 0$$

In order to ensure $I_3^* \leq 1$, we need assumption 1 as follows.

**Assumption 1. wage ceiling:** $w_3 \leq w_{us}(I)$

From stage 2.2, we know $I_{2,2}^* = \min\{I_{2,21}, I_{2,22}\}$. In order to make $I_{2,2}^* < I_3^*$, we need,

**Assumption 2: the wage distribution $F_{CA}(w,I)$ should be so (first order stochastic) dominated by $F_{US}(w,I)$ that (given $C_{US}(I)$)**
(2i) high skill premium: \[ \frac{1}{1-\beta} \frac{d\bar{w}_c(I)}{dI} < \frac{dC_{us}(I)}{dI} \left( < \frac{\beta}{1-\beta} \frac{d\bar{w}_c(I)}{dI} - \frac{dC_{as}(I)}{dI} \right); \] and

(2ii) wage floor: \[ \frac{w_{ca}(0)}{1-\beta} > \frac{w_3}{1-\beta} - C_{us}(0) > \frac{w_{as}(0)}{1-\beta} - C_{us}(0); \] and

(2iii) wage ceiling: \[ \frac{w_{ca}(I_{2,21}^*)}{1-\beta} = \beta \frac{w_3}{1-\beta} - C_{us}(I_{2,21}^*) < \frac{w_3}{1-\beta} - C_{us}(I_{3}^*). \]

Assumption 2 can ensure us to find \( I_{2,2}^* = I_{2,21}^* \leq I_{2,21}^* < I_{3}^* \) (see figure 1.5 in appendix 2), and

\[ I_{2,2}^* = (w_{ca}C_{us})^{-1}(w_3) \text{ with } \frac{dI_{2,2}^*}{dw_3} < 0 \]

(10) states that given \( w_3 \) satisfies assumption 2, an increase in it will induce lower type immigrants to move to US because the indirect attraction of being trained in US is higher.

From stage 2.1, we need \( I_{2,1}^* \leq I_{2,2}^* \) to hold the moderate situation. It requires

**Assumption 3:** \( w_2 \) should be small enough to ensure that

(3i) sufficient ladder wage difference: \( \beta w_3 - w_2 > (1-\beta)C_{us}(I_{2,2}^*); \) and

(3ii) wage floor: \( w_2 > w_{ca}(0) \)

Actually, the inequality (3i) states that to the immigrants with \( I = I_{2,2}^* \), the indirect benefit (getting \( w_3 \)) of immigrating to US (the left hand side) is higher than the immigration cost (the right hand side), which will induce the immigrants with type \( I < I_{2,2}^* \) to choose to immigrate to US as well due to the indirect attraction of \( w_3 \). Thus, if
assumption 3 holds, we know that \( I^*_{2,1} = \overline{w}_{ca}(w_2) = I_{2,11} < I_{2,12} < I^*_{2,2} \) (see figure 1.6 in appendix 2). Furthermore we can derive that

\[
I^*_{2,1} = \overline{w}_{ca}(w_2) \text{ with } \frac{dI^*_{2,1}}{dw_2} > 0
\]  

(11) states that given \( w_2 \) satisfies assumption 3, an increase in it will induce higher type immigrants to return home for the value of being back from CA is higher.

From stage 1, the moderate situation requires \( w_1 \) should be small enough relative to \( w_2 \) (given \( C_{Ca}(I) \)) which is ensured by assumption 4 below.

**Assumption 4**: \( w_1 \) should satisfy that

(4i) **sufficient ladder wage difference & wage floor**: \( \frac{w_1}{1-\beta} > \frac{w_2}{1-\beta} - C_{Ca}(0) > \frac{w_{hd}(0)}{1-\beta} - C_{Ca}(0) \) (similar to assumption 2(i)); and

(4ii) **sufficient ladder wage difference**: \( \beta w_2 - w_1 > (1-\beta)C_{Ca}(I^*_{2,1}) \) (similar to assumption 3(i)).

Under assumption 4, we can find that \( I^*_1 = \min \{I_{11}, I_{12}, I_{13}\} = I_{11} \) (see figure 1.7 in appendix 2). As a result,

\[
I^*_1 = C^{-1}_{Ca}(w_1, w_2) \text{ with } \frac{dI^*_1}{dw_1} > 0 \text{ and } \frac{dI^*_1}{dw_2} < 0
\]  

(13) shows the sharply opposite effects of \( w_1 \) and \( w_2 \) to the initial immigrants of CN: a higher \( w_1 \) will increase the upper bound of people who choose to stay home for the value of staying home is increasing; however, an increase in \( w_2 \) will attract more people to
immigrate for it’s more profitable to be trained in CA to accumulate valuable human capital so as to get the higher wage \( w_3 \).

If the four assumptions are all satisfied, the following summary shows us all the moderate solutions for the threshold talent levels in each stage.

Table 1.1 Summary

<table>
<thead>
<tr>
<th>Threshold / Stayers (Returns)</th>
<th>Stage1</th>
<th>Stage2.1</th>
<th>Stage2.2</th>
<th>Stage3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_1^* = \mathcal{C}_{G1}^1(w_3, w_2) )</td>
<td>( I_{2.1}^* = \frac{w_{ca}(w_2)}{1} )</td>
<td>( I_{2.2}^* = (w_2 \mathcal{C}_{CS}^1)^{-1}(w_3) )</td>
<td>( I_3^* = \frac{w_{as}(w_3)}{1} )</td>
<td></td>
</tr>
<tr>
<td>( \uparrow ) in ( w_1 )</td>
<td>( \uparrow ) in ( w_2 )</td>
<td>( \checkmark ) in ( w_3 )</td>
<td>( \uparrow ) in ( w_3 )</td>
<td></td>
</tr>
</tbody>
</table>

3.2 Implications from the moderate results

(i) Under globalization, China can offer increasingly competitive wages, \( w_3 \) and \( w_1 \), in its modern labour market while \( w_1 \) in its traditional labour market is relatively stable.

According to eq(9)–(12), ceteris paribus, we know that this fact will result in \( I_1^* \) and \( I_{2.2}^* \) decreasing, but \( I_{2.1}^* \) and \( I_3^* \) increasing. Recall results (1)–(3). The model shows that the amount of people choosing to emigrate in the 1st stage \( (1 \geq I \geq I_1^*) \) will increase because gaining general and specific human capital is more profitable. It also indicates the amount
of returnees from CA ($I_1^* < I < I_{2,1}^*$) will also increase because they find it more attractive to accept $w_2$. In addition, the amount of returnees from US ($I_{2,2}^* < I < I_{3}^*$) will increase as well because of the attraction of higher $w_3$. Thus, based on the four assumptions, this model can explain the simultaneous increase of Chinese emigrants and returnees.

(ii) Suppose CA is now ambitious about welcoming more immigrants. If CA’s government subsidizes immigrants’ learning cost (i.e. reduces each immigrant’s cost by a lump-sum transfer such as the cost of an ESL program), would it be an efficient policy? From table 1, such a policy could decrease $I_1^*$, that is, the 1st stage immigrants $[I_1^*, 1]$ is increasing. As a result, CA may attract a greater amount of less-talented immigrants. However, from result 2.2, we know the fraction of immigrants with $I_{2,1}^* < I < I_{2,2}^*$ will choose to stay in CA permanently. Since neither $I_{2,1}^*$ nor $I_{2,2}^*$ depends on $C_{CA}(I)$, though reducing $C_{CA}(I)$ does attract additional immigrants from CN temporarily, all the additional immigrants will just simply take advantage of the cheaper training cost and they will eventually return home in stage 2.1. In fact, the only effective way to keep immigrants is to increase $\bar{w}_{ca}(I)$ as shown in this model. Except for further developing its economy, CA’s government could also try to eliminate the job discrimination immigrants face so that the wage distribution immigrants experience, $F_{CA}(w)$, is more favourable, which in turn increases immigrants’ expected value of working in CA.

(iii) If US is experiencing a so-called “information revolution”, which is characterized by expanding the top high-tech industries such as computer, telecommunication, then its wage distribution will be biased on the right since there are
more jobs in the top end. From result 3, it is obvious to see that $I_3^*$ will decrease (so that the fraction of US immigrants, [$I_3^*$, 1], will expand) since working in US is more promising. Furthermore, if combined with the effects of increasing $w_2$ and $w_3$ in CN but assuming US's booming economy dominates the attraction of increasing $w_3$, we will observe more and more returnees with $I_1^* < I < I_{2,1}^*$, while fewer and fewer of those with $I_{2,2}^* < I < I_3^*$. Therefore, if we treat academic degrees as a good proxy of talent level, there are an increasing number of immigrants with lower university degrees, at the same time, the amount of higher university degrees returnees will decrease. This clearly explains the puzzling phenomenon of the fraction of returnees with Master's degrees increased rapidly in the period of 2001~2005; whereas, the holders of PhD degrees have been decreasing substantially.

### 4 Conclusion

In this paper, I present an inter-temporal job search model to argue that both emigration and return may have been strategically planned as an optimal life-cycle residential location sequence. Given that the moderate conditions are all satisfied, I conclude that immigration will cause CN to suffer a net loss of its talented citizens. However, whether it is an overall brain drain is rather ambiguous. The initial brain drain will later induce some brain circulation with the returnees equipped with valuable general and even specific human capital if $w_2$ and $w_3$ are competitive enough. Returnees with valuable human capitals may offset the net loss in human capital due to permanent emigrants. CA, as an entrepôt country, will experience a brain gain from CN, but brain
drain to the US. Nevertheless, the final result is still a net brain gain for CA since at least some of the immigrants will choose to stay in CA. US will experience a net brain gain, especially given the fact it actually reaps the most talented immigrants from CN.

Particularly, this paper offers answers to the two main puzzles within Chinese immigration issues:

1. The reason why China is experiencing a substantial increase in both emigrants and returnees is because the wage difference between traditional and modern labour markets is rapidly enlarged. This growth generates a strong incentive for Chinese to study and receive training abroad, and then return to capture those competitive wage offers.

2. The reason why China’s brain circulation exhibits a sharply opposite pattern according to different degrees is because of the mixed effect of China’s emerging modern labour market and the US’s top-end industrial revolution. On the one hand, immigrants who hold a relatively lower degree find it more profitable to return home and get $w_2$ given China’s emerging modern labour market. The US’s top-end industry revolution, on the other hand, absorbs those with higher degree who find $w_3$ less attractive compared to the prospect of working in these top-end industries. Thus, the amount of returnees with lower degree increases while the return of those with higher degrees decreases.
Reference List


Appendices

Appendix 1

Following the method similar to McCall's (1970) Job Search Model, the expected lifetime income from CA's labor market to a certain type potential immigrant with talent $I$ will be,

$$V_{CA}(w,I) = \max \left\{ \frac{w}{1-\beta} \int_{0}^{w} V_{CA}(w',I) dF(w',I) \right\}.$$  \hspace{1cm} (1')

Then there is a reservation wage $w_{ca}$, such that

$$\frac{w_{ca}}{1-\beta} = \beta \int_{0}^{w_{ca}} V_{CA}(w',I) dF_{CA}(w',I) = \beta E(V_{CA}(w,I))$$ \hspace{1cm} (2')

from (2') we can derive $w_{ca} = \frac{w_{ca}(I)}{1-\beta}$ with $\frac{\partial w_{ca}}{\partial I} > 0$ (So is $\frac{\partial w_{us}}{\partial I} > 0$) because smarter people have a higher probability of finding a job with a good wage and a lower learning cost, thus the higher expectation also results in a higher reservation wage.

Appendix 2

First of all, note the fact that

$$d\left( \frac{\beta w_{us}(I) - C_{US}(I)}{1-\beta} \right) = \beta d\frac{w_{us}(I)}{1-\beta} - \frac{dC_{US}(I)}{dl} \geq 0;$$

and

$$d\left( \frac{\beta w_{3} - C_{US}(I)}{1-\beta} \right) = - \frac{dC_{US}(I)}{dl} > 0;$$

\footnote{The reservation wage is the wage offer at which a job hunter is indifferent to accept the offer or reject.}
Apparently, the value function of working in US is steeper than that of returning home, then given assumption 2, we can clearly illustrate that $I_{2,2}^* = I_{2,22}^* \leq I_{2,21}^* \leq I_3^*$ by Figure 1.5 and $I_{2,1}^* = I_{2,11}^* \leq I_{2,12}^*$ by Figure 1.6.

Analogously, we can illustrate the situations given by assumption 3 and 4 in Figure 1.6 and 7 respectively.
Figure 1.6 Intelligence thresholds in Stage 2.1

Figure 1.7 Intelligence thresholds in Stage 1
CHAPTER 2
EXPORT VARIETY
AND PRODUCTIVITY IN CHINA
1 Introduction

Although the channel of how productivity affects trade variety had been articulated centuries ago, the other direction, how trade variety affects productivity, is less well understood. Drawing from the classic work on monopolistic competition (MC) in trade (e.g. Dixit and Stiglitz (1977), Krugman (1980)), where goods are assumed to be differentiable and variety is explicitly introduced, economists are able to exposit how trade variety affects productivity from the output variety effect.

The output variety effect predicts that the expansion of export varieties could boost the exporting country’s productivity based on the assumption of diminishing technical rate of substitution (i.e. concavity of production possibility frontier (PPF), see figure 2.1). Empirically, the link between export variety and productivity has been found by Feenstra et al (1999) for South Korea and Taiwan, and by Funke and Ruhwedel (2001) for OECD and East Asian countries. Particularly, based on the monopolistic competition model with endogenous technology, Feenstra and Kee (2008) test the effects of sectoral export variety on country productivity. By analyzing a panel data containing 48 countries (developed and developing) across 20 years, they found that the total increase in export variety accounts for a 3.3% average productivity growth in the exporting countries from 1980-2000.

The theoretical interaction between export variety and productivity also leads to another interesting question: can we identify the direction of causality between export variety and productivity in various cases? In fact, many economists have analyzed, although not explicitly proposed, possible answers. In a standard MC model, whether a variety (firm level) can be exported depends on two key factors: own productivity and
initially irreversible investment (costs from trade barriers as well as investment cost for marketing, promotion, etc.). Holding the initial investment constant, productivity increases export variety in an obvious way: if more and more firms’ productivity exceeds the threshold where the operational profit just covers the initial investment, more and more varieties will be exported. Likewise, holding the infrastructural productivity or productivity distribution constant, a decrease in trade barriers can also lead to more export varieties and higher aggregate productivity because of the self-selection of efficient/productive firms to the world market. For example, Melitz (2003) develops a dynamic industry model with heterogeneous firms and shows that more exposure to trade will cause market reallocation in favour of the more productive firms and thus contribute to an increase in productivity (also see Bernard and Jensen (1999), Delgado et al (2002)). From these analyses, one can expect that in developed open economies with intensive R&D activities, productivity would more likely be one of the fundamental sources of export variety expansion as well as economic growth; whereas in developing economies in the process of liberalizing trade the export-led growth in economics as well as in productivity would be significant.

This paper analyzes the effects of China's exports on its productivity growth by examining China's provincial export variety, which has been relatively lightly researched. Though the empirical strategy used in this paper is similar to Feenstra & Kee (2004)¹ (hereafter FK), there are two improvement in estimation. First of all, employing Chinese panel data makes the results more reliable: an implicit but important assumption about

¹Feenstra and Kee (2008) revised their 2004 model by exploiting the detailed 10-digit Harmonized System (HS) import data. However, since China only reported 4-digit HS provincial export data during 1998-2005, I have to follow their 2004 model which requires only aggregate trade data. Of course, giving up FK 2008 model incurs an accuracy loss in estimation, which can only be improved if more detailed HS data for Chinese province is available. Nevertheless, FK 2004 model is still well-justified in theory.
the price-factor GDP function (used in FK and here) is that the prices and production factors are all given, i.e., exogenous. However, FK's data is obtained from US imports from 48 countries including the major developed ones. Thus, it is very likely that the prices are actually endogenous since the major developed countries may have monopolistic power over some of their major exports such as electronic products from Japan and machines from Germany. Furthermore, the US itself is the largest open economy in the world suggesting it has monopsonistic power over many of its imports. As a result, if monopoly dominates, estimates of the elasticities of productivity on export varieties tend to be overstated, while if monopsony dominates, the estimates tend to be understated. On the contrary, though China has a large economy, most of its exports are characterized as low value-added and easy-to-substitute.\(^2\) In other words, Chinese exports mainly face competitive markets with very elastic demand, and as a result, most Chinese exporters are price takers to some extent. Second of all, exploring the provincial data enable us to obtain a more accurate estimation for the country-specific effect of trade variety on productivity: another key (implicit) assumption in FK's panel study is that the output elasticities of substitution between varieties within the same sector are the same across countries. That is, for example, the output elasticities of substitution in agricultural sector should be the same in both US and China. Apparently, it is too strong an assumption. While using all Chinese provincial data, I can obtain "China-specific" output elasticities of substitution without assuming identical elasticities across countries.

In addition to the improvements in estimation, there are two contributions from this paper. The first is that by exploring the Chinese provincial data, I am able to study

\(^2\)For example, by 2005 the top three markets where Chinese exports occupy the largest world shares are textiles (35%), footwears (60%), and toys (40%) which are easily found in Wal-Mart but not in luxury franchise stores.
the Chinese export variety and productivity which has not been done before. The second
is that I show by empirical means that export variety actually leads Chinese productivity
growth but not the other way around. This is consistent with the results of Kwan and
Kwok (1995) that exports are exogenous in explaining China's economic growth (and
thus productivity).

The rest of the paper will be organized in three parts. In section 2, I summarize
the mechanism of how export variety affects productivity, following the methods
discussed in FK. I also describe my dataset and estimate a system of equations relating
sectoral shares and adjusted total factor productivity (TFP) to export variety. In section 3,
I present my estimation results, as well as hypothesis tests to show the validity of my
estimation method and the robustness of my estimation results based on various
constraints imposed in the model. Finally, in section 4, I conclude that export variety
accounts for 44.1% of the variation in Chinese provincial productivity differences in level
and 36.6% of within-province productivity growth. Overall, at the sample mean, a 10% increase in export varieties of all exporting industries leads to a 1.4% increase in China's productivity.

2 The Empirical Model

2.1 Price Index and Output Variety

Feenstra (1994) derives an exact price index from a CES (constant elasticity of
substitution) aggregate good allowing both variety and taste changes in existing varieties.
This index can also apply for several goods or even industries as long as they are CES
aggregates.
Suppose there exists \( i = 1, \ldots, R \) regions. Each region \( i \) can produce \( I_i \) set of output goods. The quantity of each type of good produced in region \( i \) in period \( t \) is denoted by \( q_i^t \). The aggregate output of region \( i \), \( Q_i^t \), is characterized by a CES function of the output of each specific good produced in that region:

\[
Q_i^t = f(q_i^t, I_i^t) = \left( \sum_{j \in I_i^t} a_j(q_{ji}^t)^{\sigma-1/\sigma} \right)^{1/\sigma}, \ a_j > 0, \ i = 1, \ldots, R
\]  

(1)

where \( a_j \) is the unknown quality parameter for good \( q_{ji}^t \), and \( \sigma < 0 \) is the elasticity of substitution between goods.

If there are two regions, \( a \) and \( b \) where \( a \) is a sub-region of \( b \) (e.g. \( a \) is a province of \( b \) ), and the prices of common goods produced in both \( a \) and \( b \) are the same, then as demonstrated in FK (2004), under the assumption of perfect competition, the ratio of aggregate price levels of \( a \) and \( b \) associated with the CES production function can be evaluated by eq (2):

\[
\ln \frac{P_a^t}{P_b^t} = \left( \frac{1}{1 - \sigma} \right) \ln(\lambda^b(I_i)), \ a, b = 1, \ldots, R
\]

(2)

where \( P_i^t \) is the aggregate price level \( (i = a, b) \), and \( I_i = (I_i^a \cap I_i^b) = I_i^a \) is the set of common goods produced in both \( a \) and \( b \) at time \( t \) which is exactly the whole set of goods produced in \( a \),

\[
\lambda^b(I_i) = \frac{\sum_{j \in I_i} p_{ji} q_{ji}^t}{\sum_{j \in I_i} p_{ji} q_{ji}^t} = 1 - \frac{\sum_{j \in I_i} p_{ji} q_{ji}^t}{\sum_{j \in I_i} p_{ji} q_{ji}^t}
\]

(3)
where $\lambda^b_t(I_t)$ is the revenue share of common goods ($j \in I_t$) that are produced both in $a$ and $b$ to total goods $j \in I_t'$ produced in $b$. Therefore, $\lambda^b_t(I_t)$ is a measure for variety: ceteris paribus, if province $a$ increases its output varieties, $\lambda^b_t(I_t)$ will increase accordingly.

2.2 GDP Function with Export Variety

As is common in empirical GDP work, we assume the GDP function of a region follows a translog functional form where there are $N+1$ industries and $M$ types of production factors:

$$\ln G_t'(P_{t'}^i, V_{t'}^i) = \alpha_0 + \beta_0^i + \sum_{n=1}^{N+1} \alpha_n \ln P_{nt}^i + \sum_{k=1}^{M} \beta_k \ln \nu_{tk}^i + \frac{1}{2} \sum_{m=1}^{N+1} \sum_{n=1}^{N+1} \gamma_{mn} \ln P_{mt}^i \ln P_{nt}^i$$

$$+ \frac{1}{2} \sum_{k=1}^{M} \sum_{l=1}^{M} \delta_{kl} \ln \nu_{tk}^i \ln \nu_{lk}^i + \frac{1}{2} \sum_{n=1}^{N+1} \sum_{k=1}^{M} \phi_{nk} \ln P_{nt}^i \ln \nu_{tk}^i, \quad i = 1, \ldots, R$$

(4)

Notice that in a panel data regression setting, $\alpha_0^i$ and $\beta_0^i$ refer to region and time fixed effects respectively. To satisfy the properties of homogeneity in prices and endowments as well as symmetry, we need to impose the following restrictions:

$$\gamma_{mn} = \gamma_{nm}, \sum_{n=1}^{N+1} \alpha_n = 1, \sum_{n=1}^{N+1} \gamma_{mn} = \sum_{n=1}^{N+1} \frac{\phi_{nk}}{k},$$

$$\delta_{kl} = \delta_{lk}, \sum_{k=1}^{M} \beta_k = 1, \sum_{k=1}^{M} \delta_{kl} = \sum_{k=1}^{M} \frac{\phi_{nk}}{k},$$

(5)

From (6), the share of sector $n$ is given by the derivative of $\ln G_t'(P_{t'}^i, V_{t'}^i)$ with respect to $\ln P_{nt}^i$:

$$s_{nt}^i = \alpha_n + \sum_{m=1}^{N+1} \gamma_{mn} \ln P_{mt}^i + \sum_{k=1}^{M} \phi_{nk} \ln \nu_{tk}^i, \quad n = 1, \ldots, N + 1$$

(6)
If we take the difference of any province $i$ with that of the comparison region "*" (i.e. the whole country), we can map export variety (as part of the output variety) into the empirical GDP function as well as the share equations with minimal computation:

$$s_{ni}^i - s_{ni}^* = \sum_{k=1}^{M} \phi_{nk} (\ln \nu_{nu}^i - \ln \nu_{nu}^*) + \sum_{m=1}^{N} \gamma_{mn} \ln \lambda_{nm}^*$$

$$+ \gamma_{N+1,n} (\ln P_{N+1,n}^i - \ln P_{N+1,n}^*).$$

and

$$\ln G_i^i(P_i^i, V_i^i) - \ln G_i^* (P_i^*, V_i^*) - \frac{1}{2} (s_{ni}^i + s_{ni}^*) (\ln \nu_{nu}^i - \ln \nu_{nu}^*)$$

$$- \frac{1}{2} (s_{N+1,n}^i + s_{N+1,n}^*) (\ln P_{N+1,n}^i - \ln P_{N+1,n}^*)$$

$$= \alpha_{0}^i + \sum_{n=1}^{N} \frac{1}{2} (s_{ni}^i + s_{ni}^*) \frac{\ln \lambda_{ni}^*}{(1 - \sigma_n)}$$

where the price difference of tradable goods (sector $1$ to $N$) have been substituted by the variety variable $\ln \lambda_{ni}^*$ according to (3). Without the loss of generality, we normalize $\alpha_{0}^* = 0$. The left hand side of (8) can be interpreted as the productivity difference between province $i$ and the country "*" (the average productivity of all provinces): it is the difference of GDP net of the differences in factor endowments and prices in nontraded goods. The remaining difference is the productivity differences due to export variety shown on the right.

### 2.3 Data and Estimating Equations

With equations (7) and (8), we can estimate the parameters of interest such as the elasticity of substitution between different varieties within an industry ($\sigma_n$), the relative
price effects on the industry shares \( (\gamma_n) \), as well as the effects of relative endowments on industry shares and productivity.

The dataset covers all 31 provincial level executive districts in mainland China (excluding Hong Kong, Macau, and Taiwan). (See figure 2.2) However, due to data availability, it is an unbalanced panel dataset with 17 of the provinces starting from 1998 while the rest start no later than 2002 and all series end in 2005. This dataset contains 193 observations for each regression. All of the data was obtained from corresponding national or provincial statistical yearbooks.

To measure export variety, we need first to define what it is. Unfortunately, there is no uniform definition for variety in previous work. In micro-level studies, variety is usually defined as a brand of a firm (e.g. Hausman (1997)), while in macro-level studies, it is commonly defined as a country-specific good (e.g. Broda and Weinstein (2005)). Since this study is based on Chinese provincial level data, a natural definition of export variety is a province-specific export good. For example, if China is exporting ducks from both the Jiangsu province and the Zhejiang province, then there are two export varieties of Chinese ducks. Under this definition, no province exports the same variety, so \( \lambda_n^* \) is actually the ratio of provincial export revenue to its national counterpart for industry \( n \) at time \( t \) since each province is exporting only "unique" varieties different from the rest of the country.

We assume there are three factors of production: Labor, Capital, and (arable) Land. Labor and Land (as well as nominal GDP) are directly reported by China Statistical Yearbooks (1999-2006). Capital is constructed by the perpetual inventory method using
real investment of the whole nation as well as the 31 provinces across the 8 years. Real investment is obtained by deflating the gross domestic capital formation of the whole nation as well as 31 provinces with their respective GDP deflators. All the data on gross capital formation and GDP deflators are obtained from China Statistical Yearbooks as well. In addition, I construct the base year capital stock using an infinite sum of series of investment prior to the first year (1998), assuming that the average growth rate of investment of the first 7 years is a good proxy for the investment prior to the first year.

We aggregate up all the export goods into 7 sectors: agriculture, wood & paper, textile & clothing, chemicals & plastics, mining & metals, machinery\(^3\), and food & beverage\(^4\). The value-added of these sectors is obtained from corresponding provincial statistical yearbooks (1999-2006), which we can compare to the corresponding regional GDP to construct the value added share of each sector. The nontraded goods price is obtained by taking an equally-weighted average of the Education, Health Care & Child Care, and Rental for Housing price indices. The regional labor share in GDP, \(s_{L_i}\), is constructed by comparing the labor income to the corresponding regional GDP.

Here we use each of the 31 provinces as a specific "region", i.e. \(i = 1, \ldots, 31\), and China as a whole as the comparison region "*". By applying the homogeneity constraints on productive factors (i.e. \(\sum_{n=1}^{3} s_{n} = 1\)) and prices (i.e. \(\sum_{m=1}^{8} \lambda_{nm} = 0\)), we can rewrite (9) and (10) as follows:

\(^3\) Including transportation equipments and electronic products.
\(^4\) Including tobacco.
\[ s_{nt} = \delta_{nt} + \phi_{Ll} (\ln \ell_t - \ln \ell_t') + \phi_{Kl} (\ln k_t - \ln k_t') \]

\[ + \sum_{m=1}^{7} \gamma_{mn} \left( \frac{\ln \lambda_{nt}^m}{1 - \sigma_m} - (\ln P_{N+1,t}^m - \ln P_{N+1,t}') \right) + \varepsilon_{nt}, \quad (9a) \]

\[ n = 1, \ldots, 7. \]

and

\[ Adj.TFP_t = \ln G_t^i (P^i_t, V^i_t) \]

\[ - \frac{1}{2} (s_{Ll} + s_{Ll}') (\ln \ell_t - \ln \ell_t') - \frac{1}{2} (1 - (s_{Ll} + s_{Ll}')) (\ln k_t - \ln k_t') \]

\[ - \frac{1}{2} (\ln T_t^i - \ln T_t^i') - \sum_{n=1}^{7} \frac{1}{2} (s_{nt}^i + s_{nt}^i') (\ln P_{N+1,t}^i - \ln P_{N+1,t}') \]

\[ = \alpha_t^i + \alpha_0^i + \beta_k (\ln k_t - \ln k_t') + \beta_{s_i} (\ln P_{N+1,t} - \ln P_{N+1,t}') \]

\[ + \sum_{n=1}^{7} \frac{1}{2} (s_{nt}^i + s_{nt}^i') \frac{\ln \lambda_{nt}^i}{1 - \sigma_n} + \varepsilon_t^i, \quad (9b) \]

where \( \ln(\ell_t) = \ln(L_t / T_t) \) and \( \ln(k_t) = \ln(K_t / T_t) \). If the homogeneity constraint in prices is not violated, \( \beta_{s_i} \) in (9b) should be equal to unity, whereas \( \beta_k \) in (9b) represents the negative value of the share of Land in GDP. Note, the output shares of the comparison country (China), appearing as \( s_{nt}^i \) in (7), are measured as year fixed effects, \( \delta_{nt} \) in (9a); whereas China's national (log) GDP, \( \ln G(P_t^*, V_t^*) \), in equation (8) is treated as a year-fixed effect, \( \alpha_t^* \) in the regression function (9b). In summary, I will regress the panel data for seven sectoral share equations (with year-fixed effects only) and a TFP equation (with both region and time fixed effects).

Furthermore, with the estimated parameters, the regional estimated productivity is given by (10):

\[ \text{In fact, } \beta_{k} \text{ should be } \beta_{k} = 1 - \frac{1}{2} (s_{Ll}^i + s_{Ll}^i') - \frac{1}{2} (s_{Kt}^i - s_{Kt}^i), \text{ which is a random parameter. For the sake of simplicity, we assume the relative labor share and the relative capital share do not change for different regions and across periods so that we treat } \beta_{k} \text{ as a time- and region-invariant parameter.} \]

40
Due to the cross equation restrictions on $1/(1-\sigma_n)$ and $\gamma_{mn}$, and the multiplicative nature of these parameters, I use nonlinear system estimation for the seven share equations (9a) and one TFP equation (9b). The optimal estimates for these parameters are derived by minimizing the variance-covariance matrix of the residuals in the full system of the regression equations.

The homogeneity constraints in endowments and prices (for each of the eight equations) and the symmetry constraint in cross price effects (for the seven sectoral share equations) will also be tested.

### 3 Estimation Results and Hypothesis Tests

#### 3.1 Estimation Results

**3.1.1 Ordinary Least Square Regressions**

Table 2.1 presents the results of the nonlinear system of share equations (9a) with the TFP equation (9b), estimated by iterative Nonlinear Ordinary Least Square Regressions (NOLS). All the homogeneity constraints on prices and endowments as well as the symmetric constraints on cross-price effects are imposed in the share equations, and the last column shows the estimated coefficients of the regional productivity equation.

The upper part of table 2.1 reports $r^\gamma_{mn}$, which are the partial price effects on the share of industries in the columns due to export variety changes in the rows. Particularly,
the diagonal shows the own-price effects, which are all positive and significant. That is to say, the underlying supply curves of these industries are positively sloped. The lower part of table 2.1 shows the Rybczynski effects of endowments on the industry shares. For example, an increase in capital relative to land (significantly) hurts the agriculture and food & beverage industries but benefits the chemical & plastics, mining & metals, and machinery industries. On the other hand, an increase in the labor endowments relative to land (significantly) benefits agriculture, wood & paper but hurts chemical & plastics, mining & metals, and machinery.

The upper part of column (8) presents the NOLS estimates of $1/(1-\sigma_n)$ for each industry in the row. According to our assumption, the elasticities ($\sigma_n$) among outputs should be strictly negative. In other words, we expect the estimates of $1/(1-\sigma_n)$ to be between zero and one. As shown in the upper part of column (8), all the estimates are significant and fall in the range of zero to one. The ranking of industries according to their implied elasticities of substitution are: wood & paper (-0.235), machinery (-0.748), textile & garments (-1.322), chemical & plastics (-1.390), agriculture (-1.621), mining & metals (-4.882), and food & beverage (-8.025).

The lower part of column (8) presents the effects of the capital-land ratio and nontraded goods prices on adjusted TFP. As predicted in the model, the coefficient on the capital-land ratio should be negative of the value of the land share in GDP. That is, our estimate, -0.083, implies that the estimated share of land in China's GDP is about 8.3%.
However, the estimated coefficient on nontraded goods price is significantly less than unity which suggests a violation of the homogeneity assumption on price.\(^6\)

However, our NOLS method might have two potential problems. First of all, for a system of simultaneous regression equations there may be correlation between the error terms of these equations. For example, the error terms of the seven sectoral share equations \((9a)\) might be correlated as these tradable sectors may compete for the same resources. Thus an expansion of one sector share may induce a contraction of another. Ignoring the correlation problem will cause the estimates to be less efficient as the variance of estimation is not at a minimum. If there is cross-equation correlation among the error terms, a seemingly unrelated regression (SUR) can yield more efficient estimates (Zellner, 1962). Secondly, endogeneity might be a problem since in our adjusted TFP equation \((9b)\) productivity can also affect export variety. That is, a simultaneity problem may arise since productivity growth may help some products gain comparative advantage over their international counterparts so that they become new exported varieties (for example, Melitz, 2003; Ghironi and Melitz, 2005). Ignoring this potential endogeneity problem, if any, will cause our estimates to be biased. To overcome the endogeneity problem, we need to find valid instrumental variables (IVs) which affect productivity only via export variety. Then we can use a nonlinear two stage least square (N2SLS) method to derive unbiased estimates.

To check the validity of our estimates of NOLS, I compare them to those of SUR and N2SLS respectively in the following two subsections.\(^7\)

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\(^6\) The violation of homogeneity constraint in prices in TFP equation does not affect the rest of the estimations since we did not impose it in TFP equation.
3.1.2 Iterative Seemingly-Unrelated Regressions

Table 2.2 presents the results estimated by ISUR. The results reveal that both the partial price effects on the share of industries and the Rybczynski effects of endowments are very similar to those estimated by NOLS. The similarity also appears in column (8) except that the coefficients on Textile & Garments and Wood & Paper are above unity, but not significantly.

Even though SUR is a theoretically more efficient estimation method than OLS, a number of empirical studies reveal that this superiority is ambiguous in practice. (for example, Srivastava and Giles, 1987; Maeshiro, 1980; Heien, et al., 1998). Indeed, the closer the error covariance comes to being spherical, the more likely it is that OLS estimates will be superior. Therefore, the overall similarity between the estimates of NOLS and SUR is not surprising, it may result from the fact that residuals of the sectoral share equations do not have strong correlation. Thus, after considering the potential SUR problem, we still can confidently retain estimates of NOLS.8

7 Though the SUR and N2SLS can be combined into a N3SLS (so called "full information estimation" in theory), we choose to check for these two problems separately for the following reasons: First of all, if our estimates of NOLS were not robust, we wish to find out the main causes: SUR, endogeneity, or both. Secondly, when only one or none of the problem seriously exists in our regression system, the empirical estimates of N3SLS may be much less efficient than those of NOLS. (we discuss this empirical efficiency issue in the following subsection) Thus, even if we found significant difference between N3SLS and NOLS, we could not tell whether it is because of the SUR/endogeneity problem or just the inefficient estimation of N3SLS.

8 Strictly speaking, a reliable test for the correlation of error terms should be done before we can retain estimate results of NOLS. To test the correlation of error terms, many studies directly test for the zeros in off-diagonal error covariance matrix. (for example, Breusch and Pagan, 1980; Kariya, 1981; Shiba and Tsurumi, 1988). However, most of the tests are only justified under asymptotic arguments. Thus standard multivariate likelihood-based asymptotic tests are unreliable in finite samples, in the sense that test sizes deviate from the nominal significance levels for related simulation evidence (Dufour and Khalaf, 1998). Since the overall similarity between estimates of NOLS and SUR, doing any (unreliable) test for SUR problem seems unnecessary in our study.
3.1.3 Iterative Seemingly-Unrelated Regressions

As for the endogeneity problem, the key task is to find enough (at least as many as the endogenous variables to be replaced) valid IVs. Many economists (e.g. Eaton and Kortum, 2002; Melitz, 2003) have suggested various IVs such as tariff, transport costs and distance as these trade costs can only affect productivity through export variety. However, since all Chinese provinces face the same tariffs (except the so called "Special Economic Zones") against their exports, only IVs concerning transportation costs and distance will be useful here. Therefore, in order to find enough IVs, I also consider market demand and supply factors.

Besides all the included exogenous variables (except for the price index of nontraded goods), I find seven excluded IVs along three dimensions in addition to the land difference. They are weighted distance, road density, seaboard dummy, and border dummy for geography; lagged population density, and lagged CPI for market demand; and the policy dummy for market supply. All the relevant data except for the dummies and distance are available from provincial and national statistical yearbooks.

With respect to the distance IVs, since the export destinations are all over the world, I have to use a weighted distance to approximate the real trade distance facing each province. First of all, I assume that all Chinese exports will be shipped to the following five destinations: Hong Kong (Hong Kong, Macau, Taiwan), Singapore (South-east, South, and West Asia and Oceania), Tokyo (North-east Asia), Los Angeles (west hemisphere), and Amsterdam (Europe and Africa). Then I measure the distance between the capital of each province to the five destinations with the distance weights approximated by the export shares of those regions represented by the five destinations.
Road density is calculated by dividing total mileage of railway, road, and waterway by the provincial area. The lagged population density is measured by dividing the lagged effective provincial population by the provincial area. And effective population is the sum of the rural residents and the triple of urban residents. The idea of "effective population" comes from two reasons: firstly, the annual income of a representative urban resident is triple as high as that of a representative rural resident; secondly, an urban resident is more important for market demand than a rural counterpart because the former has to depend on trade for exchanging goods while the latter is more likely to produce most goods by himself.

The seaboard dummy indicates whether a province has seaboard and the border dummy indicates whether a province shares international borders with the other country. Finally, the policy dummy is assigned to the three provinces having the Special Economic Zones and four municipalities directly under central Government. The remaining IVs are directly given.

As mentioned, the geographical IVs are "classic" exogenous variables in explaining productivity since they may affect productivity via export variety but not the other way round. Likewise, the policy dummy is also a straightforward IV since these policies, which is based on political and geographical concerns, affect tariff which may affect productivity only via export variety as well. Since both CPI and effective population density are time series, so they may cointegrate with productivity which is

---

9The special economic zones are designed for the "experiments" of China's economic reform. In these zones, tariff and taxes are generally lower and legal procedures on business are simplified. By the year 2006, there are 6 special economic zones: Shenzhen, Zhuhai, Shantou, Xiamen, Pudong, and Hainan. The first three belong to Guangdong province, the rest three belong to Fujian province, Shanghai, and Hainan province respectively.

10The four municipalities are: Beijing, Tianjing, Shanghai, and Chongqing.
also a time series. A natural treatment is to use the lags of CPI and effective population density. Intuitively, a current production plan may base on the information in the last period such as last period's prices and number of target consumers. For example, a higher CPI or increase in population density may be treated as a positive signal to producers, and they may find it profitable to create new varieties to compete for the prospering market.

Table 2.3 presents the results estimated by N2SLS. As they were in SUR, the results reveal that both the partial price effects on the share of industries and the Rybczynski effects of endowments are very similar to those estimated by NOLS. The coefficient estimates on export varieties in (9b) change compared to NOLS. The coefficients on Textile & Garments, wood & paper, and Chemical & Plastics are all above unity, but not significantly so.

Now we need to consider which estimation, the NOLS or the N2SLS, is more reliable. After all, if the endogeneity problem is not so serious, NOLS is naturally superior to N2SLS for N2SLS actually replaces the most relevant explanatory variables with less explanatory ones (the IVs). The Hausman Test (Hausman, 1978) is widely used to test for potential endogeneity. The null hypothesis is that the regressors in the structural equations are exogenous. Under the null hypothesis, both of the estimates (NOLS and N2SLS) should be consistent, and the difference between these two vectors of parameter estimates should follow a Chi-square distribution with K degrees of freedom (K being number of unknown parameters). If the null hypothesis is not rejected, one can retain the estimates of NOLS; otherwise, the estimates from N2SLS will have to be taken. Column (6) of table 2.4 reports that the p-value of the statistic is almost unity which means we cannot reject the null hypothesis of no endogeneity. This result is consistent
with Kwan and Kwok (1995) that exports are exogenous in explaining China's economic growth (and thus productivity).

### 3.2 Specification Tests

As our NOLS estimation results are still valid after checking the SUR and endogeneity problems, we proceed to test the overall validity of the restrictions imposed on the system based on the NOLS estimation to check the overall robustness. Recall in section 2, I have imposed the following restrictions. For each of the share equations, homogeneity constraints on prices and endowments are imposed. The homogeneity constraint on endowments is imposed in the GDP function but not the homogeneity constraint on prices due to the possible measurement errors in nontraded good prices. The twenty-one symmetry constraints on the cross-price effects are also imposed on the whole system of equations.

I first test for all the homogeneity constraints one at a time. In each case, I constrain the variance-covariance matrix to be that of the unrestricted model. Conditional on all the accepted homogeneity constraints I further test for the symmetry constraints. This is done by comparing the value of the criterion function of the restricted model to a model with no symmetry constraints.

Table 2.4 presents the test statistics and the associated p-values for all the hypothesis tests. None of the homogeneity constraints for endowments are rejected (at the confidence level of 5%), nor are the homogeneity constraints in prices on all industry share equations (though it can be rejected for the agriculture industry at the confidence level of 10%). The only violation of homogeneity constraint in prices is for the TFP.
equation, which we did not impose in the previous estimation. Given that all the homogeneity constraints on endowments and prices are not rejected, table 2.5 also reports that the null hypothesis on the 21 symmetry constraints on the seven sectors cannot be rejected either.

In summary, the results of hypothesis testing support my previous specification in terms of the imposed homogeneity constraints on endowment and prices as well as the symmetry constraints on cross-equation prices.

### 3.3 Productivity Decomposition

To highlight the relationship between export variety and productivity in China, we conducted panel regressions of the estimated productivity on export variety

\[
(\sum_{n=1}^{8} \frac{1}{2}(s'_{n} + s^*_n) \frac{\ln \lambda_{nt}^*}{(1-\sigma_n)} )
\]

using the estimated parameters obtained in last section. Figure 2.3 plots the scatter graph. Both variables are averaged over time so actually we plot a “between” regression. From this graph, it is evident that the provincial export variety explains the productivity difference in a significant way.

Furthermore, we follow FK and perform a post-regression decomposition of estimated productivity based on the results in Table 2.1. Using (10), we compute the variance of estimated provincial TFP as:

\[
\text{var}(\text{Est. TFP}^i) = \text{var}(\hat{\alpha}_0^i) + \text{var}\left(\sum_{n=1}^{7} \frac{1}{2}(s'_{ni} + s^*_n) \frac{\ln \lambda_{nt}^*}{(1-\sigma_n)} \right)
\]

\[
+ 2\text{cov}(\hat{\alpha}_0^i, \sum_{n=1}^{7} \frac{1}{2}(s'_{ni} + s^*_n) \frac{\ln \lambda_{nt}^*}{(1-\sigma_n)} ) + \text{var}(\hat{\varepsilon}_t^i).
\]

\[\text{(11)}\]

Our estimation results should remain robust as long as the measurement error in nontraded goods is not systematically related to the province productivity or export variety.
The first term on the right hand side is the variance of provincial fixed effects, the second is the variance of export variety, the third is the covariance between these two, and the fourth is the error variance. By removing variance of the fixed effects and the regression error, the "variety-induced" provincial TFP is defined as:

\[
\text{Variety-induced } TFP_i^t \equiv \sum_{n=1}^{N} \left( \frac{1}{2} (s_n^i + s_n^*) \right) \frac{\ln \lambda_n^*}{(1 - \sigma_n)}.
\]

In addition, the first order difference of (10) within a province across two years reveals the growth decomposition of provincial productivity into two terms, which is the growth of variety induced provincial TFP and the change in regression errors:

\[
\text{Growth of } TFP_i^t \equiv \sum_{n=1}^{N} \left( \frac{1}{2} (s_n^i + s_n^*) \right) \frac{\ln \lambda_n^*}{(1 - \sigma_n)} - \frac{1}{2} (s_{n-1}^i + s_{n-1}^*) \frac{\ln \lambda_{n-1}^*}{(1 - \sigma_n)} + (\varepsilon_i - \varepsilon_{i-1}).
\]

The variance in the growth rate of provincial TFP is therefore the sum of the variance of the growth rate of variety-induced provincial TFP, and the variance of the difference in error terms, along with the covariance between the two terms. Table 2.5 shows the variance decomposition of provincial TFP in levels and growth rates. Surprisingly, only 36.3% of the cross-province differences in the TFP levels are explained by province fixed effects while variety-induced provincial TFP can account for about 44.1% of the provincial productivity levels. Furthermore, variety-induced TFP and province fixed effects are correlated, jointly contributing nearly 13.8% of the cross-province variation in TFP levels. Compared to the results from the cross-country literature, our variety-induced TFP can account for a striking proportion of the total TFP.
variation.\textsuperscript{12} Such a big discrepancy may be attributed to the following two reasons: first, the difference between provinces within a country should be much smaller than that between countries. Secondly, my unbalanced data covers the period from 1998 to 2005 but with more observations in the most recent 4 years (2002-2005) than those before 2001. Taking into account that China entered WTO in 2001, freer trade significantly boosted China's economic growth through fast growing exports.\textsuperscript{13} Thus, our data may contain a strong WTO effect which overstates the role of export variety expansion on TFP growth. In fact, the variety-induced TFP and its covariance with province fixed effects can explain 57.9\% of the estimated productivity in levels which is very close to 60\%, the percentage of within-country productivity difference explained by the variety-induced TFP in FK. This is not surprising: if we assume that provinces within a country are homogenous (i.e. ignoring the province fixed effect), then the estimated TFP difference in our model is (to some extent) equivalent to the FK's within-country TFP difference. The second column of Table 2.5 shows the growth decomposition of country productivity. About 36.6\% of the within-country growth in TFP can be explained by the year-to-year growth in export variety, while the reminder is explained by the change in regression errors and the correlation between the two terms. Again, export variety growth in our estimation can explain much more TFP growth than in the cross-country literature. In any event, export variety nonetheless is important in explaining provincial productivity differences in both levels and growth rates.

To further illustrate the effects of export variety on country productivity, according to (14) a 1\% increase in the export variety of each industry \( n \) would increase

\textsuperscript{12}For instance, the variety-induced TFP can account for only 2\% in FK while ours account for 44.1\%
\textsuperscript{13}According to the national statistical yearbook (1995-2005), the average export growth rate is 29\% during 2002-2005 compared to 10\% during 1995-2001.
provincial productivity by \( \frac{1}{2} (s_{m}^{t} + s_{m}^{*}) \frac{1}{(1-\sigma_{m})} \) percent. Thus, at the sample mean, a 10% increase in export varieties of all industries could lead to a 1.4% increase in China's productivity (as an average of provincial productivity). This effect is significant both statistically and economically.

4 Conclusions

Existing analyses of the export variety effects on TFP variation and growth have been restricted to cross-country studies and mainly to OECD countries. In this paper we study the case for China by estimating the effects of export variety on provincial productivity with multiple sectors and introducing export varieties into the provincial GDP function.

Estimating the seven sectoral share equations simultaneously with the GDP equation (transformed to become relative country productivity) allows us to identify and estimate the elasticity of substitution between export varieties in each sector and then infer the contribution of export variety on country productivity. The resulting elasticity estimates (measuring the degree of competition) range from a low of -0.235 in the wood & paper industry to a high of -8.025 in the food & beverage industry. The ranking I have obtained seems reasonable except for the wood & paper industry at first blush. Intuitively the competition in the machinery industry should be the lowest since this industry generally requires very high entry and operational costs. However, considering the fact that China's forest-coverage rate was only 18.21% (only one fourth of the world average) by 2005, the wood & paper industry is actually highly monopolistic, which may justify
the lowest elasticity results. Additionally, the estimation also reveals that the land share in China's GDP is about 8.3%.

I have considered the potential problems of correlated error terms in the seven sectoral share equations as well as endogeneity in the adjusted TFP equation. First of all, I conduct a SUR estimation and find that the estimates are very similar to those from NOLS which implies that error term correlation is not a serious problem. Then I conduct a N2SLS estimation to address the potential endogeneity problem. A Hausman test is applied to test the endogeneity problem of the NOLS estimation. That the p-value of the statistics is almost unity suggests the null hypothesis of no endogeneity in the system cannot be rejected. This result reinforces the hypothesis suggested by many economists that China's (as well as many Southeast Asian countries') exports are exogenous in explaining productivity growth. Then, I check the overall robustness of the NOLS estimation system by testing the specifications in my system. The results of these tests support my previous specifications on homogeneity constraints imposed on endowment and prices as well as the symmetry constraints imposed on cross-equation prices.

Finally, based on the NOLS estimation, I have also calculated the impact of export variety differences across provinces on their respective productivities. Surprisingly, export variety explains 44.1% of the total variation in provincial productivity; together with its covariance with province fixed effects, it can explain 57.9% of the estimated productivity in levels which is very close to 60%, the percentage of within-country productivity difference explained by the variety-induced TFP in FK. The rationale may be that the fixed effect across provinces is much smaller than that across countries, so export variety plays a much more important role in explaining TFP.
variation. Furthermore, export variety can explain 36.6% of the within-province productivity growth. At the sample mean, a 10% increase in export varieties of all industries leads to a 1.4% increase in country productivity.

There are many worthwhile extensions to this work. For example, we could address the effects of import varieties because many observers believe China's TFP growth benefits from the import of high-tech products. In addition, a comparative study for other developing countries such as India could help us determine quantitatively the different roles played by export variety on TFP and economic growth.
Reference List


Ghironi, F., and M. J. Melitz (2005), "International Trade and Macroeconomic Dynamics with Heterogeneous Firms", *Quarterly Journal of Economics* 120, 865-915.


Figure 2.1 Output Varieties

Production Possibility Frontier (PPF)
Figure 2.2 China Map
(including Hong Kong, Macau, & Taiwan)
Figure 2.3 Provincial productivity versus average export variety

Shanghai

Tianjin

Beijing

Guangdong

Liaoning

Zhejiang

Jiangsu

Shandong

Jilin

Heilongjiang

Fujian

Shanxi

Hebei

Hainan

Tibet

Hubei

Chongqing

Shanghai

Hunan

Henan

Guangdong

Anhui

Shaanxi

Guangxi

Guizhou

Yunnan

Sichuan

59
Table 2.1 Estimation Method: Non-linear Ordinary Least Squares Regressions
Dependent Variables-Industry shares in Column (1) to (7), and adjusted TFP in column (8)
Total system observations: 1544
Observation per equation: 193

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>0.023***</td>
<td>-0.010***</td>
<td>0.005***</td>
<td>0.004</td>
<td>-0.022***</td>
<td>-0.016***</td>
<td>0.029***</td>
<td>0.382***</td>
</tr>
<tr>
<td>Textile &amp; Garments</td>
<td>-0.010***</td>
<td>0.016***</td>
<td>0.003***</td>
<td>0.001</td>
<td>-0.004</td>
<td>0.002</td>
<td>-0.021***</td>
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</tr>
<tr>
<td>Wood &amp; Paper</td>
<td>0.005***</td>
<td>0.003***</td>
<td>0.004***</td>
<td>-0.066***</td>
<td>-0.066***</td>
<td>-0.002***</td>
<td>-0.006***</td>
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</tr>
<tr>
<td>Chemical &amp; Plastics</td>
<td>0.004</td>
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<td>-0.006***</td>
<td>0.013**</td>
<td>-0.008</td>
<td>0.002</td>
<td>0.016***</td>
<td>0.418***</td>
</tr>
<tr>
<td>Mining &amp; Metals</td>
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<td>-0.004</td>
<td>-0.006***</td>
<td>-0.008</td>
<td>0.125***</td>
<td>0.003</td>
<td>-0.021*</td>
<td>0.170***</td>
</tr>
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<td>Machinery &amp; Transportation</td>
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<td>0.002</td>
<td>-0.002***</td>
<td>0.002</td>
<td>0.003</td>
<td>0.026***</td>
<td>-0.005</td>
<td>0.572***</td>
</tr>
<tr>
<td>Food, Beverage &amp; Tobacco</td>
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<td>-0.006***</td>
<td>0.016***</td>
<td>-0.021*</td>
<td>-0.005</td>
<td>0.060***</td>
<td>0.111***</td>
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<td>-0.002</td>
<td>-0.001</td>
<td>0.010***</td>
<td>0.030***</td>
<td>0.018***</td>
<td>-0.001</td>
<td>-0.083***</td>
</tr>
<tr>
<td>Labor-Land Ratio</td>
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<td>0.002</td>
<td>0.006***</td>
<td>-0.015***</td>
<td>-0.077***</td>
<td>-0.009**</td>
<td>0.004</td>
<td>0.128***</td>
</tr>
<tr>
<td>Non-traded Goods Prices</td>
<td>0.007</td>
<td>0.003</td>
<td>0.001</td>
<td>0.003</td>
<td>0.008</td>
<td>0.004</td>
<td>0.060***</td>
<td>0.219***</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
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<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Country Fixed Effects</td>
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<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.723</td>
<td>0.4855</td>
<td>0.2033</td>
<td>0.3325</td>
<td>0.5179</td>
<td>0.7638</td>
<td>0.3304</td>
<td>0.9761</td>
</tr>
</tbody>
</table>

Note: For columns (1) to (7), each log of relative export variety coefficient is the partial price effect of the industry in that row on the share of the industry in the column. These are the point estimates of \( \gamma_{mn} \). Own price effects are underlined.

For column (8), each log of the relative export variety coefficient is the point estimate of \( 1/(1 - \sigma_n) \) of the industry in that row.

*, **, and *** indicate significance at 90%, 95% and 99% confidence levels respectively, and White-robust standard errors are in parentheses.
Table 2.2 Estimation Method: Iterated Non-linear SUR
Dependent Variables-Industry shares in Column (1) to (7), and adjusted TFP in column (8)
Total system observations: 1544
Observation per equation: 193

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>0.035***</td>
<td>-0.005***</td>
<td>0.002</td>
<td>-0.010**</td>
<td>-0.030***</td>
<td>-0.017***</td>
<td>0.029***</td>
<td>0.297***</td>
</tr>
<tr>
<td>Textile &amp; Garments</td>
<td>-0.005***</td>
<td>0.005***</td>
<td>0.002***</td>
<td>-0.000</td>
<td>0.000</td>
<td>-0.000</td>
<td>-0.008***</td>
<td>1.195***</td>
</tr>
<tr>
<td>Wood &amp; Paper</td>
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<td>0.002***</td>
<td>0.001***</td>
<td>-0.002**</td>
<td>-0.004***</td>
<td>-0.001</td>
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<td>1.533***</td>
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<tr>
<td>Chemical &amp; Plastics</td>
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<td>-0.000</td>
<td>-0.002**</td>
<td>0.016**</td>
<td>0.013**</td>
<td>0.006**</td>
<td>-0.000</td>
<td>0.286**</td>
</tr>
<tr>
<td>Mining &amp; Metals</td>
<td>-0.030***</td>
<td>0.000</td>
<td>-0.004***</td>
<td>0.013**</td>
<td>0.087***</td>
<td>-0.003</td>
<td>-0.005</td>
<td>0.208***</td>
</tr>
<tr>
<td>Mach. &amp; Transport.</td>
<td>-0.017***</td>
<td>-0.000</td>
<td>-0.001</td>
<td>0.006**</td>
<td>-0.003</td>
<td>0.036***</td>
<td>-0.006***</td>
<td>0.41***</td>
</tr>
<tr>
<td>Food, Beverage &amp; Tobacco</td>
<td>0.029***</td>
<td>-0.008***</td>
<td>-0.001</td>
<td>-0.000</td>
<td>-0.005</td>
<td>-0.007**</td>
<td>0.037***</td>
<td>0.235***</td>
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<td>Capital-Land Ratio</td>
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<td>-0.000</td>
<td>0.009***</td>
<td>0.031***</td>
<td>0.018***</td>
<td>-0.002</td>
<td>-0.090***</td>
</tr>
<tr>
<td>Labor-Land Ratio</td>
<td>0.056***</td>
<td>0.002</td>
<td>0.003**</td>
<td>-0.015***</td>
<td>-0.079***</td>
<td>-0.008*</td>
<td>0.006</td>
<td>0.066</td>
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<td>Non-traded Goods Prices</td>
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<td>0.001</td>
<td>0.003</td>
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<td>0.05</td>
<td>-0.470***</td>
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<td>YES</td>
<td>YES</td>
<td>NO</td>
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<tr>
<td>Country Fixed Effects</td>
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<td>YES</td>
<td>YES</td>
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<td>0.9660</td>
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</tbody>
</table>

Note: For columns (1) to (7), each log of relative export variety coefficient is the partial price effect of the industry in that row on the share of the industry in the column. These are the point estimates of \( \gamma_{mn} \). Own price effects are underlined.

For column (8), each log of the relative export variety coefficient is the point estimate of \( 1/(1 - \sigma_{m}) \) of the industry in that row.

*, **, and *** indicate significance at 90%, 95% and 99% confidence levels respectively, and White-robust standard errors are in parentheses.
Table 2.3 Estimation Method: Two Stage Nonlinear Least Squares Regressions

Dependent Variables: Industry shares in Column (1) to (7), and adjusted TFP in column (8)
Total system observations: 1544
Observation per equation: 193

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agriculture</td>
<td>Textile &amp; Garments</td>
<td>Wood &amp; Paper</td>
<td>Chemical &amp; Plastics</td>
<td>Mining &amp; Metals</td>
<td>Machinery &amp; Transportation</td>
<td>Food, Beverage &amp; Tobacco</td>
<td>Adj. TFP</td>
</tr>
<tr>
<td></td>
<td>Agriculture</td>
<td>Textile &amp; Garments</td>
<td>Wood &amp; Paper</td>
<td>Chemical &amp; Plastics</td>
<td>Mining &amp; Metals</td>
<td>Machinery &amp; Transportation</td>
<td>Food, Beverage &amp; Tobacco</td>
<td>Adj. TFP</td>
</tr>
<tr>
<td>Agriculture</td>
<td>0.056***</td>
<td>-0.014***</td>
<td>0.004**</td>
<td>0.007**</td>
<td>-0.040**</td>
<td>-0.033***</td>
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<td>(0.002)</td>
<td>(0.003)</td>
<td>(0.016)</td>
<td>(0.008)</td>
<td>(0.018)</td>
<td>(0.045)</td>
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<tr>
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<td>-0.000</td>
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<td>1.006***</td>
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<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.004)</td>
<td>(0.002)</td>
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<td>(0.341)</td>
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<td>Wood &amp; Paper</td>
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<td>-0.002***</td>
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<td>1.547***</td>
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<td>(0.001)</td>
<td>(0.002)</td>
<td>(0.001)</td>
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<td>(0.358)</td>
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<tr>
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<td>(0.001)</td>
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<td>(0.002)</td>
<td>(0.003)</td>
<td>(0.314)</td>
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<tr>
<td>Mining &amp; Metals</td>
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<td>-0.030</td>
<td>0.175***</td>
</tr>
<tr>
<td></td>
<td>(0.016)</td>
<td>(0.004)</td>
<td>(0.002)</td>
<td>(0.004)</td>
<td>(0.040)</td>
<td>(0.007)</td>
<td>(0.019)</td>
<td>(0.040)</td>
</tr>
<tr>
<td>Mach.&amp; Transport.</td>
<td>-0.033***</td>
<td>0.001</td>
<td>-0.003**</td>
<td>-0.003*</td>
<td>-0.006**</td>
<td>-0.003**</td>
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<td>(0.002)</td>
<td>(0.001)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.001)</td>
<td>(0.006)</td>
<td>(0.113)</td>
</tr>
<tr>
<td>Food, Beverage &amp; Tobacco</td>
<td>0.077***</td>
<td>0.013***</td>
<td>0.0110***</td>
<td>0.028***</td>
<td>0.015***</td>
<td>0.036</td>
<td>0.078**</td>
<td>0.782***</td>
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<tr>
<td></td>
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<td>(0.002)</td>
<td>(0.003)</td>
<td>(0.002)</td>
<td>(0.007)</td>
<td>(0.006)</td>
<td>(0.027)</td>
<td>(0.030)</td>
</tr>
<tr>
<td>Capital-Land Ratio</td>
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<td>-0.001</td>
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<td>0.028***</td>
<td>0.015***</td>
<td>0.005</td>
<td>0.144***</td>
</tr>
<tr>
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<td>(0.006)</td>
<td>(0.002)</td>
<td>(0.001)</td>
<td>(0.002)</td>
<td>(0.007)</td>
<td>(0.004)</td>
<td>(0.006)</td>
<td>(0.024)</td>
</tr>
<tr>
<td>Labor-Land Ratio</td>
<td>0.050***</td>
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<td>0.006***</td>
<td>0.014***</td>
<td>0.078***</td>
<td>-0.011**</td>
<td>0.000</td>
<td>-0.000</td>
</tr>
<tr>
<td></td>
<td>(0.007)</td>
<td>(0.003)</td>
<td>(0.0017)</td>
<td>(0.003)</td>
<td>(0.009)</td>
<td>(0.005)</td>
<td>(0.007)</td>
<td>(0.007)</td>
</tr>
<tr>
<td>Non-traded Goods Prices</td>
<td>-0.416***</td>
<td>(0.092)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.007)</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
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<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Country Fixed Effects</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.7262</td>
<td>0.4851</td>
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<td>0.4854</td>
<td>0.7487</td>
<td>0.0963</td>
<td>0.9664</td>
</tr>
</tbody>
</table>

Note: For columns (1) to (7), each log of relative export variety coefficient is the partial price effect of the industry in that row on the share of the industry in the column. These are the point estimates of \( \gamma_{mn} \). Own price effects are underlined.
For column (8), each log of the relative export variety coefficient is the point estimate of \( 1/(1 - \sigma_a) \) of the industry in that row.
*, **, and *** indicate significance at 90%, 95% and 99% confidence levels respectively, and White-robust standard errors are in parentheses.
<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Homogeneity in Endowments</th>
<th>Prices</th>
<th>Symmetry in Cross Price Effects</th>
<th>Hausman Test OLS vs. N2SLS</th>
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<tr>
<td>Degree of Freedom</td>
<td>1</td>
<td>1</td>
<td>21</td>
<td>139</td>
</tr>
<tr>
<td>Critical Value at 95%</td>
<td>3.84</td>
<td>3.84</td>
<td>32.67</td>
<td>167.5</td>
</tr>
<tr>
<td>Overall System</td>
<td>7.70</td>
<td>(0.9963)</td>
<td>94.39</td>
<td>(0.9986)</td>
</tr>
<tr>
<td>Agriculture</td>
<td>0.13</td>
<td>3.51*</td>
<td>(0.7145)</td>
<td>(0.0610)</td>
</tr>
<tr>
<td>Textile &amp; Garments</td>
<td>0.01</td>
<td>0.10</td>
<td>(0.9080)</td>
<td>(0.7486)</td>
</tr>
<tr>
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<td>0.04</td>
<td>0.05</td>
<td>(0.8355)</td>
<td>(0.8216)</td>
</tr>
<tr>
<td>Chemical &amp; Plastics</td>
<td>0.35</td>
<td>0.91</td>
<td>(0.5556)</td>
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<td>0.95</td>
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<td>(0.3297)</td>
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<td>0.05</td>
<td>0.84</td>
<td>(0.8287)</td>
<td>(0.3587)</td>
</tr>
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<td>Adj. TFP</td>
<td>0.92</td>
<td>121.66***</td>
<td>(0.3387)</td>
<td>(&lt;.0001)</td>
</tr>
</tbody>
</table>

Notes: All test statistics are asymptotically Chi-squared distributed with degree of freedom equals number of restrictions. Numbers in parentheses denote p-value of the test statistics.
Table 2.5 Productivity Decomposition

<table>
<thead>
<tr>
<th></th>
<th>Level Decomposition (in % of TFP)</th>
<th>Growth Decomposition (in % of TFP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variance of Estimated Province TFP</td>
<td>0.0954 (100)</td>
<td>0.0050 (100)</td>
</tr>
<tr>
<td>Variance of Province Fixed Effects</td>
<td>0.0347 (36.3%)</td>
<td>-</td>
</tr>
<tr>
<td>Variance of Variety Induced TFP</td>
<td>0.0421 (44.1%)</td>
<td>0.0018 (36.6%)</td>
</tr>
<tr>
<td>2*Covariance between Province Fixed Effects and Variety Induced TFP</td>
<td>0.0138 (14.4%)</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Author’s calculation based on regression results of Table 2.1.
CHAPTER 3
TRADE VARIETY AND PRODUCTIVITY
IN CANADA
1 Introduction

The relationship between trade variety and productivity is one of the central interests in trade and development. Although the channel of how productivity affects trade variety has been articulated centuries ago\(^1\), the other direction, how trade variety affects productivity, is less well understood.

A standard monopolistic competition model (MC) in trade (e.g. Dixit and Stiglitz (1977), Krugman (1980)) assumes goods are differentiable and varied. With this framework, economists are able to exposit how trade variety affects productivity from two effects: the input variety effect and the output variety effect.

The output variety effect predicts that the expansion of export varieties can boost the exporting country's productivity. This effect results from the assumption of diminishing technical rate of substitution (i.e. concavity of production possibility frontier (PPF), see figure 3.1a). Empirically, the link between export variety and productivity has been found by Feenstra et al (1999) for South Korea and Taiwan, and by Funke and Ruhwedel (2001) for OECD and East Asian countries. Using the monopolistic competition model augmented with endogenous technology, Feenstra and Kee (2008) (hereafter FK) test the effects of sectoral export variety on country productivity. Analyzing a panel data containing 34 countries (developed and developing) across 16 years, they found that while export variety accounts for only 2 percent of cross-country productivity differences, it explains 13 percent of within-country productivity growth.

\(^1\)For example, the pioneer work of Adam Smith's "Absolute Advantage" and David Ricardo's "Comparative Advantage".
The input variety effect is similar to that found in endogenous growth models (e.g. Romer, 1990; Grossman and Helpman, 1991), where greater variety of inputs leads to higher productivity. This effect results from the assumption of diminishing marginal productivity of productive factors (i.e. the convexity property of the iso-quant curve). Under the assumption that imports are typically used as intermediate inputs in production rather than final consumption goods, an expansion in import varieties will boost productivity growth (see Figure 3.1b). Broda, Greenfield, and Weinstein (2006) (hereafter BGW) find that new imported varieties on average account for 10 percent of productivity growth. The effects are larger in developing countries, where the median impact of new imported varieties equals 25 percent of national productivity growth.

The underlying contention that imports are typically intermediate inputs is problematic. For instance, research on imports and welfare treats imports as final consumption goods (e.g. Broda and Weinstein, 2004). If a variety of import is for final consumption, the direct effect (based on the output effect) is that it lowers the importing country's productivity growth if it competes with the domestic varieties and makes the latter disappear. In practice, it is nearly impossible to distinguish imports by intermediate inputs and final consumption goods. So the mixture of these two kinds of imports may result in an insignificant or even negative effect on importing country's productivity (I will discuss this problem in section 4 and the Appendix).

However, the existing literature on the effects of trade variety on productivity is restricted to either export variety or import variety; the total effects of both export and

---

2 Of course, imports as final consumption goods may benefit the importing country's productivity indirectly (in the long run): by forcing the less efficient domestic variety to shrink or disappear, resources can be redistributed towards more productive varieties.
import varieties have not been studied. In addition, empirical studies using industry level trade data (e.g. Harmonized System (HS) data or Standard International Trade Classification data) can only estimate the "average" (of sample countries) effects of export or import variety on productivity. Country-specific effects are usually estimated by using firm level data whose results largely rely on the sample firms and thus may not truly reflect the actual effects.

By extending FK's (2008) model to include both export and import varieties, this paper use Canadian provincial foreign trade data (HS data) to analyze the effects of trade variety and productivity in Canada. There are two contributions in the paper: first of all, including both export and import varieties allows me to study the total effect of import and export varieties on productivity; secondly, by exploring the Canadian provincial data, I am able to estimate the country-specific effect of trade variety and productivity based on the actual industrial data rather than the approximation of firm level data.

Furthermore, employing Canadian provincial panel data makes my results more reliable: an implicit but important assumption about the price-factor GDP function (used in FK and here) is that the prices and production factors are all given, i.e., exogenous. However, FK's data is obtained from US imports from 34 countries including the major developed ones. Thus, it is very likely that the prices are actually endogenous since the major developed countries may have monopolistic power over some of their major exports such as electronic products from Japan and machines from Germany. Furthermore, the US itself is the largest open economy in the world suggesting it has monopsonistic power over many of its imports. As a result, if monopoly dominates, estimates of the elasticities of productivity on export varieties tend to be overstated, while if monopsony dominates,
the estimates tend to be understated. On the contrary, Canada is a typical small open economy, as most of its exports and imports only have negligible effects on the world market. So prices facing Canadian exports and imports are mainly exogenous.

The rest of the paper will be organized in five parts. In section 2, I survey Canadian imports and exports over the last 19 years. In section 3, I derive the mechanism through which import/export variety affects productivity in an extension of FK's model. I also describe my dataset and estimate a system of equations relating sectoral shares and import shares as well as adjusted total factor productivity (TFP) to export and import variety. In section 4, I present the estimation results. In section 5, I decompose productivity to illustrate the quantitative effects of export and import variety on Canadian provincial productivity differences and productivity growth. Finally, in section 6, I conclude that export variety and import variety respectively account for 10.41% and 1.57% of the variation in Canadian provincial productivity differences in level. By excluding the joint effects with the province fixed effects, the total trade variety related effects account for 7.06% of the provincial productivity differences in level. Furthermore, the export and import variety respectively account for 9.92% and 6.95% of within-province productivity growth, and if their joint effects are also included, their total effects can account for 17.31%. Evaluated at the sample mean, a 10% increase in all trade varieties leads to a 0.90% increase in Canadian productivity, in which the export variety's contribution is 0.57% and import variety's is 0.33%.

2 An Overview of Canadian Trade: 1988-2006

In 1988, Canada signed the Free Trade Agreement (FTA) with US which has been replaced by the North America Free Trade Agreement (NAFTA) with US and Mexico
since 1992. In January 1995, Canada entered the World Trade Organization (WTO) with most of the open economies in the world. These trade agreements all aim at lowering tariff and non-tariff trade barriers between Canada and the other member countries. As a result, the Canadian economy is now broadly and deeply involved in foreign trade. To see this trend in detail, I define openness as the ratio of total value of imports and exports to the corresponding year's GDP. Figure 3.2 shows that the degree of openness increases from slightly above 40% in 1988 to about 60% in 2006. Apparently, trade plays a more and more important role on GDP and productivity growth in Canada.

To study how trade, especially trade variety, affects Canadian productivity growth quantitatively, I first define an export/import variety based on the trade data provided by Trade Analyser. Trade Analyser is a Canadian trade database which provides the most detailed (macro) level trade data for Canada. In this database, the trading commodities are described by the so-called Harmonized System (HS). The HS is an international 6-digit commodity classification developed under the auspices of the World Custom Organization (WCO). Canada has extended the HS system to 10 digits for import purposes and to 8 digits for export purposes. In the HS, goods are classified by what they are, and not according to their stage of fabrication, their use, or origin.

Since it is the most detailed macro-level dataset, the variety defined in this paper is naturally based on the HS system. A product is a HS 6-digit commodity, such as "live Sheep". An import variety is defined as a country-specific good (e.g. Broda and Weinstein (2005)) such as "live Sheep from France", and an export variety is defined as a province-specific good such as "live Sheep from Ontario, Canada".
Trade growth can be decomposed into the expansion of the intensive and extensive margins. Given the variety defined in this paper, the expansion in the intensive margin refers to the growth in value due to surviving (existing) varieties, while the expansion of the extensive margin refers to the rest of growth due to newly added varieties. Table 3.1 reports the Canadian export and import performance during 1988-2006. The growth in Canadian exports is largely explained by expansion on the intensive margin. About 79% of the growth is due to intensive margin expansion. On the contrary, about 65% of Canadian imports growth is attributed to expansion of the extensive margin. Table 3.2 reports the exports and imports in value and variety of the major Canadian partner countries in 1988 and 2006. The exports column shows that Canadian exports rely heavily on the US market. Over 80% of Canadian varieties are exported to US in 2006, which helps Canada collected 81.26% of total export revenue from the US. Compared to 1988, the export variety in 2006 in all the countries increases significantly both in number and ratio, which implies that more and more Canadian varieties (especially the surviving ones from 1988 to 2006) have kept and enhanced their competitive power advantage successfully entered more countries. From the imports column, we can observe that though overall the US is still the most important importing source country for Canada, the relative importance is decreasing, with 54.89% of import value and 54.23% of import varieties in 2006 compared to 66.36% and 68.84% in 1988 respectively. On the contrary, imports from China increased rapidly. The import value and variety from China increased by 1500% and 150% respectively from 1988 to 2006, resulting in the share of Chinese imports in value and variety increasing from 1.61% and 2.22% in 1988 to 8.82% and 3.25% in 2006 respectively. However, in aggregate, the
shares of value and variety of these eight major partner countries decrease steadily during 1988 to 2006, which implies that Canadian imports are more and more diversified owing to the reduction of its trade barriers with the rest of the world and more country competing with each other in the Canadian market.

Of course, the Canadian national level data is far from enough for strictly studying the effect of trade variety on productivity. We need many more observations that share the same trade characteristics as Canada, i.e. under the same economic circumstances. Thus, a natural way is to collect data from Canadian provinces. The panel data of all the 10 Canadian provinces is employed in section 4 after the introduction of the empirical model in section 3.

3 The Empirical Model

3.1 Effect of New Varieties in Price Indices

Feenstra (1994) derives an exact price index from a CES (constant elasticity of substitution) aggregate good allowing both variety and quality/taste changes in existing varieties. This index can also apply for several goods or industries as long as they are CES aggregates.

Suppose there exist many \( c = 1, \ldots, C \) countries. Each country \( c \) can produce a set of output varieties, \( I^c_t \), at time \( t \). The quantity of type \( j \in I^c_t \) variety produced in country \( c \) in period \( t \) is denoted by \( q^c_{jt} \). In a standard MC model, the aggregate output of country \( c \), \( Q^c_t \), is characterized by a CES function of the output of each specific good produced in that country:
\[ Q_i^c = f (q_i^c, I_i^c) = \left( \sum_{j=I_i^c} d_j (q_j^c)^{(\sigma-1)/\sigma} \right)^{\sigma/(\sigma-1)}, \quad d_j > 0, \quad c = 1, \ldots, C. \] (1)

where \( d_j \) is the unknown productivity/quality parameter for good \( q_j^c \). Note, if \( q_j^c \) is an output, then eq(1) refers to a transformation function with \( \sigma < 0 \); if \( q_j^c \) is an (intermediate) input, then eq(1) refers to a production function with \( \sigma > 1 \).

As demonstrated by Feenstra, the ratio of aggregate price levels between countries \( (c = a, b) \) associated with the CES production function can be evaluated by the product of the Sato(1976)-Vartia(1976) price index of varieties that are common, \( I_i = (I_i^a \cap I_i^b) \neq \emptyset \), and by terms reflecting the revenue share of "unique" varieties. The log form is given by:

\[
\ln \frac{P_i^a}{P_i^b} = \sum_{j \in I_i} w_j (I_i) \ln (\frac{P_j^a}{P_j^b}) + \left( \frac{1}{\sigma - 1} \right) \ln (\frac{\lambda_i^a (I_i)}{\lambda_i^b (I_i)}), \quad a, b = 1, \ldots, C. \tag{2a}
\]

where \( P_i^c \) is the aggregate price level, and the weights \( w_j (I_i) \) are constructed from the revenue shares in the two countries:

\[
w_j (I_i) = \left( \frac{s_j^a - s_j^b}{\ln s_j^a (I_i) - \ln s_j^b (I_i)} \right) \sum_{j \in I_i} \left( \frac{s_j^a - s_j^b}{\ln s_j^a (I_i) - \ln s_j^b (I_i)} \right) \tag{3}
\]

\[
s_j^c (I_i) = \frac{p_j^c q_j^c}{\sum_{j \in I_i} p_j^c q_j^c}, \quad \text{for } c = a, b, \tag{4}
\]

\[
\lambda_i^c (I_i) = \sum_{j \in I_i} p_j^c q_j^c \sum_{j \in I_i} p_j^c q_j^c = 1 - \frac{\sum_{j \in I_i} p_j^c q_j^c}{\sum_{j \in I_i} p_j^c q_j^c}, \quad \text{for } c = a, b, \tag{5}
\]
where $s_{jl}$ measures the revenue share of variety $j$ relative to the revenue of all the varieties that are common in county $a$ and $b$ at period $t$, and $\lambda^c(I_j)$ is the revenue share of common varieties ($j \in I_j$) to total varieties ($j \in I_j^c$).

The first term on the right hand side of (2) is the traditional price index, which only captures the weighted average of the price ratios for varieties in the common set $I_j$, in other words, it actually omits the effect of variety change. The second term is a correction term, which reflects changes in product variety given that the quality of the same type of good is the same. Given (2a), we can easily see that the final effect of the new product that is uniquely produced in country $a$ will cause the exact price ratio on the left to increase because the new product increases the competition for resources and drives up the factor prices; as a result, the prices of output increase.

In a special case where country $b$ "contains" country $a$ (e.g. $a$ is a province of $b$), and the prices of the same varieties sold are the same (i.e. $p^a_{jl} = p^b_{jl} \forall j \in I_j$), then

$$\ln\left(\frac{P^a_{jl}}{P^b_{jl}}\right) = 0 \text{ and } \lambda^a(I_j) = 1,$$

and eq(2a) is simplified to:

$$\ln\frac{P^a}{P^b} = (\frac{1}{1-\sigma})\ln(\lambda^b(I_j)) \quad (2b)$$

### 3.2 An Empirical GDP Function with both Export and Import Variety

First shown by Samuelson (1953), GDP can be treated as a variable profit function, which can be expressed as follows:

$$GDP = \pi = \max_{Q, Q_m} \{P Y - P M Q_M \mid (Q_Y, Q_M, V) \in T\}$$ (6)
where $T$ is the production technology, $P_Y (> 0)$ and $P_M (> 0)$ are the exogenous aggregate price levels for output $Q_Y$ and variable input $Q_M$ (intermediate input) respectively, and $V (> 0)$ is a vector of fixed inputs. Furthermore, I assume the only variable intermediate inputs are imports. Note given GDP form in eq (6) and the duality theory, the GDP is homogenous of degree one in both prices ($P_Y$ and $P_M$) and fixed inputs ($V$).\(^3\)

Empirically, the most popular variable profit form of GDP is the translog functional form proposed by Diewert (1973). For example, Kohli (2004) used it to estimate real GDP fluctuation due to the changes in terms of trade for 26 countries. Therefore, I implement a translog empirical GDP function where there are $N$ differentiated tradable output sectors, $M$ import sectors, a homogenous non-traded output sector $(N + M + 1)$, and $K$ types of productive factors:

\[
\ln G^c_i (P^c_i, V^c_i) = \alpha^c_0 + \beta^c_0 + \sum_{m=1}^{M} \alpha_m \ln P^c_{mi} + \sum_{n=M+1}^{N+M+1} \alpha_n \ln P^c_{ni} + \sum_{k=1}^{K} \beta_k \ln \nu^c_k \\
+ \frac{1}{2} \sum_{i=1}^{M} \sum_{j=1}^{M} \delta_{ij} \ln P^c_{ii} \ln P^c_{jj} + \frac{1}{2} \sum_{i=M+1}^{M+N+1} \sum_{j=M+1}^{M+N+1} \delta_{ij} \ln P^c_{ii} \ln P^c_{jj} \\
+ \frac{1}{2} \sum_{i=1}^{M} \sum_{j=1}^{K} \tau_{ij} \ln P^c_{ii} \ln \nu^c_{ij} + \sum_{m=1}^{M} \sum_{n=M+1}^{N+M+1} \delta_{mn} \ln P^c_{mi} \ln P^c_{ni} \\
+ \sum_{m=1}^{M} \sum_{k=1}^{K} \rho_{mk} \ln P^c_{mi} \ln \nu^c_{jk} + \sum_{n=M+1}^{N+M+1} \sum_{k=1}^{K} \omega_{nk} \ln P^c_{ni} \ln \nu^c_{jk},
\]

\[(7)\]

The duality theory states that the GDP measured by value-added (variable profit) method should be equivalent to that measured by aggregate cost of (fixed) inputs. That is,

$$
GDP \equiv \pi = \max_{\bar{Q}_Y, \bar{Q}_M} \{ P_Y Q_Y - P_M Q_M \mid (Q_Y, Q_M, V) \in T \} \\
\equiv c = \min_{V} \{ w \cdot V \mid (Q_Y, Q_M, V) \in T \},
$$

where $w$ is the wage vector associated with the fixed input vector $V$. 

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Notice that in a panel data regression setting, $\alpha_m^c$ and $\beta_k^c$ refer to section and time fixed effects respectively. The properties of homogeneity in prices and endowments as well as symmetry have the following implications:

\[
\sum_{m=1}^{M} \alpha_m + \sum_{n=M+1}^{M+N+1} \alpha_n = 1, \quad \sum_{k=1}^{K} \beta_k = 1,
\]

\[
\sum_{j=1}^{M} \delta_{nj} + \sum_{n=M+1}^{M+N+1} \delta_{mn} = \sum_{k=1}^{K} \rho_{nk} = 0, \quad m=1, \ldots, M,
\]

\[
\sum_{j=M+1}^{M+N+1} \delta_{jn} + \sum_{m=1}^{M} \delta_{jm} = \sum_{k=1}^{K} \rho_{kn} = 0, \quad n = M+1, \ldots, M+N+1,
\]

\[
\sum_{m=1}^{M} \rho_{mk} + \sum_{n=M+1}^{M+N+1} \omega_{nk} = \sum_{j=1}^{K} \tau_{nj} = 0, \quad k = 1, \ldots, K,
\]

\[
\delta_{ij} = \delta_{ji}, \quad i, j = 1, \ldots, M+N+1,
\]

\[
\tau_{ij} = \tau_{ji}, \quad i, j = 1, \ldots, K.
\]

From (7), the share equations are given by the derivative of $\ln G_t^c(P_t^c, V_t^c)$ with respect to $\ln P_{mt}^c$ and $\ln P_{nt}^c$:

\[
s_{mt}^c = \alpha_m + \sum_{j=1}^{M+N+1} \delta_{mj} \ln P_{mt}^c + \sum_{k=1}^{K} \rho_{mk} \ln v_{kt}^c, \quad m = 1, \ldots, M.
\]

and

\[
s_{nt}^c = \alpha_n + \sum_{j=1}^{M+N+1} \delta_{nj} \ln P_{nt}^c + \sum_{k=1}^{K} \rho_{nk} \ln v_{kt}^c, \quad n = M+1, \ldots, N+M+1.
\]

where $s_{mt}^c = -P_{mt}^c Q_{mt}^c / GDP_n^c$ and $s_{nt}^c = P_{nt}^c Q_{nt}^c / GDP_n^c$ are the negative GDP shares of import $m$ and the GDP shares of sector $n$, respectively.

In this paper, since the prices of the same types of varieties sold by any Canadian province and Canada are the same, if we take the difference of eq(7) and eq(10) of any
province (c) with that of the Canada (*), the difference of traded sector prices are replaced by eq (2b), thus we can map trade variety into the empirical GDP function as well as the share equations with minimal computation.

\[
\delta_{cl}^e - s_{cl}^* = \sum_{m=1}^{M} \frac{\delta_{ml}}{(1 - \sigma_{m})} \ln \lambda_{ml}^c + \sum_{n=M+1}^{M+N} \frac{\delta_{nn}}{(1 - \sigma_{n})} \ln \lambda_{nn}^c - \frac{1}{2}(s_{c1}^e + s_{c1}^*)(\ln \nu_{cl}^e - \ln \nu_{cl}^*)
\]

+ \sum_{k=1}^{K} \delta_{kl}^e (\ln \nu_{kl}^e - \ln \nu_{kl}^*) + \delta_{M+N+1,1}(\ln P_{M+N+1,1}^e - \ln P_{M+N+1,1}^*)
\]

\[ i = 1, \ldots, M + N + 1. \]  \tag{11}

and

\[
\ln G_i^c(P_i^e, V_i^e) - \ln G_i^c(P_i^*, V_i^*) - \sum_{k=1}^{K} \frac{1}{2}(s_{kl}^e + s_{kl}^*)(\ln \nu_{kl}^e - \ln \nu_{kl}^*)
\]

\[
- \frac{1}{2}(s_{M+N+1,1}^e + s_{M+N+1,1}^*)(\ln P_{M+N+1,1}^e - \ln P_{M+N+1,1}^*)
\]

\[ = \alpha_0^e + \beta_0^e + \sum_{i=1}^{M+N} \frac{1}{2}(s_{il}^e + s_{il}^*) \frac{\ln \lambda_{il}^e}{(1 - \sigma_{i})}. \]  \tag{12}

The left hand side of (12) can be interpreted as the productivity difference between province (c) and Canada (*): it is the difference of GDP net of the differences in factor endowments and prices in non-traded goods. The remaining difference is the productivity difference due to province and time fixed effects and trade variety shown on the right.

### 3.3 Data and Estimating Equations

With equations (11) and (12), we can estimate the parameters of interest such as the elasticity of substitution between different varieties within a sector (\(\sigma\)), the relative price effects on the relative industry shares (\(\delta\)), as well as the effects of relative endowments on sectoral shares and productivity.
The balanced panel dataset covers all 10 provinces in Canada (excluding 3 territories) from 1988 to 2006. It contains 190 observations for each regression. The trade variety data is obtained from Trade Analyser while the remaining data are all from CANSIM.

I assume there are three factors of production: Labor \( (L) \), Capital \( (K) \), and (arable) Land \( (T) \). Labor and Land (as well as real GDP (chained 1997 Canadian dollars)) are reported directly by CANSIM. Capital is constructed by the perpetual inventory method using real investment of the whole nation as well as the 10 provinces across the 19 years. Real investment is obtained by deflating the regional gross domestic capital formation with their respective GDP deflators. In addition, I construct the base year capital stock using an infinite sum of series of investment prior to the first year (1988), assuming that the average growth rate of investment of the 18 years is a good proxy for the investment prior to the first year.

Based on the North American Industry Classification System (NAICS), I aggregate all the tradable industries into 4 sectors: agriculture and forestry (AF), mining and basic metals (MB), light manufacturing (LM), and heavy and electronic manufacturing (HE).\(^4\) I compare the provincial value-added and import value of these four sectors to the corresponding regional GDP to construct the sectoral and import shares, respectively. That is, I have altogether eight shares: four sectoral shares and four corresponding import shares. The non-traded goods price is obtained by taking an

\(^4\) According to NAICS industry code, AF contains 11, 3111, 3113-7, 31211-4, 3122, 321, 3222, 323, and miscellaneous food; MB contains 21, 324, 3251-3, 3261, 3262, 3273, miscellaneous chemical products, miscellaneous non-metal products, and primary & fabricated metal products; LM contains 315, 316, 3352, 337, 339, and textile products; HE contains 3254, 333, 3341, 3361-6, 3369, electronic products, and electrical equipment & component manufacture.
equally-weighted average of the price indices of Education and Construction. The regional labor share in GDP, \( s_{Lt}^c \), is constructed by comparing the labor income to the corresponding regional GDP.

I use each of the 10 provinces as a specific "country", i.e. \( c = 1, \ldots, 10 \), and Canada as a whole as the comparison country "*". By implementing the homogeneity properties on productive factors (i.e. \( \sum_{n=1}^{3} s_{nt}^c = 1 \)) and prices (i.e. \( \sum_{m=1}^{9} \delta_{mn} = 0 \)), we can rewrite (11) and (12) as follows:

\[
RS_{nt}^c = \phi_{ln} (\ln \ell_t^c - \ln \ell_t^*) + \phi_{kn} (\ln k_t^c - \ln k_t^*) \\
+ \sum_{m=1}^{8} \delta_{mn} \left( \frac{\ln \lambda_{mt}^*}{(1 - \sigma_m)} - (\ln P_{jt}^c - \ln P_{jt}^*) \right) + \epsilon_{nt},
\]

\( n = 1, \ldots, 8. \)

and

\[
Adj. TFP_t^c = \ln G_t^c (P_t^c, V_t^c) - \ln G(P_t^*, V_t^*) \\
- \frac{1}{2} (s_{Lt}^c + s_{Lt}^*) (\ln \ell_t^c - \ln \ell_t^*) - \frac{1}{2} (k_t^c + k_t^*) (\ln k_t^c - \ln k_t^*) \\
- \frac{1}{2} (\ln T_t^c - \ln T_t^*) - \sum_{n=1}^{8} \frac{1}{2} (s_{nt}^c + s_{nt}^*) (\ln P_{jt}^c - \ln P_{jt}^*) \\
= \alpha^*_t + \alpha_0^c + \beta_k (\ln k_t^c - \ln k_t^*) + \beta_0 (\ln P_{jt}^c - \ln P_{jt}^*) \\
+ \sum_{n=1}^{8} \frac{1}{2} (s_{nt}^c + s_{nt}^*) \frac{\ln \lambda_{nt}^*}{(1 - \sigma_n)} + \zeta_t,
\]

where \( \ln(\ell_t) = \ln(L_t / T_t) \) and \( \ln(k_t) = \ln(K_t / T_t) \), \( \epsilon_{nt} \) and \( \zeta_t \) are the residuals of (13a) and (13b) respectively. If homogeneity in prices of non-traded sector is not violated, \( \beta_0 \) in (13b) should be equal to unity, whereas \( \beta_k \) in (11b) represents the
negative value of the share of Land in GDP.\(^5\) \(Rs_{c}^{e} = s_{c}^{e} - s_{c}^{*}\) is the residual sector share (\(n = 1, 2, 3, 4\)) or the negative residual import share (\(n = 5, 6, 7, 8\)). \(Adj.TFP^{e}_{c}\) is the residual TFP which is the residual GDP (the GDP difference between province \(c\) and Canada (*) net of the effects of difference in fixed product factors and the nontraded good price. Again, I emphasize that all the import shares are negative. In summary, I will regress the panel data for four relative sectoral share equations and four relative corresponding import share equations and a TFP equation (with both region and time fixed effects).

Furthermore, with the estimated parameters, the regional estimated productivity is given by (12):

\[
Est.TFP^{e}_{c} = Adj.TFP^{e}_{c} - \hat{\alpha}_{c} - \hat{\beta}_{k}(\ln k_{c}^{e} - \ln k_{c}^{*}) + \hat{\beta}_{p}(\ln P_{c}^{e} - \ln P_{c}^{*})
\hat{\alpha}_{c} + \sum_{n=1}^{8} \frac{1}{2}(s_{c}^{e} + s_{c}^{*}) \frac{\ln \lambda_{c}^{*}}{1 - \sigma_{n}} + \hat{\varepsilon}_{c}
\]

(14)

Due to the cross equation restrictions on \(1/(1-\sigma_{n})\) and \(\delta_{mn}\), and the multiplicative nature of these parameters, I use nonlinear system estimation for the eight share equations (13a) and one TFP equation (13b). The optimal estimates for these parameters are derived by minimizing the variance-covariance matrix of the residuals in the full system of the regression equations.

\(^5\) In fact, from (18) and (20), \(\beta_{k}\) should be \(\beta_{k}^{e} = 1 - \frac{1}{2}(s_{k}^{e} - s_{k}^{*}) - \frac{1}{2}(s_{k}^{*} - s_{k}^{*})\), which is a random parameter. For the sake of simplicity, we assume the relative labor share and the relative capital share do not change for different regions and across periods so that we treat \(\beta_{k}\) as a time- and region-invariant parameter.
4 Estimation Results

Before running the nonlinear regressions, there are two problems that need to be corrected. First, the error terms of the four sectoral share equations in (13a) may be correlated. For instance, the Rybczynski effect states that, ceteris paribus, an increase in a factor endowment will benefit the sectors (industries) using that factor intensively but hurt the others. The sectoral share and their corresponding import shares may also be correlated. An expansion in one import share may benefit (hurt) a sector due to the complementary (substitute) effects. I need to implement a seemingly unrelated regression (SUR) to have more efficient estimates if there is error correlation (Zellner, 1962).

Secondly, endogeneity might arise since there may be correlation between export variety and the regression errors. That is, in our adjusted TFP equation (21b), productivity can also affect the export variety as productivity growth may help some products gain competitive advantages over their international counterparts so that they can become new exported varieties. Ignoring this potential endogeneity problem will cause our estimates to be biased. To correct for such an endogeneity problem, we need to identify some instrumental variables (IVs) which are only correlated with export variety but not productivity. Furthermore, because the possible measurement error in non-traded goods price index, I also treat it endogenous. 6

In order to overcome these two problems, I conduct a three-stage Nonlinear Least Squares regression (N3SLS) which is a commonly used remedy for both SUR problem and endogeneity problem.

---

6 Import varieties are not treated endogeneous because of two reasons. Theoretically, based on the ideas of MC, a country will not invent a new variety that is identical to existing import varieties which implies perfect substitution is impossible. In practice, existing varieties also try to maintain their market status by improving quality, see table 1 for the Canadian example.
However, empirically IV estimates are the always biased (though they are consistent asymptotically), the biasness is determined by the following three factors (given the variance of error term and the IVs): the correlation of the (excluded) IVs and the error term, that of the (excluded) IVs and the endogenous variables, and the R-squared from the first stage regression (projection of the endogenous variables onto the IV space. Good (excluded) IVs should have small correlations with the error term that will converge to zero asymptotically and their correlations with the endogenous variables should converge to a non-trivial number (i.e. the excluded IVs should not be too "weak"). Furthermore, the variance of the endogenous variables should be explained by the IVs as much as possible (i.e. the R-squared should be big). The effectiveness of the excluded IVs (the non-trivial correlation with endogenous variables) and the overall fitness of IVs (R-squared) is shown in section 4.1, the overall validity of excluded IVs (uncorrelation with error terms) is shown in section 4.2 by an overidentifying test statistic.

4.1 The Selected Instrumental Variables

Many economists (e.g. Eaton and Kortum, 2002; Melitz, 2003) have suggested various IVs such as tariff, transport costs and distance as these trade costs can only affect productivity through export variety. However, since all Canadian provinces face the same tariffs against their exports, only IVs concerning transportation costs and distance will be useful here. In order to find enough IVs, I also consider market demand/supply and related indicators.

Besides the included exogenous variables of productive factors (that is, the log difference in capital/land ratio and labor/land ratio), time fixed effects, and the four import varieties, I find six additional IVs along four dimensions. They are weighted
distance and railway density for transportation; international resident ratio for demography; effective sales tax, lagged CPI for market sales and demand; the log difference in land for factor supply. All the data are available from CANSIM.

With respect to the distance IVs, since the exports destinations are all over the world, I have to use a weighted distance to approximate the real trade distance facing each province. The majority of Canadian goods are exported to North America, Western Europe, and East Asia. I assume all the exports are shipped to the following four destinations: New York (Eastern America), Los Angeles (Western America), Hong Kong (for East Asia) and Amsterdam (for Europe). Then I approximate the export distance by calculating the weighted distance between the capital city of each province to the four destinations with the distance weights of 40%, 40%, 10%, and 10% respectively. These weights roughly reflect the export shares of those regions represented by the four destinations according to table 3.2.

Since most Canadian cities (and population) are located near the Canada-US borders, the densities of railway is calculated by dividing total provincial mileage of railway by the corresponding Canada-US border length respectively. The international resident is defined in this paper as a temporary visitor or an immigrant who has been in Canada since 1948. Of course, an immigrant who have been offered a Canadian passport is legally no longer an international; however, he is still treated as an international in my paper since in general, he may still have links with the people of his home country so that

---

7 According to Statcan 2007, the biggest ten importing countries for Canadian goods are: U.S., U.K., Japan, China, Mexico, Germany, Korea (South), Netherlands, France, Belgium.
8 There are three provinces, Newfoundland and Labrador, Prince Edward Island, and Nova Scotia, do not have land border with USA, then the corresponding border length is replaced by the length of their southern sea line.
it is easier for him to access his original country's market. The ratios of urban residents and international residents are obtained by comparing the population of them to the total provincial population respectively.

Finally, the effective sales tax rate is calculated as the ratio of the total tax revenues on product sales to their corresponding provincial GDP. In addition, all the IV values in OLS except effective sales tax are logarithm values. The effective sales tax in OLS is transformed to be the logarithm of one plus the initial value.

Table 3.3 shows the OLS of the four export varieties on all the included and excluded IVs. Most of IVs have significant effects on each export varieties. For example, trade distance negatively affects LM and HE while positively affects AF and MB. These results may be explained by the facts that Asia is the increasing sales market for AF and MB varieties after 1990 and more than half of such varieties are produced in inland provinces which have longer trade distance; on the other hand, industries in LM and HE experienced various vertical and horizontal integration with US thanks to FTA and NAFTA. Not surprisingly, railway density benefits all the export sectors because it can help to effectively reduce the transportation cost. Furthermore, theoretically international residents may affect international for they have the informational advantages on both their motherlands and the host countries (see Gould, 1994 and Rauch and Trindade, 1999). The results of OLS reveal that the international resident ratio plays a (significantly) negative role on AF and MB while positive in LM and HE. It may suggest that international residents (especially those from developing countries) are more likely to boost the exports of manufacturing sectors (LM and HE) since they are more

---

9 The OLS is slightly different from the first stage of N3SLS which regresses the derivatives of the unknown parameters on all the IVs.
technology-intensive sectors while hurt resource processing sectors (AF and MB) since varieties of these sectors are less technology-intensive and may be substituted by imports from developing countries (the residents' motherlands).

All the four R-squares are all above 0.96, which shows that the IV regression can preserve most of the variation (information) of the 4 export varieties. Overall, the six excluded IVs significantly affect the endogenous variables even after controlling the included IVs. These results show the overall fitness of all IVs in explaining the endogenous variables and the effectiveness of the exogenous IVs which, loosely speaking, help to reduce the biasness of the coefficient estimates for the endogenous variables.\(^{10}\)

4.2 The Three-Stage Nonlinear Least Squared System Estimation

After finding enough excluded IVs, I conduct N3SLS System Regressions to estimate the interesting coefficients. Table 3.4 presents the results of the nonlinear system of share equations (11a) with the TFP equation (11b). All the homogeneity properties on prices and endowments as well as the symmetric property on cross-price effects are implemented in the share equations, and the last column shows the estimated coefficients of the regional productivity equation.

The upper part of Table 3.4 reports \(\delta_{mn}\), which are the partial price effects on the share of traded sectors and corresponding import sectors in columns (1) to (8) due to

\(^{10}\) There are two points make this statement not so strict. First of all, in the first stage of N3SLS, it actually projects the derivatives of the unknown parameters onto the IV space (see last footnote). Secondly, the effectiveness of excluded IVs would better be shown by testing the "weak IV" hypothesis (see Staiger and Stock 1997, Stock and Yogo, 2003). However, I choose to use OLS for two reasons. Above all, the direct OLS of endogenous variables on all IVs is straightforward and the results should not be very different from the first stage of N3SLS. In addition, most of the estimates of the excluded IVs are significant in explaining the endogenous variables which make us confidently ignore the "weak IV" problem.
export and import variety changes in the rows. Particularly, the diagonal of the upper-left shows the own-price effects. Theoretically, the own-price effects should be positive for exports to reflect the upward-sloping supply curves and should be negative for imports to reflect the downward-sloping demand curves. However, except for AF in exports and MB in imports, the rest of the own-price estimates are insignificant and even have wrong signs. The overall poor estimation of own-prices is mainly attributed to the inherent multilinearity problem between the export and import sectors (see table 3.3).

The lower part of table 3.4 of column (1) to (4) presents the Rybczynksi effects of endowments on the traded sector shares. We can observe that, in general, an increase in capital relative to land hurts the sectoral supplies (except MB) while a relative increase in labor has the opposite effect: it benefits the sectoral supplies (except MB). The lower part of column (5) to (8) shows that a relative increase in capital benefits the import demands; on the other hand, a relative increase in labor hurts the import demands. The results are surprising and interesting since theoretically, as a capital abundant country, Canada is supposed to import labor intensive goods and export capital intensive goods. However, the results suggest that Canadian traded output sectors except MB are mainly labor intensive while import sectors are mainly importing capital goods. Two reasons may account for this "puzzle". First of all, about 80% of the Canadian exports and 60% of imports occur with the US. Such deep trade dependence is at least partly owing to the horizontal and vertical integration with US traded sectors. Not surprisingly, it is a typical production pattern that the US branches main focus on R&D (capital intensive) while Canadian branches focus on intermediate production (relatively labor intensive). Secondly, Canadian nontraded sector (e.g. financial service, real estate, insurance etc.) is
overall capital intensive. Nevertheless, it is an interesting phenomenon and further investigations and comparative studies with the other similar countries (e.g. Australia) are worthwhile.

The upper part of column (8) presents the NSUR estimates of $1/(1-\sigma_n)$ for each industry in the row. By assumption, the elasticities ($\sigma_n$) among outputs should be strictly negative while those among intermediate inputs (i.e. the imports) should be more than unity. In other words, we expect the estimates of $1/(1-\sigma_n)$ to be strictly between zero and one for export variety and negative for import variety. Furthermore, these estimates imply that the smaller (in absolute value) the $\sigma_n$ is, the less substitutive between varieties (as inputs or outputs) and the larger contribution in productivity growth a new variety will make. As shown in column (8), all the top four estimates (for export variety) are significant and fall in the range of zero to one. The ranking of industries according to their implied elasticities of substitution are: HE (-0.45), LM (-0.77), AF (-3.33), and MB (-5.10). The results show that the average substitution levels facing Canadian outputs are small in HE and LM, and modestly high in AF and MB. The results are quite intuitive: goods in AF and MB are in general homogenous and contain little technology, thus they are more easy-to-substitute than LM and HE. The lower four estimates (for import variety) are, however, not all negative, and the estimate for HE is insignificant. The elasticities of substitution are: MB (0.25), LM (1.27), AF (1.35), and HE (142.86). The elasticity of import variety in MB is 0.25 (violating the "above-unity assumption") and the elasticity of HE is 142.86 that seems too high to fit the reality. These odd estimates may suggest that a significant fraction of the imports in MB and HE may be used as final consumption goods rather than intermediate inputs, and they may eventually substitute.
for the domestic counterparts. (See Appendix) Nevertheless, the coefficient estimates are still useful since they can be treated as the net the effect of the new import variety on productivity.

One approach to assess the reasonableness of these elasticities is by comparing them with priors. Unfortunately, there is no comparable studies for Canada. Then the second best is to compare similar studies for US or a group of countries, for instance, FK (2008) for 34 countries' exports (to US) and BGW (2006) for 73 countries' imports. FK split all the exports into seven sectors whereas four in mine. The correspondence of FK's export sectors and mine as well as the estimated elasticities are shown in table 3.5. Compare with FK's elasticities, my estimates for HE and LM lie between FK's, but AF and MB are larger (that is, the contribution in productivity growth is smaller).

Considering FK's estimates contain a lot of developing countries such as India and Mexico whose exports are supposed to be more important in boosting productivity than the developed ones, my estimates for Canada still seem reasonable. As for import elasticities, BGW estimate the import elasticities for more than 200 industries (based on 3-digit HS industry categorization) of 73 countries. Unfortunately, the detailed elasticities for Canada are unavailable, they only provide a median elasticity of 5. Simply comparing this median import elasticity with my results is not meaningful due to the poorly estimated elasticities of MB and HE. However, BGW also estimate that the contribution of new import varieties on Canadian productivity is 0.057% annually during 1994~2003. The aggregate import contribution based on my estimates is can be compared to BGW's which will be shown in section 4.3.
The lower part of column (8) presents the effects of the capital-land ratio and non-traded goods prices on adjusted TFP. As predicted in the model, the coefficient on the capital-land ratio should be the negative value of the land share in GDP. That is, our estimate, -0.251, implies that the estimated share of land in Canadian GDP is about 25.1%. However, the estimated coefficient of non-traded goods price is significantly less than unity suggesting a violation of the homogeneity assumption on price which I do not impose in my estimation system.

Overall, this system introduces six excluded IVs for five endogenous variables. Thus, the system has nine overidentifying restrictions (one in each of the nine regressions). The overidentifying statistic is 6.9868 (with nine degrees of freedom) and its p-value is 0.5379, which implies that we can not reject the null hypothesis of no correlation between the excluded IVs with the error terms in the system. In other word, there is no reason to reject the overall validity of the selected IVs.

4.3 Productivity Decomposition

To highlight the effects of export and import variety on productivity in Canada, I conducted panel regressions of the estimated productivity on export variety

\[
\frac{1}{2} \left( s_{n1}^e + s_{n1}^i \right) \frac{\ln \lambda_{n1}^*}{(1 - \sigma_n)}
\]

using the estimated parameters obtained in last section. Figure 3.3 plots the scatter graph. Both variables are averaged over time so actually we plot a "between" regression. From this graph, it is evident that the provincial export variety explains the productivity difference in a significantly way.
Furthermore, I perform a post-regression decomposition of estimated productivity based on the results in table 3.4. Using (14), I compute the variance of estimated provincial TFP as:

\[
\text{var}(\text{Est.}TFP^c) = \text{var}(\alpha_0^c) + \text{var}(\text{variety.ex}) + \text{var}(\text{variety.im}) \\
+ 2 \text{cov}(\text{variety.ex}, \text{variety.im}) + 2 \text{cov}[\alpha_0^c, \text{variety.ex}] \\
+ 2 \text{cov}[\alpha_0^c, \text{variety.im}] + \text{var}(\epsilon_i^c).
\]  

(15)

where

\[
\text{variety.ex}_i = \sum_{n=1}^{N} \frac{1}{2} (s_{nt}^c + s_{nt}^*) \frac{\ln \lambda_n^*}{(1 - \sigma_n)}, \quad \text{variety.im}_i = \sum_{n=5}^{8} \frac{1}{2} (s_{nt}^c + s_{nt}^*) \frac{\ln \lambda_n^*}{(1 - \sigma_n)}.
\]

The first term on the right hand side is the variance of province fixed effects, the second and the third term are the variance of export variety and import variety respectively, the covariance of the export and import variety and their respective covariance with the province fixed effects are presented from the fourth to the sixth term. The last term is the error variance. By removing variance of the fixed effects and the regression error, the "variety-induced" provincial TFP is defined as:

\[
\text{Variety-induced } TFP_i^c = \sum_{n=1}^{N} \frac{1}{2} (s_{nt}^c + s_{nt}^*) \frac{\ln \lambda_n^*}{(1 - \sigma_n)} = \text{variety.ex}_i + \text{variety.im}_i.
\]  

(16)

In addition, the first order difference of (14) within a province across two years reveals the growth decomposition of provincial productivity into three terms, which is the growth of variety induced provincial TFP in export and import plus the change in regression errors:
Growth of $TFP^c_t = (\text{Variety-induced } TFP^c_t - \text{Variety-induced } TFP^c_{t-1}) + (\varepsilon_t^c - \varepsilon_{t-1}^c)$

$$= (\text{variety.ex}_t - \text{variety.ex}_{t-1}) + (\text{variety.im}_t - \text{variety.im}_{t-1}) + (\varepsilon_t^c - \varepsilon_{t-1}^c).$$ (17)

The variance in the growth rate of provincial TFP is therefore the sum of the variance of the growth rate of variety-induced provincial TFP (in export and import), and the variance of the difference in error terms, along with the covariance between them.

Table 3.6 shows the variance decomposition of country TFP in levels and growth rates. 85.37% of the cross-province differences in the TFP levels are explained by province fixed effects while trade variety-induced provincial TFP can account for about 7.06% of the provincial productivity levels. Particularly, the variance of export variety induced TFP can account for 10.41% of the provincial productivity levels and 1.57% by import variety but their accountability is reduced slightly by 0.48% if the joint effect of them (the covariance between them) is included. Furthermore, variety-induced TFP and province fixed effects are correlated, jointly with the province fixed effects, the contribution of export variety to the cross-province variation in TFP levels is reduced by 12.35% which means the total effect of export variety is completely absorbed by the province fixed effect; however, such joint effect of province fixed effect with import variety is increased by 7.91%. The second column of table 3.6 shows the growth decomposition of provincial productivity. About 17.31% of the within-province growth in TFP can be explained by the year-to-year growth in trade variety. Specifically, growth in export variety and import variety can respectively explain 9.92% and 6.95% of within-province TFP growth, and their joint effect accounts for 0.44%. FK find that the export variety can explain, on average of the 34 countries, 13% of within country productivity.
growth. Compared to 9.92% in my result, FK's is a little bit higher. Again, the difference is reasonable considering FK includes developing countries whose exports play a more important role in productivity growth. The reminder within-province growth is explained by the change in regression errors and the error correlation with the trade variety terms.

To further illustrate the effects of trade variety on Canadian productivity, according to (16) a 1% increase in the export variety of each sector n would increase provincial productivity by \( \frac{1}{2} (s_{n}^{*} + s_{n}') \) percent. Thus, at the sample mean, a 10% increase in trade varieties of all industries could lead to a 0.90% increase in Canadian (the average province) productivity, of which the export variety's contribution is 0.57% and the import variety is 0.33%. This effect reveals that trade variety plays an economically significant role in TFP growth.

Furthermore, since the annual growth rate in import varieties is about 2.2% (by author's calculation from table 3.1), the annual gain in Canadian productivity due to import variety growth is 0.0726, higher than BGW's estimation, 0.057%. The difference can be explained by two reasons. First of all, there is a TFP measurement difference between mine and BGW. My estimated TFP is the TFP of traded sectors while BGW's includes the nontraded sector. Secondly, the accuracy of variety measurement is different. Mine is based on 10-digit HS data (for imports) while BGW's is based on 6-digit HS data. BGW find that the productivity gain from import variety will be much higher if they use more detailed HS data. In a word, my estimation for the aggregate effect of the import variety on TFP seems justifiable.
5 Conclusions

Existing literature using macro-level data analyzes of the effects of trade variety on TPF variation by export or import separately and has been restricted under a cross-country circumstance. In this paper I have attempted to study the case for Canada by estimating the effects of both export and import variety on province productivity with multiple sectors.

Estimating the eight share equations (four sectoral shares and four corresponding import shares) simultaneously with the GDP equation (transformed to become relative province productivity) allows me to identify and estimate the elasticity of substitution between trade varieties in each sector, and then infer the contribution of export variety to province productivity. The resulting elasticity estimates of export variety (degree of competition) range from a low of -0.45 in HE sector, to a high of -5.10 in the MB sector. The ranking I have obtained seems quite intuitive: goods in AF and MB are in general easy-to-substitute, thus their elasticities of substitution are larger than LM and HE. The estimated elasticities of import variety seem not so consistent with assumption in section 1. The elasticity of import variety in MB is 0.25 (smaller than the "above unity assumption") and the elasticity of Heavy and Electronic Manufacturing is 142.86 which seems too high to fit the reality. These odd estimates may suggest that a significant fraction of the imports in MB and HE may be used as final consumption goods rather than intermediate inputs, and they may eventually substitute for the domestic counterparts. My estimates for export elasticities seem reasonable compared to those of FK's; furthermore, the aggregate productivity contribution of import varieties in this paper is also comparable to that of BGW.
Finally, based on the N3SLS estimation, I have also calculated the impact of trade variety differences across provinces on their respective productivities. I find that export variety and import variety respectively account for 10.41% and 1.57% of the variation in Canadian provincial productivity differences in level. By excluding the joint effects with the province fixed effects, the total trade variety related effects account for 7.06% of the provincial productivity differences in level. Furthermore, the export and import variety respectively account for 9.92% and 6.95% of within-province productivity growth, and if their joint effects of them are also included, their total effects can account for 17.31%. Evaluated at the sample mean, a 10% increase in all trade varieties leads to a 0.90% increase in Canadian productivity, in which the export variety's contribution is 0.57% and import variety's is 0.33%.

There are many worthwhile extensions to this work. For example, a comparative study with other developed and developing countries (all should be small open economies) such as Australia and South East Asian countries could help us study quantitatively the different roles played by export and import variety on TFP and economic growth. In addition, since a real exchange rate can be modeled as a ratio of exact price index, a cross-country study using the link of exact price index and variety can help us investigate the effects of relative variety change (between a pair of countries) on real exchange rate dynamics.
Appendix: Effect of Imports as Final Consumption Varieties

Suppose the aggregate imports for final consumption also follow the CES form as shown by eq (1) and the expenditure share of imports on intermediate inputs is \( \alpha (0 < \alpha < 1) \), then the comprehensive price index of imports is given by

\[
P = \frac{1}{\alpha (1-\alpha)^{1-\alpha}} P_I^{\alpha} P_F^{(1-\alpha)}
\]

where \( I \) and \( F \) are the sets of imports used for intermediate input and final consumption respectively;

\[
P_I = \left( \sum_{i=1} e_i(p_i)^{1-\sigma_i} \right)^{\frac{1}{1-\sigma_i}} \quad \text{and} \quad P_F = \left( \sum_{j=F} e_j(p_j)^{1/\sigma_j} \right)^{\frac{1}{1-\sigma_j}}
\]

Thus, if conditions for the special case (for deriving 2b) are held, the exact price ratio between region \( a \) and \( b \) shown by eq(2) is,

\[
\ln \frac{P_a}{P_b} = \left( \frac{1}{1-\sigma} \right) \ln(\lambda^b(I_i))
\]

\[
= \left( \frac{\alpha}{1-\sigma_i} \right) \ln(\lambda^b(I_{i,j})) + \left( \frac{1-\alpha}{1-\sigma_F} \right) \ln(\lambda^b(I_{F,j})) - C
\]

where \( I_{i,j} \) and \( I_{F,j} \) are the sets of imports used for intermediate input and final consumption by region \( a \) (which is "contained" in \( b \); \( C \) is a constant with \( C = \alpha^a (1-\alpha)^{(1-\alpha)} \); finally, though \( \sigma_i > 1 \) (for it is the elasticity of input), \( \sigma_F < 0 \) since by competition, the imports for final consumption may replace some of domestic output varieties which thus play a reverse role in output variety on productivity, i.e. the substitution effect decreases productivity by reducing domestic output varieties.

For the sake of simplicity, I assume \( \lambda^b(I_{i,j}) = \lambda^b(I_{F,j}) = \lambda^b(I_i) \), then

\[95\]
\[ \sigma = 1 - \left( \frac{\alpha}{1 - \sigma_l} + \frac{1 - \alpha}{1 - \sigma_F} \right)^{-1} \]

Therefore, \( \sigma \) is not consistent with \( \sigma_l \) for two reasons: first of all, not all imports are used as intermediate inputs, i.e. \( \alpha < 1 \); secondly, some imports may replace the domestic outputs, i.e. \( -\infty \ll \sigma_F < 0 \). Therefore, as an estimation of \( \sigma_l \):

\[
\sigma \text{ will be } \begin{cases} 
\text{equal to } \sigma_l \text{ if } \alpha = 1; \\
\text{overstated if } \frac{\sigma_l - 1}{\sigma_l - \sigma_F} \leq \alpha < 1; \\
\text{wrong (} \sigma < 1 \text{) if } \alpha < \frac{\sigma_l - 1}{\sigma_l - \sigma_F}. 
\end{cases}
\]
Reference List


Mechanism of productivity gain from variety growth:
Suppose the production function is given by (1), where $\sigma > 1$ for input or $\sigma < 0$ for output. Therefore, as shown on figure 3.1a, given the production function and prices an increase of input (output) varieties from V1 only to V1 and V2, the minimum cost given output decreases from C1 to C2 (as shown on figure 3.1b, the maximum revenue given input increases from R1 to R2).
Figure 3.3 Foreign Trade Openness of Canada: 1988-2006
Figure 3.4 Provincial Productivity versus average trade variety

cof=3.86234, se=1.79433, t=2.15
Table 3.1 Trade Performance in Value and Variety during 1988-2006

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Value</td>
<td>Variety</td>
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<td>Disappeared</td>
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<td>12837</td>
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<tr>
<td>New</td>
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<td>Growth due to intensive margin (100%)</td>
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</tr>
<tr>
<td>Growth due to extensive margin (100%)</td>
<td>21.04</td>
<td>--</td>
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</tbody>
</table>

Note: All values are in 1995 million Canadian Dollars unless otherwise indicated.
Table 3.2 Export/Import Value and Variety of Major Canadian Partner Countries: 1988 and 2006

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td></td>
<td>Value</td>
<td>Variety</td>
<td>Value</td>
<td>Variety</td>
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<tr>
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<td>(86.31)</td>
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<td>(0.36)</td>
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<td>(6.11)</td>
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<td>(20.05)</td>
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<td>(12.56)</td>
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<td>3739</td>
<td>(15.7)</td>
</tr>
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<td>2814</td>
<td>(12.02)</td>
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<td>(6.36)</td>
<td>3860</td>
<td>(16.49)</td>
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<td>(0.87)</td>
<td>1407</td>
<td>(6.01)</td>
</tr>
<tr>
<td>Total</td>
<td>121633</td>
<td>(87.80)</td>
<td>21701</td>
<td>(92.70)</td>
</tr>
</tbody>
</table>

Note: All values are in 1995 million Canadian Dollars. The figures in parenthesis are the corresponding shares with respect to the Canadian total. China includes Hong Kong, and Germany includes East Germany before 1990.
Table 3.3 Estimation Method: Ordinary Least Squares
Dependent Variables-Export Variety Index
Observation per equation: 190

<table>
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<tr>
<th>Independent Variables</th>
<th>(1) Agriculture &amp; Forestry</th>
<th>(2) Mining &amp; Basic Metals</th>
<th>(3) Light Manufacturing</th>
<th>(4) Heavy &amp; Electronic Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Sales Tax</td>
<td>0.1016</td>
<td>5.6866***</td>
<td>-6.8517***</td>
<td>0.2039</td>
</tr>
<tr>
<td></td>
<td>(0.8871)</td>
<td>(1.5300)</td>
<td>(2.3755)</td>
<td>(1.3043)</td>
</tr>
<tr>
<td>(lag) CPI</td>
<td>0.4618</td>
<td>-7.1790***</td>
<td>-1.0810</td>
<td>4.4652***</td>
</tr>
<tr>
<td></td>
<td>(1.0781)</td>
<td>(1.8594)</td>
<td>(2.8869)</td>
<td>(1.5851)</td>
</tr>
<tr>
<td>Capital/Land Ratio</td>
<td>-0.2562**</td>
<td>1.6168***</td>
<td>-2.5345***</td>
<td>-0.1802</td>
</tr>
<tr>
<td></td>
<td>(0.1200)</td>
<td>(0.2069)</td>
<td>(0.3213)</td>
<td>(0.1764)</td>
</tr>
<tr>
<td>Labor/Land Ratio</td>
<td>1.0280***</td>
<td>-1.5045***</td>
<td>4.8273***</td>
<td>1.5778***</td>
</tr>
<tr>
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<td>(0.1281)</td>
<td>(0.2209)</td>
<td>(0.3430)</td>
<td>(0.1884)</td>
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<tr>
<td>Difference in Land</td>
<td>1.1883***</td>
<td>0.0091</td>
<td>1.8203***</td>
<td>1.1431***</td>
</tr>
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<td>(0.0929)</td>
<td>(0.1603)</td>
<td>(0.2489)</td>
<td>(0.1366)</td>
</tr>
<tr>
<td>Agriculture &amp; Forestry</td>
<td>1.0300***</td>
<td>0.8082***</td>
<td>-1.6405***</td>
<td>-0.9881***</td>
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<td>(0.1028)</td>
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<td>(0.2752)</td>
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<tr>
<td>Mining &amp; Basic Metals</td>
<td>0.0191</td>
<td>0.9934***</td>
<td>0.4373*</td>
<td>0.0341</td>
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<tr>
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<td>(0.0978)</td>
<td>(0.1687)</td>
<td>(0.2620)</td>
<td>(0.1438)</td>
</tr>
<tr>
<td>Light Manufacturing</td>
<td>-0.2038***</td>
<td>0.0841</td>
<td>0.5793***</td>
<td>0.6027***</td>
</tr>
<tr>
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<td>(0.0627)</td>
<td>(0.1081)</td>
<td>(0.1678)</td>
<td>(0.0921)</td>
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<tr>
<td>Heavy &amp; Electronic Manufacturing</td>
<td>-0.4218***</td>
<td>-0.4647***</td>
<td>-0.1011</td>
<td>-0.4296***</td>
</tr>
<tr>
<td></td>
<td>(0.0725)</td>
<td>(0.1250)</td>
<td>(0.1941)</td>
<td>(0.1066)</td>
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<tr>
<td>International Residents Ratio</td>
<td>-3.0551***</td>
<td>-3.1578***</td>
<td>5.4625***</td>
<td>5.2730***</td>
</tr>
<tr>
<td></td>
<td>(0.4228)</td>
<td>(0.7292)</td>
<td>(1.1321)</td>
<td>(0.6216)</td>
</tr>
<tr>
<td>Trade Distance</td>
<td>6.7183***</td>
<td>7.3077***</td>
<td>-13.5105***</td>
<td>-11.7075***</td>
</tr>
<tr>
<td></td>
<td>(0.6479)</td>
<td>(1.1174)</td>
<td>(1.7348)</td>
<td>(0.9526)</td>
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<tr>
<td>Railway Density</td>
<td>0.0451***</td>
<td>0.0676***</td>
<td>0.0189**</td>
<td>0.0168***</td>
</tr>
<tr>
<td></td>
<td>(0.0034)</td>
<td>(0.0059)</td>
<td>(0.0091)</td>
<td>(0.0050)</td>
</tr>
<tr>
<td>Years</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.9799</td>
<td>0.9801</td>
<td>0.9698</td>
<td>0.9884</td>
</tr>
</tbody>
</table>

Note: *, **, and *** indicate significance at 90%, 95% and 99% confidence levels respectively, and White-robust standard errors are in parentheses.
Table 3.4 Estimation Method: Three Stage Non-linear Least Squares

Dependent Variables—Industry shares in Column (1) to (4), import shares of corresponding industries in column (5) to (8), and adjusted TFP in column (9)

Total system observations: 1710

Observation per equation: 190

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
<th>(9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AF</td>
<td>MB</td>
<td>LM</td>
<td>HE</td>
<td>AF</td>
<td>MB</td>
<td>LM</td>
<td>HE</td>
<td>ALL</td>
</tr>
<tr>
<td>Agriculture, Forestry</td>
<td>0.111***</td>
<td>-0.018</td>
<td>-0.023***</td>
<td>-0.053***</td>
<td>-0.006**</td>
<td>-0.004</td>
<td>0.003**</td>
<td>-0.046</td>
<td>0.231***</td>
</tr>
<tr>
<td>(0.030)</td>
<td>(0.0149)</td>
<td>(0.004)</td>
<td>(0.022)</td>
<td>(0.003)</td>
<td>(0.005)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.038)</td>
<td>(0.056)</td>
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<tr>
<td>Mining &amp; Basic Metals</td>
<td>-0.018</td>
<td>-0.033</td>
<td>0.020***</td>
<td>-0.017</td>
<td>0.001</td>
<td>0.001</td>
<td>-0.002</td>
<td>0.300***</td>
<td>0.164***</td>
</tr>
<tr>
<td>(0.0149)</td>
<td>(0.0241)</td>
<td>(0.005)</td>
<td>(0.019)</td>
<td>(0.004)</td>
<td>(0.007)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.060)</td>
<td>(0.028)</td>
</tr>
<tr>
<td>Light Manufacture</td>
<td>-0.023***</td>
<td>0.020***</td>
<td>0.000</td>
<td>0.018***</td>
<td>-0.001</td>
<td>-0.000</td>
<td>-0.001*</td>
<td>-0.062***</td>
<td>0.566***</td>
</tr>
<tr>
<td>(0.004)</td>
<td>(0.005)</td>
<td>(0.001)</td>
<td>(0.005)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.0003)</td>
<td>(0.011)</td>
<td>(0.099)</td>
<td>(0.099)</td>
</tr>
<tr>
<td>Heavy &amp; Electronic Manufacture</td>
<td>-0.053**</td>
<td>-0.017</td>
<td>0.018***</td>
<td>-1.257</td>
<td>-0.013***</td>
<td>-0.023***</td>
<td>-0.002*</td>
<td>1.278</td>
<td>0.692***</td>
</tr>
<tr>
<td>(0.022)</td>
<td>(0.019)</td>
<td>(0.005)</td>
<td>(3.187)</td>
<td>(0.004)</td>
<td>(0.006)</td>
<td>(0.001)</td>
<td>(3.189)</td>
<td>(0.070)</td>
<td>(0.070)</td>
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<tr>
<td>Import in A&amp;F</td>
<td>-0.006**</td>
<td>0.001</td>
<td>-0.001</td>
<td>-0.013***</td>
<td>0.007***</td>
<td>0.003</td>
<td>-0.000</td>
<td>0.027***</td>
<td>-2.787***</td>
</tr>
<tr>
<td>(0.003)</td>
<td>(0.004)</td>
<td>(0.001)</td>
<td>(0.004)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.000)</td>
<td>(0.008)</td>
<td>(0.604)</td>
<td>(0.604)</td>
</tr>
<tr>
<td>Import in MB</td>
<td>-0.004</td>
<td>0.001</td>
<td>-0.000</td>
<td>-0.023***</td>
<td>0.003</td>
<td>-0.031***</td>
<td>-0.007***</td>
<td>0.029**</td>
<td>1.329***</td>
</tr>
<tr>
<td>(0.005)</td>
<td>(0.007)</td>
<td>(0.001)</td>
<td>(0.006)</td>
<td>(0.002)</td>
<td>(0.007)</td>
<td>(0.001)</td>
<td>(0.012)</td>
<td>(0.139)</td>
<td>(0.139)</td>
</tr>
<tr>
<td>Import in LM</td>
<td>0.003**</td>
<td>-0.002</td>
<td>-0.001*</td>
<td>-0.002*</td>
<td>-0.000</td>
<td>-0.007***</td>
<td>-0.000</td>
<td>0.007***</td>
<td>-3.753***</td>
</tr>
<tr>
<td>(0.001)</td>
<td>(0.002)</td>
<td>(0.0003)</td>
<td>(0.001)</td>
<td>(0.000)</td>
<td>(0.001)</td>
<td>(0.000)</td>
<td>(0.003)</td>
<td>(0.897)</td>
<td>(0.897)</td>
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<tr>
<td>Import in H&amp;E</td>
<td>-0.046</td>
<td>0.300***</td>
<td>-0.062***</td>
<td>1.278</td>
<td>0.027***</td>
<td>0.029**</td>
<td>0.007***</td>
<td>-1.595</td>
<td>0.007</td>
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<tr>
<td>(0.038)</td>
<td>(0.060)</td>
<td>(0.011)</td>
<td>(3.189)</td>
<td>(0.008)</td>
<td>(0.012)</td>
<td>(0.003)</td>
<td>(3.192)</td>
<td>(0.017)</td>
<td>(0.017)</td>
</tr>
<tr>
<td>Capital-Land Ratio</td>
<td>-0.029***</td>
<td>0.228***</td>
<td>-0.015***</td>
<td>-0.023***</td>
<td>0.024***</td>
<td>0.060***</td>
<td>0.019***</td>
<td>0.063***</td>
<td>-0.251***</td>
</tr>
<tr>
<td>(0.006)</td>
<td>(0.015)</td>
<td>(0.002)</td>
<td>(0.006)</td>
<td>(0.003)</td>
<td>(0.011)</td>
<td>(0.003)</td>
<td>(0.015)</td>
<td>(0.036)</td>
<td>(0.036)</td>
</tr>
<tr>
<td>Labor-Land Ratio</td>
<td>0.022***</td>
<td>-0.232***</td>
<td>0.014***</td>
<td>0.029***</td>
<td>-0.026***</td>
<td>-0.075***</td>
<td>-0.020***</td>
<td>-0.097***</td>
<td>-0.251***</td>
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<tr>
<td>(0.006)</td>
<td>(0.0142)</td>
<td>(0.002)</td>
<td>(0.006)</td>
<td>(0.003)</td>
<td>(0.011)</td>
<td>(0.003)</td>
<td>(0.015)</td>
<td>(0.036)</td>
<td>(0.036)</td>
</tr>
<tr>
<td>Non-traded Goods Prices</td>
<td>0.422***</td>
<td>(0.109)</td>
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<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
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<tr>
<td>Year Fixed Effects</td>
<td>0.5616</td>
<td>0.6214</td>
<td>0.6032</td>
<td>0.5050</td>
<td>0.7083</td>
<td>0.5391</td>
<td>0.5403</td>
<td>0.6249</td>
<td>0.6635</td>
</tr>
</tbody>
</table>

Note: For columns (1) to (8), each log of relative export/import variety coefficient is the partial price effect of the industry in that row on the share of the industry in the column. These are the point estimates of . For column (9), each log of the relative export/import variety coefficient is the point estimate of 1/(1 - 2) of the industry in that row.

*, **, and *** indicate significance at 90%, 95% and 99% confidence levels respectively, and White-robust standard errors are in parentheses.
Table 3.5 The Correspondence of FK’s Export Sectors to Mine

<table>
<thead>
<tr>
<th>FK</th>
<th>This Paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture (-2.086)</td>
<td>Agriculture and Forestry (-1.35)</td>
</tr>
<tr>
<td>Woods &amp; Paper (-0.669)</td>
<td>Mining &amp; Basic metals (-5.10)</td>
</tr>
<tr>
<td>Mining &amp; Basic metals (-0.637)</td>
<td>Light Manufacturing (-3.33)</td>
</tr>
<tr>
<td>Textile &amp; Garments (-0.698)</td>
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</tr>
<tr>
<td>Petroleum &amp; Plastics (-1.976)</td>
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</tr>
<tr>
<td>Machinery &amp; Transport (-0.575)</td>
<td>Heavy &amp; Electronic Manufacturing (-0.45)</td>
</tr>
<tr>
<td>Electronics (-0.024)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Level Decomposition</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td></td>
<td>(in % of TFP)</td>
</tr>
<tr>
<td>Variance of Estimated Province TFP</td>
<td>0.1653 (100)</td>
</tr>
<tr>
<td>Variance of Province Fixed Effects</td>
<td>0.1411 (85.37%)</td>
</tr>
<tr>
<td>Variance of Export Variety Induced TFP</td>
<td>0.0172 (10.41%)</td>
</tr>
<tr>
<td>Variance of Import Variety Induced TFP</td>
<td>0.0026 (1.57%)</td>
</tr>
<tr>
<td>2*Covariance between Export Variety and Imports Induced TFP</td>
<td>-0.0008 (-0.48%)</td>
</tr>
<tr>
<td>2*Covariance between Province Fixed Effects and Export Variety Induced TFP</td>
<td>-0.0204 (-12.35%)</td>
</tr>
<tr>
<td>2*Covariance between Province Fixed Effects and Import Variety Induced TFP</td>
<td>0.0131 (7.91%)</td>
</tr>
<tr>
<td>Total Trade Variety Related Effects</td>
<td>0.0117 (7.06%)</td>
</tr>
</tbody>
</table>

Source: Author’s calculation based on regression results of Table 3.4.