ESSAYS ON IMMIGRATION, INNOVATION, AND TRADE

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ABSTRACT

This thesis comprises three essays on immigration, innovation, and trade. The first essay utilizes an enhanced gravity model to estimate the effect of lagged immigration waves on Canadian imports and exports, by province. Empirically, this model was tested using Canadian data on import and export flows to the top 40 countries of origin for immigrants to Canada based upon the composition of the most recent wave of immigrants. The results are consistent with previous studies, where immigrants increased both import and export trade flows. By adding the provincial immigrant wave variable, it was also found that new immigrants affect imports almost immediately, whereas for exports, the immigrant effect is not significant for at least 5 years and may take as long as 20 years to reach full impact.

The second essay utilizes an enhanced gravity model to estimate the effect of innovative capability on Canadian provincial exports to Canada's top 60 importing countries. Empirically, this model was tested using Canadian data on export flows to Canada's top 60 importing countries. The results are supportive of a province's innovative capability leading to increased exports, where innovative capacity is measured by international patents, scientific journal articles, and R&D expenditures. For example, in terms of innovative capacity as measured by international (U.S.) patents, provinces with higher levels of international patents had higher levels of total exports, where this effect was greater for exports to developing versus developed countries. Furthermore, provincial R&D expenditures as well as the number of provincial scientific publications (in addition to provincial international patents) were found to be significant drivers in increasing the amount of provincial *hi-tech* exports to developed countries.

The third essay utilizes an augmented national ideas production function to examine skilled immigrants' impact on Canadian innovation at the provincial level. Empirically, this model was tested using Canadian data by province on innovation flow over an 11 year time period, where innovation flow is defined in terms of international (U.S.) patents. It was found that skilled immigrants, who are proficient in either English or French, have a significant and positive impact on innovation flow in their home province. Further, in examining skilled immigrants by source region, it was found that skilled immigrants from developed countries have the greatest impact on their home province's innovation flow. This is true of North American/European skilled immigrants for all skill-level categories including language proficiency, education, and immigrant class. For immigrants from developing countries, only highly educated Eastern Europeans and Low Income Asians classified as "Independent Workers" are both significant and positively related to their home province's innovation flow.

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INTRODUCTION

This thesis consists of three empirical essays on immigration, innovation, and trade. I chose to focus on exports and trade as proxies for international competitiveness. However, I want to note upfront that neither immigration nor innovation directly affects trade. Instead, any impacts on trade reflect an improvement in the efficient allocation of factors of production (such as immigrants, skilled workers, etc.). For instance, immigrants may induce firms to increase efficiency via lowered transaction costs due to closer connections to their home countries. Additionally, more innovation may enhance skilled workers, changing the mix of capital to skilled labor, which could provide efficiency gains. Thus, identifying an impact on trade also identifies an improvement on efficiency, which implies increased international competitiveness.

The first essay in this series of papers linking immigration, innovation, and trade, "Canada's Immigration Policy: Is There a Link between Immigration and Trade?" examines the link between immigration waves and Canada's trade flows by province. In this essay, two main hypotheses are tested regarding the provincial trade effect of immigration. First, immigrants increase the level of trade. Second, because of transactions costs, immigrants' effect on imports is more rapid than on exports. Other propositions include i) geographical distance between new and old countries will negatively impact trade; ii) common language in new and old countries will positively impact trade; and iii) the existence of a Canadian trade office in immigrants' home countries will positively impact trade. It is proposed that immigrants cause increased trade with their home countries due to increased demand for imports as a result of preferences for their home countries' goods and increased demand for imports and exports due to their existing business connections with their home country, which lowers transactions costs of bi-lateral trade.

The framework for the model used in this essay is similar to the augmented gravity models of Head and Ries (1998), Wagner *et al.* (2002) and Gould (1994) that incorporate immigrants as determinants of trade. However, while my study also considers immigrants' impact on trade between immigrants' home and source regions, it differs from previous studies in that it additionally examines the *timing* of immigrants' impact on *provincial-level* trade (versus national or regional-level trade) as well as the associated policy implications.

The results of this essay should have consequences for provincial immigration policy in that individual Canadian provinces stand to benefit from the gains of trade resulting from increased immigration to their province. The addition of lagged immigration waves to the standard gravity equation helps to define the length of time that is necessary for immigrant groups to have arrived in a province before their presence actually impacts trade flows between their new province and home country. Thus, the results should aid provinces in their formulation of immigration policies to enhance trade.

The second essay in this series of papers linking immigration, innovation, and trade, "Canada's Innovation Strategy: Is there a Link between Innovation and International Competitiveness?" examines how technology and innovation may result in increased trade through comparative advantage (Ricardian model) and/or through a higher stock of human capital/knowledge (Heckscher-Ohlin model). The hypothesis that is being tested is that enhanced levels of technology and innovation lead to an increase in a country's competitiveness via greater trade, where it is hypothesized that (1) a province's infrastructure will help to facilitate increased exports and (2) a province's innovative capability will lead to increased exports.

The methodology that is used to examine these questions is an augmented gravity model similar to Martínez-Zarzoso and Márquez-Ramos (2005) that incorporates measures of technology and innovation as determinants of trade. However, this essay differs from previous research in several ways. First, it specifically examines the impact of both hard and soft infrastructure as well as innovative capability on Canadian exports by province. Previous studies have examined these impacts on inter-country trade, but not at the province-country level. Additionally, this essay's use of both U.S. (international) patents and exporting country (in this case Canadian) patents as proxies for innovative capability is novel in that typically only U.S. patents are employed in this fashion. Both types of patents are included in order to differentiate between the impacts of Canadian and U.S. patents on province-to-country exports. Finally, in contrast to Martínez-Zarzoso and Márquez-Ramos (2005), which examines infrastructure and innovations' effects on exports using technology indices to represent a country's specific innovative capability, my study includes U.S. and Canadian patents, research and development expenditures, the number of scientific publications, as well as the number of scientific tertiary graduates as proxies for innovative capability. Therefore, specific innovative factors that lead to increased exports can be identified, thereby distinguishing this paper from Martínez-Zarzoso and Márquez-Ramos, who demonstrate that increased innovation as defined by a broad-based "technology index" leads to increased exports, but do not indicate the particular innovative factors that are driving this increase in exports.

The results of this essay should aid policymakers in evaluating the effectiveness of Canada's Innovation Strategy (February 2002), where a primary intent of this strategy is to enhance Canada's innovation performance vis-à-vis other countries so that Canada can better compete in an increasingly competitive global economy. Therefore, an empirical investigation examining the links between innovation and trade should help to determine whether or not increasing levels of innovation results in greater international competitiveness in terms of increasing export levels.

The third essay in this series of papers linking immigration, innovation, and trade, "Increasing Canada's International Competitiveness: Is there a Link between Skilled Immigrants and Innovation*?"* examines how skilled immigrants, through increased human-capital, increase technology and innovation. To date, the immigrant-innovation link has not been highly studied in the economic literature. As noted by Gould (1994), "One particularly relevant issue is whether immigrant links lead to an increase in the worldwide transfer of technology. This question is especially relevant in light of the recent work in endogenous growth and the international diffusion of knowledge."

Thus, this essay studies the abovementioned link between skilled-workers (explicitly skilled immigrants) and innovation by examining skilled immigrants' impact on Canadian innovation at the provincial level. The methodology used to conduct this study follows Chellaraj *et al.* (2005), where the authors utilize a modified national ideas production function based upon Romer (1990) that is commonly used in innovation studies (Stern *et al.* 2000; Porter and Stern 2000).

Using this novel approach of employing a model of idea generation augmented by skilled immigrants as an input into the national ideas production function, five main hypotheses are tested regarding the determinants of innovative output. The first three of these follow from the national ideas production function, where the quantity of human capital devoted to the ideas-producing sector as well as the stock of knowledge or ideas already in existence that are available to the idea-workers are expected to increase the rate of new ideas produced. These three hypotheses are: (1) Greater provincial stocks of innovation will lead to greater provincial innovation flows; (2) Increased numbers of provincial R&D researchers will lead to greater provincial innovation flows; and (3) Increased levels of provincial R&D expenditures will lead to greater provincial innovation flows.

The final two hypotheses follow from the idea that the productivity of skilled immigrants, like the productivity of skilled domestic workers, is augmented by the stock of knowledge in such a way as to create knowledge spillovers and thus increase the rate of new ideas produced. These two hypotheses are: (4) Greater numbers of skilled immigrants by province will increase that province's innovation flow; and (5) Skilled immigrants from source countries that are similar to Canada will increase innovation flow more than immigrants from dissimilar countries. This last hypothesis is based upon the notion that it is easier for skilled immigrants from countries that are more like Canada (i.e. developed/European) to integrate and work with the pre-existing skilled Canadian labor force.

This study is (to my knowledge) the first to examine the contribution of skilled immigrants to Canadian innovation using an augmented national ideas production function approach. A link between skilled immigrants and innovation would demonstrate that skilled immigrants are a means of augmenting the existing Canadian labor force to achieve innovation and increased productivity. Another novel feature of this study is that it examines these impacts at the regional level (i.e., by province). This enables one to draw conclusions at the provincial level, which is especially important since immigration policy continues to devolve to the provinces.

All three of the aforementioned essays are connected through their investigation of the links between immigration, innovation, and trade. For example, the first essay takes up the linkages between immigration and trade; the third essay examines the linkages between immigration and innovation; and the second essay completes the analysis by investigating the linkages between innovation and trade. In addition, all three essays are related in that they examine these linkages at the provincial level for a small open economy (Canada), where policy implications can thus be drawn at the sub-national level. Finally, these three associated essays illustrate how separate policies such as immigration policy, innovation policy/strategy, and trade policy should be integrated given that choices made for one policy will have spillover effects on the other related policies.

CHAPTER 1

ESSAY 1: CANADA'S IMMIGRATION POLICY: IS THERE A LINK BETWEEN IMMIGRATION AND TRADE?

1.1 INTRODUCTION

Immigration policy has taken on increased importance in Canada in the past five years for a number of economic reasons. First, with the need for more skilled labor in Canada, provinces are placing greater importance on immigration policy (Hirsch 2006). Second, provinces are promoting increased trade with countries from which immigrants originate. As a result, provinces are taking a larger role in the formulation of their own immigration policies, aimed largely at increasing the flow of immigrants to their province.

The main vehicles for increased provincial participation in immigration policy are the PNP (Provincial Nominee Program) and federal-provincial agreements on immigration. The PNP, which allows provinces through an agreement with the government of Canada to play a more direct role in selecting immigrants who wish to settle in that province, began in the late 1990s and now includes all provinces except Quebec.[1] Quebec, although not part of the PNP, has the authority to set its own immigration policy with a few exceptions through the Canada-Quebec Accord (Citizenship and Immigration Canada 1991).

Although the PNP has grown five-fold in the past five years, it is disproportionately used in smaller provinces that may have more difficulty attracting new immigrants than larger provinces. For example, in 2005, 62% of all Prince Edward Island immigrants came through the PNP program. Other provinces with a relatively high

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[1] As part of the recently signed Canada-Ontario Immigration Agreement (November 2005), Ontario has the authority to develop its own pilot PNP, which began May 24, 2007.

percentage of PNP nominees to total immigrants in 2005 include: Manitoba at 57%, New Brunswick at 40%, Saskatchewan at 22%, and both Nova Scotia and Newfoundland at 17% (Government of Manitoba 2005). Thus, the PNP provides smaller provinces with a greater role in provincial immigration policy than it does larger provinces. However, various federal-provincial agreements such as the Agreement for Canada-British Columbia Co-operation on Immigration (Citizenship and Immigration Canada 2004a), the Canada-Ontario Immigration Agreement (Citizenship and Immigration Canada 2005), and the Canada-Quebec Accord (Citizenship and Immigration Canada 1991) provide larger provinces with the ability to help set provincial immigration policies. For instance, both British Columbia and Ontario, through partnerships with the government of Canada, assist in the development and implementation of policies and programs that impact immigration in their respective provinces.

Thus, there is room for provincial policymakers to influence provincial international trade through provincial immigration policies such as the PNP and/or federal-provincial agreements on immigration. Some provinces are already making this connection. For instance, there are a number of provincial nominees that have proposed value added import/export businesses as part of the Provincial Nominee-Business (PN-B) component of the Manitoba PNP, which contributes to trade between Manitoba and immigrants' home countries.[2] A similar program for business immigrants is underway in British Columbia.

To date, there has been little economic analysis of how immigration affects provincial economies in terms of trade with the exception of Wagner, Head, and Ries

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[2] This information was provided by Mary Backhouse of Manitoba Labour and Immigration in a phone conversation on April 10, 2007.

(2002). However, while this study also considers how immigration impacts exports and imports at the provincial level, it differs from previous research in that it also examines the timing of immigrants' impact on trade as well as the associated policy implications.

When new immigrants arrive, they bring with them an array of social, business, and political contacts from their home country, as well as preferences for consumer products. This set of contacts and preferences is often revealed in the linkages the immigrants make with their home country after arriving. Thus, while immigrants will enter the labor force and contribute to economic prosperity, they will also affect the trade flows between their new and old countries. This relationship has been found in previous studies such as Rauch (2001) and Rauch and Trindade (2002).

In this paper, two main hypotheses are tested regarding the provincial trade effect of immigration. First, immigrants increase the level of trade. Second, because of transactions costs, immigrants' effect on imports is more rapid than on exports. Other propositions include i) geographical distance between new and old countries will negatively impact trade; ii) common language in new and old countries will positively impact trade; and iii) the existence of a Canadian trade office in immigrants' home countries will positively impact trade.

This paper utilizes an enhanced gravity model to determine the effects of lagged waves of immigration on Canadian import and export flows (2001-2005 average) to the top 40 countries of origin for immigrants to Canada based upon the composition of the most recent wave of immigrants (1996-May 15, 2001). A wave of immigrants is defined by the number of immigrants from the same 40 countries[3] who immigrated to Canada

[3] The 40 countries chosen as the baseline were the top 40 countries in terms of the number of immigrants coming to Canada from the most recent immigrant wave (1996 through May 15, 2001).

during a given time period and were living in a particular province in 2001. The sum of all the immigrant waves represents the total number of immigrants (or the stock of immigrants) who were residing in a given province in 2001 and had immigrated to Canada during various time periods (waves). Immigration waves are included to determine whether or not there is a time lag between when a group of immigrants arrive and when this same group impacts trade. It is expected that there will be a greater lag between the time when a wave of immigrants arrive in Canada and when this wave affects exports versus imports vis-à-vis their home countries. It is hypothesized that the discrepancy in time lags is due to the greater ease of importing compared to exporting.

The inclusion of lagged provincial immigration waves differentiates this paper from both Wagner *et al.* (2002) and Head and Ries (1998), which considered the population of immigrants from country i (an immigrant's home country) residing in province/region j or country j (Canada). Gould (1994) considered the length of stay of immigrants in the U.S. by including the average stay of the immigrant stock as well as its squared value (to identify potential nonlinearities). In Gould's study, both immigrant stay and squared immigrant stay variables indicated that immigrant-link effects increase at a decreasing rate over time for import flows and that exports increase only after several years. More importantly, Gould found that overall, the length-of-stay effects were small and of low statistical significance. This study adds to the previous literature by including lagged Canadian provincial immigration wave data to determine whether or not, as hypothesized, immigration is positively related to imports from, and exports to immigrants' home countries.

This paper is similar to Wagner *et al.*'s study in that it uses sub-national level data instead of country level data for Canada. However, this paper's dataset includes all 10 provinces as opposed to Wagner *et al.*, which employed 3 provinces and 2 regions. The use of provincial-level data enables one to examine the effects of GDP, distance, common language, trade promotion activities, and immigration *waves* on provincial trade flows to countries outside of Canada. Therefore, I can examine trade flows at the provincial level versus the national or regional level, which will have policy implications for how each province can benefit from current and future provincial immigrants' trade with their home countries.

This study's findings will help to inform provincial immigration policymakers in that individual Canadian provinces stand to benefit from the gains of trade resulting from increased immigration to their province. The addition of lagged immigration waves to the standard gravity equation helps to define the length of time that is necessary for immigrant groups to have arrived in a province before their presence actually impacts trade flows between their new province and home country.

In what follows, section 1.2 reviews gravity models and the role of immigration. The next section describes the theoretical framework followed by section 1.4's description of the data. Section 1.5 presents the empirical findings followed by a concluding section.

1.2 GRAVITY MODELS AND IMMIGRATION

There have been a number of past trade studies that specifically examine immigration as an explanatory factor for trade flows. A seminal study in this area was conducted by Head and Ries (1998), which used Canadian trade data with 136 partners from 1980-1992. Their hypothesis that immigrants may expand trade with their country of origin was tested using a gravity model. They found that a 10 percent increase in immigrants yielded a 1 percent increase in exports and a 3 percent increase in imports.

Another related Canadian study, which used regional level data for 3 provinces (British Columbia, Quebec, and Ontario) and 2 regions (the Prairies and Atlantic Canada) is Wagner, Head and Ries (2002). Wagner *et al.*'s dataset included 160 foreign countries from 1992-1995, where they found similar results to Head and Ries (1998) with respect to immigrants' impact on both exports and imports. For example, depending on their specification, Wagner *et al.* (2002, 518) found that a 10 percent increase in immigrants increases exports by 0.81-1.56 percent and imports by 2.51-4.13 percent. A further study using U.S. data is Gould (1994), which employed a gravity model with a sample of 47 trading partners (plus the U.S.) for 1970-1986. He found that trade is positively influenced by immigration, with exports more strongly affected than imports.

Akin to Head and Ries (1998), Wagner *et al.* (2002), and Gould (1994), an augmented gravity equation is used to estimate immigrants' impact on bilateral trade between their countries of origin and destination province. The basic gravity equation or model relates bilateral trade flows to GDP, distance, and other factors that affect trade barriers and is originally associated with the work of Tinbergen (1962) and Pöyhönen (1963). The gravity model takes its name from the fact that it models the flows of bilateral trade analogously with the law of gravity in physics, where trade as measured in exports from country i to country j is directly related to a product of their national incomes and inversely related to the distance between them. Other variables often included in a gravity model are remoteness measures, common language, and membership in an economic or trade union.

As noted in the Introduction, the theory behind immigrants increasing trade with their home countries is based upon both a network effect (which leads to both increases in imports and exports) as well as a taste effect (which leads to increases in imports only). These effects are measured by estimating separate equations for imports and exports, where it is presumed that immigrants affect import businesses (due to both network and taste effects) more than export businesses (which are only impacted by network effects). It is hypothesized that immigrants' networks can be used to transmit information about current opportunities for profitable international trade (Rauch 2001).[4] Thus, immigrants increasing trade via a network effect, lower informal trade barriers. Informal trade barriers may result from inadequate information about international trading opportunities (Rauch and Trindade 2002), where these barriers may help to explain the home bias found in international trade by McCallum (1995), Helliwell (1998) and others.

This aforementioned home consumption bias, which translates into a preference by consumers for products produced in their own country compared to otherwise identical imports, illustrates that national borders have a greater effect on trade than would normally be predicted by a traditional gravity model. This effect dates back to Armington (1969), who notes that consumers display a bias toward domestically produced goods. Home consumption bias is often used as an explanation as to why countries trade less than what would be suggested by the Heckserh-Ohlin-Vanek (HOV) theorem, which predicts that countries will export products that are made from factors in great supply (Trefler 1995). Thus, it is posited that immigrants, via a network effect,

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[4] The aforementioned network effect was found to be stronger for differentiated products versus homogenous products in a study of Chinese immigrant networks (Rauch and Trindade 2002). This suggests that immigrant network information is more important for differentiated products vis-à-vis homogenous products.

lower informal trade barriers, which helps mitigate home consumption bias and will thus result in increased levels of trade. Consequently, immigrants, due to home bias or preferences for their home countries' goods, will impact imports more than exports. This helps to offset native Canadians' home bias for their own countries' goods, which would in the absence of immigrants, imply lower levels of imports.

The model described below builds upon the work of the aforementioned studies to include a provincial immigration wave effect on trade. The augmented gravity model considers lagged immigration waves by province to accommodate a potential time lag in immigrants' impact on trade. Thus, this modified model should predict both the actual impacts of immigration on trade as well as the timing of these impacts by province. This relates back to the main hypotheses of this paper: 1) immigrants will increase trade and 2) immigrants' effect on imports is more rapid than on exports.

1.3 THE MODEL

The framework for the model used in this paper is similar to the Anderson and Van Wincoop (2003) gravity model. A point of departure from the Anderson and Van Wincoop model is that this paper explores trade flows between Canada and the top 40 immigrant countries of origin for immigrants to Canada based upon the composition of the most recent wave of immigrants. Since one of the main hypotheses is to determine whether or not immigrants to Canadian provinces affect trade, a vector of variables is included to capture arrival of immigrants in various waves (pre-1961, 1961-1970, 1971-1980, 1981-1990, 1991-1995, and 1996-2001).[5]

[5]This paper focuses on the impact of immigration on trade. However, there is no evidence that immigration precedes trade creation since the relationship between trade and immigration is a simultaneous process.

GDP is included in this model as a measure of the size of the economy. Dummy variables for English and French as well as interaction variables for English*Quebec and French*Quebec are also included to determine the influence of a common language between home country and province. For example, if one of the primary or secondary languages spoken in a country is English, the English dummy variable takes on a value of 1, and 0 otherwise (same holds true for French). Finally, a dummy variable for whether or not a Canadian trade office is present in a country is included. The full model can be seen in equation 1 depicted below:

(1) $TRADE_{pc} = a + bGDP_p + cGDP_c + dDIST_{pc} + eWAVES_{cp} + fLANG_c + gTRADEOFF_c + e_{cp},$

where $TRADE_{pc}$ is the logarithm of exports of goods from province p to country c or the logarithm of imports of goods into province p that were produced in country c; GDP_p and GDP_c are the logarithms of gross domestic product by province and trading country, respectively; $DIST_{pc}$ is the logarithm of the distance from the capital of province p to the capital of country c; $WAVES_{cp}$ are the logarithms of lagged provincial immigration waves from country c to province p; $LANG_c$ is a vector of dummy variables that indicate whether one of the primary or secondary languages spoken in a country is English or French and also includes interactions of the aforementioned English and French dummy variables with a Quebec dummy; $TRADEOFF_c$ is a dummy variable that indicates whether or not Canada has a trade office in a country; and e_{cp} is the error term. Other models include provincial and country dummy variables to capture provincial and country fixed effects.

Thus, I acknowledge the potential of this reverse-causality problem, which is a perennial issue in immigration-trade studies.

The above model, which includes TRADE as a dependent variable and GDP and DIST as independent variables, is a standard gravity model that is utilized in many trade studies to forecast import and export flows. This model adds several new variables to the standard gravity model, WAVES, LANG, and TRADEOFF, to determine their impact on TRADE.

WAVES is included to allow for a lagged effect on trade. For example, a wave of recent immigrants may affect trade flows differently than a wave of more established immigrants. The rationale behind the disparity in effect based on immigrant length of stay is that it takes time for migrants to establish themselves in their new locale and make the contacts that would enable trade. Immigrants may need time to establish business connections with their home countries for exports just as they may need time to establish themselves in their new country to impact imports. Relating back to the second main hypothesis that immigrants' effect on imports is more rapid than on exports, it is presumed that exports take a longer time to establish than imports because of the greater complexity of setting up an export business versus simply importing goods from a foreign country. Another explanatory factor contained in the immigrant wave variable in addition to the aforementioned years-since-migration effect is a cohort effect. Unfortunately, these two effects cannot be easily disentangled. Thus, care should be taken as to the interpretation of the immigrant wave results, since the timing of an immigrant wave and its cohort characteristics are not readily discernible.

The LANG variable is included to measure if there is an affect on trade of similarities in language between an immigrant's home country and their new country since it is hypothesized that common language in new and old countries will positively impact trade. Thus, dummy variables for English and French language as the primary or secondary language spoken in the home country are included as well as the interaction of these language variables with a Quebec dummy, since Quebecers are primarily French speakers in contrast to the rest of Canadians, who predominantly speak English. Finally, TRADEOFF is included to capture the effect of trade promotion activities undertaken by the Canadian government, with the belief that these activities would lead to increased trade between immigrants' home and new country.

The inclusion of country and provincial fixed effects will help alleviate the selectivity issue of immigrants potentially choosing provinces that provide better economic opportunities, where enhanced economic opportunity may lead to increased trade and thus a spurious correlation between immigrant flows and provincial trade. The fixed effects models should mitigate the selectivity bias since country dummies reflect the average skill level in each country and provincial dummies reflect the average economic opportunity in each province in the cross-sectional model. For example, if there is a Pakistan skill-level effect, that should be captured in the Pakistan dummy variable and if there is a Saskatchewan economic effect that should be captured in the Saskatchewan dummy variable.[6]

1.4 DATA

The trade data are from Statistics Canada (2001-2005) and are for an average of exports of goods in millions of Canadian dollars for 2001-2005 from each of the 10 Canadian

[6] To further address this concern, I estimated auxiliary regressions which contained education variables for 2001 secondary and tertiary gross enrolment rates (World Bank 2001) to account for skill selectivity by country in models without country fixed effects. I found these education variables to be insignificant with the main results unchanged.

provinces to the 40 aforementioned countries and an average of imports of goods in Canadian dollars for 2001-2005 into the 10 provinces from the 40 countries.

This sample of 40 countries was chosen to assign disproportionate weight to the mix of immigrants who are currently coming to Canada versus those who came say 30 years ago. This reflects the fact that provinces are less likely to attract immigrants from Western Europe and are more likely to attract immigrants from Asia. My sample represents just over 86% of immigrants residing in Canada in 2001 who immigrated to Canada during the 1996-2001 time period. Given the changing mix of countries-of-origin over time, this sample represents approximately 73% of the stock of all immigrants in Canada in 2001. However, the most recent wave of immigrants (1996-2001) represents over 17% of the stock of all immigrants living in Canada in 2001. Finally, in terms of 2001-2005 average trade, the countries in my sample represent 88% of Canada's imports and 95% of Canada's exports.

2001-2005 average trade was used because the data is somewhat lumpy for smaller provinces, so that the average of the last five years worth of trade flows provides a more accurate picture of exports and imports than just including 2005 exports or imports. There are some potential problems with Canadian trade data as noted by Statistics Canada (2007). For example, according to Statistics Canada (2007, 3), "Customs-based trade statistics more accurately measure imports rather than exports. This occurs because Customs agents are typically more vigilant with respect to goods entering the country than they are with those leaving the country." Additionally, it is noted in the same document (Statistics Canada 2007, 9) "Prior to April 1984, export statistics were presented by province of lading, indicating the province in which the goods were last laden aboard a carrier for export. Since April 1984, trade data are presented by province of origin, which represents the province in which the goods were grown, extracted or manufactured. Import statistics by province of clearance indicate the province in which the goods were cleared by Customs either for immediate consumption or for entry into a customs bonded warehouse for furtherance to a different province/territory. Consequently, the provincial data shown in these tables may not always coincide with the province in which the goods are consumed."

Thus, it appears that there is better tracking by Customs agents of imports than exports. However, it seems that there are more distortions in the import data compared to the export data. Previous studies using provincial trade data have noted similar problems with the trade data, particularly for import data.[7] One potential solution is to attempt to re-allocate imports from industries such as motor vehicle manufacturing, which appear to be assigned based on port of entry (not consumption). However, the reassignment of these imports may in fact create new errors in the data.[8] Thus, I decided to use the Canadian trade data based on my belief that the benefits of using the data "as-is" are greater than the costs of modifying the data.[9]

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[7] For example, Wagner (2000, 47-48) cites Statistics Canada with regard to potential measurement problems with trade data between Canadian provinces and countries. Referring to imports, Wagner found that automobile imports were reported on the basis of port of entry, not consumption, but that other products seemed to be reported on the basis of the province of consumption. Wagner concludes that there is no practical way of countering the inaccuracies in the trade data, but that one should be aware of the potential errors when interpreting his results.

[8] Based on the 2001-2005 average imports used in my analysis, I found that approximately 68% of motor vehicle imports are allocated to Ontario even though Ontario represents approximately 39% of the 2001-2005 total provincial population. I could change Ontario's allocation of motor vehicle imports to 39%, but the true percent might be higher or lower than that number based on other factors such as Ontarian's preferences for imports, Ontarian wealth, etc. Additionally, this Ontarian "auto effect" should be captured by its provincial fixed effect.

[9] The errors-in-variables problem in my trade data would increase the variation in the disturbance term, but this should not bias in the coefficients. It would, however, increase the standard errors of the coefficients, which would decrease the likelihood of obtaining statistically significant coefficients. Additionally, classical measurement error in the explanatory variables would bias the coefficients and t-statistics to 0,

The GDP data is the July 2001 estimated GDP in millions of Canadian dollars by country from the CIA (Central Intelligence Agency, *The World Factbook* (2002)), and by province from Statistics Canada (2001a). Great circle distances were computed using the longitude and latitude of provincial capitals and country capitals, which were obtained from the website http://www.indo.com/distance/ and are reported in miles. This is the same technique that was used in Anderson and Van Wincoop (2003) and has been commonly used in the literature. In sensitivity analysis, Anderson and Van Wincoop found that doubling and halving their measure of distance internal to states, provinces, and the other industrialized countries in their sample had little effect on their results.[10]

The immigration wave data was collected from Statistics Canada (2001b, 2001c) for the following periods: before 1961, 1961-1970, 1971-1980, 1981-1990, 1991-2001, 1991-1995, and 1996-May 15, 2001.[11] The sum of all the immigrant waves represents the total number of immigrants (or the stock of immigrants) who were residing in a given province in 2001 and had immigrated to Canada up through May 15, 2001. Whether or not English or French is a primary or secondary language was taken from the CIA, *The World Factbook* (2006). Finally, whether or not Canada has a trade office in a given country was taken from Foreign Affairs and International Trade Canada (2006-2007), Canadian Trade Commissioner Office, *Our Offices in Canada and Abroad*.

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again suggesting it would be more difficult to find statistically significant results. Only in the event that the measurement error in the dependent variable and the explanatory variables are correlated would there be any further bias, but given that the variables are derived from different sources, such a possibility is unlikely. (See Kennedy 2003, 160).

[10] I utilize external distance (i.e. distances between Canadian provinces and countries external to that province) whereas Anderson and Van Wincoop employ internal distance (i.e. distances between two provinces or two states within a country). These two measures of distance are not directly comparable because external distance encompasses national borders, which leads to higher barriers to trade due to home consumption bias.

[11] It should be noted that earlier waves of immigrants might impact future immigrant waves, which could lead to autocorrelation of the error terms for the immigrant wave variables. This also implies that earlier immigrant waves might have a greater impact on trade than the direct effect of that particular wave's coefficient.

1.5 RESULTS

Using the log-log specification in equation 1, both imports and exports are used separately as dependent variables. Variable definitions and sources are listed in Appendix 1.2. The model for imports is reported in columns 1-6 of Table 1.1. Columns 1-3 include: provincial and country GDP[12]; English and French dummy variables; interactions of the language variables with a Quebec dummy; and a trade office dummy variable as independent variables, whereas columns 4-6 include provincial and country dummy variables to account for fixed effects. The specifications in columns 1-3 (4-6) also contain provincial immigrant waves as explanatory variables, which are categorized as follows. Column 1 (4) is the base specification, which depicts the sum of all provincial immigrant waves from before 1961 through May 15, 2001, which represents the stock of immigrants residing in a given province in 2001. The base model in column 1 (4) is included as a benchmark to compare a more general version of the gravity model, which includes immigrant stocks to models that include immigrant waves in columns 2-3 (5-6). Column 2 (5) includes the following immigrant waves: before 1961, 1961-1970, 1971-1980, 1981-1990, and 1991-2001. Column 3 (6) only differs from column 2 (5) in that it separates the 1991-2001 wave into two waves: 1991-1995 and 1996-2001.

As expected, the stock of immigrants living in a province in 2001 has a highly significant and positive impact on 2001-2005 imports to Canadian provinces, which is consistent with the first main hypothesis that immigrants increase trade (see column 1).

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[12] I also estimated a model that includes both the size of the provincial economy and provincial fixed effects. This was done in supplementary regressions where I use trade divided by provincial GDP as the dependent variable and include all of the independent variables except provincial GDP (since I include provincial fixed effects). I found these results to be consistent with the findings from my main specifications described below.

By including separate variables for immigration waves, one can ascertain the timing of these impacts. In column 2, both the 1961-1970 and the 1991-2001 immigrant waves are significant (at the 10% and 5% levels respectively). This suggests that there is virtually no time lag for immigrants to establish themselves in a province before immigration actually impacts imports. Another explanation is that the cohort of recent immigrants (1991-2001) as well as the 1961-1970 cohort have certain characteristics that would suggest a larger impact on imports such as preferences for home country goods and/or knowledge of home markets. Cohort characteristics such as immigrant classification and education level may serve as proxies for knowledge of home market.[13,14] Although I employ the same set of 40 countries in each wave, the percentage of immigrants from these countries has changed over time so that each cohort is fairly representative of the actual mix of immigrants for each time period.[15] Thus, my sample's composition of immigrants by cohort closely mirrors the overall trend in changing mix of immigrants by source country over time with a decline in immigrants from Western European countries and an increase in immigrants from Asia and other developing regions. If I assume that my sample closely approximates all immigrants coming to Canada, I can make the generalization that more recent cohorts of immigrants are more likely to have a university degree and are more likely to have entered Canada as Economic Immigrants[16] than earlier

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[13] For instance, Head and Ries (1998, 60) found that Independent Immigrants impact trade in both imports and exports between Canada and their home countries more than other immigrant groups using 1980-1992 data.

[14] Unfortunately, the associated immigrant class and education level data for the group of immigrants in this study is unavailable, where immigrant characteristics vary for each cohort.

[15] For example, in the 1991-2001 cohort, the top 3 immigrant countries in my sample for all of Canada were China, India, and the Philippines at 12.9%, 10.2%, and 8.0% of their cohort total respectively. Comparing this to the 1961-1970 wave, I found that the top 3 immigrant countries in that cohort were the United States, the United Kingdom, and Germany at 37.1%, 10.9%, and 7.2% of their cohort respectively.

[16] According to Citizenship and Immigration Canada (2004b), *Annual Report to Parliament on Immigration 2004*, Economic Immigrants are defined as people selected as permanent residents for their skills and

immigrant cohorts (Picot and Sweetman 2005, 5). Consequently, taking the cohort effect into consideration, it may be the case that recent cohorts of immigrants are more highly educated and have stronger business connections with their home countries than earlier cohorts and thus have a greater impact on imports, *ceteris paribus*. Nonetheless, caution should be used in interpreting these results.

Column 3 provides a finer look at more recent immigration as it breaks the decade of the 1990s into two distinct immigration waves. As can be seen, results are similar in this model vis-à-vis column 2, where now both the 1991-1995 and 1996-2001 immigration waves are significant at the 5% level. Thus, column 3's results reinforce column 2's results, which indicate that new immigrants almost immediately increase the importation of goods and services from their home countries. It is also interesting to note the magnitude of the effects of immigration waves on imports. For example, in column 2, the coefficient on each immigration wave on-average increases with time (similar results can be seen in column 3). This is depicted in the first graph in Figure 1.1, which illustrates the lagged effect of immigration on 2001-2005 imports, which peaked in the 1990s. Since this is a log-log specification, the coefficients can be interpreted directly as elasticities. This means that in column 1, that a 10% increase in the stock of immigrants, increases imports in that province by 3%.

The results of Table 1.1 for 2001-2005 Canadian provincial imports from the 40 respective trading partners match very closely with Head and Ries' findings if one examines the cumulative impact of immigration as seen above. Adding up the significant waves in columns 2 and 3 yields similar results, where the cumulative impact of

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ability to contribute to Canada's economy, including skilled workers, business people, and provincial nominees.

immigration is 0.159 (0.065 + 0.094) in column 2 and 0.232 (0.065 + 0.080 + 0.087) in column 3. These results illustrate that a 10% increase in all significant lagged provincial immigrant waves yields between a 1.59% and 2.32% increase in provincial imports. Head and Ries (1998, 47) ascertain that a 10 percent increase in immigrants yielded a 3 percent increase in imports, using Canadian data for 136 trading partners from 1980-1992. The findings in columns 4-6 (which account for provincial and country fixed effects) are similar to the results in columns 1-3. The main difference is that in fixed effects specifications, the 1961-1970 immigrant wave is not significant. However, the main results hold and thus we find that the general immigration results are robust to alternate specifications.

The above import results demonstrate that there is a need for provincial policymakers to incorporate the notion that immigrants help to promote imports into their provinces. This effect is nontrivial in that a 10 percent increase in all significant lagged provincial immigrant waves yields between a 1.59% and 2.32% increase in provincial imports, with the most recent immigrants accounting for most of this increase. Also, today's immigration policy almost immediately affects imports in that there is virtually no time lag before a wave of immigrants actually affects imports from their home country into their respective provinces.[17]

The provincial and country GDP variables are significant at the 5% level and are positively related to imports for the specifications in columns 1- 3. This is consistent with previous studies that use a gravity model to predict levels of trade. Thus, both provincial and country GDP matter in terms of imports. This indicates that larger

[17] As noted earlier, some of this is due to a cohort effect, where the mix of recent immigrants and their associated immigrant class and education levels also contribute to this increase in imports.

provinces (i.e. Ontario and Quebec) are more likely to have a higher level of imports, *ceteris paribus*, than smaller provinces (i.e. Prince Edward Island, Newfoundland, and Saskatchewan).

Distance is negatively related to imports in columns 1-3 but is not significant in any of the specifications[18,19]. This indicates that distance to home country from a province is not very important in predicting the level of provincial imports. It was presumed that geographical distance between new and old countries would negatively impact trade. One explanation is that the sample of countries of origin for recent immigrants contains a relatively large number of countries from regions such as Asia and Africa as opposed to Europe. (For a list of countries, see Appendix 1.1.) This means that among the countries in the sample, there is a greater North-South distance between trading partners than would exist with a broader sample of trading partners that represents all regions of the world fairly equally. Thus, this unusually large North-South distance between trading partners in the sample could translate into wider differences in endowments, which could then lead to more opportunities for trade. This effect, which was found by Melitz (2007, 972) might then mitigate the negative impact of the transportation costs of distance, still causing the distance variable to be negative, but not significant.

Whether or not the primary or secondary language spoken in a home country is English or French is not significant in any of the models in columns 1-3. The same is

[18] Distance is positively related to imports in columns 4-6, but is not significant in any of these specifications. However, the country-specific aspects of distance become impossible to isolate in fixed effects models (Melitz 2007, 974), so I do not attempt to analyze the distance results in columns 4-6.

[19] In sensitivity analysis, in specifications that include provincial and country population instead of GDP and the trade office dummy variable is omitted, one finds that distance is statistically significant at anywhere from the 6 to 10% level.

true for the English and French interaction variables with the Quebec dummy. It was proposed that common language in new and old countries will positively impact trade since the *a priori* belief was that a common language would help to foster trade. However, Wagner *et al*. (2002, 519) also found that language effects were not statistically significant for imports (and exports) in regressions that included both fixed effects and immigration. Language variables were not included in the fixed effects models, but it was found that the English dummy variable was positive and statistically significant at the 5% level in a specification which included distance, provincial and country GDP, and the language dummy variables (English, French, Quebec*English, Quebec*French). Finally, the trade office dummy variable is positive and significant in all specifications at the 5% level, indicating that the presence of a trade office in an immigrant's home country strongly impacts trade between an immigrant's country of origin and province of residence.[20]

The model for exports is reported in columns 1-6 of Table 1.2. As expected, the stock of immigrants living in a province in 2001 has a highly significant and positive impact on 2001-2005 exports to Canadian provinces, which is consistent with the first main hypothesis that immigrants increase trade (see column 1). The timing of these impacts can be seen by examining the immigration wave variables in columns 2 and 3. In column 2, the 1971-1980 immigrant wave is significant at the 5% level, which demonstrates that there is a time period of approximately 20 years where immigrants need to establish themselves in a province before immigration actually impacts exports.

[20] It should be noted that the presence of a trade office can be the result of trade rather than a cause of trade, which may lead to possible endogeneity in the empirical specification. Nevertheless, results of specifications without the trade office dummy yielded similar findings to those that included the trade office dummy.

Again, as with imports, some of this immigrant wave effect can be attributed to a cohort effect. Nonetheless, these findings coupled with the results for imports provide credence to the second main hypothesis which states that because of transactions costs, the effect on imports is more rapid than on exports.

Column 3 provides a finer look at more recent immigration as it breaks the decade of the 1990s into two distinct immigration waves. In this model, not only is the 1971-1980 wave significant at the 5% level, but the 1991-1995 wave is significant at the 10% level. This suggests that immigrants may impact exports sooner than implied earlier – i.e. perhaps in 5-10 years versus 20 years. This also implies that the 1971-1980 cohort as well as the 1991-1995 cohort may have certain characteristics that impact exports. Immigrants in the 1991-1995 cohort are more likely to have a university degree and have entered Canada under the Economic classification (Picot and Sweetman 2005, 5), which as with imports, implies a greater likelihood of establishing business connections. Perhaps the years-since-migration effect for the 1971-1980 cohort trumps the cohort effect for those who migrated during this time period, although cohort characteristics may still play a role. In summary, the "life-cycle" of the effects of immigration waves on exports differs from those on imports. This can be seen in graph 2 of Figure 1.1, where the lagged effects of immigration on exports peak in the 1970s (versus in the 1990s for imports).

Again, these immigration results are comparable to Head and Ries (1998, 47), which found that a 10 percent increase in immigrants yielded a 1 percent increase in exports. Looking at column 1, a 10% increase in the stock of immigrants, increases exports in that province by 1.5%. Adding up the significant waves in columns 2 and 3 yields similar results, where the cumulative impact of immigration is 0.083 in column 2 and 0.12 (0.072 + 0.048) in column 3. These results illustrate that a 10% increase in all significant lagged provincial immigrant waves yields between a 0.83% and 1.2% increase in provincial exports. The findings in columns 1-3 are similar to the results in columns 4-6, which account for provincial and country fixed effects. Thus, taking the import and export results together, a 10% increase in all significant lagged provincial immigrant waves increases imports by 1.59%-2.32% and exports by 0.83%-1.2%. However, the magnitude of these trade effects is relatively small compared to the total amount of provincial international trade, which is consistent with previous studies.[21]

To further examine the time frame in which immigrants impact exports, one can compare column 3, where both the 1971-1980 and 1991-1995 waves are significant, to column 6 in the fixed effects model, where only the 1971-1980 wave is significant. Thus, one can still conclude that immigrants impact exports with a time lag greater than that of imports, but can be less certain of the length of that time lag. Policymakers need to be aware that their effective immigration policy will have ramifications on future exports with a lag of at least 5-10 years and perhaps as long as 20 years. For example, if Manitoba would like to increase its provincial exports to Asia, one channel to do this would be through a targeted immigration policy for immigrants from countries in that region.

[21] For example, the expected value of Ontario's average net exports to China for 2001-2005 would have increased by $16.3 million if the total number of Chinese immigrants in Ontario went from 164,890 to 0. This represents 0.14% of total Ontarian-Chinese trade of $11.3 billion, where Chinese immigrants in Ontario are the third largest immigrant group located in any province. On the other hand, if the number of Ontarian immigrants from China doubled from 164,890 to 329,780, the expected value of Ontario's average net exports to China for 2001-2005 would have decreased by $3.8 million, which illustrates that there is a smaller impact (per immigrant) after a certain threshold number of immigrants is reached. As a point of comparison, Head and Ries (1998, 53-54) found that a 233,000 reduction in immigrant stock (i.e. all immigrants for 1992 coming to Canada from their sample of 136 countries) would cause an increase in net exports of $1.2 billion out of total trade of $274 billion in 1992 (or approximately 0.44%).

Both provincial and country GDP are significant at either the 5% or 10% level and are positively related to exports in columns 1-3, which is consistent with the predictions of a gravity model. In 5 of the 6 columns, the distance variable is insignificant and is negatively related to exports, while in column 1, the distance variable is still insignificant, but is positively related to exports.[22] Again, as noted with imports, it is surmised that the larger than normal North-South distance between trading partners due to sample composition might be causing the distance variable to be insignificant. Finally, the same results for language and trade office hold for exports as they did for imports.

The above analysis assumed that immigrants located in a given province affect trade from that province only. However, immigrants located in a given province might also affect trade from other provinces. Herander and Saavedra (2005) examined this effect using U.S. state data, where they found that local immigrants have a greater effect on state exports to the immigrants' home country than do co-nationals residing outside the state. Following Herander and Saavedra, I tested whether or not out-of-province immigrants impact trade between a given province and the immigrants' home country by adding out-of-province immigrant wave variables to the base model. An out-of province immigrant wave (as defined for province i) is the total number of immigrants from each country in the sample who came to Canada during a particular immigrant wave (say 1991-2001) who are living in all other provinces in 2001 except province i. It was found that out-of-Province immigrants are not significant in impacting trade between province i and the immigrants' home countries, leaving the main results unchanged.

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[22] In sensitivity analysis, in specifications that include provincial and country population instead of GDP and the language and trade office dummy variables are omitted, one finds that distance is statistically significant at anywhere from the 5% to 11% level.

Finally, in order to fully evaluate international trade's impacts at the provincial level, one should examine whether the increase in trade comes at the cost of reduced inter-provincial trade (i.e. trade diversion). To do this, I used the sum of exports and imports between provinces as the total trade variable, where 2001-2002 average trade was used (since 2002 was the latest year available). The independent variables included distance between provincial capitals, GDP in 2001 of the exporting and importing province, various provincial immigrant waves for the exporting province, and provincial fixed effects for the importing provinces.

The results can be seen in Appendix 1.3, where columns 1-3 respectively depict models with exporter provincial immigrant stock, all exporter provincial immigrant waves including 1991-2001, and all exporter provincial immigrant waves with 1991-2001 divided into two periods. Columns 4-6 differ only in that they include provincial importer fixed effects. The noteworthy findings are illustrated in models that include both the 1991-1995 and 1996-2001 exporter provincial wave variables since in all other models, the immigrant variables are insignificant. In column 3 (6), one finds that the 1991-1995 wave is significant at the 10% (5%) level and positively impacts inter-provincial trade, whereas the 1996-2001 wave is also significant at the 10% (5%) level and negatively impacts inter-provincial trade. Only in column 6, is the 1981-1990 immigrant wave variable significant (at the 10% level), where the results indicate that this wave negatively impacts inter-provincial trade.

Based on these results, one can infer that the 1991-1995 immigrant wave increases inter-provincial trade and thus has a trade creation effect. This cohort of immigrants also leads to increased trade of both imports and exports between immigrants' countries of origin and their current province of residence. Therefore, one can conclude that the increased trade between home country and province associated with the 1991-1995 immigrant wave does not come at the expense of less trade inter-provincially. However, the 1996-2001 immigrant wave and potentially the 1981-1990 immigrant wave lead to decreased inter-provincial trade and as a result have a trade diversion effect. Thus, the increased trade between home country and new province associated with the most recent immigrants is somewhat mitigated by the trade diversion effect of decreased inter-provincial trade.

1.6 CONCLUSION

The modified gravity model described above allows for the examination of how GDP, distance, lagged immigration waves, common language, and trade promotion activities affect trade flows between immigrants' destination province and their home countries. The results are consistent with previous studies, where immigrants increased both import and export trade flows. By adding the lagged provincial immigrant wave variable, it was also found that immigrants most strongly affect the importation of goods from their home countries to Canadian provinces almost immediately, whereas immigrants most strongly affect the exportation of goods from Canadian provinces to their home countries after at least 5 years. This indicates that there is a longer time lag for immigrants to affect exports than imports by province, which is not surprising given the greater complexity of exporting goods versus importing goods. It is also possible that some of this effect is due to the cohort characteristics of each immigrant wave, where the cohort effect and the years-since-migration effect are difficult to separate.

Provincial and country GDP are significant and are positively related to both imports and exports. The distance between the capital of a province and the capital of a foreign country is insignificant for both imports and exports, but has the expected negative sign. As noted in the results section, it appears that the insignificance of the distance variable stems from an idiosyncrasy of the sample in that it contains a relatively large number of countries from regions such as Asia and Africa as opposed to Europe, which leads to greater differences in endowments and thus more opportunities to trade. Thus, given the particular sample, the negative impact of distance based on traditional factors such as transportation costs is somewhat mitigated.

The language variables were found to be insignificant in impacting trade. Although this is contrary to what was expected, Wagner *et al*. (2002, 519) also found that language effects were not statistically significant in impacting trade in regressions that included both fixed effects and immigration. Finally, whether or not immigrants' countries of origin have a Canadian trade office is highly significant in impacting trade between immigrants' home countries and their new provinces.

The above results have implications for Canada's policymakers. For example, if provinces want to increase their international trade, is it reasonable for them to target certain groups of immigrants? If so, this could impact immigration policy in that certain countries' immigrants or certain types of immigrants (i.e. more highly educated, more Economic class immigrants, etc.) may be targeted over others based on their impact on trade. Also, the results of this study demonstrate that policymakers should be aware of the lagged effect of immigration on international trade flows. For instance, if policymakers would like to increase exports to certain countries via an immigration policy, there will be a time lag of at least 5 years before exports actually increase. Also, there is evidence that there is a trade-diversion effect of reduced inter-provincial trade associated with very recent immigrants, so some of the increase in province-country trade associated with these immigrants is mitigated by this reduced inter-provincial trade. However, immigrants who have lived in Canada for 5-10 years appear to have a trade-creation effect of increased inter-provincial trade in addition to their positive impact on province-country trade.

Finally, each province should find it beneficial to promote immigration since provincial exports and imports are positively influenced by immigration. As noted earlier, provincial policymakers are beginning to influence provincial international trade through provincial immigration policies such as the PNP and/or federal-provincial agreements on immigration. However, it appears that future opportunities exist for co-operation between immigration and trade offices at the provincial level in helping to facilitate trade via immigration. In sum, more research into how immigration affects sub-national imports and exports should help to provide further insights into the linkages between immigration and trade flows by region.

Table 1.1: Regression Results: Imports as the Dependent Variable

Log-Log Specification[a,b]

Variable	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Constant	-130.43 (3.83)**	-96.01 (2.53)**	-75.27 (1.94)*	-167.77 (1.82)*	-178.52 (1.91)*	-173.10 (1.86)*
Provincial Immigrant Stock (Pre-1961-2001)	0.30 (5.70)**			0.22 (3.68)**		
Pre-1961 Provincial Immigrant Base		-0.033 (1.02)	-0.045 (1.38)		-0.011 (0.30)	-0.018 (0.47)
1961-1970 Provincial Immigrant Wave		0.065 (1.75)*	0.065 (1.75)*		0.061 (1.53)	0.056 (1.43)
1971-1980 Provincial Immigrant Wave		0.053 (1.29)	0.036 (0.87)		0.036 (0.82)	0.022 (0.51)
1981-1990 Provincial Immigrant Wave		0.059 (1.43)	0.049 (1.20)		0.054 (1.23)	0.044 (1.01)
1991-2001 Provincial Immigrant Wave		0.094 (2.24)**			0.038 (0.81)	
1991-1995 Provincial Immigrant Wave			0.080 (2.06)**			0.068 (1.64)*
1996-2001 Provincial Immigrant Wave			0.087 (2.19)**			0.086 (2.05)**
Distance	-1.33 (0.39)	-2.02 (0.55)	-2.76 (0.76)	11.45 (1.08)	13.36 (1.24)	13.45 (1.25)
Provincial GDP	8.38 (6.73)**	6.68 (4.08)**	5.65 (3.36)**			
Country GDP	2.70 (3.10)**	2.28 (2.46)**	2.03 (2.20)**			
English	1.24 (0.33)	0.15 (038)	0.58 (0.14)			
French	-3.73 (0.82)	-3.96 (0.85)	-3.87 (0.84)			
English*Quebec	-5.56 (0.57)	-6.21 (0.62)	-6.83 (0.69)			
French*Quebec	3.27 (0.25)	2.47 (0.18)	2.47 (0.19)			
Trade Office	25.81 (4.80)**	25.09 (4.54)**	26.0 (4.73)**			
Provincial Fixed Effects	No	No	No	Yes	Yes	Yes
Country Fixed Effects	No	No	No	Yes	Yes	Yes
N	400	400	400	400	400	400
R^2	0.37	0.36	0.37	0.47	0.46	0.47

a: * indicates significance at the 10% level and ** indicates significance at the 5% level

b: The absolute values of the t-statistics are given in parentheses.

Table 1.2: Regression Results: Exports as the Dependent Variable

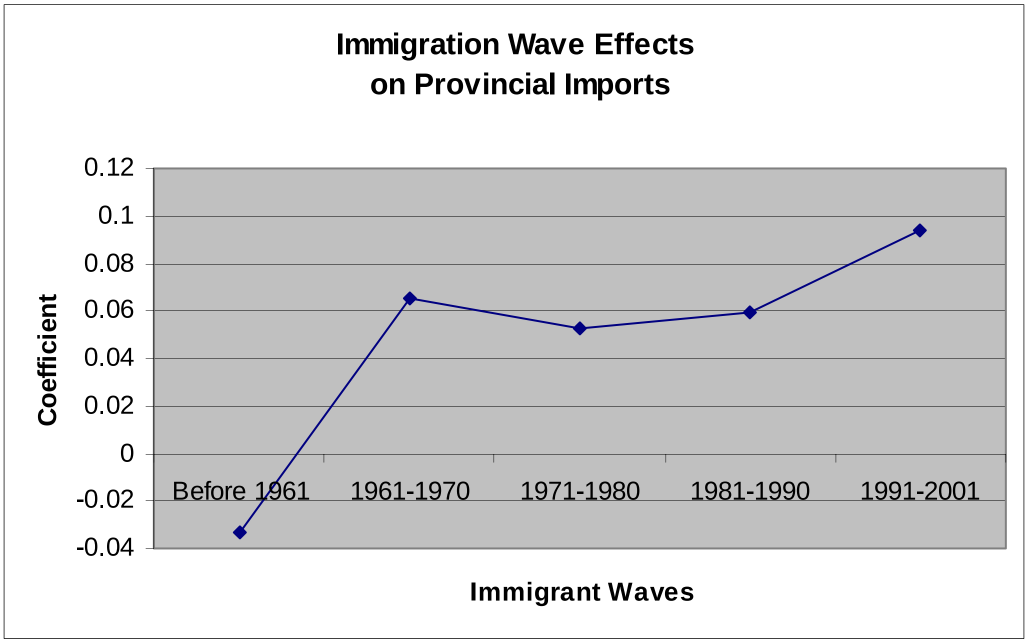
Log-Log Specification[a,b]

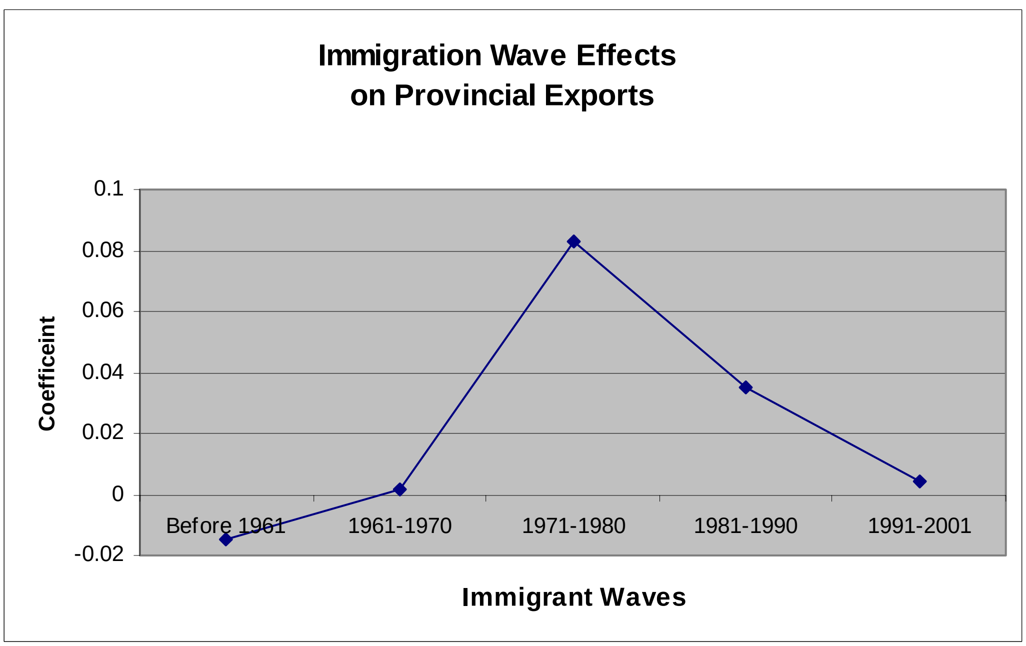
Variable	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Constant	-69.52 (2.80)**	-48.80 (1.78)*	-42.03 (1.50)	-17.01 (0.25)	-17.57 (0.25)	-5.34 (0.08)
Provincial Immigrant Stock (Pre-1961-2001)	0.15 (3.93)**			0.16 (3.68)**		
Pre-1961 Provincial Immigrant Base		-0.015 (0.65)	-0.020 (0.84)		-0.036 (1.27)	-0.043 (1.50)
1961-1970 Provincial Immigrant Wave		0.0014 (0.05)	0.001 (0.04)		-0.0076 (0.26)	-0.0087 (0.30)
1971-1980 Provincial Immigrant Wave		0.083 (2.78)**	0.072 (2.38)**		0.087 (2.69)**	0.079 (2.41)**
1981-1990 Provincial Immigrant Wave		0.035 (1.17)	0.035 (1.18)		0.019 (0.59)	0.022 (0.68)
1991-2001 Provincial Immigrant Wave		0.0041 (0.14)			-0.012 (0.34)	
1991-1995 Provincial Immigrant Wave			0.048 (1.71)*			0.044 (1.42)
1996-2001 Provincial Immigrant Wave			-0.025 (0.88)			-0.047 (1.53)
Distance	0.32 (0.13)	-0.54 (0.21)	-0.90 (0.34)	-0.58 (0.07)	-1.14 (0.14)	-2.56 (0.32)
Provincial GDP	3.46 (3.81)**	2.72 (2.30)**	2.42 (1.99)**			
Country GDP	1.48 (2.32)**	1.28 (1.92)*	1.25 (1.87)*			
English	1.47 (0.53)	-0.43 (0.15)	-0.64 (0.22)			
French	2.63 (0.79)	1.73 (0.51)	2.077 (0.62)			
English*Quebec	-3.61 (0.50)	-3.17 (0.44)	-3.07 (0.43)			
French*Quebec	-0.47 (0.05)	-0.61 (0.06)	-0.91 (0.1)			
Trade Office	24.88 (6.35)**	24.51 (6.16)**	24.67 (6.2)**			
Provincial Fixed Effects	No	No	No	Yes	Yes	Yes
Country Fixed Effects	No	No	No	Yes	Yes	Yes
N	400	400	400	400	400	400
R^2	0.28	0.28	0.29	0.36	0.36	0.36

a: * indicates significance at the 10% level and ** indicates significance at the 5% level

b: The absolute values of the t-statistics are given in parentheses.

Figure 1.1: Immigration Wave Effects on Provincial Imports and Exports





CHAPTER 2

ESSAY 2: CANADA'S INNOVATION STRATEGY: IS THERE A LINK BETWEEN INNOVATION AND INTERNATIONAL COMPETITIVENESS?

2.1 INTRODUCTION

Technology and innovation have taken on increased importance in Canada in the past five years with the launching of a federal innovation strategy in February 2002 (Government of Canada 2002). Canada's Innovation Strategy contains two companion documents[1] that provide a blueprint for how innovation, skills, and learning can be improved. The main impetus for this strategy is to enhance Canada's innovation performance vis-à-vis other countries so that Canada can better compete in an increasingly competitive global economy. Several key initiatives follow from this innovation strategy, which include increasing R&D investment in Canada, expanding the number of highly qualified skilled-workers, and supporting innovation at the local level. With regards to this last point, provincial governments are playing a sizable role in the national science and technology system through a variety of provincial initiatives such as the funding of university and private-sector research, influencing the business environment through a number of policies and tax incentives as well as supporting regional innovation networks.[2]

Following the lead of the federal government, a number of provinces have subsequently formulated their own provincial-level innovation strategies. In Atlantic Canada, New Brunswick, Nova Scotia, and Newfoundland/Labrador all have formal

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[1] These documents are entitled *Achieving Excellence: Investing in People, Knowledge and Opportunity* and *Knowledge Matters: Skills and Learning for Canadians*.
[2] See Industry Canada (2007) for more details.

innovation strategies. New Brunswick's Innovation Agenda was established in February 2003 and includes an independent, non-profit Innovation Foundation as well as a $20 million Innovation Fund (Government of New Brunswick 2003). Nova Scotia launched its own innovation strategy shortly thereafter (June 2003) entitled *Innovative Nova Scotia* along with a 16-member province-level advisory council on innovation (Government of Nova Scotia 2003). Newfoundland and Labrador just recently announced their innovation strategy (*Innovation Newfoundland and Labrador: A Blueprint for Prosperity*) in March 2006 (Government of Newfoundland and Labrador 2006). Prince Edward Island (which has the smallest population of all of the provinces) is the only province in Atlantic Canada without its own innovation strategy. However, Prince Edward Island receives innovation funding from the Atlantic Innovation Fund (AIF) and is also part of the New Brunswick/Prince Edward Island Research Grid, which is designed to provide increased bandwidth to the research, industry, and academic communities in the aforementioned provinces (Atlantic Canada Opportunities Agency 2007; Industry Canada 2004).

Not surprisingly, both Quebec and Ontario in Central Canada have their own large-scale innovation strategies. Quebec's research and innovation strategy (*Québec's Research and Innovation Strategy- An Innovative, Prosperous Québec)* was announced in December 2006 with the promise of $1.2 billion in investments in research and innovation (Gouvernement du Québec 2006). In Ontario, the Ministry of Research and Innovation was created in June 2005 to help establish a strategic plan, which was published in November 2006 with a commitment of nearly $1.7 billion in research and innovation during the 5-year period ending in 2009/10 (Government of Ontario 2007).

Finally, in Western Canada (which includes the Prairies), provincial governments have either launched their own formal innovation strategies since the establishment of the 2002 federal innovation strategy or have a working innovation infrastructure in place. For instance, Manitoba launched its Innovation Framework in April 2003 to promote innovation as a way to create jobs and improve the lives of Manitobans (Government of Manitoba 2003). British Columbia just recently released its *B.C. Research and Innovation Strategy*, which calls for five key actions to make British Columbia the most productive province in Canada by 2015 (Government of British Columbia 2007). Alberta and Saskatchewan have not proposed new, formal innovation strategies since the release of the 2002 federal innovation strategy. However, both provinces have mechanisms in place to help foster innovation in their respective locales such as the Alberta Science and Research Authority's innovation initiatives in Alberta (Government of Alberta 2007) and the Canada-Saskatchewan Business Service Centre and Innovation Place in Saskatchewan (Government of Canada 2007b).

Given the increasing role of provincial governments in contributing to innovation policy, I seek to examine how provincial innovation impacts a province's economic competitiveness. To date, there has been minimal economic analysis of the success of Canada's Innovation Strategy in terms of enhancing Canada's competitiveness via increased trade. In particular, given that one of the main goals of Canada's Innovation Strategy is to support innovation at the local level, a point of interest is whether or not a province's innovative capacity[3] translates into increased provincial exports. To address these issues, two main hypotheses will be tested regarding the provincial trade effect of

[3] Each province has its own research and technology resources (see Government of Canada 2007b) indicating that there is a concerted effort to regionalize the federal innovation policy as seen above.

technology and innovation. First, it is hypothesized that a province's infrastructure will help to facilitate increased exports. Second, on a related note, it is also inferred that a province's innovative capability will lead to increased exports.

The methodology that will be used to examine these questions is an augmented gravity model that incorporates measures of both hard and soft infrastructure as well as innovative capability as explanatory variables. The model is employed to determine the effects of technology and innovation on Canadian export flows by province to Canada's top 60 importing countries (or conversely, Canada's top 60 export markets). The augmented gravity equation is estimated for not only the entire group of 60 countries, but also for the subset of developing and developed countries. The gravity model thus serves as a backdrop for the question of how technology and innovation impact trade. Before one can use the gravity model (or any other model) to determine technology and innovations' impact on trade, one must first define what is meant by technology and innovation. Thus, a discussion of ways to measure technology and innovation including several empirical studies that have created measures for these factors follows.

Next, a variety of methods for modeling technology, innovation, and trade are considered. However, prior to examining gravity models that incorporate technology and innovation as independent variables to estimate trade flows, one needs to step back and consider the literature on trade and innovation. It then becomes apparent that one could model trade as impacting innovation just as readily as one could model innovation as impacting trade. A discussion of the variants of models that include trade and innovation thus ensues. After all of the relevant models are reviewed, augmented gravity models that specifically include infrastructure and innovation as explanatory variables in determining trade flows are examined. These models serve as the basis for the model used in this paper, which examines infrastructure and innovations' effects on Canadian provinces' exports.

This paper differs from previous research in several ways. First, it specifically examines the impact of both hard and soft infrastructure as well as innovative capability on Canadian exports by province. Previous studies have examined these impacts on inter-country trade, but not at the province-country level. Therefore, examining trade flows at the provincial level versus the national level will have policy implications for how each province can benefit from their respective innovation policies. Given the diversity between (as well as within) geographic regions, differences in innovative capability from province to province can be quite large. For example, in Nova Scotia's Innovation Policy it is pointed out that Nova Scotia falls behind many other provinces in financing the commercialization process of innovative products and services (Government of Nova Scotia 2003). In general, the Atlantic Provinces' innovative capability lags behind the rest of Canada. Thus, examining innovative capabilities such as patents and research and development expenditures at the provincial level should provide further insights into what innovation policies provide the greatest regional impact in terms of enhancing exports.

Additionally, the paper's use of both U.S. (international) patents and exporting country (in this case Canadian) patents as proxies for innovative capability is novel in that typically only U.S. patents are employed in this fashion. Both types of patents are included in order to differentiate between the impacts of Canadian and U.S. patents on province-to-country exports. It is surmised that U.S. patents will have a greater impact on exports than non-U.S. patents since U.S. patents are typically viewed as a signal of international competitiveness.

Finally, in a similar study, Martínez-Zarzoso and Márquez-Ramos (2005) examine infrastructure and innovations' effects on exports, where technology indices are employed to represent a country's specific innovative capability. In contrast, this study includes U.S. and Canadian patents, research and development expenditures, the number of scientific publications, as well as the number of scientific tertiary graduates as proxies for innovative capability. Therefore, specific innovative factors that lead to increased exports can be identified, thereby distinguishing this paper from Martínez-Zarzoso and Márquez-Ramos, who demonstrate that increased innovation as defined by a broad-based "technology index" leads to increased exports, but do not indicate the particular innovative factors that are driving this increase in exports.

In what follows, section 2.2 synthesizes previous work on developing the theory behind gravity models as well as some empirical applications. The next section provides some background on various ways economists measure and assess the effects of technology and innovation. Section 2.4 examines the linkages between trade and innovation. In section 2.5, special attention is given to past studies that have utilized the basic gravity model with the addition of independent variables that measure infrastructure and innovation, which sets up a discussion of the theoretical model. The next section describes the empirical model followed by section 2.7's description of the data. Section 2.8 presents the empirical findings followed by a concluding section.

2.2 THE GRAVITY MODEL

The gravity model has served as a fundamental tool in estimating trade flows for imports and exports. The basic gravity equation or model relates bilateral trade flows to GDP, distance, and other factors that affect trade barriers (Anderson and Van Wincoop 2003). Other variables often included in a gravity model are remoteness measures, common language, and membership in an economic or trade union. The first gravity models are often attributed to Tinbergen (1962) and Pöyhönen (1963), who conducted studies on trade flows using gravity equations with only simple underlying theory attached.

Gravity models have been empirically successful and thus have led to their wide use in the estimation of trade flows. However, gravity models have often been criticized for their lack of theoretical foundation. The critics claim that the gravity model does a good job of accurately explaining the data, but does not relate to any formal trade theory. However, as Deardorff (1998) points out, the previous criticisms that the basic gravity equation is without a theoretical foundation are no longer accurate since many of its past detractors have now gone on to provide it with theoretical underpinnings.

Further, Deardorff (1998) details why he believes the basic gravity model can follow from theory by illustrating how one can use a Heckscher-Ohlin (H-O) framework to explain the basic gravity model. He demonstrates this by employing two extreme cases; a case with frictionless trade (case I) and a case with impeded trade (case II). In case I, using an H-O model with frictionless trade, Deardorff finds that the derived expected trade flows in homogenous goods corresponds exactly to the simple frictionless gravity equation whenever preferences are identical and homothetic. In Case II, using an H-O model where countries produce different goods, Deardorff also finds results consistent with a gravity model. Moreover, Gravity equations have also been used to explain trade in differentiated products using models with Armington preferences as well as models with monopolistic competition.

In sum, Deardorff (1998) illustrates that one can justify even a basic form of the gravity equation (i.e. using the value of exports from country i to j as the dependent variable, and national incomes of the respective trading partners plus distance between trading partners as independent variables) using standard trade theory. Subsequent studies have arrived at the same conclusion. For example, Feenstra, Markusen, and Rose (2001) find that a simple gravity equation is consistent with a number of theoretical trade models, which depend upon whether or not goods are homogenous or differentiated and whether or not there are barriers to entry. They find that a monopolistic competition model or a reciprocal dumping model with free entry applies to trade in differentiated goods. In contrast, they find that a model with Armington product differentiation or a reciprocal dumping model with barriers to entry applies to trade in homogenous goods.

As noted above, the gravity model has been used in a number of applied studies with much success. For example, Helpman (1987) tests the proposition that if countries are completely specialized in their outputs, tastes are identical and homothetic, and there is free trade worldwide, the volume of trade among countries in a particular region is proportional to their GDP. Using a group of OECD countries in his empirical analysis, Helpman interprets the close fit of the gravity equation with the bilateral data on trade as evidence that the monopolistic competition model holds.

Building upon Helpman (1987), Hummels and Levinsohn (1995) find that the gravity equation works empirically for both OECD countries as well as developing countries. Hummels and Levinsohn expected the gravity model to work well for trade between developed countries, where goods are differentiated and demands are identical and homothetic, which is consistent with the monopolistic competition model. However, they were surprised to find that the gravity equation was a good predictor for trade between developing countries, where the assumption of complete specialization in production does not appear to hold. According to Hummels and Levinsohn, this suggests one of several possibilities, such as goods from developing countries should also be considered differentiated, the Armington assumption is really correct, or the role of country size in a traditional H-O model is incorrect.

Hummels and Levinsohn's empirical results demonstrate what Deardorff (1998), Feenstra *et al.* (2001) and others have asserted, that a large class of models can be depicted by the gravity equation. Therefore, one is not bound by a one-size-fits-all theory in using a gravity model, which has important implications for this study because multiple forms of trade are examined (i.e. Canadian provincial exports to both developing and developed countries), which cannot be explained by one trade theory alone. For instance, in the sample of developed countries, trade occurs between Canadian provinces (which are developed) and developed countries, which typifies North-North trade. Generally, this type of trade is intra-industry, where a monopolistic competition model likely holds (see Helpman, 1987). However, in the sample of developing countries, trade occurs between Canadian provinces and developing countries or North-South trade, which is more likely to be characterized by inter-industry trade. Thus, a standard H-O model would be more applicable to this type of trade.

Now that some background on the gravity equation as a tool for estimating trade flows has been provided, one can incorporate technology and innovation into this model.

However, before adding these variables to the gravity model, some insight as to how past studies have defined and measured technology and innovation should be informative.

2.3 TECHNOLOGY AND INNOVATION

In order to examine the question of how technology and innovation affect trade, one must first define what is meant by technology and innovation. A particularly useful definition of innovation is “the search for, and the discovery, development, improvement, adoption, and commercialization of new processes, new products, and new organizational structures and procedures” (Shy 1995). This definition is broad enough to encompass a variety of different aspects of innovation and technological adoption. Thus, one can classify technologies that reduce cost separately from technologies that alter the interaction between firms.

One tangible way of measuring innovation is to use a country’s or an industry’s research and development (R&D) expenditures. In developed countries, industries can be characterized according to the ratio of their R&D expenditures to output sales. According to Shy, industries that exhibit high R&D ratios include aerospace (23%), office machines and computers (18%), electronics (10%) and drugs (9%) based on OECD, 1980 data. Additionally, R&D is generally classified into two categories: process innovation or the search for cost-reducing technologies and product innovation or the search for technologies for producing new products.

There are other ways one can measure technology and innovation besides using R&D expenditures. For example, patents by industry and by country could be used as a way to measure innovation. Increased technology could be defined as an expansion of the technology sector and thus could be examined in a Heckshcher-Ohlin type framework. Innovation could also be viewed as "transportation" innovation, where decreased transportation costs (i.e. process-innovation in transportation) could lead to increased trade.

There have been a number of papers that explicitly examine the issue of measuring innovation. For example, Mairesse and Mohnen (2002) used the European Community Innovation Survey questionnaire for 1992 on R&D-intensive manufacturing industries in seven European countries to derive an accounting framework for innovation. The variables that they used to explain the share of innovative sales for a particular industry include: a dummy for R&D-performing firms, the R&D to sales ratio for R&D-performing firms, a dummy for R&D done on a continuous basis, a dummy for collaborative R&D, a measure of the strength of the perceived competition, and a measure of proximity to basic research.

Audretsch and Feldman (1996) used a major database that provides a direct measure of innovative activity to quantify innovation. To measure the spatial distribution of innovative activity, they used the United States Small Business Administration's Innovation Data Base (SBIDB), which is a compilation of 8074 commercial innovations introduced in the U.S. in 1982. The innovations are by 4-digit SIC code and were formed from the new product announcement sections in over 100 technology, engineering and trade journals that span every industry. Audretsch and Feldman used this data to calculate state shares of industry innovations and industry shares of state innovations. They also used industry R&D to sales ratio, university research and the amount of skilled labor as well as other variables to measure innovation.

As can be seen, there are a number of ways one can measure technology and innovation by industry and by country. These measures, although difficult to come by in developed countries, may be nearly impossible to obtain in developing countries. Thus, in selecting a dataset, one needs to be cognizant of the potential data limitations due to lack of available data on innovation and technology variables in certain regions or countries. The next section includes a discussion of the linkages between trade and innovation, which is then followed by a discussion of infrastructure and innovations' impact on trade using a gravity model approach.

2.4 TRADE AND INNOVATION

This section examines the relationship between trade and innovation. There is both a literature examining trade's impact on innovation as well as a related literature examining innovation's impact on trade. While this study focuses on the latter relationship, it is important to note that the direction of causation of trade's impact on innovation vis-à-vis innovation's impact on trade can flow both ways.

The first strand of literature relates to trade's impact on innovation. One such study in this literature estimates a model using bilateral trade in manufactures for a cross-section of 19 OECD countries in 1990 (Eaton and Kortum 2002). In this study, the role of trade in spreading the benefits of new technology is examined where the authors find that an improvement in a country's state of technology raises welfare almost everywhere. Thus, Eaton and Kortum (2002) ascertain that increases in trade lead to increases in technology adoption. The second research stream relates to innovation's impact on trade. For instance, within this research framework, Spencer and Brander (1983) combine industrial organization and trade theory to examine how cost-reducing R&D can increase a country's exports in imperfectly competitive international markets. My study focuses on this second research path, where I examine infrastructure and innovation's impact on trade.

Following Spencer and Brander (1983), I hypothesize that enhanced innovation can impact trade in terms of lowering production costs. For instance, innovation can lower transactions costs via reductions in transportation and infrastructure costs. Thus, countries with enhanced roads and Internet capacity may be able to increase trade due to the resulting lower costs of conducting business. However, in addition to lowering costs, I also hypothesize that innovation may also influence trade via product differentiation as well as through creating strategic advantages. Increasing product differentiation may impact trade by offering consumers either more variety or a superior product. Strategic advantages can be created by enhancing the productivity of a particular sector following a Ricardian framework of comparative advantage. Strategic advantages can also be created by enhancing *endogenous* endowments following a Heckscher-Ohlin framework where differences in relative endowments form the basis for trade.

As noted above, innovation can increase overall trade between countries via a variety of mechanisms. However, one can also examine innovation's impact on trade at the *industry* level. For instance, the introduction of computer technologies may affect capital intensive industries more than say the natural resource sector. Since innovation and R&D have similar attributes as public goods, investment in a particular industry may result in knowledge spillovers onto other sectors of an economy. This would especially be the case for industries with high R&D levels such as aerospace; office machines and computers; electronics; and drugs (Shy 1995). Thus, one needs to be aware of how the pattern of effects of technology and innovation differ across industries with respect to trade. Therefore, in addition to examining infrastructure and innovation's impact on total trade, I also examine infrastructure and innovations impact on hi-tech trade, which includes industries with high R&D levels as noted by Shy (1995). Thus, it is surmised that infrastructure and innovation should have an even greater impact on hi-tech trade compared to total trade.

2.5 THE AUGMENTED GRAVITY MODEL: INFRASTRUCTURE AND INNOVATIVE CAPABILITY

There have been several recent papers that examine technology and innovations' effects on trade via the mechanisms discussed above. As detailed below, these studies include independent variables for technological innovation as well as transport and Internet infrastructure in an augmented gravity model to determine their impact on exports. The first study considers technological innovation as both increasing a country's technology endowment as well as reducing costs. The latter two papers focus on innovation solely as cost-reducing.

Martínez-Zarzoso and Márquez-Ramos (2005) use a gravity equation augmented with technological innovation and transport infrastructure variables to analyze their impact on international trade (exports). They examine innovation as both a mechanism to reduce transactions costs via enhanced transport and Internet infrastructure as well as a way to increase a country's technology endowment (i.e. the Heckscher-Ohlin Model). Both reduced costs and increased technology endowment are hypothesized to increase exports.

Martínez-Zarzoso and Márquez-Ramos' enhanced gravity model includes the standard independent variables such as income and population in the exporter's market and destination market; dummy variables for adjacency; whether or not a country is an island; whether or not a country is landlocked; distance between the capitals of the exporter and destination market; and a dummy variable for common language. Their model also includes technology variables measuring technological innovation in the exporter and importer countries as well as infrastructure variables measuring the level of transport infrastructure in the exporter and importer countries. In their study, they select two technology indices derived from a variety of data sources in order to capture various aspects of the technological innovation process. These indices are a technology achievement index, TAI (United Nations Development Programme, 2001 and authors' calculations) and ArCo (Archibugi and Coco, 2002). TAI is based upon the creation of technology, diffusion of recent innovations, diffusion of old innovations, and human skills, whereas ArCo is based upon the creation of technology, diffusion of technology, and development of human skills. The transport infrastructure indices (Central Intelligence Agency, 2003 and authors' calculations) are derived from data on kilometers of paved roads and kilometers of motorways per square kilometer, taking into account the quality of roads.

Martínez-Zarzoso and Márquez-Ramos' empirical model includes 62 countries using 1999 data with a total of 3,782 bilateral trade flows, where they divided their sample into developed and developing countries. They found, using an OLS model with a log-log specification, that investing in transport infrastructure and technological innovation leads to the improvement and maintenance of the level of competitiveness (i.e.

exports) for developed countries. However, they found that for developing countries, only investment in technology is significant in increasing competitiveness.

Bougheas, Demetriades, and Morgenroth (1999) examine hard infrastructure's impact on trade using an augmented gravity model. The motive behind their paper is to demonstrate the relationship between the stock of infrastructure and the volume of trade by assuming that infrastructure reduces transport costs, which in turn enhances trading opportunities based upon a Dornbusch-Fischer-Samuelson (DFS) model. They hypothesize that differences in the volume and quality of infrastructure across countries may be responsible for differences in transport costs, which may then be able to account for differences in competitiveness. In other words, transport costs are not only a function of distance, but also depend upon the availability of public infrastructure, such as road, port, and telecommunication networks. In the DFS model, transport costs alter trade volumes, but not the pattern of trade.

Bougheas *et al.* (1999) estimate an augmented gravity model of bilateral trade flows between the core six EU countries and nine European countries, including the core six using data from 1970-1990. They use two different proxies for infrastructure; the stock of public capital and the length of the motorway network in both the exporting country and the destination country. Adding these variables to distance and GDP, they find that infrastructure has a positive impact on the volume of trade (exports), which is consistent with the predictions of the DFS model.

Another study that examines the impact of infrastructure on trade is Freund and Weinhold (2004). However, in their study, they examine soft infrastructure's effect on increasing export growth via an Internet-related reduction in fixed costs. To measure

Internet development across countries, they used data from the Internet Software Consortium on the number of web hosts attributed to each country that is obtained from counting top-level host domain names. Their sample included 56 countries over the 1995-1999 time period. They estimated their model using a panel growth regression, where growth in exports between countries i and j was the dependent variable and importing country GDP growth, growth in the level of competition, Internet growth, and proximity to market were the independent variables. They found that Internet growth affects trade primarily through the exporting country.

Freund and Weinhold also conducted a cross-sectional gravity model estimation to test whether an impact of the Internet on trade patterns exists in the cross section as well as in the time series. Their augmented gravity model included the usual independent variables such as GDP in country i and j; population in country i and j; distance between country i and j; a common language dummy; a free trade agreement dummy; a dummy for a colonial link; and a dummy for adjacency. It also included lagged variables for the number of web hosts attributed to each country as additional independent variables, where trade (exports) was the dependent variable. Again, they found that the number of web hosts was positive and statistically significant.

As can be seen, technology and innovation play a role in increasing trade (and growth) and conversely, trade also plays a role in increasing technology and innovation. The focus of this paper is on the former, where the impact of technology and innovation on trade is examined using the following augmented gravity equation.

(1) $X_{ij} = ß_0(Y_i)^{ß1}(Y_j)^{ß2}(D_{ij})^{ß3}(A_{ij})^{ß4}u_{ij}$,

where X_{ij} are exports from region i to region j; Y_i and Y_j are region i and j's respective GDPs; D_{ij} is the distance from the capital of region i to the capital of region j; A_{ij} are any other factor(s) either aiding or resisting trade between i and j; and u_{ij} is the log-normally distributed error term with $E(\ln u_{ij}) = 0$. The main factors included in A_{ij}, which serve to augment the basic gravity equation, include infrastructure and innovation capability variables, which are discussed in more detail in the empirical model which follows.

The above theoretical model is based on new trade theory, which emphasizes endowment differences in technology as an important factor in determining trade flows. Following Helpman and Krugman (1996) in the development of the theoretical framework, the following increasing returns-to-scale factors are included: hard and soft infrastructure and innovative capability.[4] It is assumed that transportation costs are of the Samuelson "iceberg" type, where only a fraction of the quantity exported reaches the final destination. Thus, hard infrastructure is introduced into the model as a cost-reducing technology following Bougheas *et al.* (1999), where an increase in hard infrastructure is expected to lead to greater levels of trade. Soft infrastructure is also introduced into the model following Freund and Weinhold (2004), where it is assumed that increased levels of soft infrastructure reduce the fixed cost to enter a particular market and therefore increase trade. As noted above in the DFS model, trade volumes can change without changing the composition of traded goods.

Finally, based upon an augmented Heckscher-Ohlin Model, innovative capability variables are included, where it is assumed that increased innovative capability increases productivity of highly skilled workers and thus increases exports in commodities which intensively use this more abundant factor of production. This follows from the

[4] This also follows from Martínez -Zarzoso and Márquez -Ramos (2005).

Rybczynski Theorem, where innovation alters the size of sectors, expanding some and contracting others, which could also lead to greater trade as "relative endowments" become more different across countries. In the following section, equation (1) is converted into an empirical specification so that the above theory can be tested using data on Canadian provincial exports to Canada's top 60 export markets (countries).

2.6 EMPIRICAL MODEL

The framework for the empirical model follows Martínez-Zarzoso and Márquez-Ramos (2005)'s augmented gravity model described above. The model is used to determine the effects of technology and innovation on Canadian export flows by province to Canada's top 60 importing countries (or conversely, Canada's top 60 export markets). Provincial and country GDP are included in the model as a measure of the size of each trading partner's economy. A dummy variable for common language is also included to determine the influence of a common language between province and country.

Independent variables that measure both process (cost-reducing) and product (quality and variety-enhancing) innovation are included. For example, variables that measure province p and country c's transportation infrastructure (paved roads) are included as a measure of hard technology enhancement, whereas variables that measure province p and country c's hi-tech infrastructure (Internet users) are included as a measure of soft technology enhancement. Hard infrastructure (paved roads) is thought to improve transportation conditions in such a way as to reduce costs, while soft infrastructure (the Internet) is thought to reduce the fixed costs of entering a market. The infrastructure variables are lagged to prevent any potential of reverse causality between roads/Internet and trade. It should also be noted that the paved road variable represents a stock variable, whereas Internet users are a flow variable.

Variables that measure province p and country c's innovative capability such as R&D expenditures, the number of Canadian and U.S. (international) patents granted, the number of scientific publications, and the number of scientific tertiary graduates are included to capture potential product-innovation, which is expected to enhance trade through increased product quality and variety. R&D expenditures and scientific tertiary graduates are included as proxies for inputs to innovation, whereas patents and scientific publications are added to capture innovative outputs. It is expected that greater levels of patents, R&D expenditures, and scientific articles will generate increased levels of technology and innovation. Likewise, greater numbers of scientific tertiary graduates should augment the amount of skilled-human capital with the potential for knowledge spillovers, which should indirectly lead to increased levels of technology and innovation. Both U.S. and Canadian patents are included as proxies for potential innovative output to determine whether the country of origin of a patent (i.e. U.S. versus non-U.S.) matters in terms of impacting trade, where it is hypothesized that U.S. patents have a greater impact on trade than non-U.S. patents. All innovation variables are lagged to both ensure that the potential for endogeneity between innovation and trade is mitigated as well as to provide a gestation period for innovative capability to impact trade. Additionally, all of the innovation variables represent flows versus stocks.

In order to detect multicollinearity, a matrix of simple correlation coefficients between all pairs of independent variables was computed. It was found that the provincial innovation variables were highly correlated with GDP (correlation coefficient above 0.70), but not with GDP per capita. Therefore, gravity equations are estimated using provincial and country GDP per capita as independent variables and exports per capita (for consistency) as the dependent variable. Equation 2 includes hard and soft infrastructure variables as well as innovation variables.

(2) $EXPORTS_{pc}/POP_p = a + bGDP_{p}/POP_p + cGDP_c/POP_c + dDIST_{pc} + eCOMLANG_{pc} + fINFRAST_p + gINFRAST_c + hINNOVATE_p + iINNOVATE_c + u_{pc}$,

where $EXPORTS_{pc}/POP_p$ is the logarithm of exports per capita of goods from province p to country c; GDP_{p}/POP_p and GDP_c/POP_c are the logarithms of GDP per capita by province and country, respectively; $DIST_{pc}$ is the logarithm of the distance from the capital of province p to the capital of country c; $COMLANG_{pc}$ is a vector of dummy variables indicating whether or not province p and country c have a common language; $INFRAST_p$ and $INFRAST_c$ include provincial and country measures (in logs) for cost-reducing technologies for hard infrastructure (ROADS[5], measured as (km of paved roads)/(land area in km^2)) and soft infrastructure (INTERNET, measured as number of Internet users per capita); $INNOVATE_p$ and $INNOVATE_c$ include provincial and country measures (in logs) for innovative capability such as R&D expenditures per capita, the number of Canadian and U.S. patents granted per capita, the number of scientific publications per capita, and the number of scientific tertiary graduates per capita; and u_{pc} is the log-normally distributed error term with $E(\ln u_{pc}) = 0$. Other models include country dummy variables to capture country fixed effects.

[5] The road variable as a proxy for hard infrastructure is typically measured as a variant of (paved roads (km))/(land area (km^2)) as in Martínez-Zarzoso and Márques-Ramos 2005; Bougheas, Demetriades, and Mamuneas 2000. The above specification for paved roads follows these studies. However, models using (paved roads (km))/(population) were also estimated, which yielded similar results to those of the main specifications.

Equation (2) is estimated using White's parameter covariance matrix estimator in LIMDEP using the Hetero command. White's estimator is used because it is consistent even when the disturbances of a linear regression model are heteroskedastic.[6] Additionally, the infrastructure and innovation variables are all lagged to avoid any problems of endogeneity with the dependent variable (provincial exports per capita).

2.7 DATA

The trade data are from Statistics Canada (2004-2005) and are for an average of exports of goods in millions of Canadian dollars for 2004-2005 from each of the 10 Canadian provinces to the 60 aforementioned countries. 2004-2005 average trade was used because the data is somewhat lumpy for smaller provinces, so that the average of the last two year's worth of trade flows provides a more accurate picture of exports than only including 2005 exports.

The countries in this sample were chosen based upon the criteria that they received Canadian imports of at least $100 million (Canadian dollars) on average per year over the 2004-2005 time period. In terms of 2004-2005 average trade, the sample countries represent close to 99% of Canada's exports. A sample size of 60 is also consistent with previous related studies (i.e. Martínez-Zarzoso and Márquez-Ramos (2005) used a sample size of 62 countries to determine technological innovation's impact

[6] As noted in Greene (2003), heteroskedasticity has some potentially serious implications for inferences based upon the results of OLS. The application of more appropriate estimation techniques requires a detailed formation of Ω, where the form of the heteroskedasticity may be unknown. Thus, Greene (2003) recommends using the White estimator, which provides an appropriate estimate for the variance of the least squares estimator, even if heteroskedasticity is related to the variables in X. This estimator takes the following form: $(X'X/n)^{-1}V(X'X/n)^{-1}$ where $V = n^{-1}\Sigma e^2 X'X$. As noted by White (1980), in the fixed regressor case, this amounts to replacing the *i*th diagonal element of Ω, σ^2, with e^2, the *i*th squared residual term.

on exports; Freund and Weinhold (2004) used a sample size of 56 countries to determine the effect of the Internet on international trade).

There are some potential problems with Canadian trade data as noted by Statistics Canada. For example, according to Statistics Canada (2007c, 9), "Prior to April 1984, export statistics were presented by province of lading, indicating the province in which the goods were last laden aboard a carrier for export. Since April 1984, trade data are presented by province of origin, which represents the province in which the goods were grown, extracted or manufactured. Import statistics by province of clearance indicate the province in which the goods were cleared by Customs either for immediate consumption or for entry into a customs bonded warehouse for furtherance to a different province/territory. Consequently, the provincial data shown in these tables may not always coincide with the province in which the goods are consumed." Thus, it appears that there are more distortions in the import data compared to the export data. Previous studies using provincial trade data have noted similar problems with Canadian trade data (McCallum 1995; Wagner, Head and Ries 2002). Given that this study employs provincial export data only, the main concern with the trade data is that Customs agents are better at tracking imports than exports, thus providing greater potential for errors in the export data (Statistics Canada 2007c). However, the errors should not be systematic and thus should not materially affect the results.[7]

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[7] The errors-in-variables problem in the trade data would increase the variation in the disturbance term, but this should not bias the coefficients. It would, however, increase the standard errors of the coefficients, which would decrease the likelihood of obtaining statistically significant coefficients. Additionally, classical measurement error in the explanatory variables would bias the coefficients and t-statistics to 0, again suggesting it would be more difficult to find statistically significant results. Only in the event that the measurement error in the dependent variable and the explanatory variables are correlated would there be any further bias, but given that the variables are derived from different sources, such a possibility is unlikely. (See Kennedy 2003, 160).

Great circle distances are computed using the longitude and latitude of provincial capitals and country capitals, which were obtained from the website http://www.indo.com/distance/ and are reported in kilometers. This is the same technique that was used in Anderson and Van Wincoop (2003) and has been commonly used in the literature. In sensitivity analysis, Anderson and Van Wincoop found that doubling and halving their measure of distance internal to states, provinces, and the other industrialized countries in their sample had little effect on their results.[8]

The GDP data is the July 2004 estimated GDP in millions of Canadian dollars by province from Statistics Canada (2004) and by country from the CIA (Central Intelligence Agency), *The World Factbook* (2005). Data for the common language dummy variable were obtained for each country from the following three sources: CIA, *The World Factbook* (2006); Encyclopedia Britannica Online (2007); and Ethnologue: Languages of the World (2007). In order for a province-country pair to share a common language, both must share at least one common official language. For each country, at least two of the three aforementioned sources must have listed a language as an official language in order for that language to be considered as an official language in the dummy variable calculation. The official language for each province is English, except for Quebec, whose official language is French. New Brunswick is the only province that has two official languages (English and French).

Data on hard infrastructure (paved roads) by Canadian province is from Transportation Association of Canada (1995). Road data at the country level is from

[8] I utilize external distance (i.e. distances between Canadian provinces and countries external to that province) whereas Anderson and Van Wincoop employ internal distance (i.e. distances between two provinces or two states within a country). These two measures of distance are not directly comparable because external distance encompasses national borders, which leads to higher barriers to trade due to home consumption bias.

various years of the CIA *World Factbook*. 1995 data was employed to ensure that that the level of infrastructure was established well before any trade took place. Paved roads were chosen as a proxy for hard infrastructure because of data availability, consistency over time, and geographical independence.[9] For example, data was available for telephone mainlines per thousand population. However, given the advent of cell phones, telephone mainlines are becoming less reliable as an indicator of infrastructure capability. In contrast, roadway technology remains relatively stable over time. Port data was also available, but the number of ports are dependent upon the geography of a particular country (i.e. whether or not it is landlocked, is an island, etc.). Finally, previous related studies use paved roads as a proxy for hard infrastructure (Martínez-Zarzoso and Márquez-Ramos 2005; Bougheas *et al.* 1999).

Data on soft infrastructure (Internet users per capita) by province is from Statistics Canada (2007b) and by country is from The World Bank Group (2007). 2000 and 1997 Internet user data was employed to ensure that the infrastructure was in place well before any trade took place.[10] Freund and Weinhold (2004) examined the effect of the Internet on international trade using the number of web hosts attributable to each country as a proxy for Internet connectedness. However, they note that since most sites with .org, .edu, .net, .com, and .int domain names typically reside in the United States, the U.S. Internet measure is likely to be biased downward. They compared their results to those in

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[9] However, it should be noted that the data for paved roads by country are unreliable and thus are not suitable for time-series work. However, since this study is cross-sectional, the data reliability problem is somewhat mitigated, but one should still be cognizant of potential measurement errors due to varying definitions across countries (Canning 1998).

[10] Although 1995 road data was used, it was felt that 1995 Internet user data would be too far back in time since Internet use has become much more pervasive in recent years. Additionally, 1995 was chosen as a base year for road data to accommodate data availability for paved roads by Canadian province.

an earlier version of their paper, which used the number of Internet users in each country and found that the results were similar.[11]

Data on innovation includes research and development expenditures, Canadian and U.S. patents, scientific publications as well as scientific tertiary graduates by province and country. Provincial gross domestic expenditures on research and development (GERD) per capita are from the Institut de la Statistique Québec. Country GERD per capita is from UNESCO Institute for Statistics. 2003 and 2000 GERD statistics are used to provide measures of more recent and lagged research and development expenditures. Both provincial and country Canadian patents per capita are from the Canadian Intellectual Property Office (CIPO) *Annual Reports* for 2003-2004 and 2000-2001. Provincial U.S. patents per capita are from the Institut de la Statistique Québec. Country U.S. patents per capita are from the United States Patent and Trademark Office (USPTO). 2003 and 2000 patent data is used to provide measures of more recent and lagged patent grants. Provincial scientific publications per capita are from the Institut de la Statistique Québec. Country scientific publications per capita are from the National Science Foundation (2006). Provincial scientific tertiary graduates per capita are from Statistics Canada (2006). Country scientific tertiary graduates per capita are from the UNESCO Institute for Statistics. 2003 and 2000 scientific publications as

[11] Freund and Weinhold note that the number of Internet users in each country was available for only 34 of the 56 countries in their sample. This suggests that they chose the number of web hosts per country due to data availability. In any event, their results were similar using either measure of Internet connectedness. Also, it appears that using Internet users by country eliminates the aforementioned bias found in the U.S. caused by using web hosts by country.

well as scientific tertiary graduates per capita are used to provide measures of more recent and lagged knowledge capability and human capital potential, respectively.[12]

R&D expenditures and patent citations are commonly used measures of innovation, which are highly correlated with innovation (Feldman and Florida 1994)[13]. Scientific articles as well as scientific tertiary enrollment are also often used as proxies for technological capabilities, where all of the aforementioned innovation variables are typically included in a variety of technological capability indexes (Archibugi and Coco 2005). R&D expenditures and scientific tertiary graduates were chosen as proxies for inputs to innovation. The number of scientific tertiary graduates rather than scientific tertiary enrollment was chosen for consistency since the remaining innovation variables all represent flows rather than stocks. Thus, the number of scientific tertiary graduates should provide a means of capturing the human skills component, which is a key input to the innovative process. Patents and scientific publications were selected as proxies for innovative output. Both U.S. and Canadian patents were included to determine whether or not there is a qualitative distinction between the two types of patents in terms of their impact on trade. Typically, patents are measured as "international patents", which are defined as those patents which are granted by the USPTO to a non-US inventor (or in the case of the US, by a major foreign patent granting agency) (see Stern, Porter, and Furman, 2000 for example). In this paper, U.S. patents and international patents are synonymous. Scientific publications were included to account for the role of academic

[12] Due to the lack of data for scientific publications as well as scientific tertiary graduates for many of the developing countries in the total sample, these variables are included only in the sample of developed countries.
[13] Feldman and Florida conduct simple correlations between 1982 Small Business Administration innovation data and patent counts, R&D expenditure, and high-technology employment by state and find the correlations to be quite high at 0.9344, 0.8551, and 0.9737 respectively.

institutions in the innovation process. However, a drawback of using this variable is that English-speaking countries (and provinces) are likely to be over-represented since most of the journals monitored by the Institute for Scientific Information are in English (Archibugi and Coco 2005).

2.8 RESULTS

2.8.1 Descriptive Statistics

As can be seen in Table 2.1, the level of exports, infrastructure and innovation varies greatly by province and region. Starting with total exports to the entire sample of 60 countries, the Prairies have the highest level of total 2004/2005 exports per capita ($17,995), while the Atlantic provinces exhibit the lowest level of total exports per capita ($8,955). The top exporting provinces (per capita) are Alberta ($23,083), Ontario ($16,023), New Brunswick ($13,348), and Saskatchewan ($13,101) indicating that provincial size as measured by total population is not necessarily a driving force behind total exports per capita. However, in terms of 2004/2005 *hi-tech* exports per capita to countries in the 20 developed country sample, provincial size appears to be of greater importance, at least for the top exporters[14]. Central Canada has by far the highest level of hi-tech exports per capita ($1,364) with both Quebec ($1,735) and Ontario ($1,139) at the front of the pack. For the next tier of hi-tech exporters, size does not appear to be as important since after Quebec and Ontario, Manitoba ($447) and Alberta ($424) have the next highest levels of hi-tech exports per capita. In terms of regions, Atlantic Canada falls at the bottom with lower hi-tech exports per capita than any other region ($83).

[14] See footnote b in Table 2.1 for a detailed account of industries that are considered hi-tech. The list is from Hecker (2005).

Thus, as noted earlier, there is a large disparity in both total and hi-tech provincial exports per capita among provinces and regions.

Next, turning to the infrastructure variables, the length of paved roads per 1,000 kilometers squared (in 1995) is the greatest in Atlantic and Central Canada. Not surprisingly, Western Canada, which is much more sparsely populated, has much lower levels of paved roads per 1,000 kilometers squared. However, given the above provincial and regional export levels, it does not appear that paved roads either foster or inhibit international exports (i.e. Prince Edward Island has the greatest amount of paved roads per 1,000 kilometers squared at 727.9 and yet has both below average total and hi-tech exports). This is borne out later in the regression results. Internet users per 1,000 population (in 2003) also vary greatly by province, with the highest user rate in Western Canada and the lowest user rate in Eastern Canada. Quebec has the lowest user rate (436) of any province mainly due to its large French-speaking population, who are less-likely to use the Internet (Gandal 2006). As with infrastructure, the descriptive statistics do not point to any sort of relationship between Internet use and exports, which can also be seen in the regression results to follow.

To continue, the innovative capability variables can now be compared across provinces and regions. It is interesting to first compare the level of Canadian patents versus U.S. patents per 100,000 population (for 2003). The level of Canadian patents does not vary that much from province-to-province or region-to-region. For instance, for Canadian patents, the Canadian average is 4.1, where the Prairies have the highest level at 5.3 and Atlantic Canada has the lowest level at 1.5. However, for U.S. patents, there is much greater inter-regional (and inter-provincial) variation with the Canadian average at

10.5, Central Canada at the top with 12.5, and Atlantic Canada again at the bottom with 2.5. Thus, Central Canada is a leader in both hi-tech exports per capita and U.S. patents per capita, which implies that greater numbers of U.S. patents result in increased levels of hi-tech exports (which can be seen later in the regression analysis)[15].

Continuing with the innovation measures, R&D expenditures per capita (for 2003) vary greatly by region, with Central Canada at the top ($950) and Atlantic Canada at the bottom ($358). Thus, it appears that higher levels of R&D expenditures imply greater hi-tech exports (which again is found later in the regression results). Scientific articles per 100,000 population (for 2003) do not vary as much by region, where the Canadian average is 101, Western Canada is slightly above average at 104, Central Canada is right at average at 100 , and Atlantic Canada is below average at 88. The same holds true for scientific tertiary graduates per 100,000 population (for 2003) by region, where the Canadian average is 136 with Central Canada and Atlantic Canada slightly above this average at 146 and 144 respectively, and Western Canada below average at 114.

What can be seen after comparing all of the innovation capability variables is that Atlantic Canada greatly lags the rest of Canada for every innovation measure except for the number of scientific tertiary graduates per capita. Unfortunately, as will be seen in the regression results section to follow, the number of scientific tertiary graduates appears to have no effect on either provincial total or hi-tech exports, likely because university graduates are a highly mobile form of human-capital and migrate to other provinces (or countries) to follow job opportunities.

[15] It is also found that U.S. patents are a predictor of total exports.

2.8.2 Regression Results

Using the log-log specification in equation (2), *total* exports per capita are used as the dependent variable. Variable definitions and sources are listed in Appendix 2.1. Tables 2.2-2.4 display regression results for the entire sample, developing countries, and developed countries, respectively. Table 2.5 presents regression results for developed countries using *hi-tech* exports as the dependent variable.

Column 1 includes the base model with distance, provincial (exporter) and country (importer) GDP per capita, and the common language dummy variable. Column 2 adds provincial and country 1995 paved roads and 2000 Internet users as proxies for hard and soft infrastructure to determine their impact on provincial exports. Column 3 includes 2003 provincial and country research and development expenditures, Canadian patents and U.S. patents to account for both inputs to innovation (R&D expenditures) as well as innovative outputs (patents). Both U.S. (International) and non-U.S. (Canadian) patents are included to determine whether or not there is a qualitative distinction between the two types of patents in terms of their impact on trade. In Tables 2.4 and 2.5, which contain samples of developed countries only, two more innovation variables have been added to column 3, 2003 provincial and country scientific publications as well as 2003 scientific tertiary graduates. These variables are not included in Table 2.2 (total sample) or Table 2.3 (developing country sample) due to the large number of missing data points for these variables for developing countries. Column 4's specification adds all of the variables from columns 2 and 3 together into one model (i.e. base specification + infrastructure variables + innovation variables). Column 5 adds country dummy variables to the specification in column 4 to account for fixed effects.

Column 6 is the same as column 4 except that the Internet user variables as well as the innovation variables are lagged. The Internet user variables are from 1997 instead of 2000 to account for any lagged effect of Internet use on trade. The length of paved roadways (divided by land area) for 1995 was chosen again since reliable data by province was unavailable between 1995 and 2005. This limited the choice to using 1995 and/or 2005 data. However, using 2005 road data could cause possible endogeneity problems given the dependent variable is for 2004/2005 provincial exports per capita. Thus, the stock of hard infrastructure is included for only one time period (no lags), whereas the flow of soft infrastructure (Internet users per capita) is included for both 2000 and 1997 to account for more recent and lagged effects of Internet use on trade.[16] The innovation variables are from 2000 instead of 2003 to pick up any lagged effect of R&D expenditures and patent grants (and for developed countries, scientific publications and scientific tertiary graduates) on trade. Column 7 adds country dummy variables to the specification in column 6 to account for fixed effects.

2.8.3 Infrastructure and Trade: Entire Sample

As expected, for the entire sample, which includes 40 developing countries and 20 developed countries, all the variables in the base model (Table 2.2, column 1) are significant at the 5% level and have the expected signs. Thus, the base gravity model holds, where distance is significant and negatively related to provincial exports per

[16] Although 2003 and 2000 was chosen for the current and lagged innovation variables, 2000 and 1997 was chosen for the current and lagged Internet use variable for two reasons. First, 2000 Internet use is somewhat correlated with the 2000 innovation variables, so it was preferred to use 2000 Internet use with the 2003 innovation variables (columns 4 and 8) and 1997 Internet use with the 2000 innovation variables (columns 11 and 14). Second, since Internet use is considered a proxy for soft infrastructure, selecting a greater time lag than 1-2 years between Internet use and the dependent variable (2004/2005 provincial exports per capita) was deemed appropriate.

capita, trading partners' respective GDPs per capita are significant and positively related to provincial exports per capita, and sharing a common language is also significant and positively related to provincial exports per capita. However, provincial and country roads are not significant, indicating that hard infrastructure is not an important factor in explaining provincial exports.

Continuing with Table 2.2 results, 2000 country Internet users per capita (which are a proxy for soft infrastructure) are significant and positively related to provincial exports per capita at the 5% or 10% level (columns 2 and 4). The soft infrastructure (Internet users) results can be compared to Freund and Weinhold (2004) since they employ a large sample of both developed and developing countries. They found that Internet growth affects trade primarily through the exporting country, whereas I found this effect for the importing country only. However, the provincial Internet use variable may not be a very good proxy for soft infrastructure. This is likely due to the inclusion of Quebec, which has a low number of Internet users as a result of its large numbers of native French speakers (who are less likely to use the Internet), but still has high levels of exports.[17] The models which include country fixed effects are largely consistent with the above results for the variables of interest.

2.8.4 Infrastructure and Trade: Developing Countries

Given the heterogeneous nature of the countries in the dataset, more information may be gleaned by separating countries into two groups: developing and developed (as defined

[17] The issue of Quebec's relatively low Internet usage rate was examined by Gandal (2006), who used a unique dataset on home Internet use in Quebec. He found that on average, native English speakers spent approximately 26% more time on the Internet than native French speakers, which is likely a result of significant web content being available only in English. Given that Quebec has a large number of native French speakers; it is then not surprising that Quebec's Internet use lags behind that of the other provinces.

by the United Nations Statistics Division (2007)). This was also done by Martínez-Zarzoso and Márquez-Ramos (2005) in a similar study to determine whether or not technology impacts trade flows differently for developing versus developed countries. The countries used in this study are listed in Appendix 2.2 by category. Table 2.3 displays results for developing countries only.

The base model results are comparable to those in Table 2.2 (see column 1) except that country GDP per capita is not quite significant (but is still positively related to provincial exports per capita). Also, distance is less significant with a t-statistic of only 1.67 in column 1, Table 2.3 versus 3.29 in column 1, Table 2.2. This indicates that distance is less of a barrier for N-S trade, which typically consists of inter-industry goods that are more highly specific to a given region and thus have fewer substitutes.

As in Table 2.2, 2000 country Internet users per capita are significant and positively related to provincial exports per capita in columns 2 and 4, which implies that developing countries with more advanced soft infrastructure import more goods from Canadian provinces. This could indicate that increased levels of soft infrastructure help to facilitate the importation of goods. However, unlike in Table 2.2, country roads are significant (at the 10% level) and are *negatively* related to a country's importation of Canadian goods (in column 2 only). This could signify that as developing countries increase their level of hard infrastructure (paved roads), they may import less from far-away countries like Canada and import more from neighboring countries, where a better road-network facilitates more local trade of goods that are *substitutes* for Canadian imports.

2.8.5 Infrastructure and Trade: Developed Countries

Table 2.4 displays results for developed countries only. The R^2 in the base model in column 1 is 0.291 with all of the variables significant at the 5% level except for provincial GDP per capita, which is still positive, but not quite significant. The high R^2 (compared to 0.039 in column 1, Table 2.2 and 0.027 in column 1, Table 2.3) is expected since the base gravity model has the most explanatory power for trade between two developed regions. One reason this is true is that typically trade between developed countries is intra-industry, where each country has similar skill-intensive products. These products have a large number of substitutes, so transportation costs (distance) are a much larger impediment to intra-industry trade than to inter-industry trade. This can be seen in the high significance of the distance variable, where the t-statistic is 6.09 for distance in column 1, Table 2.4 in the developed country sample compared to 1.67 in column 1, Table 2.3 in the developing country sample.

Unlike in Tables 2.2 and 2.3, 2000 country Internet users are not positively related to a country's importation of Canadian goods in the sample of developed countries (Table 2.4, columns 2 and 4), which indicates that the number of Internet users per capita in developed countries does not affect how much they import from Canadian provinces. However, in column 6 (which includes both infrastructure and innovation variables), 1997 country Internet users per capita are significant and *negatively* related to a country's level of Canadian imports at the 5% level. Perhaps this indicates that in the long-run, having higher levels of soft-infrastructure may serve as a deterrent to imports.

As in Table 2.3, country roads are significant and *negatively* related to a country's level of Canadian imports in the sample of developed countries (Table 2.4, columns 4 and

6) in specifications which include both infrastructure and innovation variables. Again, this may suggest that as developed countries increase their level of hard infrastructure (paved roads), they may import less from far-away countries like Canada and import more from neighboring countries, where a better road-network facilitates more local trade of goods that are *substitutes* for Canadian imports. However, caution should be used in interpreting both infrastructure results since neither infrastructure variable was significant in the infrastructure only specification (column 2).

In terms of the exporting country's hard infrastructure, it should be noted that Martínez-Zarzoso and Márquez-Ramos (2005) found that exporter roads were significant and positively related to exports when examining trade between developed countries, whereas the above results imply no such significance (i.e. see provincial roads). This disparity in results may be due to differences in how inter-regional trade is modeled. For instance, in this study, distance between trading partners is much greater since trade between Canadian provinces and developed countries is examined, with only the U.S. in close proximity to Canada. This differs from Martínez-Zarzoso and Márquez-Ramos' study, where they examine trade between developed countries, which are mainly located within Western Europe. Thus, Martínez-Zarzoso and Márquez-Ramos' study suggests that high quality road networks are significant for exporting countries in terms of shipping goods almost entirely within Europe. In this study, the high-quality provincial road networks are not significant in increasing exports to other developed countries, which is likely the result of Canadian exports being shipped overseas (except for the U.S.), thereby mitigating the importance of roads as a means of transportation. Bougheas *et al.* (1999) also found roads to be significant and positively related to exports.

However, the same issues hold as discussed previously, since their sample included trade among the 9 core European Union and Scandinavian countries, which are all in high geographic proximity to one another.

2.8.6 Infrastructure and Trade in Hi-Tech Goods: Developed Countries

Now that infrastructure's impact on *total* exports has been examined, it would be informative to determine infrastructure's affect on *hi-tech* exports. To do this, export data was collected from 6 industries, which are defined as hi-tech in Hecker (2005).[18] However, the smaller provinces (i.e. Newfoundland, Prince Edward Island, New Brunswick, and Saskatchewan) do not export hi-tech products to a large number of (mostly developing) countries. Given the lack of hi-tech export data to developing countries for the aforementioned provinces, the analysis of the effect of infrastructure on hi-tech exports is limited to developed countries only.

As can be seen, Table 2.5 displays results for *hi-tech* exports to developed countries only. The R^2 in the base model in column 1 is only 0.118 (compared to 0.291 in Table 2.4) with all of the variables significant at the 5% or 10% level, except distance, which is insignificant. However, in this specification, distance is now *positively* related to hi-tech exports per capita (whereas in all previous models, distance was negatively related to total exports). This result may be due to the nature of the traded goods, where regions that are further apart (in distance) may also have distinct technologies from each other and thus trade more hi-tech goods. This result may also suggest a misspecification

[18] These industries (classified by NAICS code) are: 3254: Pharmaceutical and medicine manufacturing; 3341: Computer and peripheral equipment manufacturing; 3342: Communications equipment manufacturing; 3344: Semiconductor and other electronic component manufacturing; 3345: Navigational, measuring, electromedical, and control instruments manufacturing; 3364: Aerospace product and parts manufacturing.

of the model, where the distance variable might not capture the Canada-U.S. trade relationship well since virtually all trade is with the U.S.[19]

Country roads were also found to be significant at the 5% level and are positively related to provincial exports per capita (column 2). Thus, increasing an importing country's hard infrastructure (roads), leads to increased imports of *hi-tech* goods from Canadian provinces, which was the opposite case for total goods imports (i.e. better roads seemed to cause fewer total imports for samples of developing and developed countries). Perhaps in the case of hi-tech goods, better roads facilitate intra-country trade as well as imports from nearby countries of goods that are *complementary* to hi-tech imports from Canadian provinces, thereby leading to higher levels of hi-tech Canadian imports.

Differing from previous specifications, provincial roads are significant (Table 2.5, columns 4 and 5) at the 10% level and are *negatively* related to provincial exports. However, these results do not hold for the model with only infrastructure variables (column 2) or for models that include lagged Internet and innovation variables (columns 6 and 7). Nonetheless, if a dummy variable for Prince Edward Island (which has a disproportionately large number of paved roads per land area) is included in columns 4 and 5; provincial roads are no longer significant. Thus, not too much weight should be attributed to this result. However, it could potentially indicate that better provincial road infrastructure may facilitate more inter-provincial trade in hi-tech goods and less province-country trade.

As in Table 2.4 with total goods, 2000 country Internet users are not positively related to a country's importation of Canadian hi-tech goods. However, as before, 1997

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[19] This problem could be mitigated by using a weighted average distance from province to U.S. using the inverse of state GDPs as weights such as $DIST_{SK\text{-}US} = SUM\ [(DIST_{SK\text{-}STATE})/GDP_{STATE}]$. This would reduce the distance for "peripheral" provinces (i.e. BC, AB, SK, and Atlantic) and may provide better results.

country Internet users per capita are significant and *negatively* related to a country's level of Canadian imports at the 10% level (Table 2.5, column 6). Perhaps this indicates that in the long-run, having higher levels of soft-infrastructure may serve as a deterrent not only to total imports, but also to hi-tech imports.

In summary, as can be seen in Tables 2.2-2.5, a province's infrastructure does not lead to increased exports. This is contrary to the first main hypothesis that a province's infrastructure will help to facilitate increased exports. However, upon closer examination, the results are consistent with the far-flung proximity of trading partners with trade occurring between Canadian provinces and 60 other geographically dispersed countries, where only the U.S. is in close geographic proximity to Canada. Thus, provincial hard infrastructure (roads) is not as significant in overseas trade as it would be in overland trade. It is also found that provincial soft infrastructure (Internet users) was insignificant in leading to more provincial exports. Some of this may be due to the extremely low Internet usage in Quebec vis-à-vis the other provinces, coupled with Quebec's higher than average export levels. Additionally, it was found that an importing country's infrastructure can play a role in increasing (and sometimes decreasing) provincial exports to those countries, so Canadian policymakers should also take note of that.

2.8.7 Innovation and Trade: Entire Sample

Now that the infrastructure related results have been examined, we can turn to the log-log specification in equation (2) to determine how innovation affects provincial exports. The base models with distance, provincial (exporter) and country (importer) GDP, and the common language dummy variable were discussed in the sections on Infrastructure and Trade (Tables 2.2-2.5, column 1).

To begin, the impact of the exporting provinces' innovation variables on total provincial exports for the entire sample will be examined. In Table 2.2 (columns 3-5), 2003 provincial U.S. patents per capita are significant at the 5% or 10% level and are positively related to provincial exports per capita, while in columns 6 and 7, 2000 provincial U.S. patents per capita are significant at the 10% level and are positively related to provincial exports per capita.

Next, the impact of importing countries' innovation variables on provincial exports to these countries will be considered. In columns 3 and 4, 2003 country R&D expenditures per capita are significant at the 10% level and are positively related to provincial exports per capita, while in column 6, 2000 country R&D expenditures per capita are significant at the 5% level and are positively related to provincial exports per capita. Additionally, 2000 country U.S. patents per capita are significant in column 6 at the 5% level and are positively related to provincial exports per capita. Finally, 2003 country Canadian patents per capita are only significant (at the 10% level) in column 4, while 2000 country Canadian patents per capita are not significant (see column 6).

Thus, based on the above results, countries that spent more on R&D in both 2000 and 2003 imported more goods from Canadian provinces in 2004/2005. Additionally, countries that attained more U.S. patents imported more from Canadian provinces in 2004/2005, but this occurs with a lag since only 2000 country U.S. patents are significant. More importantly, from a Canadian public policy perspective, provinces with greater numbers of U.S. patents (both recent and with a lag) tended to export more.

The above results illustrate that Canadian provinces tend to export more to countries that invest more in R&D and attain more U.S. patents. However, given that country Canadian patents are only significant in one of the specifications; this may also imply that a country's acquisition of Canadian patents may serve as a *substitute* for Canadian imports, while a country's R&D expenditures and acquisition of U.S. patents may serve as *compliments*. Additionally, U.S. patents may be a better "proxy" for innovation than Canadian patents since Canadian patents were not significant for provinces in any of the specifications.

Thus, in terms of increasing Canada's international competitiveness, it appears that attaining greater numbers of U.S. (international) patents is the best way for provinces to increase their total exports, where a 1% increase in 2003 provincial U.S. patents per capita increases 2004/2005 provincial exports per capita by approximately 2.51-2.77% (columns 3-5, Table 2.2). This is consistent with the second main hypothesis of the paper which states that a province's innovative capability will lead to increased exports.

2.8.8 Innovation and Trade: Developing Countries

As in the above analysis of infrastructure's impact on trade, it is informative to divide the dataset into both developing and developed countries. Table 2.3 displays results for developing countries only. The results are comparable to those in Table 2.2, with the number of provincial U.S. patents having an even greater impact on provincial exports to developing countries. Specifically, for exports to developing countries, a 1% increase in 2003 provincial U.S. patents per capita increases 2004/2005 provincial exports per capita by approximately 3.84% (column 3, Table 2.3) versus 2.51-2.77% for the entire sample (column 3-5, Table 2.2). However, the significance level is higher for the 2003 provincial U.S. patent variable in the total sample (5-10% significance level) versus the developing country sample (10% or slightly above the 10% significance level).

It is also found that a country's per capita R&D expenditures are again significant at the 10% level in 2003 and at the 5% level in 2000 (see columns 3, 4, and 6) in the developing country sample. This differs from the developed country sample results to follow (Table 2.4), where a country's R&D expenditures are not a significant factor in terms of affecting the importation of Canadian goods. However, an increased level of R&D expenditures for developing countries may be indicative of increased innovative capacity translating into greater openness to trade. Thus, in terms of trade policy, Canadian provinces may want to target their exports to developing countries with higher levels of R&D expenditures since these countries appear to be more open to trade vis-à-vis their cohort of developing countries with lower levels of R&D expenditures.

These results are not directly comparable to Martínez-Zarzoso and Márquez-Ramos (2005) because they examine trade between developing countries only or between developed countries only, whereas in this specification, trade between developed provinces and developing countries is considered. Additionally, their Internet variable is embedded in an innovation index, which includes U.S. patents, but not R&D expenditures. However, they did find that in the case of trade between developing countries, both exporter and importer TAI (technology achievement index) was significant. Thus, Martínez-Zarzoso and Márquez-Ramos' results are comparable to these results in a macro sense in that in both cases, country and provincial innovation variables are found to be significant and positively related to exports.

2.8.9 Innovation and Trade: Developed Countries

Table 2.4 presents the results for developed countries only. The results are similar to those of the entire sample (Table 2.2) and developing countries only (Table 2.3) for provincial exports (but weaker). However, the results for importing countries differ, particularly for 2003 country Canadian patents, which are now highly significant and *negatively* related to a country's importation of Canadian goods. Different results are expected, given the different composition of trade inherent between two developed regions versus trade between developed provinces and developing countries. To illustrate, trade flows between Canadian provinces and developing countries represent North-South (N-S) trade, whereas trade flows between Canadian provinces and developed countries represent North-North (N-N) trade. Given that the number of developing countries (40) is twice as great as the number of developed countries (20), the entire sample results are more closely aligned with N-S trade. Thus, the composition of trade in the developed country sample is expected to be quite distinct from that of the other two samples given it is more representative of intra-industry trade (versus inter-industry trade, which is more common in a N-S model).

Further, as noted at the beginning of the Regression Results section, Table 2.4 contains two additional innovation variables: provincial and country scientific publications per capita as well as scientific tertiary graduates per capita. These variables were readily available for the sample of 20 developed countries and 10 Canadian provinces, but were missing for many of the developing countries in the total sample (Table 2.2) and developing countries sample (Table 2.3).

To begin, using the sample of developed countries; it is found that 2003 and 2000 provincial U.S. patents are not as significant as they were in samples that included all countries or just developing countries. For instance, while provincial U.S. patents are not significant in any of the specifications in Table 2.4, in unreported specifications both 2003 and 2000 provincial U.S. patents were found to be significant. For example, as noted above, a 1% increase in 2003 provincial U.S. patents per capita increased 2004/2005 provincial exports per capita by 2.51-2.77% for the total sample and 3.84% for the sample of developing countries. However, using the sample of developed countries, a 1% increase in 2003 provincial U.S patents per capita only yielded a 0.61% increase in 2004/2005 exports per capita.[20] Therefore, the second main hypothesis of the paper that a province's innovative capability will lead to increased exports holds for developed countries, but not as strongly.

Now that the provincial innovation variable results have been examined, the country innovation variable results can be reported. As noted in the previous section, country R&D expenditures are not a significant factor in terms of affecting the importation of Canadian goods into developed countries (but were a significant factor for the entire sample as well as the sample of developing countries only).

Conversely, one can now observe that 2003 country U.S. patents are significant in addition to 2000 country U.S. patents (see columns 3, 4, and 6) at the 5% level and are positively related to provincial exports per capita. Also, 2003 country Canadian patents per capita are significant at the 5% level and are *negatively* related to provincial exports per capita (columns 3 and 4). This reinforces the substitution effect discussed earlier,

[20] These results were found in an unreported specification that included all of the variables reported in column 3 plus country fixed effects.

where countries (in this case, developed countries) are more likely to import goods from Canadian provinces when these countries have fewer Canadian patents (at least in the short run). In this case, Canadian patents can be viewed as a *substitute* for importing Canadian goods, much like Canadian foreign direct investment in a country might be viewed as a substitute for Canadian imports. Again, U.S. patents can be seen as a *complement*, so countries with greater numbers of U.S. patents will import more Canadian goods. This also highlights the idea that countries will trade more if they have their own unique (and differing) technologies.

It is also found that 2000 scientific publications per capita and both 2003 and 2000 scientific tertiary graduates per capita for countries are significant at the 5% level and are *negatively* related to a country's 2004/2005 imports of provincial goods (see columns 4 and 6). These results indicate that developed countries that are adding to their knowledge base in the form of greater numbers of published scientific journal articles and are investing more in human capital in the form of higher numbers of scientific bachelor's, master's and Ph.D. level graduates may view the importation of Canadian goods as *substitutes* for their own goods. Thus, a country's increases to its knowledge base as well as its investment in human capital appear to be mechanisms used to increase the competitiveness of a country's own products at the expense of other country's imports.

These results can be compared to Martínez-Zarzoso and Márquez-Ramos (2005) since they examined trade between developed countries. They found that only exporter TAI (technology achievement index) was significant and positively related to exports, which is consistent with the findings in this paper that provincial (exporter) innovation is significant and positively related to exports. However, this paper's results also indicate that importer innovation is significant and could be negatively or positively related to imports. Perhaps no effect in importer innovation was found by Martínez-Zarzoso and Márquez-Ramos because their results may have been obfuscated by their use of TAI, where a number of innovation variables are aggregated into one index, which could cancel out positive and negative effects.

2.8.10 Innovation and Trade in Hi-Tech Goods: Developed Countries

Following the above analysis of innovation's impact on total exports, one can examine innovation's impact on *hi-tech* exports. As before, when infrastructure's impact on provincial exports was examined, the analysis of the affect of innovation on hi-tech exports is limited to developed countries only (see Table 2.5). The R^2 in column 4 is only 0.281 (compared to 0.533 in column 4, Table 2.4). However, distance is *positively* related to hi-tech exports (whereas in all previous models, distance was negatively related to total exports). As noted earlier, this may be due to the nature of the traded goods, where regions that are further apart (in distance) also have distinct technologies from each other and thus trade more hi-tech goods.

The results in Table 2.5 are actually quite different from those in Table 2.4. For instance, 2003 provincial R&D expenditures are now significant at the 10% level and positively related to provincial hi-tech exports (see columns 4 and 5). Additionally, both 2003 and 2000 provincial scientific publications are significant at the 5 % and 10% levels respectively and are positively related to provincial hi-tech exports (see columns 3-7). Nonetheless, akin to Table 2.4 results, Provincial U.S. patents are not significant in any of the specifications in Table 2.5. However, in unreported specifications it was found that 2000 provincial U.S. patents were significant at the 5% or 10% level and are positively related to provincial hi-tech exports per capita.[21] Finally, 2000 provincial Canadian patents per capita are now significant at the 10% level and are *negatively* related to provincial hi-tech exports per capita (see columns 6 and 7).

What is striking about the aforementioned results is the order of magnitude of the significance of the provincial innovation variables. To demonstrate, a 1% increase in 2003 provincial R&D expenditures per capita, 2003 provincial scientific publications per capita, and 2000 provincial U.S. patents per capita leads to a respective 13.28 -14.86%, 19.38-22.34%, and 9.81-12.18% increase in 2004/2005 provincial hi-tech exports per capita[22]. This again supports the second main hypothesis that a province's innovative capability will lead to increased exports, where it is also found to hold not just for total exports, but also for hi-tech exports.

Another interesting corollary that stems from these results is that lagged provincial Canadian patents actually hinder the exportation of Canadian hi-tech goods. This may suggest that provinces that focus on the generation of more Canadian patents are more likely to sell their hi-tech products within Canada rather than exporting these goods to other countries. Perhaps this also helps stem the tide of other countries' hi-tech imports, although the answer to this question is beyond the scope of this study.

Finally, the significance of R&D expenditures as well as scientific publications in increasing a province's hi-tech exports suggests that current policies to increase

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[21] These results were found in unreported specifications that included all of the variables reported in column 3, where the innovation variables were from 2000 instead of 2003 in models both with and without country fixed effects.

[22] As noted above, the 2000 U.S. patent results are from unreported specifications as referred to in the previous footnote.

provincial innovation funding as well as to attract high-caliber research scientists are on the right track. For instance, the Canada Foundation for Innovation (CFI) was established in 1997 by the Government of Canada to help fund research infrastructure. To date the CFI has committed more than $3.75 billion in support of a variety of projects at a large number of research institutions and municipalities across Canada (Canada Foundation for Innovation 2007). The Canadian Research Chair Program (established in 2000) is another example of a program designed to increase the innovative capability of provinces by attracting high caliber researchers to Canadian universities and affiliated research institutes with a $300 million per year investment (Government of Canada 2007a).

Interestingly, the number of provincial scientific tertiary graduates was not significant in increasing the amount of provincial hi-tech exports. One explanation for this result is that university graduates are quite mobile and are likely to relocate to areas with the best job opportunities. Thus, if provinces want to increase their innovative capability through a more highly skilled workforce, increasing the number of scientific tertiary graduates may not be an effective policy unless commensurate jobs follow.

Now that provincial innovation results have been examined, country innovation results can be considered. 2003 country R&D expenditures are now found to be significant at the 10% level and *negatively* related to a country's importation of Canadian hi-tech goods (see column 3). 2003 country Canadian patents are again highly significant and *negatively* related to the importation of Canadian hi-tech goods (see columns 3 and 4). Additionally, 2003 country U.S. patents are also highly significant and positively related to the importation of Canadian hi-tech goods (see columns 3 and 4).

Therefore, based on the above results, countries with greater numbers of U.S. patents tend to import more hi-tech goods from Canadian provinces, while countries with higher R&D expenditures and higher numbers of Canadian patents tend to import fewer hi-tech goods from Canadian provinces. Thus, countries may view U.S. patents (an innovative output) as complementary to high-tech Canadian imports while they may view R&D expenditures (an input to innovation) as a substitute, where countries may be investing in their own technology to stem the tide of hi-tech imports. As noted earlier, these countries likely view Canadian patents as a substitute for importing Canadian hi-tech goods (much like Canadian foreign direct investment would serve as a substitute for Canadian hi-tech imports).

In summary, as can be seen in Tables 2.2-2.5, a province's innovative capability leads to increased exports. Additionally, provincially held Canadian patents did not prove to be a good proxy for innovation in terms of increasing provincial exports, whereas, provincially held U.S. patents were highly significant and positively related to a province's exports. However, although provincial U.S. patents were significant in increasing exports to the sample of all countries as well as to developing countries, they were not as significant in increasing exports to developed countries. It was also found that provincial R&D expenditures and provincial scientific publications as well as provincial U.S. patents were significant in increasing hi-tech exports to developed countries. Interestingly, provincial Canadian patents actually served as a deterrent to provincial hi-tech exports, which may suggest that Canadian patents help to foster more inter-provincial trade of hi-tech Canadian goods rather than exports to other countries of these goods.

2.9 CONCLUSION

The gravity model has been an empirical success in estimating trade flows between countries. Its main criticism of lacking a theoretical foundation has been recently countered (Deardorff 1998; Feenstra *et al.*2001), where trade economists now acknowledge that the gravity model has a theoretical basis. Thus, the gravity equation continues to be widely used in empirical trade models. Standard gravity models are used to estimate the volume of trade between two countries by typically including the GDP of each country as well as the distance between each country as independent variables. These models can easily be augmented to determine technology and innovation's impact on trade (Martínez-Zarzoso and Márquez-Ramos 2005; Bougheas *et al.* 1999; and Freund and Weinhold 2004).

Using an augmented gravity model, the impact of infrastructure and innovation on Canadian exports by province to Canada's top 60 export markets (for the average of 2004-2005 exports) was examined. More information was gleaned from the results by grouping these 60 export markets (countries) into two categories: developing and developed countries. It was hypothesized that a province's infrastructure would help to facilitate increased exports. This was not borne out in the results. However, the importing countries' infrastructure was significant in some cases in facilitating trade. For instance, a higher level of road infrastructure in developing and developed country samples resulted in a decrease in imports of total goods from Canadian provinces. This may suggest that with improvement in hard infrastructure, a country may import less from far-away countries like Canada and import more from neighboring countries, where a better road-network facilitates more local trade of goods that are *substitutes* for Canadian imports. Conversely, it was also found that a higher level of road infrastructure in developed countries leads to an increase in imports of *hi-tech* goods from Canadian provinces. This may be due to better roads facilitating intra-country trade as well as imports from nearby countries of goods that are *complementary* to hi-tech imports from Canadian provinces.

Country Internet users per capita were significant and positively related to total provincial exports to all countries as well as to developing countries (but not to developed countries). This implies that Canadian provinces are more likely to export to developing countries that have higher levels of soft infrastructure as measured by Internet users. This further suggests that better soft infrastructure in developing countries lowers trade barriers (costs).

It was also hypothesized that a province's innovative capability would lead to increased exports. This hypothesis was found to be consistent with this study's findings, where the innovation results have implications for Canadian public policy in terms of increasing provinces' international competitiveness. For instance, if provincial policymakers would like to increase provinces' total exports, they should consider ways of fostering an environment that leads to an increase in applications for U.S. patents. To illustrate, a 1% increase in 2003 provincial U.S. patents increases 2004/2005 provincial exports by 2.51-2.77% (columns 3-5, Table 2.2). This impact is even greater for provincial exports to developing countries, where a 1% increase in 2003 provincial U.S. patents increases 2004/2005 provincial exports by 3.84% (column 3, Table 2.3). In the case of provincial exports to developed countries, U.S. patents do not have as great of an impact, where a 1% increase in 2003 provincial U.S. patents only results in a 0.61% increase in 2004/2005 provincial exports (unreported results).

If policymakers would like to increase not only exports, but also *hi-tech* exports, other factors in addition to provincial U.S. patents lead to increased provincial exports of hi-tech goods. For example, provincial R&D expenditures as well as the number of provincial scientific publications are both significant drivers in increasing the amount of provincial hi-tech exports. Thus, a course of action that fosters more provincial R&D as well as creates an environment conducive for provincial researchers to increase their output of scientific journal articles should be an instrumental part of any hi-tech export policy. Any policy should also be tailored to a specific province and region, where as seen in the descriptive statistics, Atlantic Canada lags far behind the rest of Canada in terms of innovative capability and thus needs to play catch-up in order to compete.

Furthermore, in targeting export markets for their province's products, provincial policymakers should be aware of how a country's innovative capability affects its propensity towards Canadian imports. For example, developing countries with higher levels of R&D expenditures import greater amounts of Canadian goods, likely due to lower barriers to trade, which translate into greater amounts of Canadian imports. However, for developed countries, increased levels of R&D no longer lower trade barriers and thus have no impact on how much that country imports from abroad. Moreover, countries that have higher levels of U.S. patents are likely to be superior export markets for Canadian goods due to their differing technological expertise, whereas countries that have higher levels of Canadian patents are likely to be inferior export markets for Canadian goods due to their competing technology.

Finally, it was postulated that U.S. patents would have a greater impact on exports than non-U.S. patents since U.S. patents are typically viewed as a signal of international competitiveness. The results support this hypothesis. It was found that increasing the number of provincially held U.S. patents increases total provincial exports as well as hi-tech exports; whereas increasing the number of provincially held Canadian patents had no affect on provincial exports and potentially a negative affect on provincial hi-tech exports. However, it was also found that for developed countries, increasing the number of Canadian patents awarded to these countries may actually serve as a deterrent to Canadian imports. Thus, developed countries appear to view the acquisition of Canadian patents as a substitute for the importation of Canadian goods, much like Canadian foreign direct investment. Consequently, Canadian policymakers should be aware of both the apparent lack of impact of provincial Canadian patents on provincial exports (and possible negative impact on provincial high-tech exports) as well as the potentially negative impact of country Canadian patents on provincial exports to developed countries. Further research into the question of how the acquisition of a country's own patents versus the acquisition of international patents (i.e. U.S. patents) affects a country's international competitiveness would be helpful in providing additional insights.

Table 2.1: **Descriptive Statistics**

Mean Values

Province/Region	Total Exports[a]	Hi-Tech Exports[b]	Paved Roads[c]	Internet User[d]	Can. Patents[e]	U.S. Patents[f]	R&D Exps[g]	Scientific Articles[h]	Scientific Tertiary Grads[i]
Newfoundland/ Labrador	$8,661	$50	25.7	455	1.0	1.5	$324	76	127
Prince Edward Island	$5,245	$251	727.9	511	0.7	1.5	$320	81	61
Nova Scotia	$6,140	$114	301.9	520	1.4	3.0	$437	128	187
New Brunswick	$13,348	$35	100.1	452	2.0	2.8	$289	49	118
Total Atlantic	**$8,955**	**$83**	**73.4**	**483**	**1.5**	**2.5**	**$358**	**88**	**144**
Quebec	$9,143	$1,735	68.1	436	4.8	14.0	$927	91	130
Ontario	$16,023	$1,139	78.8	542	3.9	11.7	$965	106	155
Total Central	**$13,421**	**$1,364**	**72.4**	**501**	**4.2**	**12.5**	**$950**	**100**	**146**
Manitoba	$8,221	$447	20.1	498	3.8	4.8	$392	88	103
Saskatchewan	$13,101	$61	33.2	469	2.5	4.7	$396	109	120
Alberta	$23,083	$424	66.3	588	6.8	9.3	$580	121	133
Total Prairies	**$17,995**	**$362**	**41.0**	**545**	**5.3**	**7.5**	**$504**	**112**	**124**
British Columbia	$8,006	$209	42.3	559	3.2	9.2	$491	95	102
Total Western	**$13,610**	**$295**	**41.5**	**551**	**4.4**	**8.2**	**$498**	**104**	**114**
Total Canada (excluding territories)	**$13,149**	**$949**	**57.2**	**515**	**4.1**	**10.5**	**$771**	**101**	**136**

a: Total Exports = (2004/2005 total exports in Canadian dollars to the entire sample of 60 countries)/(2004 population) or total exports per capita.
b: Hi-Tech Exports = (2004/2005 hi-tech exports in Canadian dollars to the sample of 20 developed countries)/(2004 population) or hi-tech exports per capita. Hi-tech industries (classified by NAICS code) are: 3254: Pharmaceutical and medicine manufacturing; 3341: Computer and peripheral equipment manufacturing; 3342: Communications equipment manufacturing; 3344: Semiconductor and other electronic component manufacturing; 3345: Navigational, measuring, electromedical, and control instruments manufacturing; 3364: Aerospace product and parts manufacturing.
c: Paved Roads = (paved roads in km/land area in km^2)* 1,000 or paved roads (km) per 1,000 km^2 for 1995.
d: Internet Users = (Internet users per capita) * 1,000 or Internet users per 1,000 population for 2000.
e: Canadian Patents = (Canadian patents per capita) * 100,000 or Canadian patents per 100,000 population for 2003.
f: U.S. Patents = (U.S patents per capita) * 100,000 or U.S. patents per 100,000 population for 2003.
g: R&D Expenditures = R&D expenditures per capita in Canadian dollars for 2003.
h: Scientific Articles = (Scientific Articles per capita) * 100,000 or Scientific articles per 100,000 population for 2003.
i: Scientific Tertiary Graduates = (Scientific Tertiary Graduates per capita) * 100,000 or Scientific tertiary graduates per 100,000 population for 2003.

Table 2.2: Regression Results: Infrastructure and Innovation's Impact on Exports: Developed and Developing Countries

(2004/2005 Provincial Total Exports)/(2004 Provincial Population) as the Dependent Variable[a,b,c]
Log-Log Specification (Developed and Developing Countries[d])

Variable[e]	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Constant	-43.58 (2.09)**	-25.98 (1.54)	22.75 (0.60)	30.97 (0.75)	10.91 (0.31)	38.07 (0.94)	34.52 (0.91)
Distance	-1.95 (3.29)**	-2.21 (3.13)**	-1.97 (3.76)**	-2.31 (3.39)**	-3.42 (2.60)**	-2.01 (4.02)**	-3.72 (2.83)**
2004 Provincial GDP per capita	4.27 (2.20)**	1.66 (1.25)	-0.62 (0.21)	-1.26 (0.53)	-1.19 (0.46)	-1.92 (0.60)	-2.07 (0.68)
2004 Country GDP per capita	1.81 (2.52)**	-2.67 (1.84)*	1.17 (1.38)	-1.12 (1.55)		0.54 (0.46)	
Common Language	1.42 (3.16)**	0.99 (2.99)**	0.70 (2.79)**	1.07 (2.62)**	0.69 (1.32)	1.30 (2.58)**	0.85 (1.42)
1995 Provincial Roads		-0.38 (0.86)		0.26 (0.35)	0.24 (0.37)	0.60 (0.97)	0.59 (1.02)
1995 Country Roads		-0.42 (1.35)		-0.61 (1.53)		-0.39 (1.22)	
Provincial Internet Users per capita[f]		6.72 (1.47)		2.74 (0.69)	3.26 (0.76)	1.52 (0.90)	1.98 (0.97)
Country Internet Users per capita[f]		2.84 (2.26)**		1.70 (1.84)*		0.018 (1.26)	
Provincial R&D Expenditures per capita[g]			-2.00 (1.37)	-2.18 (0.92)	-2.55 (1.08)	-2.79 (1.14)	-3.20 (1.32)
Country R&D Expenditures per capita[g]			0.048 (1.73)*	0.040 (1.70)*		0.026 (2.06)**	
Provincial Canadian Patents per capita[g]			0.28 (0.25)	0.80 (0.61)	0.72 (0.50)	0.0082 (0.007)	0.11 (0.10)
Country Canadian Patents per capita[g]			0.00055 (0.11)	0.0055 (1.66)*		-0.0012 (0.12)	
Provincial U.S. Patents per capita[g]			2.71 (2.05)**	2.51 (1.77)*	2.77 (1.68)*	4.00 (1.76)*	4.23 (1.93)*
Country U.S. Patents per capita[g]			-0.0062 (0.18)	-0.014 (0.39)		0.048 (2.24)**	
Country Fixed Effects	No	No	No	No	Yes	No	Yes
N	600	600	600	600	600	600	600
R^2	0.039	0.068	0.0915	0.105	0.242	0.127	0.244

a: * indicates significance at the 10% level and ** indicates significance at the 5% level.
b: The absolute values of the t-statistics are given in parentheses.
c: Results are corrected for heteroskedasticity (using the ;Hetero command in LIMDEP).
d: For a full list of sample countries, see Appendix 2.2.
e: Provincial variables refer to characteristics of the exporting provinces, whereas country variables refer to characteristics of the importing countries.
f: 2000 Internet users per capita are included in columns 1-5 and 1997 Internet users per capita are included in columns 6-7.
g: 2003 innovation variables are included in columns 1-5 and 2000 innovation variables are included in columns 6-7.

Table 2.3: Regression Results: Infrastructure and Innovation's Impact on Exports: Developing Countries

(2004/2005 Provincial Total Exports)/(2004 Provincial Population) as the Dependent Variable[a,b,c]

Log-Log Specification (Developing Countries[d])

Variable[e]	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Constant	-60.77 (2.10)**	-46.08 (1.72)*	31.84 (0.58)	37.99 (0.63)	12.66 (0.24)	46.30 (0.81)	41.11 (0.79)
Distance	-2.48 (1.67)*	1.63 (1.37)	-2.79 (1.80)*	-2.37 (1.78)*	-2.33 (0.97)	-1.98 (1.56)	-2.83 (1.28)
2004 Provincial GDP per capita	5.91 (2.06)**	2.29 (1.18)	-1.11 (0.26)	-2.06 (0.60)	-2.14 (0.55)	-3.08 (0.65)	-3.07 (0.68)
2004 Country GDP per capita	2.34 (1.63)	-3.75 (2.01)**	2.16 (1.33)	-0.86 (0.88)		1.23 (0.59)	
Common Language	1.83 (2.05)**	1.69 (1.57)	0.67 (1.13)	2.26 (1.46)	2.07 (1.42)	2.27 (1.36)	2.25 (1.58)
1995 Provincial Roads		-0.44 (0.68)		0.50 (0.46)	0.51 (0.50)	0.92 (1.02)	0.95 (1.09)
1995 Country Roads		-0.84 (1.86)*		-0.96 (1.60)		-0.63 (1.30)	
Provincial Internet Users per capita[f]		9.10 (1.41)		3.26 (0.60)	3.47 (0.53)	2.09 (0.86)	2.21 (0.74)
Country Internet Users per capita[f]		3.43 (2.48)**		1.90 (2.14)**		0.014 (0.81)	
Provincial R&D Expenditures per capita[g]			-3.15 (1.48)	-3.23 (0.93)	-3.19 (0.95)	-4.27 (1.19)	-4.44 (1.28)
Country R&D Expenditures per capita[g]			0.051 (1.83)*	0.042 (1.73)*		0.032 (1.97)**	
Provincial Canadian Patents per capita[g]			0.62 (0.36)	1.53 (0.79)	1.54 (0.72)	0.13 (0.08)	0.09 (0.05)
Country Canadian Patents per capita[g]			0.0042 (1.28)	0.0073 (1.97)**		-0.0054 (0.45)	
Provincial U.S. Patents per capita[g]			3.84 (1.92)*	3.41 (1.64)	3.37 (1.45)	5.81 (1.74)*	5.97 (1.87)*
Country U.S. Patents per capita[g]			-0.0088 (0.25)	-0.018 (0.47)		0.048 (2.19)**	
Country Fixed Effects	No	No	No	No	Yes	No	Yes
N	400	400	400	400	400	400	400
R^2	0.027	0.062	0.0915	0.105	0.234	0.126	0.237

a: * indicates significance at the 10% level and ** indicates significance at the 5% level.
b: The absolute values of the t-statistics are given in parentheses.
c: Results are corrected for heteroskedasticity (using the ;Hetero command in LIMDEP).
d: For a full list of sample countries, see Appendix 2.2.
e: Provincial variables refer to characteristics of the exporting provinces, whereas country variables refer to characteristics of the importing countries.
f: 2000 Internet users per capita are included in columns 1-5 and 1997 Internet users per capita are included in columns 6-7.
g: 2003 innovation variables are included in columns 1-5 and 2000 innovation variables are included in columns 6-7.

Table 2.4: Regression Results: Infrastructure and Innovation's Impact on Exports: Developed Countries

(2004/2005 Provincial Total Exports)/(2004 Provincial Population) as the Dependent Variable[a,b,c]
Log-Log Specification (Developed Countries[d])

Variable[e]	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Constant	-14.68 (1.48)	-8.90 (0.83)	-5.29 (0.27)	10.40 (0.45)	5.97 (0.56)	13.63 (0.56)	-2.69 (0.22)
Distance	-1.66 (6.09)**	-1.69 (5.58)**	-1.53 (5.53)**	-1.70 (6.71)**	-1.25 (2.94)**	-1.88 (6.67)**	-1.16 (2.92)**
2004 Provincial GDP per capita	1.04 (1.55)	0.66 (0.68)	0.71 (0.78)	0.43 (0.44)	0.46 (0.80)	0.63 (0.63)	0.70 (1.16)
2004 Country GDP per capita	2.04 (3.45)**	1.54 (2.31)**	0.55 (0.58)	0.29 (0.27)		-2.82 (2.84)**	
Common Language	1.01 (3.54)**	1.06 (3.71)**	1.34 (4.46)**	1.39 (4.72)**	0.084 (0.35)	1.70 (5.68)**	0.12 (0.49)
1995 Provincial Roads		-0.14 (1.02)		-0.19 (1.27)	-0.16 (1.62)	-0.064 (0.37)	-0.044 (0.41)
1995 Country Roads		0.085 (0.76)		-0.36 (3.02)**		-0.46 (3.45)**	
Provincial Internet Users per capita[f]		0.22 (0.12)		-0.18 (0.10)	0.022 (0.02)	-0.41 (0.55)	-0.25 (0.51)
Country Internet Users per capita[f]		0.36 (1.23)		-0.81 (1.65)		-0.75 (2.65)**	
Provincial R&D Expenditures per capita[g]			0.0036 (0.05)	0.24 (0.29)	0.28 (0.51)	0.28 (0.42)	0.47 (1.02)
Country R&D Expenditures per capita[g]			-0.64 (1.08)	-0.94 (1.63)		0.13 (0.22)	
Provincial Canadian Patents per capita[g]			-0.51 (1.00)	-0.59 (1.16)	-0.56 (1.87)*	-0.64 (1.17)	-0.55 (1.56)
Country Canadian Patents per capita[g]			-1.52 (5.70)**	-1.54 (6.00)**		0.0062 (1.07)	
Provincial U.S. Patents per capita[g]			0.67 (1.12)	0.61 (0.94)	0.50 (1.25)	0.77 (1.30)	0.49 (1.26)
Country U.S. Patents per capita[g]			2.20 (8.91)**	2.63 (9.41)**		1.38 (5.06)**	
Provincial S&E Articles per capita[g]			-0.12 (0.23)	0.17 (0.28)	-0.18 (0.46)	0.15 (0.27)	0.25 (0.76)
Country S&E Articles per capita[g]			-0.69 (1.55)	-0.66 (1.40)		-1.97 (4.23)**	
Provincial S&E Grads per capita[g]			0.12 (0.30)	-0.09 (0.22)	0.12 (0.48)	-1.00 (1.14)	-0.67 (1.21)
Country S&E Grads per capita[g]			-0.31 (0.80)	-0.90 (2.08)**		-1.24 (3.69)**	
Country Fixed Effects	No	No	No	No	Yes	No	Yes
N	200	200	200	200	200	200	200
R^2	0.291	0.300	0.503	0.533	0.809	0.519	0.809

a: * indicates significance at the 10% level and ** indicates significance at the 5% level.
b: The absolute values of the t-statistics are given in parentheses.
c: Results are corrected for heteroskedasticity (using the ;Hetero command in LIMDEP).
d: For a full list of sample countries, see Appendix 2.2
e: Provincial variables refer to characteristics of the exporting provinces, whereas country variables refer to characteristics of the importing countries.
f: 2000 Internet users per capita are included in columns 1-5 and 1997 Internet users per capita are included in columns 6-7.
g: 2003 innovation variables are included in columns 1-5 and 2000 innovation variables are included in columns 6-7.

Table 2.5: Regression Results: Infrastructure and Innovation's Impact on Hi-Tech Exports: Developed Countries

(2004/2005 Provincial Hi-Tech Exports)/(2004 Provincial Population) as the Dependent Variable[a,b,c,d]
Log-Log Specification (Developed Countries[e])

Variable[f]	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Constant	-602.02 (2.48)**	-611.06 (2.46)**	45.10 (0.22)	153.56 (0.70)	73.27 (0.66)	126.44 (0.60)	-82.85 (0.76)
Distance	5.77 (1.48)	6.56 (1.49)	2.58 (1.02)	3.79 (1.37)	7.32 (1.45)	0.059 (0.03)	7.74 (1.56)
2004 Provincial GDP per capita	18.79 (2.47)**	10.15 (1.87)*	-5.20 (0.68)	-13.32 (1.87)*	-13.38 (1.79)*	3.15 (0.40)	4.91 (0.64)
2004 Country GDP per capita	33.39 (1.84)*	29.89 (1.48)	23.06 (1.03)	16.18 (0.88)		-8.26 (0.46)	
Common Language	3.81 (1.93)*	5.82 (2.10)**	1.81 (0.51)	5.85 (1.75)*	5.07 (1.58)	7.32 (2.03)**	5.54 (1.60)
1995 Provincial Roads		-1.55 (1.04)		-3.47 (1.73)*	-3.38 (1.70)*	-1.86 (1.05)	-1.73 (0.97)
1995 Country Roads		2.85 (2.00)**		1.34 (0.98)		0.63 (0.66)	
Provincial Internet Users per capita[g]		18.14 (1.39)		6.30 (0.61)	5.37 (0.48)	-4.94 (0.79)	-6.70 (1.06)
Country Internet Users per capita[g]		2.31 (0.52)		-9.15 (0.99)		-3.94 (1.68)*	
Provincial R&D Expenditures per capita[h]			5.68 (0.90)	13.28 (1.70)*	14.86 (1.91)*	5.14 (0.75)	8.12 (1.22)
Country R&D Expenditures per capita[h]			-15.56 (1.76)*	-12.42 (1.49)		-4.02 (0.58)	
Provincial Canadian Patents per capita[h]			2.81 (0.78)	2.22 (0.60)	2.45 (0.61)	-7.90 (1.69)*	-8.20 (1.76)*
Country Canadian Patents per capita[h]			-11.57 (2.15)**	-11.21 (2.19)**		0.18 (1.14)	
Provincial U.S. Patents per capita[h]			-0.49 (0.11)	-4.31 (0.88)	-5.49 (1.09)	7.97 (1.62)	5.87 (1.21)
Country U.S. Patents per capita[h]			17.64 (2.49)**	17.64 (2.16)**		5.84 (1.65)	
Provincial S&E Articles per capita[h]			19.38 (2.02)**	22.34 (2.14)**	21.47 (2.08)**	19.92 (1.93)*	17.90 (1.77)*
Country S&E Articles per capita[h]			10.24 (1.34)	15.63 (1.46)		0.70 (0.26)	
Provincial S&E Grads per capita[h]			-0.14 (0.02)	-2.75 (0.34)	-2.18 (0.28)	-9.69 (0.87)	-8.65 (0.78)
Country S&E Grads per capita[h]			3.22 (0.98)	-0.42 (0.10)		-3.30 (1.27)	
Country Fixed Effects	No	No	No	No	Yes	No	Yes
N	200	200	200	200	200	200	200
R^2	0.118	0.143	0.254	0.281	0.315	0.294	0.317

a: * indicates significance at the 10% level and ** indicates significance at the 5% level.
b: The absolute values of the t-statistics are given in parentheses.
c: Results are corrected for heteroskedasticity (using the ;Hetero command in LIMDEP).
d: Hi-tech industries (classified by NAICS code) are: 3254: Pharmaceutical and medicine manufacturing; 3341: Computer and peripheral equipment manufacturing; 3342: Communications equipment manufacturing; 3344: Semiconductor and other electronic component manufacturing; 3345: Navigational, measuring, electromedical, and control instruments manufacturing; 3364: Aerospace product and parts manufacturing.
e: For a full list of sample countries, see Appendix 2.2.
f: Provincial variables refer to characteristics of the exporting provinces, whereas country variables refer to characteristics of the importing countries.
g: 2000 Internet users per capita are included in columns 1-5 and 1997 Internet users per capita are included in columns 6-7.
h: 2003 innovation variables are included in columns 1-5 and 2000 innovation variables are included in columns 6-7.

CHAPTER 3

ESSAY 3: INCREASING CANADA'S INTERNATIONAL COMPETITIVENESS: IS THERE A LINK BETWEEN SKILLED IMMIGRANTS AND INNOVATION?

3.1 INTRODUCTION

The link between immigration and innovation in Canada has been largely ignored. In contrast, the immigrant-trade link has been more thoroughly examined in Canada (Head and Ries, 1998; Wagner, Head and Ries, 2002; Partridge and Furtan, Forthcoming 2008), as well as in other countries such as the U.S. (Gould 1994) and the U.K. (Girma and Yu 2000).[1] Yet, understanding the immigration-innovation link is of both major policy and academic interest. As noted by Gould (1994, 314), "One particularly relevant issue is whether immigrant links lead to an increase in the worldwide transfer of technology. This question is especially relevant in light of the recent work in endogenous growth and the international diffusion of knowledge." Thus, this paper investigates the aforementioned immigration-innovation linkage utilizing a method first used by Romer (1990), who was a pioneer in the development of endogenous growth theory.

The dearth of research in this area is noted by Helliwell (1998), where he observes that the linkages between migration and growth require additional research. He acknowledges that there have been a number of studies that demonstrate the linkages between immigrants and trade flows, but that there has been a lack of work illuminating the connections between immigrants and growth, or immigrants and technological

[1] With respect to Canada, Head and Ries (1998), using data at the country level, estimate that a 10% increase in immigrants leads to an approximate 3% increase in imports from immigrants' countries of origin coupled with an approximate 1% increase in exports to immigrants' home countries. Similar findings were found for Canada in Wagner *et al.* (2002) as well as in Partridge and Furtan (Forthcoming 2008) using data at the provincial level. Further, empirical studies have demonstrated that the addition of immigrants to a country's pre-existing labor force adds "new" ties with the global economy (Rauch 2001; Rauch and Trindade 2002).

transfer. One exception is a study that considers the contribution of skilled immigrants and international graduate students on U.S. Innovation (Chellaraj, Maskus, and Mattoo 2005), which will serve as a foundation for this paper.

Innovation has taken on increased importance in Canada in the past five years with the launching of a Federal Innovation Strategy in February 2002 (Government of Canada 2007). One of the main goals of this initiative is to increase the number of highly qualified skilled-workers. For example, one of the key documents[2] associated with Canada's Innovation Strategy contains an entire section devoted to the "skills challenge" facing Canada. Much of the discussion pertaining to this "skills challenge" revolves around the notion of attracting greater numbers of skilled immigrants in an increasingly competitive global market for highly skilled workers as a way to close the "skills" gap. Thus, addressing this "skills challenge" (via increasing the number of skilled immigrants as well as by other means) is a high priority for Canada, where highly qualified skilled-workers are viewed as an integral link to increased levels of innovation.

Thus, in this paper, the link between skilled-workers (explicitly skilled immigrants) and innovation is considered by examining skilled immigrants' impact on Canadian innovation at the provincial level. The methodology to conduct this study follows Chellaraj *et al*. (2005), where the authors utilize a modified national ideas production function that is commonly used in innovation studies (Stern, Porter, and Furman 2000; Porter and Stern 2000). The technique employed in the national ideas production function was originated by Romer (1990) in a seminal paper describing how technological change is endogenous (rather than exogenous as originally proposed by Solow, 1956).

[2] *Achieving Excellence: Investing in People, Knowledge and Opportunity*

The approach of employing a model of idea generation augmented by skilled immigrants as an input into the national ideas production function is thus used to determine the impact of skilled immigrants on Canadian innovation. This linkage was found in the U.S., where a 10 percent increase in the six-year cumulative number of skilled immigrants increased later patent applications by 0.74 percent and increased later patent grants by 0.91-0.98 percent, where patent applications and grants are used as proxies for innovative activity (Chellaraj *et al.* 2005). The U.S. data provides strength to the hypothesis that skilled immigrants, through increased human-capital, increase innovation. Given that immigrants make up a higher percentage of the labor force in Canada than in the U.S. (Freeman 2006), the potential for immigrants to impact innovation in Canada is even greater.

In addition to the influence of immigrant labor on innovation, there is a clear affect on Canada's resident labor force. Finding a positive relationship between skilled immigrants and levels of innovation (measured by both U.S. patents and scientific publications) would imply that skilled immigrants create positive synergy with pre-existing workers in the Canadian labor market. Borjas (1995) posits a similar argument when he calls for the U.S. to admit more skilled immigrants because of the production complementarities that exist between skilled labor and capital, which may include external effects in production. Thus, an increase in innovation levels due to skilled immigrants should result in increased levels of productivity of Canada's labor force. This is consistent with Freeman (2006, 25), who notes that "Emigrant scientists, engineers, or entrepreneurs working in an advanced country could create innovations that improve productivity in that country…".

This study is (to my knowledge) the first to examine the contribution of skilled immigrants to Canadian innovation using an augmented national ideas production function approach. A link between skilled immigrants and innovation would demonstrate that skilled immigrants are a means of augmenting the existing Canadian labor force to achieve innovation and increased productivity. Another novel feature of this study is that it examines these impacts at the regional level (i.e., by province). This enables one to draw conclusions at the provincial level, which is especially important since immigration policy continues to devolve to the provinces (Partridge and Furtan, Forthcoming 2008). I also use provincial level data to provide cross-sectional variation so that I can focus on one country (Canada). Without a provincial breakdown, I would have too little data to identify impacts on Canada as a whole.

Further, skilled immigrants to each province are segmented by region and skill level (i.e. education, language ability and immigrant classification). Thus, the results should help policymakers determine the importance of the aforementioned immigrant attributes in impacting Canadian innovation (as measured by proxies such as U.S. patents granted as well as the number of scientific journal articles by province). For example, Canada has special immigration tracks for entrepreneurs, the self-employed, and investors, which are part of the Business immigrant classification. Thus, the results will allow policymakers to ascertain whether this category of skilled immigrants contributes to Canada's innovative capability.

In this paper, five main hypotheses are tested regarding the determinants of innovative output. The first three of these follow from the national ideas production function, where the quantity of human capital devoted to the ideas-producing sector as well as the stock of knowledge or ideas already in existence that are available to the idea-workers are expected to increase the rate of new ideas produced. These three hypotheses are: (1) Greater provincial stocks of innovation will lead to greater provincial innovation flows; (2) Increased numbers of provincial R&D researchers will lead to greater provincial innovation flows; and (3) Increased levels of provincial R&D expenditures will lead to greater provincial innovation flows.

The final two hypotheses follow from the idea that the productivity of skilled immigrants, like the productivity of skilled domestic workers, is augmented by the stock of knowledge in such a way as to create knowledge spillovers and thus increase the rate of new ideas produced. These two hypotheses are: (4) Greater numbers of skilled immigrants by province will increase that province's innovation flow; and (5) Skilled immigrants from source countries that are similar to Canada will increase innovation flow more than immigrants from dissimilar countries. This last hypothesis is based upon the notion that it is easier for skilled immigrants from countries that are more like Canada (i.e. developed/European) to integrate and work with the pre- existing skilled Canadian labor force.

In what follows, section 3.2 synthesizes previous work on developing the theory behind the national ideas production function as well as some empirical applications. The next section articulates the linkages between skilled immigrants and innovation. In section 3.4, special attention is given to the base national ideas production function augmented to include independent variables for skilled immigrants, which sets up a discussion for the theoretical model. The next section describes the model followed by section 3.6's description of the data. Finally, section 3.7 presents the empirical findings followed by a concluding section.

3.2 NEW GROWTH THEORY AND THE NATIONAL IDEAS PRODUCTION FUNCTION

The national ideas production function follows from endogenous or new growth theory as posited by Romer (1990). Romer's (1990) model of economic growth diverged from earlier models (Solow 1956; Shell 1967) of the traditional or neoclassical growth school by assuming that technological change was endogenous rather than exogenous as previously specified. In other words, Romer's model assumes that technological change is a direct result of deliberate actions taken by people who are responding to market incentives. This implies that improvements in technology must provide benefits that are at least partially excludable, where the extent of excludability depends upon both the technology itself as well as the legal system in a particular locale. The two other major premises in Romer's model are that (1) technological change is at the crux of economic growth (following Solow) and that (2) technology is a non-rival input since a person or firm's use of it does not limit its use by another interested party.

As can be seen by the aforementioned premises, Romer (1990)'s model portrays technology/knowledge as a quasi-public good, where he depicts growth as a function of the accumulation of a partially excludable, non-rival input. Romer (1990) further notes that the non-rivalry of knowledge has two key implications for growth theory: (1) non-rival goods can be accumulated without bound on a per capita basis, but human capital cannot and (2) knowledge spillovers result from the incomplete excludability of knowledge itself. From this, Romer (1990) concludes that a non-rival input such as knowledge, which has a productive value, does not coincide with output being a constant-returns-to-scale function of all inputs. Therefore, Romer introduces market power into his model in order to satisfy its major premises or conditions.

Following from the above discussion, Romer (1990)'s formal model of the economy includes three sectors: the research sector, an intermediate goods sector, and a final goods sector. The focus of this paper is on Romer's modeling of the research sector, where he posits that if an individual researcher (j) possesses an amount of human capital (H^j) and has access to a portion of the total stock of knowledge implicit in previous designs (A^j), the rate of production of new designs by researcher j will be $\delta H^j A^j$, where δ is a productivity parameter. Thus, if one sums across all people engaged in research, the aggregate stock of new designs or the national ideas production function (as described in Stern *et al.* 2000) is obtained.

(1) $\dot{A}_t = \delta H^{\lambda}_{A,t} A^{\Phi}_t$

where $\dot{A}_t$ is the rate of new ideas produced or the rate of technological progress; $H_{A,t}$ is the quantity of human capital devoted to the ideas-producing sector; λ is the productivity of resources in $H_{A,t}$; A_t is the stock of knowledge or ideas already in existence that are available to the idea-workers; Φ is the ability of the stock of ideas (A_t) to support new innovation, where $\Phi > 0$ connotes that prior research increases current R&D productivity (the "standing on shoulders" effect) and $\Phi < 0$ implies that prior research has led to the discovery of the easier ideas and new invention becomes more difficult (the "fishing out" hypothesis).

As noted by Romer (1990), equation (1) contains two substantive assumptions and two functional form assumptions. The substantive assumptions are that (1) devoting more human capital to research yields a higher rate of new ideas produced and that (2) the larger the total stock of ideas or knowledge, the higher the productivity of a researcher working in the R&D sector. The two functional form assumptions are that the output of new ideas produced is linear in each of H_A and A when the other is held constant[3]. As can be seen below, Romer's model with endogenous technological change serves as the foundation for the national ideas production function in empirical studies.

Two related papers that empirically estimate the parameters associated with the national ideas production function are Stern *et al.* (2000) and Porter and Stern (2000). The first study utilizes what the authors describe as "… a novel dataset of patenting activity and its determinants in a sample of 17 OECD countries from 1973 through 1996." (Stern *et al.* 2000, 17). The second study employs a subset of the first paper's dataset using data from 1973-1993 for the same set of 17 OECD countries (Porter and Stern 2000). Since Stern *et al.* (2000) is more closely related to this paper's analysis of factors that impact innovation, a more detailed examination of Stern *et al.*'s paper follows.

Stern *et al.* (2000) use a panel dataset (as noted above) of 17 countries over twenty years[4]. Similarly, I also use a panel dataset, but with 7 provinces/regions over eleven years. Stern *et al.* (2000) utilize a more generalized production function than Romer,

$$(2)\ \dot{A}_{j,t} = \delta_{j,t}\,(X_{j,t}^{INF}, Y_{j,t}^{CLUS}, Z_{j,t}^{LINK})\, H_{j,t}^{A\,\lambda} A_{j,t}^{\Phi}$$

[3] Romer (1990) notes that these assumptions are made largely for analytical convenience.
[4] Stern *et al.* (2000) lose 3 years of data because they lag their independent variables by 3 years. After estimating models with a variety of lag structures, I also settled upon a 3 year lag structure.

where $\dot{A}_{j,t}$ is the flow of new-to-the world technologies from country j in year t, $H_{j,t}^{A}$ is the total level of capital and labor resources devoted to the ideas sector of the economy, and $A_{j,t}$ is the total stock of knowledge held by an economy at a given point in time to drive future ideas production. The innovation of Stern *et al.*'s model is that they add several new explanatory variables. These include X^{INF}, which represents the level of cross-cutting resource commitments and policy choices which make up the common innovation infrastructure; Y^{CLUS}, which denotes the particular environments for innovation in a country's industrial clusters; and Z^{LINK}, which measures the strength of linkages between the common infrastructure and the nation's industrial clusters.

To estimate the above model, the authors use a log-log specification, which includes country dummies and year dummies or a time trend. Their main specification estimates the relationship between innovative output (international patents granted to establishments in country j in year (t+3) or $PATENTS_{t+3}$)[5] and the drivers of national innovative capacity. These drivers include $A_{j,t}$ as measured by GDP per capita or patent stock; H^{A} as measured by full-time science and engineers employed in all sectors and R&D expenditures in all sectors; X^{INF} as measured by a country's openness to international trade and investment, the strength of protection for intellectual property, the share of GDP spent on higher education, and the stringency of antitrust polices; Y^{CLUS} as measured by a country's percentage of R&D funded by private industry; and Z^{LINK} as measured by the percentage of R&D performed by universities as well as the strength of venture capital markets.

[5] In sensitivity analysis, the authors also use the number of publications in international academic journals as their dependent variable.

Using the above empirical specification, Stern *et al.* (2000) find a robust relationship between PATENTS and the measures associated with each source of national innovative capacity. The empirical model in this paper follows the basic framework of Stern *et al.* (2000) in that an augmented national ideas production function is employed using panel data (for provinces instead of countries). However, a distinctive feature of this paper's model is that it includes skilled immigrants as a key determinant in estimating a province/region's "production" of international (U.S.) patents. A discussion of the aforementioned linkages between skilled immigrants and innovation is next, followed by an exposition of the augmented national ideas production function.

3.3 SKILLED IMMIGRANTS AND INNOVATION

Given the quasi-public nature of knowledge, Romer (1990) finds that too little human capital is devoted to research without government subsidy of human capital for two main reasons. First, research has positive external effects, which are non-excludable and thus cannot be fully captured in the market price of the related goods/services. Second, research produces an input that is purchased by a sector that engages in monopoly pricing. Both of these effects cause human capital to be under-compensated and thus lead to less research than the social optimum (Romer 1990).

Therefore, since the research sector (as depicted in equation (1)) exhibits increasing returns to scale, in order to increase the rate of new ideas produced (i.e. innovation), governments may want to consider ways of increasing the accumulation of total human capital to promote greater amounts of "technological spillovers" than would otherwise result with no intervention. Romer (1990) suggests using subsidies as a means of increasing total human capital. These subsidies can be in the form of schooling and training (see also Grossman and Helpman, 1994). Grossman and Helpman (1991) also observe that the mobility of highly skilled personnel between firms represents another vehicle for the spread of technical information among innovating firms. This supports the main premise of this paper, where it is posited that the mobility of highly skilled immigrants between countries will lead to increased levels of innovation and can be achieved through a targeted immigration policy.

Thus, it is proposed that there is a link between skilled immigrants and levels of innovation (as measured by both U.S. patents and scientific publications), where skilled immigrants create positive synergy with pre-existing workers in the Canadian labor market. Akin to Chellaraj *et al*. (2005), skilled immigrants are hypothesized to increase innovation, whereby skilled immigrant workers have a complementary skill set to those of native workers. It is then inferred that a by-product of this aforementioned synergy between skilled immigrant workers and native workers is increased levels of productivity of Canada’s labor force, providing a positive feedback loop for even further increases to innovation.

There are a variety of ways that skilled immigrants positively impact their host country’s innovative capability (Regets 2001). These positive impacts include increasing R&D and economic activity due to availability of additional high-skilled workers; increasing knowledge flows and collaboration; increasing ties to foreign research institutions; and increasing export opportunities for technology. Regets (2001) also makes a strong case that the movement of workers between firms/institutions (i.e. foreign skilled immigrants moving from source country to host country firms/institutions) is a powerful source of knowledge transfer for technology, business practices, and networks of contacts. Thus, it is likely that skilled immigrants have a "brain-gain" effect on their host country, whereby they add increased human capital to their host country's labor force, which is likely to help foster increased levels of innovation.

Although the link between immigration and the transfer of technology is a topic of interest (Gould 1994), there has been very little research on the connections between immigrants and growth, or immigrants and technological transfer (Helliwell 1998). However, there have been some recent studies that are relevant to the topic. One such study, Chander and Thangavelu (2004), employs a two-period model where entrepreneurs maximize lifetime utility, taking as given the educational investment decision of workers, where workers simultaneously decide to invest in education to maximize lifetime utility. Using this theoretical model, the authors find that a commitment to seeking high-skilled immigrant workers can shift an economy from a low-technology to a hi-technology equilibrium and thus encourage entrepreneurs to adopt new technology and encourage domestic workers to invest more in education. Another recent study of interest, Chellaraj *et al*. (2005) is more germane to this paper and will be discussed in detail in the following section.

3.4 THE AUGMENTED NATIONAL IDEAS PRODUCTION FUNCTION WITH SKILLED IMMIGRANTS

In order to determine the impact of skilled immigrants on Canadian innovation at the provincial level, Canadian provincial-level data is employed over an eleven year time period. A similar study using time series data for the United States was conducted by

Chellaraj *et al.* (2005) for the years 1965-2001[6]. Chellaraj *et al.* estimate an innovation production function in which international graduate students and skilled immigrants are an input into the development of new ideas, where they employ Stern *et al.* (2000) and Porter and Stern (2000)'s models (discussed previously in section 3.2) as the basis for their modified national ideas production function. As Chellaraj *et al.* (2005) note, the major innovation in their approach is in their definition of $H_{A,t}$. In previous studies, such as those mentioned above, $H_{A,t}$ is measured by R&D expenditures as well as the number of scientists and engineers. However, Chellaraj *et al.* also include international graduate students and skilled immigrants as inputs into idea generation.

Their basic econometric specification utilizes a log linear estimation of the modified national ideas production function, where patent applications in time period (t+5) (as a percentage of the labor force[7]) and patent grants in time period (t+7) (as a percentage of the labor force) are the dependent variables. Their explanatory variables include: A_t, which is defined as the cumulative patents awarded over a 5- year period as a proportion of the labor force; H^A, which consists of total Ph.D. scientists and engineers as a proportion of the labor force as well as total real R&D expenditures as a proportion of the labor force. Further, they also include the following variables as part of H^A: foreign graduate students as a proportion of total graduate students; total graduate students as a proportion of the labor force; the cumulative number of doctorates earned in science and engineering in U.S. universities over a 5-year period as a percentage of the labor force;

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[6] The authors note that they do not include the period after September 11, 2001 so that they may discover whether foreign students and skilled immigrants could account for increases in technical productivity prior to that period.

[7] The authors scale most of the relevant variables so that they are measured in proportion to the aggregate labor force. They do this to mitigate any problems with stationarity in the levels of patents, immigrants, and graduate students resulting from time-series estimation. I follow this convention for the same reasons in my specifications.

and the cumulative number of skilled immigrants over a period of 6-years as a proportion of the labor force. Finally, they include a time dummy as well as a dummy variable to capture the effect of the Bayh-Dole Act[8].

For the results of interest, Chellaraj *et al*. (2005) find that total patent stock is significant and results in increased levels of patent applications, but has only a marginal impact on the levels of patent grants, where patent applications and grants are used as proxies for innovative activity. They also find that Ph.D. engineers and scientists are significant and positively related to both patent applications and grants, but that real R&D spending is not significantly different from zero (except in one specification), perhaps due to collinearity between real R&D spending and the cumulative number of doctorates earned in engineering and science.

More importantly for the purposes of this study, Chellaraj *et al.* (2005) find that both skilled immigrants and international graduate students are significant and positively related to patent applications as well as patent grants. For instance, they find that a 10 percent increase in the six-year cumulative number of skilled immigrants increases patent applications (after five years) by 0.74 percent and increases patent grants (after seven years) by 0.91-0.98 percent. Further, they find that foreign graduate students have a much larger impact on innovation than skilled immigrants, where a 10 percent increase in foreign graduate students as a proportion of total graduate students increases patent applications (after five years) by 4.65-4.78 percent and increases patent grants (after seven years) by 6.35-7.34 percent.

[8] The Bayh-Dole Act of 1980 permits a university, small business, or non-profit institution to elect to pursue ownership of an invention before the government.

Although Chelleraj *et al.* (2005) find that international graduate students have a much greater impact on innovation than skilled immigrants; I chose to exclude international graduate students from this study because the data does indicate where graduates locate after completing their studies. Unlike provincial skilled immigrants who are tracked by province of residence based upon their 2003 tax returns, provincial international graduate students are not tracked by province of residence once they graduate. Therefore, even if these international graduate students stay in Canada upon graduation, it is likely that they will find employment outside of the province/region where they earned their graduate degree. This is in contrast to Chellaraj *et al*.'s study, where foreign graduate students are quite likely to remain within the United States for at least the early portion of their careers. This is supported by a recent Oak Ridge Associated Universities report commissioned by the National Science Foundation that asserts that more than 71% of foreign citizens who received science and engineering doctorates from U.S. universities in 1999 were in the U.S. in 2001. Even more importantly for the purposes of examining foreign graduate students' longer-term impact on innovation, 58% of foreign graduate students who received a science and engineering doctorate from a U.S. university in 1991 were in the U.S. in 2001 (Finn 2003).

3.5 MODEL

As noted above, this study utilizes an augmented national ideas production function to examine skilled immigrants' impact on Canadian innovation at the provincial level following Chellaraj *et al*. (2005); Stern *et al.* (2000); and Porter and Stern (2000). The national ideas production function that is employed takes the same general form of equation (1) as introduced in section 3.2, which is now labeled equation (3).

$$(3)\ \dot{A}_{p,t} = \delta H^{\lambda}_{A,p,t} A^{\Phi}_{p,t}$$

where $\dot{A}_{p,t}$ is the annual U.S. patent grants by province[9]; $H_{A,p,t}$ includes real R&D expenditures by province, the number of R&D researchers by province, and skilled immigrants by province; and $A_{p,t}$ is real GDP by province[10]. The national ideas production function also implicitly includes the assumpton that innovative activity should concentrate geographically in those industries where the direct knowledge-generating inputs are the greatest and where knowledge spillovers are the most prevalent (Audretsch and Feldman 1996). Therefore, the use of provincial-level data should help to best capture any agglomeration effects associated with innovation at the sub-national level.

The above model, which includes the rate of new ideas produced as the dependent variable and the quantity of human capital devoted to the ideas-producing sector as well as the stock of ideas as independent variables, is a standard "national ideas production function" (Stern *et. al* 2000; Porter and Stern 2000) which is based upon Romer's model with endogenous technological change (Romer 1990). However, akin to Chellaraj *et al.* (2005), skilled immigrants are added to the standard human capital variables of R&D expenditures and the number of R&D researchers included in $H_{A,t}$. This follows from new growth theory where the productivity of skilled workers (both domestic and foreign) is augmented by the stock of knowledge in such a way as to create knowledge spillovers (Romer, 1990; Grossman and Helpman, 1991, 1994). Thus, the only variation on this model vis-à-vis Romer and others is its inclusion of foreign "human capital" as an

[9] In sensitivity analysis, I also use the number of scientific journal articles by province as a measure of innovation.
[10] In sensitivity analysis, I also use U.S. patent stock as a measure of innovation stock.

additional resource input into the innovation production function. This allows one to use immigration policy as another policy tool (besides subsidizing education and training for domestic workers) to increase human capital and thus promote more innovation.

The productivity of each resource is allowed to vary, as can be seen in equation (4).

$$(4)\ H^{\lambda}_{A,p,t} = H^{\lambda R}_{R,p,t}\, H^{\lambda S}_{S,p,t}\, H^{\lambda I}_{I,p,t}$$

where H_R is real gross domestic expenditures on research and development or GERD[11]; H_S is the number of R&D researchers by province; and H_I is the number of skilled immigrants by province (using education, language ability and immigrant class as proxies for skill level)[12].

Following equations (3) and (4), the succeeding empirical model is derived in equation (5).

$$(5)\ INNOVFLOW_{p,t+3} = a + bRDEXP_{p,t} + cRSRCHRS_{p,t} + dIMMIGRANT_{p,t} + eINNOVSTK_{p,t} + e_{p,t}$$

where $INNOVFLOW_{p,t+3}$ is the logarithm of the number of U.S. Patents granted by province per 100,000 provincial labor force[13]; $RDEXP_{p,t}$ is the logarithm of real R&D expenditures by province (in 1997 Canadian dollars) as a percent of the provincial labor

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[11] I also include subcategories of GERD such as GOVERD (provincial real R&D for the government sector), HERD (provincial real R&D for the higher education sector), and BERD (provincial real R&D for the business enterprise sector).
[12] As noted by Chellaraj *et al.* (2005), there is some overlap between skilled immigrants and the number of R&D researchers, where it is difficult to differentiate between these two factors.
[13] The number of scientific journal articles by province per 100,000 provincial labor force is also used in sensitivity analysis.

force[14]; $RSRCHRS_{p,t}$ is the logarithm of the number of R&D researchers (FTE) by province per 100,000 provincial labor force; $IMMIGRANT_{p,t}$ is the logarithm of the cumulative number of skilled immigrants over the preceding 5 year period by province per 100,000 provincial labor force; $INNOVSTK_{p,t}$ is the logarithm of the provincial real GDP (in 1997 Canadian dollars) divided by provincial labor force[15]; and $e_{p,t}$ is the error term.

The parameters in equation (5) are estimated using a panel dataset of 7 Canadian provinces/regions over a period of eleven years[16]. Additionally, equation (5) is estimated using White's parameter covariance matrix estimator in LIMDEP using the Hetero command. White's estimator is used because it is consistent even when the disturbances of a linear regression model are heteroskedastic.[17] Province and year dummy variables are included to capture fixed effects. A log-log specification is used in order to interpret the regression coefficients in terms of elasticities. Further, a 3-year lag between the rate of new ideas produced (INNOVFLOW) and the drivers of national innovative capacity (RDEXP; RSRCHRS; IMMIGRANT; INNOVSTCK) was chosen. This is based upon historical evidence that a number of years of conducting research in an area is required before patents are applied for and then granted. The choice of a 3-year time lag is

[14] Real provincial R&D expenditures (GERD) are broken down by the government, higher education, and business enterprise sectors.

[15] In sensitivity analysis, I also use U.S. patent stock as a measure of innovation stock. However, I find that GDP/LF is a superior measure of innovation stock and therefore use it in the base models.

[16] The provinces/regions as well as the time period were chosen based upon the availability of skilled immigrant data, which was the limiting factor. More specifics on data availability and selection for provinces/regions as well as time period are provided in section 3.6.

[17] As noted in Greene (2003), heteroskedasticity has some potentially serious implications for inferences based upon the results of OLS. The application of more appropriate estimation techniques requires a detailed formation of Ω, where the form of the heteroskedasticity may be unknown. Thus, Greene (2003) recommends using the White estimator, which provides an appropriate estimate for the variance of the least squares estimator, even if heteroskedasticity is related to the variables in X. This estimator takes the following form: $(X'X/n)^{-1}V(X'X/n)^{-1}$ where $V = n^{-1}\Sigma e^2X'X$. As noted by White (1980), in the fixed regressor case, this amounts to replacing the *i*th diagonal element of Ω, σ^2, with e^2, the *i*th squared residual term.

consistent with previous studies, where Stern *et al.* (2000) and Porter and Stern (2000) also use a 3-year lag and Chellaraj *et al.* (2005) use a 5 or 7 year lag[18]. Finally, like Chellaraj *et al.*, I chose to scale the variables by the provincial labor force to mitigate any problems with stationarity in the levels of patents and immigrants. This also provides a basis for comparing innovative activity adjusting for size of province/region.

In terms of the choice of variable measures, the number of U.S. patents granted by province per 100,000 provincial labor force was selected as the main dependent variable since U.S. (International) patents are commonly used as a proxy for innovation level. Canadian patents were considered as a measure of innovation, but were not chosen for two reasons. First, in a companion paper (Partridge 2008); it was found that Canadian patents are not a good proxy for innovative capability vis-à-vis U.S. patents when determining innovation's affect on Canadian exports by province using a gravity model. Second, the dataset for Canadian patents by province (2000-2005) was much more limited compared to U.S. patents by province (1993-2005). In sensitivity analysis, the number of science and engineering journal articles by province per 100,000 provincial labor force was also used as a measure of innovation flow following Stern *et al.* (2000).

For innovation stock, real GDP divided by the provincial labor force (GDP/LF) was chosen, again following Stern *et al*. (2000), which used GDP/POP. GDP is divided by labor force instead of population for consistency purposes since all of the variables in this study are divided by labor force. In sensitivity analysis, GDP/LF is compared to U.S. patent stocks (sum of the last 5 years of U.S. patents per 100,000 provincial labor force). GDP/LF was selected as the base measure of innovation stock for two reasons. First, it was found that GDP/LF is significant and positively related to innovation flow, whereas

[18] I tried a number of different lag structures and found the 3-year lag to be the best fit with the data.

U.S. patent stocks were not significant (see Table 3.7). Second, U.S. patent data by province is only available for 1993-2005, which means that if patent stock is lagged by three years, three years worth of data is lost. Then, an additional five years of data is lost by summing up the previous 5 years of patents to calculate patent stocks (per Chellarj *et al.* 2005). This would leave only 6 years worth of usable data.

Real R&D expenditures by province (in 1997 Canadian dollars) as a percent of the provincial labor force in total as well as by sector (higher education, government, and business enterprise) were selected to determine whether or not such expenditures increase innovation flow. Business enterprise R&D expenditures are expected to have the greatest impact on innovation flow as measured by U.S. patents, whereas higher education R&D expenditures are expected to have the greatest impact on innovation flow as measured by science and engineering journal articles. Government R&D expenditures are expected to have a positive effect on both types of innovation flow since these funds benefit both the university and business sectors. The number of R&D researchers by province per 100,000 labor force was chosen because this measure should be a good proxy for skilled human-capital that contributes to innovation flows.

Finally, to construct the skilled immigration variables, I utilize a dataset that was purchased as a special data tabulation from Statistics Canada (which will be discussed in greater detail in the following section). The variables of interest measure immigrants' skill level by education, language ability, and immigration class. The skilled immigrant variables that equate skill-level with education are: the sum of the previous 5 years of immigrants with a bachelor's degree or higher level of education per 100,000 LF; the sum of the previous 5 years of immigrants with a master's degree or higher level of education per 100,000 LF. The skilled immigrant variables that equate skill-level with language ability are: the sum of the previous 5 years of immigrants who speak English and/or French per 100,000 LF; the sum of the previous 5 years of immigrants who speak the province's official language per 100,000 LF. Finally, the skilled immigrant variables that equate skill-level with immigrant class are: the sum of the previous 5 years of Skilled immigrants per 100,000 LF; the sum of the previous 5 years of Independent immigrants per 100,000 LF[19]. In some specifications, immigrants are also categorized by the following source regions: Western Europe/North America; Eastern Europe; High Income Asia; Low Income Asia; Middle East/North Africa; and Other (see Appendix 3.2 and section 3.6 for more details).

Although Chellaraj *et al*. (2005) define their skilled immigrant variable as the number of skilled immigrants cumulated over the preceding six-year period divided by the labor force, I use a five-year period so that I gain an extra year of data (the immigration dataset is for immigrants from 1988-2002). Chellaraj *et al.* (2005) define skilled immigrants as including both those coming to the U.S. under H1-B1 visas and employment-based immigration. This closely corresponds to my measure of Independent Immigrants. However, the novelty of my study's skilled immigration variables compared to Chellaraj *et al.* is that it includes more comprehensive measures of skilled immigrants (i.e. by education level, language ability and immigration classification). It also

[19] Skilled Immigrants include Skilled Worker (P.A.). Independent Immigrants include Skilled Worker (P.A.), Business (P.A.) (which includes Entrepreneur P.A., Self-Employed P.A., Investor P.A., and Other Business P.A. – Abroad), and Other Economic (which includes Business Class S.D. and Skilled Workers S.D.). P.A. = Principal Applicant and S.D. = Spouse or Dependent. The Independent Immigrant category is a pre-IRPA immigration category that includes skilled workers selected for their labor market skills and business immigrants selected on the basis of their business experience and other related skills. Note: the Immigration and Refugee Protection Act (IRPA) came into effect on June 28, 2002 (citizenship and Immigration Canada 2006).

examines skilled immigrants by source region to determine whether or not region matters in determining a skilled immigrant's impact on innovation flow.

3.6 DATA

Data on innovation includes U.S. patents, scientific publications, research and development expenditures, and R&D researchers by province. Data on provincial U.S. patents, science and engineering articles, and real gross domestic expenditures on research and development (GERD) are all from the Institut de la Statistique Québec. GERD is also broken down into categories by sector for higher education (HERD), government (GOVERD), and business enterprise (BERD). Data for Provincial R&D researchers is found in various Science Statistics catalogues published by Statistics Canada, which provide the provincial distribution of personnel engaged in research and development (R&D) by occupation category. Data was extrapolated for 1996 and 1997 provincial R&D researchers based upon 1995 and 1998 data due to gaps in reporting.

Except for provincial R&D researchers, which is defined in a straightforward manner, more details on the definitions of the remaining innovation variables follow to provide further clarification. First, U.S. patents are categorized as Utility patents, which protect the technical aspects of a product and accounted for almost 94% of the patents granted by the USPTO in 2003. Each utility patent has one or more owners who are called "assignees", where Utility patents are assigned to a province if at least one "assignee" is from that province (Institut de la Statistique Québec 2007). Next, scientific publications are derived from the Science Citation Index (SCI) database for articles, reviews and notes. The number of publications per province is established by selecting all publications that have at least one author whose institutional address is in that province (Institut de la Statistique Québec 2007).

As noted above, R&D expenditures by province (GERD) are subcategorized into three sectors: HERD; BERD; and GOVERD. Beginning in 1985, GERD included expenditures in the social sciences and humanities in addition to natural science and engineering. The provincial definition of GERD is for expenditures that are assigned to the province in which the performing establishment is located. The funding is for R&D carried out in a province, not R&D funding from a province. However, it should be noted that there are some limitations with GERD, such as ambiguity in its definition as well as problems with the survey design in the collection of GERD related data, which may cause sector estimates to vary from +/- 5% to +/- 15% in accuracy (Thompson 2006). However, Thompson (2006) notes that GERD can show trends in R&D expenditures by sector and province from year-to-year, where these estimates are sufficiently reliable for their main use as an aggregate indicator for science policy.

Given that GERD is segmented by sector, more detailed definitions are also included regarding the nature of these expenditures by sector as provided in Thompson (2006). GOVERD or government R&D expenditures are distributed among the following government sub-sectors: the Federal Government, the provincial government, and the provincial research organizations (PRO)[20]. BERD or business enterprise R&D expenditures are comprised of the R&D expenditures by all firms, organizations and institutions that are either for-profit or are not-for-profit institutes that serve the aforementioned for-profit firms. BERD also includes government-owned enterprises

[20] PRO includes the New Brunswick Research and Productivity Council, the “Centre de recherche industrielle du Québec (CRIQ)”, the Industrial Technology Centre (Manitoba), the Saskatchewan Research Council, The Yukon Research Institute, the Nunavut Research Institute, and the Aurora Research Institute.

such as Ontario Hydro and Canadian National Railways. HERD or higher education R&D expenditures are comprised of expenditures by all universities, colleges of technology, and other institutes of post-secondary education. HERD also includes all research institutes, experimental stations, and clinics operating under the direct control of or administered by higher education establishments. Thompson (2004) also provides details on the funding sources for HERD, which include the Federal Government; the provincial governments and provincial research organizations; the business sector; the private-non-profit sector; foreign sources; and universities and affiliated institutions.

Provincial GDP data is in millions of Canadian dollars (1997=100) and provincial labor force data is in thousands of persons. Both are from Statistics Canada (2007b; 2007a). The immigration data is also from Statistics Canada (2007c).[21] It consists of recent immigrants by province along with their respective countries of last permanent residence[22], highest level of completed education upon landing, language proficiency, and immigrant classification. The immigration counts are for tax filers 15 years of age or older. The full cohort of immigrants are based upon the tax year 2003, which includes data for the 15 landing years prior to the tax year, where the tax year is used to provide a province of residence. The 2003 tax year was selected because it was the most recent year that immigration data could be made available by Statistics Canada. The years of landing are divided into the following time periods: 1988-1990, 1991-1995, 1996-2001, and 2002

[21] The immigration data is from a special data tabulation from Statistics Canada based upon the Longitudinal Immigration Database (IMDB). This data was provided by Ian Marrs, Technical Officer, IMDB, Social and Aboriginal Statistics Division, Statistics Canada.

[22] The data includes 16 countries of last permanent residence, which are for the 16 largest immigrant producing source countries. This set of countries is derived from aggregating the top 5 immigrant source countries for each province/region for immigrants who landed in Canada between 1988 and 2002 and are residing in that province/region in 2003. The remaining countries are aggregated into an “other” category.

(with the entire period ranging from 1988-2002). Annual immigration numbers were then estimated in order to create the skilled immigrant variables.[23]

To provide a sense of what the immigrant data is measuring, one can use Chinese immigrants in Ontario for illustrative purposes. For instance, 91,220 Chinese immigrants that landed in Canada during the 1988-2002 time period filed 2003 tax returns in Ontario (and thus were living in Ontario in 2003). Further, 3,310 of these immigrants landed in Canada during the 1988-1990 time period, 16,990 landed during the 1991-1995 time period, 59,160 landed during the 1996-2001 time period and 11,755 landed in 2002. Thus, the 91,220 Ontarian Chinese immigrants are the cumulative number of immigrants that landed in Canada within the last 15 years (i.e. between 1988 and 2002) and currently (in 2003) reside in Ontario.

As noted above, immigrants are categorized by number of years of education, language proficiency, and immigrant classification. Specifically, the number of years of education is divided into the following categories: 0-9 years of schooling, 10-12 years of schooling, 13 or more years of schooling, Trade Certificate/Non-University diploma, Bachelor's degree, and Master's degree/Doctorate. Moreover, language proficiency is categorized as: English, French, both English and French, and neither English or French. Finally, immigrant class is categorized into the following groups: Family, Business (principal applicant), Skilled Worker (principal applicant), Other Economic, Refugee, and Other. The above data was used to generate the skilled immigrant variables based upon education level, language ability and immigrant classification.[24]

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[23] In section 3.5, skilled immigrants were defined as the sum of the previous 5 years of immigrants with certain skills per 100,000 LF.

[24] Education level, language ability, and immigrant classification are commonly used as proxies for immigrant skill-level. For instance, Antecol, Cobb-Clark, and Trejo (2003) classify immigrant skill-level

Further, the immigrant data includes detailed information on immigrants from 16 countries of origin (plus all other immigrants as one aggregate group)[25]. The 16 countries were chosen based upon the criteria that they were ranked as one of the top 5 immigrant producing countries for at least one of the Canadian provinces[26] in tax year 2003 (where the top 5 immigrant producing countries for each province were those that had the largest cumulative number of immigrants who landed in Canada between 1988 and 2002 and were residing in a particular province in 2003). More specifically, the selected countries are a summation of the countries found in both the Canada and provincial Standard Summary Tables (SST) for tax year 2003[27], which means that the countries that are included appear in at least one of the SSTs. A list of all of the provinces and countries are included in Appendices 3.1 and 3.2 with a list of the top 5 countries of origin by region for tax year 2003 in Appendix 3.3. This data was used to construct skilled immigrant variables, which reflected immigrants' region of last permanent residence.

The sample includes six provinces (Quebec, Ontario, Manitoba, Saskatchewan, Alberta, and British Columbia) and one region (Atlantic Canada which includes Newfoundland/Labrador, Prince Edward Island, Nova Scotia, and New Brunswick) over 11 years and is predicated on the availability of data. For instance, the immigration data prescribed the decision to aggregate the Atlantic Provinces due to disclosure issues for small provinces such as Prince Edward Island. Additionally, detailed immigration data

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in terms of language fluency, education and income (relative to natives), while Chellaraj *et al.* (2005) employ immigrant class as a proxy for skill-level.

[25] Thus, I have the associated data for all immigrants combined, not just those represented by the top 16 countries.

[26] The one exception is for the Atlantic provinces of New Brunswick, Newfoundland, Prince Edward Island, and Nova Scotia, which are aggregated into one region due to confidentiality issues.

[27] As noted above, the 2003 tax year was selected because it was the most recent year that immigration data could be made available by Statistics Canada.

was obtained for the years 1988-2002. The construction of the skilled immigration variables necessitated summing up the previous 5 years of data, which left 11 years of usable data instead of 15. Therefore, in estimating the regression equations for the base models, 1995-2005 data is used for the dependent variable and 1992-2002 data is used for the independent variables (based upon a 3-year lag). These models are discussed in detail in the following section.

3.7 RESULTS

3.7.1 Descriptive Statistics

As can be seen in Table 3.1, there is a great disparity among provinces for most of the innovation variables. For instance, the Atlantic Provinces have the lowest number of U.S. patents per 100,000 labor force at 4.2 compared to the Canadian average of 14.1. Both Quebec and Ontario have the highest levels of U.S. patents per 100,000 labor force at 21.3 and 20.3 respectively. This same trend holds for the number of R&D researchers per 100,000 labor force, GDP/LF, and real gross domestic expenditures in R&D (GERD) divided by the labor force. In terms of the provincial allocation of GERD, there is much more uniformity of provincial R&D expenditures in the government (GOVERD) and higher education (HERD) sectors versus the business enterprise (BERD) sector, where there is a large disparity between Quebec and Ontario at the top and Atlantic Canada and Saskatchewan at the bottom. As can be seen later in the regression results, there appears to be a link between a province's allocation of R&D expenditures and the resulting impact on innovative output (in terms of patents and scientific articles).

The aforementioned inequality between provinces with the highest levels of U.S. patent grants (per 100,000 labor force) and those with the lowest levels is likely due to agglomeration effects associated with urbanization economies. This is supported by empirical studies, such as Feldman and Florida (1994), which find using U.S. state-level innovation data that innovations cluster geographically in areas that contain concentrations of specialized resources indicative of technological infrastructure. Thus, using population size of the largest CMA in a province as a proxy for technological infrastructure, it is found that the provinces with the largest CMAs also have the highest levels of innovation For instance, Quebec and Ontario have both the largest urban centers in Canada in 2001 respectively at 3.4 million for the Montreal CMA and 4.7 million for the Toronto CMA and the highest levels of U.S. patents (per 100,000 labor force) in Canada. This compares to Atlantic Canada, which has by far the lowest level of U.S. patents (per 100,000 labor force) in Canada, with its largest CMA in Halifax, NS with just over 359,000 people in 2001 (Statistics Canada 2007d).

In contrast to the variables discussed above, there is less disparity among the provinces in terms of their respective numbers of scientific articles per 100,000 labor force. For instance, although the Atlantic Provinces are still at the bottom, other provinces such as Quebec, Manitoba, and British Columbia have similarly low levels of scientific articles per 100,000 LF. However, Quebec's low levels may partly be explained by its high number of French speakers, where there is a bias towards English for journal article publications (Archibugi and Coco 2005). Conversely, Saskatchewan has the highest level of innovative output in terms of scientific articles, closely followed by Alberta and Ontario. Thus, it appears that in terms of the creation of basic science and engineering knowledge, the presence of high-caliber research universities as well as R&D

expenditures in higher education are more important than agglomeration effects resulting from urbanization economies.

Next, Table 3.2 provides a look at the skill variation of immigrants by province. The Atlantic Provinces and Saskatchewan have the highest percentage of highly educated immigrants, whereas Manitoba has the lowest percent. Quebec and Ontario are near the Canadian average. Atlantic Canada has by far the highest percent of immigrants that speak English or French with Alberta and British Columbia having the lowest percent of English or French speakers. It should be noted that Quebec has a high percentage of immigrants that speak English or French, but has a relatively low percent of immigrants that speak French only (which is the official language of the province) compared to the other provinces, which have much higher percentages of immigrants that speak their province's official language (English). Atlantic Canada as well as Quebec have the highest percentages of immigrants who landed as Skilled workers with Manitoba having the lowest percentage of immigrants classified as Skilled workers. Finally, Atlantic Canada and British Columbia have the highest percentage of immigrants classified as Independents with Manitoba again falling at the bottom. Given that it is later found that immigrant skill-level matters in terms of impacting innovation, provinces should be mindful of the skill-mix of their immigrants, with particular attention paid to language proficiency, which is later found to be highly significant.

Finally, Table 3.3 presents an overview of the skill variation of Canadian immigrants by source region of the world. In terms of skill levels of immigrants, immigrants from the sample of developed countries (i.e. Western Europe/North America) are highly skilled in all categories (education, language ability, and immigrant class). For instance, 93.6% of the sample of immigrants from developed countries speak English or French, 28.6% have at least a Bachelor's degree, and 31.0% landed as Skilled workers, where average levels for all immigrants coming to Canada are 59.0% for language, 25.9% for tertiary education, and 19.6% for Skilled workers respectively.

Other immigrant groups with high levels of educational attainment are from Low Income Asia with 32.6% of these immigrants having immigrated to Canada with at least a Bachelor's degree. Outside of the developed countries, a large percentage of immigrants from the sample of Middle Eastern/North African countries speak English or French (74.7%), whereas very few immigrants from the sample of Eastern European countries speak English or French (19.5%). In addition to immigrants from the sample of developed countries, immigrants from the sample of Middle Eastern/North African countries also had high skill levels with 28.3% landing as Skilled immigrants. As with language skills, a low percentage of the sample of immigrants from Eastern European countries landed as Skilled immigrants. Also, an extremely high percentage of immigrants from High Income Asian countries landed as Independent immigrants (70.8%). In the regression results to follow, it is found that a skilled immigrant's source region matters greatly in terms of their impact on innovation at the provincial level.

3.7.2 Regression Results: Base Model + Skilled Immigrants

Table 3.4 reports the results of the base model, which is augmented by skilled immigrants by education level, language ability and immigrant class. Using the log-log specification in equation (5), provincial U.S. patents per 100,000 provincial labor force are employed as the dependent variable. All independent variables are lagged by 3 years following Stern *et al.* (2000) and Porter and Stern (2000) to ensure that there is an adequate gestation period between research performance and patent grants. Variable definitions and sources are listed in Appendix 3.4.

Column 1 (of Table 3.4) includes the base model with real provincial GDP divided by the provincial labor force and the number of R&D researchers by province per 100,000 provincial labor force. Column 2 adds real R&D expenditures by province or GERD divided by the provincial labor force. Column 3 segments GERD by sector to include business enterprise R&D expenditures (BERD), government R&D expenditures (GOVERD), and higher education R&D expenditures (HERD). BERD, GOVERD, and HERD are included to determine whether or not there is a distinction between the three types of R&D expenditures in terms of their impact on innovation flow (PATENTS). Finally, columns 4-9 add the skilled immigration variables, which measure immigrant skill level by education (columns 4 and 5), language ability (columns 6 and 7), and immigrant classification (columns 8 and 9). Columns 1-9 also include province and year dummy variables to account for fixed effects.

Upon examining the base model in column 1, it is found that innovation stock (as measured by GDP/LF) is not significant, where Stern *et al.* (2000) found this measure of innovation stock (as well as the stock of international patents) to be significant and positively related to patent grants. These results are contrary to the first main hypothesis of this paper, which states that greater provincial stocks of innovation will lead to greater provincial innovation flows. However, Chellaraj *et al.* (2005) also found that their measure of innovation stock (cumulative patents awarded as a proportion of the labor force) was not significant in one of their two specifications and was only significant at the 10% level (and is positively related to patent grants) in their other specification.

Yet, upon further examination, the insignificance of the innovation stock variable may be due to the inclusion of lagged GDP data in the full sample (which includes the early 1990s). To illustrate, when the number of years in the sample is reduced by eliminating data from the early 1990s, GDP/LF is significant and positively related to patent grants (see Table 3.6, column 2; Table 3.7, columns 1, 3 and 6). By eliminating GDP data from the early 1990s (when the Canadian economy was in recession), the expected results of greater stocks of innovation leading to greater innovation flows are found. Additionally, assuming the results from Tables 3.6 and 3.7 hold, one can further note that since the elasticity of patent grants with respect to increases in the stock of knowledge ranges from 1.89 to 2.33, there is a dynamic spillover from knowledge to the flow of new ideas. This affirms the "standing on shoulders" effect (where $\Phi > 0$) discussed in section 3.2, where prior research increases current R&D productivity.

Next, R&D researchers are found to be significant at the 5% level and are positively related to patent grants (with a 3-year lag) in all specifications (i.e. columns 1-9). This is consistent with the second main hypothesis of this paper which states that increased numbers of provincial R&D researchers will lead to greater provincial innovation flows. These results also correspond to those of previous studies such as Chellaraj *et al.* (2005), where total Ph.D. scientists and engineers as a proportion of the labor force were significant and positively related to patent applications (with a 5-year lag) as well as patent grants (with a 7-year lag). Stern *et al*. (2000) also found that full-time equivalent scientists and engineers in all sectors were significant and positively related to patent grants (with a 3- year lag).

Turning to GERD, real R&D expenditures are not significant (column 2)[28]. However, if total R&D expenditures are broken down by sector, government R&D expenditures (GOVERD) are found to be significant at the 10% level and positively related to U.S. patents in columns 3, 5, and 8. Higher education R&D expenditures (HERD) are also found to be significant at the 5% level and *negatively* related to U.S. patents in all specifications (columns 3-9). Finally, business enterprise R&D expenditures (BERD) are not significant in any of the specifications.

As noted above, while provincial government R&D has a positive effect on patent flow, provincial higher education R&D has a *negative* effect on patent flow. However, as can be seen later in Table 3.6, R&D expenditures' affect on innovation flow depends upon how innovation flow is defined. For instance, if it is defined as the annual number of science and engineering (S&E) journal article publications by province, higher education R&D expenditures are found to be significant and *positively* related to innovation flow. Thus, the above R&D results support the third main hypothesis that increased levels of provincial R&D expenditures will lead to greater provincial innovation flows, where increases in government R&D result in greater numbers of patents and increases in higher education R&D result in greater numbers of S&E journal article publications. It should also be noted that there may be a crowding out effect in terms of R&D expenditures impacting the number of patents, where greater (government-funded) higher education R&D spending may crowd out (privately-funded) business sector spending, resulting in decreased levels of patent flows.

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[28] Chellaraj *et al.* (2005) also found that the coefficients on real R&D spending were not significantly different from 0 except for in one specification. Nonetheless, Stern *et al*. (2000) found a significant and positive relationship between R&D expenditures in all sectors and patent grants.

Continuing with Table 3.4 results, skilled immigrants' impact on innovation flow (columns 4-9) now will be examined. It is found that only skilled immigrants as defined as language proficient are significant (at the 5% level) and are positively related to patent flows (columns 6 and 7). These results illustrate that a 10% increase in provincial skilled immigrants, where skill-level is defined as language proficiency, yields between a 7.2% and 7.3% increase in provincial patent flow. In comparison, Chellaraj *et al.* (2005) found that a 10% increase in U.S. skilled immigrants increases U.S. patent flows by just under 1%. However, these results are not directly comparable, since Chelleraj *et al*.'s definition of skilled immigrants is based upon immigrant classification (i.e. immigrants coming to the U.S. under H1-B1 visas and employment-based immigration), whereas the definition used here is based upon language proficiency[29].

This supports the fourth main hypothesis that greater numbers of skilled immigrants by province will increase that province's innovation flow. The results demonstrate the paramount importance of immigrants being able to communicate effectively with native Canadians in order to foster innovation. This ability to communicate in a common language with the existing skilled labor force appears to trump prior education level as well as immigrant class upon landing. These results show that there may be a need to provide more weight to language proficiency for in-coming immigrants if provincial policymakers want to promote greater innovation in their home provinces.

3.7.3 Regression Results: Skilled Immigrants by Source Region

[29] It should be noted that although not significant, the coefficients on the Skilled and Independent immigrant variables are 0.075 and 0.12, which closely resemble Chellaraj *et al.*'s coefficients on their skilled immigrant variables (0.091-0.098) using comparable definitions of skill.

Turning to Table 3.5 results, skilled immigrants are now broken down by source region of the world. Source regions include Western Europe/North America, Eastern Europe, High Income Asia, Low Income Asia, Middle East/North Africa, and Other (see Appendix 3.2 for countries included in each region). As noted in the Data section, the immigrant data set includes detailed information on immigrants from 16 countries of origin based upon the criteria that they were ranked as one of the top 5 immigrant producing countries for at least one of the Canadian provinces/regions in tax year 2003. Each of these 16 countries were allocated to a particular region, with Haiti assigned to the "Other" region since Haiti did not fit very well into any of the specified regions. The "Other" region therefore includes all other immigrant source countries not listed in Appendix 3.2 plus Haiti. In the discussion to follow, the main focus will be on the findings from the previously named regions with much less emphasis on the "Other" region[30].

Again using the log-log specification in equation (5), provincial U.S. patents per 100,000 provincial labor force is used as the dependent variable. As before, all independent variables are lagged by 3 years. Table 3.5 includes the base model as depicted earlier with GDP/LF, RSRCHERS, BERD, GOVERD, and HERD as independent variables. Corresponding to Table 3.4 (columns 4-9), Table 3.5 (columns 1-6) includes skilled immigrant variables that measure immigrant skill-level by education

[30] The main focus is on the named regions for two reasons. First, skilled immigrants from the 15 countries assigned to these named regions typically represent at least half of all of the skilled immigrants in the sample. For instance, immigrants from these 15 countries comprise 53% of all Skilled and all Independent immigrants, 53.6% of all immigrants with a bachelor's degree or higher, 56.8% of all immigrants with a master's degree or higher, and 48.7% of all immigrants who are proficient in English, French or both for immigrants landing in Canada between 1988 and 2002. Second, one cannot draw too many conclusions from the "Other" category since it is comprised of a large number of skilled immigrants from a variety of disparate countries.

(columns 1 and 2), language ability (columns 3 and 4), and immigrant classification (columns 5 and 6). However, these skilled immigrant variables now reflect skilled immigrants by source region rather than all skilled immigrants (as in Table 3.4). For instance, in column (1), skilled immigrants by region are defined as immigrants from each region who have at least a bachelor's degree level of education, whereas in column (6), skilled immigrants by region are defined as immigrants from each region who landed as Independent immigrants. As before, columns 1-6 include province and year dummy variables to account for fixed effects.

The results from the base model in Table 3.5 remain fairly consistent with the specifications from Table 3.4. Categorizing skilled immigrants by region increases the explanatory power of the model, where the R^2 values for columns 4-9 in Table 3.4 are in the 0.96 range and the R^2 values in columns 1-6 in Table 3.5 are in the 0.97 range. In Table 3.5, R&D researchers are again found to be significant and positively related to U.S. patents in columns 1, 5, and 6, which indicates that increased numbers of provincial R&D researchers will lead to greater provincial innovation flows (hypothesis 2). A significant and *negative* relationship is also found between higher education R&D expenditures and patent flows (see columns 1, 2, 5, and 6). However, while government R&D expenditures are no longer found to be significant, business enterprise R&D expenditures are now found to be significant and *positively* related to patent flows (in columns 2-4). Therefore, these results continue to lend support to hypothesis 3, which states that increased levels of provincial R&D expenditures will lead to greater provincial innovation flows, where business enterprise R&D expenditures are now found to be significant rather than government R&D expenditures and positively related to patent flows.

Continuing with Table 3.5 results, we can now determine whether or not, holding immigrant skill-level constant, an immigrant's source region has an impact on innovation flow. A key result is that skilled Western European/North American immigrants are found to be significant (at the 5% level) and positively related to U.S. patents in columns 2-6. Thus, unlike the Table 3.4 results, we find here that skilled immigrants from developed countries as defined by all measures of skill-level, not just language proficiency, are positively related to innovation flow. This illustrates that Western European/North American skilled immigrants are strongly associated with greater levels of innovation, where a 10% increase in skilled Western European/North American immigrants results in an increase in patent flows of between 3.0% and 6.8% (with the highest impact for language proficient immigrants who speak the province's official language).

Thus, these findings again support hypothesis (4), which states that greater numbers of skilled immigrants by province will increase that province's innovation flow, but with the corollary that source region also matters. This lends support to hypothesis (5), which states that skilled immigrants from source countries that are similar to Canada will increase innovation flow more than immigrants from dissimilar countries, where Western Europe/North American immigrants have more in common with native Canadians than immigrants from any other region. Thus, these results indicate that it may be easier for skilled immigrants from developed European and North American countries to better integrate and work with the pre-existing skilled Canadian labor force.

Another important finding is that Eastern European immigrants (in addition to Western European/North American immigrants) with a master's degree or more of education are significant (at the 5% level) and positively related to U.S. patents (see column 2), where Bosnia-Herzegovina and Poland are the only two countries included in the Eastern European category (based upon the criteria that only countries that were one of the top five immigrant source countries for at least one province are included). However, in further analyzing these results, Polish immigrants are found to comprise almost the entire population of Eastern European immigrants with a master's degree or Ph.D. at 92.1%, where Bosnian-Herzegovina immigrants constitute a mere 7.9% of the total. Therefore, in interpreting the Eastern European results, the primary focus will be placed upon highly educated Polish immigrants.

When assessing the quality of higher education internationally, both Shanghai's Jiao Tong University's Institute of Higher Education (2007) as well as *The Times Higher Education Supplement* (2004) find that developed countries typically comprise the vast majority of top tier universities in the world. For instance, Liu and Cheng[31] (2005) find that 55.4% of the world's top 500 universities are in France, Germany, the U.K, and the U.S. (the sample of North American/ Western European countries). According to Liu and Cheng's study, Poland has 2 of the top 500 universities (Jagiellonian University and Warsaw University), whereas China (which includes Hong Kong and Taiwan) has 16 and India 3. Further, in terms of the world's top 100 science universities, which is more germane in terms of providing inputs to innovation, Warsaw University ranked 80th in 2004 (*The Times Higher Education Supplement* 2004).

[31] Liu and Cheng are both affiliated with the Institute of Higher Education at Jiao Tong University.

At first blush, it may seem surprising that highly educated Asian immigrants are not significant, but that highly educated Eastern Europeans are. However, if one takes into account the number of highly ranked universities *per capita* in China versus Poland, the likelihood of a Polish immigrant attending a highly ranked university in Poland is much greater than that of a Chinese immigrant attending a highly ranked university in China[32].

Thus, it appears that highly educated Europeans (from both Eastern and Western Europe) as well as highly educated North Americans contribute to greater levels of Canadian innovation, which is likely at least in part due to the quality of education received in these countries. Other studies have noted such a disparity in quality of education by immigrant source country, particularly among developed and developing countries (i.e. Coulombe and Tremblay 2006). Greenwood and McDowell (1991, 613) go even further and note that "Knowledge acquired through work experience and skills accumulated have country-specific aspects, and hence some portion of an immigrant's accumulated human capital may not be perfectly transferable internationally."

Other factors may also come into play. For instance, it may be that highly educated North Americans and Europeans are better able to work with highly educated Canadians due to greater similarities in their educational training than immigrants from other regions of the world. Additionally, North Americans and Europeans are more likely to share a common Judeo-Christian religious heritage with the majority of native Canadians, which is less likely to be the case for immigrants from other regions. These factors have helped Eastern European immigrants in Western Europe successfully integrate into their host countries' societies. For instance, Polish immigrants in Ireland have been able to prosper

[32] To illustrate, China has 16 top 500 universities in a country of 1.4 billion people, while Poland has 2 top 500 universities in a country of 38.6 million people. Population statistics are from the *CIA World Factbook* (2000).

due the Poles good standard of education and skill as well as their shared Catholic faith with the native Irish (Roberts 2008, 15). Thus, these factors lend credence to hypothesis (5), which states that skilled immigrants from source countries that are similar to Canada will increase innovation flow more than immigrants from dissimilar countries.

In terms of highly educated immigrants from all other countries or the "Other" category, they are found to be significant and *negatively* related to U.S. patents (columns 1 and 2) at the 5% level. Given the vast assortment of countries contained in this category, it is difficult to make any generalizations about this result. However, it does imply that the average quality of education in countries in the "Other" category is likely to be quite a bit lower than that of the 15 countries assigned to the 5 named regions.

As noted previously, only language proficient Western European/North American immigrants are significant and positively related to U.S. patents (Table 3.5, columns 3 and 4), whereas in Table 3.4, columns 5 and 6, all language proficient immigrants were significant and positively related to U.S. patents. One explanation for this is that non-Western immigrants with language proficiency still may not be able to communicate as well with the native Canadian labor force as their language proficient Western immigrant counterparts. Another possibility is that a non-Western immigrant's non-standard accent (in either English or French), may result in discrimination in terms of their employment and/or success in the Canadian labor market (Scassa 1994). Both of these explanations lend credence to hypothesis (5), which states that skilled immigrants from source countries that are similar to Canada will increase innovation flow more than immigrants from dissimilar countries, where Western Europeans and Americans that speak English and French are better integrated into the Canadian innovation community.

Finally, as discussed earlier, Western European/North American immigrants who landed as Skilled and Independent workers are significant (at the 10% level) and positively related to U.S. patents. However, immigrants from Low Income Asia (China, India, Philippines, and Sri Lanka) who landed as Independent immigrants are also significant and are positively related to U.S. patents. Perhaps a number of these immigrants that landed under the Entrepreneur, Self-employed, or Investor classification had pre-existing links to established networks of immigrants from their home countries, which might enable them to better foster innovation as measured by U.S. patent grants. This would be especially true for Chinese and Indian immigrants, which comprise over 75% of Low Income Asians who landed as Independent workers, since there are long-standing communities throughout Canada of established immigrants from these source countries.

3.7.4 Regression Results: S&E Articles vs. U.S. Patents as the Dependent Variable

Table 3.6 includes the number of science and engineering (S&E) journal articles (JOURNALS) published by province per 100,000 provincial labor force as an alternative measure of innovative capability (akin to Stern *et al.* 2000). As noted by Stern *et al.,* PATENTS are a better proxy for commercializable output, whereas JOURNALS provide a more accurate representation of basic scientific and engineering activity. Both measures of innovative capacity are included to determine how various types of R&D expenditures affect each kind of innovative output, where it is hypothesized that greater spending on higher education R&D leads to more innovative output in terms of journal articles and that greater spending on business sector R&D leads to more innovative output in terms of patents.

Thus, in comparing columns 1 and 2 in Table 3.6, where column 1 includes JOURNALS per 100,000 LF as the dependent variable and column 2 includes PATENTS per 100,000 LF, government R&D expenditures are found to be significant at the 10% level and positively related to both JOURNALS and PATENTS. However, business sector R&D expenditures are found to be significant at the 5% level and *negatively* related to JOURNALS. This may indicate that provinces that have very high levels of BERD, such as Quebec and Ontario (see Table 3.1) may be benefiting from agglomeration effects due to urbanization economies, where more emphasis is placed upon commercializable output (PATENTS) and less emphasis is placed upon basic science and engineering activity (JOURNALS). Higher education R&D expenditures are also found to be significant (at the 5% level) and *positively* related to JOURNALS, but *negatively* related to PATENTS. This is consistent with more higher education R&D contributing to basic science and engineering knowledge, but crowding out money that could potentially have been spent on business sector R&D for the commercialization of innovation.

Again, in terms of supporting the third main hypothesis that increased levels of provincial R&D expenditures will lead to greater provincial innovation flows, provincial government R&D is found to have a positive effect on both patent flow and journal article publications. Additionally, provincial higher education R&D has a positive effect on journal article publications. However, business sector R&D has a negative effect on journal article publications and higher education R&D has a negative effect on patents. Thus, there are trade-offs in terms of a province's allocation of R&D expenditures.

What this suggests is that in terms of a provincial-level innovation policy, increasing the level of government R&D will help to foster increases in both patents (commercializable output) and journal articles (basic science and engineering knowledge). This may provide the biggest "bang for the buck" in determining what sectors to target for increased provincial R&D funding, where a 10 percent increase in provincial government R&D expenditures increases patents by 2.2% and journal articles by just under 1%. It should be noted that a province has more *direct* control over government and higher education sector R&D spending compared to business enterprise sector R&D spending, since both GOVERD and HERD contain some provincially administered funding sources. However, a province does have *indirect* control over BERD expenditures in that it can foster a more business-friendly climate to attract more private business investment and its associated R&D.

Another noteworthy result from Table 3.6 is that GDP/LF is now significant (at the 5% level) and positively related to U.S. patents (using 1993-2003 data, which does not include the recession of the early 1990s). However, GDP/LF is significant and *negatively* related to science and engineering (S&E) journal articles. This may be the result of journal article publications being counter-cyclical to the state of the economy. S&E journal articles, when included as in an input into innovation, are found to be nearly significant and are positively related to U.S. patents (Table 3.6, column 2). This is consistent with the idea that basic scientific and engineering knowledge should help to facilitate the commercialization of innovative products. Finally, in comparing the explanatory power of both models, there is a much higher R^2 when patents are used as the dependent variable in column 2 than when S&E journal articles are used as the dependent variable in column 1 (0.966 versus 0.885).

3.7.5 Regression Results: U.S. Patent Stocks vs. GDP/LF as Measures of Innovation Stocks

In Table 3.7, U.S. patent stocks and GDP/LF are compared as measures of knowledge stock as a robustness check to the base model, where PATENTS per 100,000 LF is the dependent variable. Chelleraj *et al.* (2005) use the stock of U.S. patents as their stock innovation variable, whereas Stern *et al.* (2000) use both GDP/POP as well as the stock of U.S. patents (and compare them). Following Chellaraj *et al.* (2005) in formulating the innovation stock variable, the last 5 years of U.S. patent stocks are summed up and divide by the labor force[33]. Thus, this new measure of innovation stock is compared to GDP/LF (which is used in the base specifications) to see which provides better results. As noted by Stern *et al.* (2000), patent stock provides a more direct measure of knowledge stock (but is less inclusive), whereas GDP/LF is a more comprehensive, composite measure of technical sophistication. A priori, there was no preference given to either measure of knowledge stock since both have advantages and disadvantages.

Columns 1-3 in Table 3.7 include the base model with PATENTS as the dependent variable and the following independent variables: RSCHERS plus GDP/LF (column 1), patent stock (column 2) and both GDP/LF and patent stock (column 3). The only difference between columns 1-3 and 4-6 is that columns 4-6 add R&D expenditures

[33] Stern *et. al* (2000) have a slightly different specification for their innovation stock variable, where they use the cumulative number of patents from 1973 until (t-1). Given the limited number of years of time series data in this study, Chelleraj *et al.*'s technique was chosen for its better fit with the existing data.

by sector to the base model. All specifications again include provincial and year fixed effects.

GDP/LF is found to be a better measure of innovation stock than the sum of the last 5 years of U.S. patents per 100,000 LF. For instance, GDP/LF is significant and positively related to U.S. patents in 3 out of 4 specifications (columns 1, 3 and 6), whereas patent stock is not significant in any of the specifications. Additionally, the base model, which includes only GDP/LF as a measure of innovation stock (column 1) has more explanatory power than the base model which includes only patent stock as a measure of innovation stock (column 2). Further, a major drawback of using patent stock as a measure of innovation stock is that there is only 6 years worth of time series data for the sample due to data lost in summing up U.S. patents, where data for U.S. patents by provinces only dates back to 1997.

Using the aforementioned truncated sample for 2000-2005, hypothesis (2) holds when using GDP/LF, where greater provincial stocks of innovation will lead to greater provincial innovation flows. These results were not found in Tables 3.4 and 3.5 for samples that included time series data from the early 1990s for GDP. As noted previously, it is speculated that GDP/LF was not significant in the larger sample because of the recession in the early 1990s. Thus, based upon these results and the fact that the sample would have had to have been reduced down to 6 years worth of data instead of 11 years to accommodate the construction of the patent stock variable, GDP/LF was used as a proxy for innovation stock in all of the specifications.

3.8 CONCLUSION

The augmented national ideas production function described above allows for the examination of how knowledge stock, R&D expenditures, the number of R&D researchers, and skilled immigrants affect innovation flow by Canadian province. The results are consistent with previous studies, where each of the above factors had a significant and positive affect on the flow of new-to-the world technologies as measured by U.S. patents.

For instance, provincial innovation stock as measured by GDP/LF was found to be significant and positively related to provincial patent flow in samples that excluded GDP data from the recessionary years of the early 1990s. This supports the first main hypothesis that greater provincial stocks of innovation will lead to greater provincial innovation flows. The number of provincial R&D researchers was also found to be significant and positively related to provincial patent flows in nearly all specifications, which is consistent with the second main hypothesis that increased numbers of provincial R&D researchers will lead to greater provincial innovation flows.

Although total provincial R&D expenditures (GERD) was insignificant, when broken down by sector, provincial level government R&D expenditures (GOVERD) was significant and *positively* related to provincial U.S patents as well as to science and engineering (S&E) journal articles. Additionally, although provincial level higher education R&D expenditures (HERD) were significant and *negatively* related to U.S. patents, they were *positively* related to S&E journal articles. Finally, provincial level business enterprise R&D expenditures (BERD) were significant and *negatively* related to S&E journal articles (with typically no affect on U.S. patents, but with a positive affect on U.S. patents in some specifications).

Thus, the above results appear to support the third main hypothesis that increased levels of provincial R&D expenditures will lead to greater provincial innovation flows with the corollary that there may also be a crowding out effect. In other words, the results point to greater (government-funded) higher education R&D spending crowding out (privately-funded) business sector spending, resulting in decreased levels of patent flows, but increased levels of S&E journal articles. Consequently, if provincial policymakers are interested in targeting certain sectors of R&D spending to achieve the highest payoff in terms of increasing both commercializable outputs (i.e. patents) and basic science and engineering knowledge (i.e. S&E journal articles), they should increase GOVERD spending. This can be done at the provincial level via the provincial governments as well through provincial research organizations like the Saskatchewan Research Council.

By categorizing skilled immigrants in terms of education, language ability, and immigrant classification, skilled immigrants, who were proficient in either English or French, were found to have a significant and positive impact on innovation flow in their home province. This result provides support for the fourth main hypothesis that greater numbers of skilled immigrants by province will increase that province's innovation flow.

Further, in examining skilled immigrants by source region, skilled immigrants from developed countries (which include France, Germany, the U.K, and the U.S.) had the greatest impact on their home province's innovation flow. This was true of North American/European skilled immigrants for all skill-level categories including language proficiency, education, and immigrant class. For immigrants from developing countries, only highly educated Eastern Europeans (where over 92% of this category are Polish) and Low Income Asians (where over 75% of this category are Chinese and Indian) classified as “Independent Workers” were both significant and positively related to their home province’s innovation flow.

Thus, this supports the fifth main hypothesis that skilled immigrants from source countries that are similar to Canada will increase innovation flow more than immigrants from dissimilar countries. This is based upon the notion that it is easier for skilled immigrants from countries that are more like Canada (i.e. developed/European) to integrate and work with the pre-existing skilled Canadian labor force than for skilled immigrants from countries that are more unlike Canada (i.e. developing/non-European). Tying this back to the above results for developing countries, the Eastern European educational system may have more in common with those of Western Europe/North America than do non-European countries’ educational systems in terms of quality and type of training. Thus, highly educated Eastern Europeans may be better integrated into the Canadian innovation community, which would help them to better foster innovation. It is also presumed that Low Income Asians who land in Canada as “Independent” immigrants (which include immigrants that came under the Entrepreneur, Self-employed, or Investor classification in addition to other categories) may have pre-existing links to established networks of immigrants from their home countries, which might enable them to better foster innovation.

The above results have implications for Canada’s policymakers. For example, if provinces want to increase innovation, they can do so through a number of channels. First, merely increasing the number of provincial R&D researchers has a strong impact on innovation flow in terms of increasing the number of U.S. patents by province.

However, this may be difficult to do in the Atlantic and Prairie Provinces (with the exception of Alberta) since these regions currently have low numbers of R&D researchers (per 100,000 of their labor forces) and do not have large urban centers to enable them to achieve agglomeration economies. For instance, Orlando and Verba (2005) find that more populous regions (in the U.S.) are more conducive to innovation in terms of patent output. They cite two key reasons for this outcome. First, more populous places have thick markets for cheap and abundant inputs to innovation. Second, knowledge spillovers result from more people in one place creating opportunities to learn from one another. However, they further note that based upon their empirical findings, research activity related to incremental innovations associated with mature technologies is not disadvantaged by locating in sparsely populated areas to avoid the high cost of doing business in large urban centers. Thus, for smaller provinces/regions that still want to promote innovative output, increases in R&D researchers and their related research activity may be best targeted towards work on mature versus newly emerging technologies.

Increasing the amount of provincial research and development expenditures by the government sector was found to increase not only patent flow (which is a proxy for commercializable output), but also the number of S&E journal articles (which provides a foundation for basic science and engineering knowledge). Thus, in terms of policy, both small and large provinces can gain from increasing government sector R&D. However, increasing provincial R&D spending on higher education increases a province's output of basic S&E knowledge at the expense of commercializable output due to government sector crowding out of business sector R&D. Therefore, provincial policymakers may want to decide in advance whether or not they want to "compete" in the production of knowledge "inputs" or "outputs". Given that agglomeration economies play an important role in a region's ability to compete in producing innovative outputs in terms of patents, it may be that smaller provinces/regions may decide to focus more on basic research as their innovative comparative advantage.

Finally, in terms of using immigration policy to foster provincial innovation, provinces/regions may want to target certain types of immigrants (i.e. immigrants who are language proficient, highly educated, etc.) based upon their impact on innovation. Currently, the Atlantic Provinces have the highest proportion of skilled immigrants in terms of education, language compatibility, and number of Independent skilled-workers, whereas Manitoba has the lowest percentage of skilled immigrants. Thus, provinces such as Manitoba, that are attracting less-skilled immigrants vis-à-vis other regions may want to focus on trying to increase the skill-set of their incoming international migrants.

Additionally, provinces/regions may also want to direct their efforts towards attracting more immigrants from regions whose workers may be more compatible with their existing workforce. This last proposition may create its own separate host of problems in that it would likely lead to the admission of more immigrants from developed/Western regions and fewer immigrants from developing/non-Western regions. Given the political as well as practical problems associated with a targeted country-of-origin immigration policy, provinces may want to work on establishing more effective ways of integrating newly arrived skilled immigrants from developing/non-Western countries into their local labor force. For instance, finding more ways to increase the English and/or French language skills of recently arrived skilled immigrants should pay high returns in terms of incorporating foreign skilled labor into the local labor market. However, more research into how skilled immigrants affect innovation flow should help to provide further insights into the linkages between skilled immigrants and innovation flows by region.

Table 3.1: Descriptive Statistics for Base Innovation Variables by Province/Region

Mean Values and (Std. Dev.)

Province/Region	U.S. Patents[a]	Scientific Articles[b]	R&D Researchers[c]	GDP[d]	GERD[e]	BERD[f]	GOVERD[g]	HERD[h]
Atlantic	4.2 (0.7)	168.6 (10.7)	366.2 (76.2)	$47,707.27 ($3,265.24)	$526.27 ($53.52)	$111.09 ($19.58)	$144.80 ($12.88)	$268.18 ($50.72)
Quebec	21.3 (5.8)	171.0 (10.7)	719.7 (123.3)	$53,213.18 ($3,857.12)	$1,220.50 ($239.65)	$746.65 ($179.00)	$99.72 ($14.06)	$372.33 ($59.75)
Ontario	20.3 (2.7)	192.7 (10.4)	742.9 (89.7)	$62,941.47 ($53,78.76)	$1,389.57 ($225.22)	$875.61 ($179.85)	$200.53 ($9.80)	$307.52 ($62.00)
Manitoba	10.0 (2.5)	175.8 (15.9)	369.4 (43.2)	$52,751.42 ($3,572.33)	$604.17 ($90.40)	$198.51 ($42.65)	$129.95 ($26.81)	$251.28 ($54.82)
Saskatchewan	11.2 (2.8)	201.8 (15.8)	329.4 (30.5)	$57,823.08 ($4,529.79)	$604.70 ($101.85)	$154.59 ($21.71)	$139.73 ($16.33)	$310.37 ($94.58)
Alberta	15.7 (2.3)	198.6 (14.8)	393.0 (32.2)	$67,902.50 ($4,699.26)	$706.12 ($59.99)	$337.56 ($42.70)	$100.98 ($7.07)	$261.64 ($41.54)
British Columbia	15.8 (2.5)	175.6 (13.0)	410.3 (55.6)	$57,197.38 ($2,547.55)	$620.99 ($122.50)	$345.00 ($85.17)	$59.65 ($7.61)	$212.54 ($43.68)
Total Canada (excluding territories)	**14.1 (6.4)**	**183.4 (18.1)**	**493.6 (186.0)**	**$57,076.61 ($7,409.71)**	**$844.69 ($366.48)**	**$428.42 ($307.76)**	**$124.24 ($46.10)**	**$288.76 ($77.27)**

a: U.S. Patents = U.S patents by province per 100,000 provincial labor force for 1995-2005.
b: Scientific Articles = Scientific articles by province per 100,000 provincial labor force for 1995-2005.
c: R&D Researchers = R&D researchers by province per 100,000 provincial labor force for 1992-2002.
d: GDP = Real gross domestic product by province in Canadian dollars (1997=100) divided by the provincial labor force for 1992-2002.
e: GERD = Real gross domestic expenditures in R&D for all sectors by province in Canadian dollars (1997=100) divided by the provincial labor force for 1992-2002.
f: BERD = Real gross domestic expenditures in R&D for the business enterprise sector by province in Canadian dollars (1997=100) divided by the provincial labor force for 1992-2002.
g: GOVERD = Real gross domestic expenditures in R&D for the government sector by province in Canadian dollars (1997=100) divided by the provincial labor force for 1992-2002.
h: HERD = Real gross domestic expenditures in R&D for the higher education sector by province in Canadian dollars (1997=100) divided by the provincial labor force for 1992-2002.

Table 3.2: Descriptive Statistics for Skilled Immigrants by Destination Province/Region

Percent of each category (1988-2002)

Immigrant Destination Province/Region	Total Immigrants[a]	Percent of Skilled Immigrants by Destination Province/Region					
		BS+MS +PhD[b]	MS+PhD[c]	English &/or French[d]	Common Language[e]	Skilled[f]	Independent[g]
Atlantic	14,785	36.1%	12.5%	75.5%	73.1%	22.7%	54.8%
Quebec	249,525	24.7%	6.5%	66.5%	44.1%	24.9%	45.1%
Ontario	1,048,845	26.5%	5.7%	60.0%	59.0%	19.4%	42.6%
Manitoba	30,695	21.9%	4.3%	55.5%	54.6%	13.1%	31.6%
Saskatchewan	9,045	29.5%	9.8%	60.5%	59.6%	17.3%	37.6%
Alberta	133,875	25.1%	5.6%	54.7%	53.8%	17.4%	39.6%
British Columbia	341,470	25.1%	5.1%	51.1%	50.6%	17.4%	49.9%
Total Canada (excluding territories)	**1,832,300**	**25.9%**	**5.8%**	**59.0%**	**54.6%**	**19.6%**	**44.0%**

a: Total Immigrants = Immigrants living in a province in 2003 who landed in Canada between 1988 and 2002.
b: BS+MS+PhD = Percent of immigrants living in a province in 2003 with a Bachelor's degree or higher level of education who landed in Canada between 1988 and 2002.
c: MS+PhD = Percent of immigrants in a province in 2003 with a Master's degree or higher level of education who landed in Canada between 1988 and 2002.
d: English &/or French = Percent of immigrants living in a province in 2003 who speak English &/or French who landed in Canada between 1988 and 2002.
e: Common Language = Percent of immigrants living in a province in 2003 who speak the province's official language who landed in Canada between 1988 and 2002. The official language for every province is English, except for Quebec, which is French. New Brunswick's official language is both English and French, but since the data for New Brunswick is aggregated with the rest of Atlantic Canada, we consider Atlantic Canada's official language as English only for the purposes of this study.
f: Skilled = Percent of immigrants living in a province in 2003 who are classified as Skilled Worker (P.A.) who landed in Canada between 1988 and 2002. Note: P.A. = Principal Applicant.
g: Independent = Percent of immigrants living in a province in 2003 who are classified as Skilled Worker (P.A.), Business (P.A.) (which includes Entrepreneur, Self-Employed, Investor, and Other Business), or Other Economic (which includes Business Class (S.D.) or Skilled Worker (S.D.)) who landed in Canada between 1988 and 2002. Note: S.D. = Spouse or Dependent.

Table 3.3: Descriptive Statistics for Skilled Immigrants by Source Region of the World

Percent of each category (1988-2002)

Immigrant Source Region of the World	Total Immigrants[a]	Percent of Skilled Immigrants by Source Region of the World					
		BS+MS +PhD[b]	MS+PhD[c]	English &/or French[d]	Common Language[e]	Skilled[f]	Independent[g]
W. Europe/N. America Immigrants	123,560	28.6%	11.9%	93.6%	93.6%	31.0%	57.1%
E. Europe Immigrants	84,765	13.4%	2.6%	19.5%	19.5%	4.1%	8.0%
High Income Asia Immigrants	155,965	13.4%	2.7%	47.4%	47.4%	17.1%	70.8%
Low Income Asia Immigrants	537,285	32.6%	6.8%	51.9%	51.9%	19.7%	38.6%
Middle East/N. Africa Immigrants	55,455	20.9%	4.8%	74.7%	74.7%	28.3%	57.8%
All Other Countries' Immigrants	875,270	25.2%	5.2%	63.3%	63.3%	19.3%	43.3%
Total Immigrants	**1,832,300**	**25.9%**	**5.8%**	**59.0%**	**59.0%**	**19.6%**	**44.0%**

a: Total Immigrants = Immigrants from selected regions of the world living in Canada in 2003 who landed in Canada between 1988 and 2002. A listing of all of the countries by region can be found in Appendix 2.
b: BS+MS+PhD = Percent of immigrants from selected regions of the world living in Canada in 2003 with a Bachelor's degree or higher level of education who landed in Canada between 1988 and 2002.
c: MS+PhD = Percent of immigrants from selected regions of the world living in Canada in 2003 with a Master's degree or higher level of education who landed in Canada between 1988 and 2002.
d: English &/or French = Percent of immigrants from selected regions of the world living in Canada in 2003 who speak English &/or French who landed in Canada between 1988 and 2002.
e: Common Language = Percent of immigrants from selected regions of the world living in Canada in 2003 who speak at least one of Canada's official languages (which are English and French) who landed in Canada between 1988 and 2002. For Canada as a country, Common Language and English &/or French are identical.
f: Skilled = Percent of immigrants from selected regions of the world living in Canada in 2003 who are classified as Skilled Worker (P.A.) who landed in Canada between 1988 and 2002. Note: P.A. = Principal Applicant.
g: Independent = Percent of immigrants from selected regions of the world living in Canada in 2003 who are classified as Skilled Worker (P.A.), Business (P.A.) (which includes Entrepreneur, Self-Employed, Investor, and Other Business), or Other Economic (which includes Business Class (S.D.) or Skilled Worker (S.D.)) who landed in Canada between 1988 and 2002. Note: S.D. = Spouse or Dependent.

Table 3.4: Base Specification + Skilled Immigrants by Education Level, Language Ability, & Immigrant Class

PATENTS/100,000$LF_{p,t+3}$ as the Dependent Variable[a,b,c,d]

Log-Log Specification

Variable	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
Constant	-6.86 (0.97)	-6.94 (0.97)	-5.93 (0.92)	-5.19 (0.79)	-9.91 (1.34)	-6.86 (1.20)	-6.64 (1.16)	-5.81 (0.91)	-3.95 (0.53)
GDP/$LF_{p,t}$	0.44 (0.69)	0.36 (0.55)	0.54 (0.90)	0.44 (0.71)	0.96 (1.40)	0.39 (0.73)	0.39 (0.73)	0.51 (0.86)	0.32 (0.44)
RSRCHRS/ 100,000$LF_{p,t}$	0.56 (4.87)**	0.52 (4.88)**	0.35 (2.71)**	0.31 (1.86)*	0.54 (2.86)**	0.39 (2.97)**	0.38 (2.93)**	0.34 (2.54)**	0.35 (2.66)**
GERD/$LF_{p,t}$		0.18 (1.17)							
BERD/$LF_{p,t}$			0.10 (1.01)	0.12 (1.09)	0.11 (1.04)	0.15 (1.46)	0.15 (1.47)	0.11 (1.07)	0.12 (1.08)
GOVERD/$LF_{p,t}$			0.26 (1.98)*	0.23 (1.51)	0.25 (1.91)*	0.12 (0.89)	0.10 (0.72)	0.24 (1.73)*	0.23 (1.57)
HERD/$LF_{p,t}$			-0.43 (2.28)**	-0.45 (2.31)**	-0.45 (2.45)**	-0.67 (3.00)**	-0.67 (2.99)**	-0.44 (2.32)**	-0.47 (2.35)**
BSPLUS/ 100,000$LF_{p,t}$				0.14 (0.49)					
MSPLUS/ 100,000$LF_{p,t}$					-0.35 (1.54)				
LANG/ 100,000$LF_{p,t}$						0.72 (3.31)**			
COMLANG/ 100,000$LF_{p,t}$							0.73 (3.31)**		
SKILL/ 100,000$LF_{p,t}$								0.075 (0.38)	
INDEPENDENT/ 100,000$LF_{p,t}$									0.12 (0.55)
Province Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	77	77	77	77	77	77	77	77	77
R^2	0.957	0.960	0.963	0.963	0.964	0.967	0.967	0.963	0.963

a: * indicates significance at the 10% level and ** indicates significance at the 5% level.
b: The absolute values of the t-statistics are given in parentheses.
c: Results are corrected for heteroskedasticity (using the ;Hetero command in LIMDEP).
d: All variables are by province/region. The dependent variable includes data from 1995-2005 and the independent variables, which are lagged 3 years include data from 1992-2002.

Table 3.5: Augmented Specification with Skilled Immigrants broken down by Source Region of the World

$PATENTS/100,000LF_{p,t+3}$ as the Dependent Variable[a,b,c,d]

Log-Log Specification

Variable	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6
Constant	-4.16 (0.44)	1.92 (0.27)	0.76 (0.08)	1.55 (0.17)	-6.98 (0.79)	-3.79 (0.48)
$GDP/LF_{p,t}$	0.63 (0.75)	0.087 (0.13)	-0.34 (0.36)	-0.33 (0.40)	0.51 (0.61)	0.24 (0.32)
$RSRCHRS/100,000LF_{p,t}$	0.36 (2.10)**	0.15 (0.57)	0.25 (1.63)	0.19 (1.26)	0.40 (2.82)**	0.33 (2.46)**
$BERD/LF_{p,t}$	0.091 (0.86)	0.30 (2.14)**	0.20 (1.77)*	0.23 (1.84)*	0.14 (1.11)	0.15 (1.46)
$GOVERD/LF_{p,t}$	0.11 (0.75)	0.017 (0.10)	-0.025 (0.16)	0.027 (0.17)	0.12 (0.76)	0.090 (0.51)
$HERD/LF_{p,t}$	-0.50 (2.27)**	-0.39 (2.12)**	-0.39 (1.65)	-0.37 (1.54)	-0.57 (2.50)**	-0.52 (2.33)**
Skill-Level	BS+MS +PhD	MS+PhD	English &/or French	Common Language	Skilled	Independent
W. Europe/N. America Immigrants	0.17 (1.09)	0.30 (2.36)**	0.48 (3.02)**	0.68 (2.61)**	0.42 (3.52)**	0.46 (4.02)**
E. Europe Immigrants	0.11 (0.79)	0.47 (2.15)**	-0.23 (1.34)	-0.15 (0.99)	0.010 (0.16)	0.023 (0.22)
High Income Asia Immigrants	-0.015 (0.10)	-0.0018 (1.60)	-0.19 (0.66)	-0.10 (0.53)	0.16 (1.12)	0.047 (0.29)
Low Income Asia Immigrants	0.070 (0.65)	-0.26 (1.35)	0.30 (1.28)	0.36 (1.24)	-0.046 (0.25)	0.18 (1.82)*
Middle East/N. Africa Immigrants	-0.00019 (0.34)	-0.00015 (0.20)	-0.14 (0.92)	-0.083 (0.69)	0.00044 (0.57)	0.00097 (1.65)
All Other Countries' Immigrants	-0.57 (2.42)**	-0.46 (2.26)**	0.32 (0.58)	-0.18 (0.42)	0.33 (0.72)	-0.056 (0.21)
Province Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
N	77	77	77	77	77	77
R^2	0.970	0.974	0.971	0.970	0.970	0.970

a: * indicates significance at the 10% level and ** indicates significance at the 5% level.
b: The absolute values of the t-statistics are given in parentheses.
c: Results are corrected for heteroskedasticity (using the ;Hetero command in LIMDEP).
d: All variables are by province/region. The dependent variable includes data from 1995-2005 and the independent variables, which are lagged 3 years include data from 1992-2002.

Table 3.6: Comparison of Provincial Science and Engineering Journal Articles and U.S. Patents as Dependent Variables

Log-Log Specification[a,b,c,d]

Variable	Col. 1 Dependent Variable: $ARTICLES/100{,}000LF_{p,t+3}$	Col. 2 Dependent Variable: $PATENTS/100{,}000LF_{p,\ t+3}$
Constant	10.14 (4.22)**	-24.51 (2.38)**
$GDP/LF_{p,t}$	-0.52 (2.32)**	1.93 (2.38)**
$ARTICLES/100{,}000LF_{p,t}$		0.73 (1.63)
RSRCHRS/ $100{,}000LF_{p,t}$	0.025 (0.61)	0.39 (2.77)**
$BERD/LF_{p,t}$	-0.11 (3.12)**	0.035 (0.29)
$GOVERD/LF_{p,t}$	0.097 (1.86)*	0.22 (1.75)*
$HERD/LF_{p,t}$	0.12 (1.72)*	-0.41 (1.81)*
Province Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
N	70	70
R^2	0.885	0.966

a: * indicates significance at the 10% level and ** indicates significance at the 5% level.
b: The absolute values of the t-statistics are given in parentheses.
c: Results are corrected for heteroskedasticity (using the ;Hetero command in LIMDEP).
d: All variables are by province/region. The dependent variable includes data from 1996-2005 and the independent variables, which are lagged 3 years include data from 1993-2002.

Table 3.7: Comparison of GDP and U.S. Patent Stocks as Measures of Stocks of Innovation

$PATENTS/100,000LF_{p,t+3}$ as the Dependent Variable[a,b,c,d]
Log-Log Specification

Variable	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col.6
Constant	-24.60 (2.37)**	-4.78 (2.77)**	-29.87 (2.39)**	-16.12 (1.49)	-0.88 (0.32)	-22.27 (1.69)
$GDP/LF_{p,t}$	1.89 (2.02)*		2.33 (2.13)**	1.37 (1.54)		1.95 (1.77)*
$PATSTOCK/100,000LF_{p,t}$ [e]		-0.0021 (0.007)	0.28 (1.08)		0.21 (0.68)	0.43 (1.36)
$RSRCHRS/100,000LF_{p,t}$	0.92 (3.57)**	1.04 (4.02)**	0.84 (3.53)**	0.69 (2.12)**	0.62 (2.11)**	0.56 (1.88)*
$BERD/LF_{p,t}$				0.11 (0.80)	0.19 (1.47)	0.13 (0.97)
$GOVERD/LF_{p,t}$				0.011 (0.064)	-0.04 (0.19)	-0.069 (0.34)
$HERD/LF_{p,t}$				-0.35 (1.26)	-0.48 (1.75)*	-0.43 (1.60)
Province Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
N	42	42	42	42	42	42
R^2	0.974	0.973	0.975	0.975	0.975	0.976

a: * indicates significance at the 10% level and ** indicates significance at the 5% level.
b: The absolute values of the t-statistics are given in parentheses.
c: Results are corrected for heteroskedasticity (using the ;Hetero command in LIMDEP).
d: All variables are by province/region. The dependent variable includes data from 2000-2005 and the independent variables, which are lagged 3 years include data from 1997-2002.
e: PATSTOCK/100,000LF = Σ(previous 5 years of U.S. Patents)/100,000 LF

CONCLUSION

The preceding three essays on immigration, innovation and trade provide a variety of policy prescriptions for increasing Canada's international competitiveness via immigration, innovation and trade policy at the provincial level. Although each of these essays can be viewed as stand-alone papers, taken together, they provide a more holistic approach for provincial policymakers to increase Canada's international competitiveness.

In the first essay, it was found that immigrants increased both import and export trade flows. However, by adding the lagged provincial immigrant wave variable, it was also found that immigrants most strongly affect the importation of goods from their home countries to Canadian provinces almost immediately, whereas immigrants most strongly affect the exportation of goods from Canadian provinces to their home countries after at least 5 years. In the second essay, it was found that increasing the number of U.S. patents by province increased that province's total exports as well as hi-tech exports. Additionally, provincial R&D expenditures as well as the number of provincial scientific publications were also found to be significant drivers in increasing the amount of provincial hi-tech exports.

Thus, taken together, essays one and two suggest that both immigration and innovation policy have an affect on trade, where immigrants increase both imports and exports via their links to their home countries and innovation increases exports by increasing the stock of human capital/knowledge. Therefore, provincial-level trade policy should consider the effects of immigration and innovation in terms of their impact on provincial trade, where provinces with greater levels of immigrants and innovative capability have a strategic advantage in terms of trade vis-à-vis provinces with fewer immigrants and less capacity for innovation.

As noted above, in the first essay it was found that immigrants increased both import and export trade flows at the provincial level. In terms of skilled immigration, in the third essay, it was found that language proficient skilled immigrants increased innovation flow in their home province. Further, skilled immigrants of all skill levels (i.e. language proficient, highly educated and skilled/independent immigrant class) from developed countries were found to increase innovation flow in their home province.

Thus, taken together, the results of essays one and three suggest that immigration policy has an affect on both trade and innovation policies, where increased numbers of immigrants lead to greater levels of trade and increased numbers of skilled immigrants lead to greater levels of innovation. Therefore, provincial policymakers need to consider the implications of immigration policy in terms of increased international competitiveness via increased levels of trade as well as innovation. Additionally, an immigrant's length of stay, skill-set, and source region all have an impact on a province's trade and/or innovation capability. Thus, provinces should be cognizant of how their current and projected immigrant mix may impact their international competitiveness.

Finally, as noted above, in the third essay, it was found that skilled immigrants increased innovation flow in their home province, where in the second essay it was found that increased innovation flow in a particular province increased that province's exports (both total and hi-tech). Thus, taken together, the results of essays two and three suggest that innovation policy is linked to both immigration and trade policy, where skilled immigrants cause an increase in innovative capability which in turn leads to increased exports. Thus, skilled-immigrants serve as a key input to an effective innovation policy, where a positive outcome of increased innovation is enhanced trade. Therefore, immigration policy can be used to foster provincial innovation, where provinces/regions may want to target certain types of immigrants (i.e. immigrants who are language proficient, highly educated, etc.) based upon their impact on innovation, which has positive spillover effects on provincial exports.

To conclude, the common thread in my three essays on immigration, innovation, and trade is that provincial policymakers can impact their provinces' international competitiveness by coordinating their innovation and trade policies with their immigration policies. For instance, provincial policymakers can influence innovation and international trade through immigration policy using the Provincial Nominee Program (PNP) as well as federal-provincial agreements on immigration. Thus, provinces can use immigration policy as a tool to increase innovation by attracting skilled immigrants from source regions with the appropriate skill-set to augment a province's pre-existing native workforce. Additionally, provinces can use immigration policy as a tool to increase international trade by attracting immigrants from source countries/regions, where increased trade with these countries/regions is a high priority for that particular province.

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CHAPTER 3

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Appendix 1.1: Provinces and Countries included in Study

Provinces (n =10)	Countries (n = 40)
Alberta	Afghanistan
British Columbia	Algeria
Manitoba	Bangladesh
New Brunswick	Bosnia and Herzegovina
Newfoundland and Labrador	China (People's Republic)
Nova Scotia	Columbia
Ontario	Congo (Democratic Republic and former Zaire)
Prince Edward Island	Croatia
Quebec	Egypt
Saskatchewan	France (including Monaco, French Antilles)
	Germany
	Ghana
	Guyana
	Haiti
	Hong Kong (Special Administrative Region)
	India
	Iran
	Iraq
	Jamaica
	Japan
	Lebanon
	Mexico
	Morocco
	Pakistan
	Philippines
	Poland
	Romania
	Russia (Russian Federation)
	Saudi Arabia
	Somalia
	South Africa (Republic)
	South Korea
	Sri Lanka
	Taiwan
	Trinidad and Tobago
	Ukraine
	United Kingdom
	United States
	Vietnam
	Yugoslavia* (Serbia and Montenegro)

* Lagged variables include Serbia and Montenegro only for consistency.

Appendix 1.2: Variable Definitions and Sources

Variable	Definition	Source
Imports	The 2001-2005 average of imports of goods in millions of Canadian dollars to each of the 10 Canadian Provinces from each of the 40 countries.	Statistics Canada (2001-2005)
Exports	The 2001-2005 average of exports of goods in millions of Canadian dollars from each of the 10 Canadian Provinces to each of the 40 countries.	Statistics Canada (2001-2005)
Pre-1961 Provincial Immigrant Base	Immigrants who came to Canada before 1961 and are residing in a given province in 2001[a]	Statistics Canada (2001b ; 2001c)
1961-1970 Provincial Immigrant Wave	Immigrants who came to Canada between 1961 and 1970 and are residing in a given province in 2001[a]	Statistics Canada (2001b ; 2001c)
1971-1980 Provincial Immigrant Wave	Immigrants who came to Canada between 1971 and 1980 and are residing in a given province in 2001[a]	Statistics Canada (2001b ; 2001c)
1981-1990 Provincial Immigrant Wave	Immigrants who came to Canada between 1981 and 1990 and are residing in a given province in 2001[a]	Statistics Canada (2001b ; 2001c)
1991-2001 Provincial Immigrant Wave	Immigrants who came to Canada between 1991 and May 15, 2001 and are residing in a given province in 2001[a]	Statistics Canada (2001b ; 2001c)
1991-1995 Provincial Immigrant Wave	Immigrants who came to Canada between 1991 and 1995 and are residing in a given province in 2001[a]	Statistics Canada (2001b ; 2001c)
1996-2001 Provincial Immigrant Wave	Immigrants who came to Canada between 1996 and May 15, 2001 and are residing in a given province in 2001[a]	Statistics Canada (2001b ; 2001c)
Distance	Great Circle distances in miles between provincial capitals and country capitals	Bali and Indonesia on the Net (2007)
Provincial GDP	Provincial GDP estimates for July, 2001 in millions of Canadian dollars.	Statistics Canada (2001a)
Country GDP	Country GDP estimates for July, 2001 in millions of Canadian dollars.	CIA, *The World Factbook* (2002) (GDP data) IMF, *International Financial Statistics Yearbook* (2006) (exchange rates used to convert GDP from US dollars to Canadian dollars)
English	A dummy variable for whether or not English is a primary or secondary language spoken in a given country, where English equals 1 if it is a primary or secondary language spoken and equals 0 if it is not.	CIA, *The World Factbook* (2006)
French	A dummy variable for whether or not French is a primary or secondary language spoken in a given country, where French equals 1 if it is a primary or secondary language spoken and equals 0 if it is not.	CIA, *The World Factbook* (2006)
English*Quebec	Interaction of the English dummy variable with the Quebec dummy variable	Constructed by author
French*Quebec	Interaction of the French dummy variable with the Quebec dummy variable	Constructed by author
Trade Office	A dummy variable for whether or not Canada has a trade office in a given country.	Foreign Affairs and International Trade Canada (2006-2007), Canadian Trade Commissioner Service, *Our Offices in Canada and Abroad*

[a] For consistency, provincial immigrants are from the same 40 countries that comprised the top 40 countries in terms of the number of immigrants coming to Canada from the most recent immigrant wave (1996-May 15, 2001).

Appendix 1.3: Regression Results: Total Trade (Exports + Imports) as the Dependent Variable

Log-Log Specification[a,b,c]

Variable	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Constant	-5.47 (6.70)**	-6.55 (4.35)**	-4.74 (2.73)**	2.42 (3.29)**	1.16 (0.80)	1.68 (2.13)**
Exporter Provincial Immigrant Stock (Pre-1961-2001)	-0.0056 (0.05)			0.0015 (0.014)		
Exporter Pre-1961 Provincial Immigrant Base		0.19 (0.60)	0.21 (0.70)		0.25 (0.82)	0.30 (1.0)
Exporter 1961-1970 Provincial Immigrant Wave		0.13 (0.20)	-0.11 (0.17)		0.083 (0.13)	-0.23 (0.37)
Exporter 1971-1980 Provincial Immigrant Wave		0.27 (0.40)	0.40 (0.60)		0.35 (0.52)	0.51 (0.79)
Exporter 1981-1990 Provincial Immigrant Wave		-0.62 (0.82)	-1.04 (1.33)		-0.81 (1.07)	-1.37 (1.78)*
Exporter 1991-2001 Provincial Immigrant Wave		0.090 (0.20)			0.19 (0.41)	
Exporter 1991-1995 Provincial Immigrant Wave			1.53 (1.86)*			2.01 (2.46)**
Exporter 1996-2001 Provincial Immigrant Wave			-1.03 (1.71)*			-1.28 (2.17)**
Distance	-1.16 (18.10)**	-1.17 (17.47)**	-1.20 (17.70)**	-1.21 (17.97)**	-1.22 (17.30)**	-1.27 (17.85)**
Exporter Provincial GDP	0.96 (6.21)**	1.01 (5.33)**	0.97 (5.15)**	0.95 (6.23)**	1.02 (5.45)**	0.97 (5.32)**
Importer Provincial GDP	0.95 (24.69)**	0.95 (24.33)**	0.95 (24.76)**			
Importer Provincial Fixed Effects	NO	NO	NO	YES	YES	YES
N	90	90	90	90	90	90
R^2	0.93	0.94	0.94	0.94	0.94	0.95

a: * indicates significance at the 10% level and ** indicates significance at the 5% level
b: The absolute values of the t-statistics are given in parentheses.
c: The Inter-provincial trade data was obtained from Statistics Canada (2001-2002), Interprovincial and international trade flows at producer prices, annual (dollars) (19635 series), Table 386-0002.

Appendix 2.1: Variable Definitions and Sources

Variable	Definition	Source
Exports per capita	The 2004-2005 average of net exports per capita of goods in millions of Canadian dollars from each of the 10 Canadian Provinces to each of the 60 countries.	Statistics Canada (2004-2005) (export data) Statistics Canada (2007a) (population data)
Distance	Great Circle distances in kilometers between provincial capitals and country capitals	Bali and Indonesia on the Net (2007)
Provincial GDP per capita	Provincial GDP per capita estimates for July, 2004 in millions of Canadian dollars.	Statistics Canada (2004)
Country GDP per capita	Country GDP per capita estimates for July, 2004 in millions of Canadian dollars.	CIA, *The World Factbook* (2005) (GDP data) IMF, International Financial Statistics Yearbook (2006) (exchange rates used to convert GDP from US dollars to Canadian dollars)
Common Language	A dummy variable for whether or not a province and a country share a common language, where common language equals 1 (0) if a province-country pair share (do not share) a common language.	CIA, *The World Factbook* (2006); Encyclopedia Britannica Online (2007); Ethnologue: Languages of the World (2007)[a]
Provincial Roads	Paved Provincial roads (km)/Provincial land area (km^2) in 1995.	Transportation Association of Canada (1995), Road Lengths (paved roads in kilometers), p.8; Statistics Canada (2005), land area (km^2) by province and territory.
Country Roads	Paved Country roads (km)/Country land area (km^2) in 1995.	CIA, *The World Factbook* (various years).
Provincial Internet Users per capita	Provincial Internet Users per capita for 1997 and 2000.	Statistics Canada (2007b)
Country Internet Users per capita	Country Internet Users per capita for 1997 and 2000.	The World Bank Group (2007)
Provincial R&D Expenditures per capita	Provincial Gross domestic expenditure on research and development (GERD) is gross expenditure on research and development performed on the Province during a given period. This variable measures GERD per capita and was collected for 2000 and 2003.	Institut de la Statistique Québec (2007), GERD as a percentage of GDP, Quebec, other provinces, and Canada 1996-2005.
Country R&D Expenditures per capita	Country Gross domestic expenditure on research and development (GERD) is gross expenditure on research and development performed on the Country during a given period. This variable measures GERD per capita and was collected for 2000 and 2003.	UNESCO Institute for Statistics, Total gross domestic expenditure on R&D (GERD) as a percentage of GDP.
Provincial Canadian Patents per capita	Canadian Patents granted to residents of a given province per capita for 2000 and 2003.	Canadian Intellectual Property Office (CIPO) *Annual Reports* for 2000-2001 (Table 12: Patents – Annual Statistical Report for the period January-December 2000 All Disciplines); 2003-2004 (Table 14: Patent Applications filed and granted by origin as stated by applicant)[b].

Variable	Definition	Source
Country Canadian Patents per capita	Canadian Patents granted to residents of a given country per capita for 2000 and 2003.	Canadian Intellectual Property Office (CIPO) *Annual Reports* for 2000-2001 (Table 20: Patents – Applications Filed and Granted to Residents of Foreign Countries for the Period January-December, 2000); 2003-2004 (Table 10: Patent applications filed and granted to residents of Canada and foreign countries)[b].
Provincial U.S. Patents per capita	U.S. Utility Patents granted to residents of a given province per capita for 2000 and 2003.	Institut de la Statistique Québec (2007), Inventions Patented by the USPTO: by province (Utility Patents) for 2000 and 2003.
Country U.S. Patents per capita	U.S. Utility Patents granted to residents of a given country per capita for 2000 and 2003.	United States Patent and Trademark Office (USPTO), Patents by Country, State, and Year – Utility Patents, Number of Patents Granted as Distributed by Year of Patent Grant, Breakout by U.S. State and Foreign Country of Origin for 2000 and 2003.
Provincial Science & Engineering (S&E) Articles per capita	The number of science and engineering publications per capita authored or coauthored by residents of a given province for 2000 and 2003.	Institut de la Statistique Québec (2007), Number of Natural Science & Engineering Publications per 100,000 population by province and territory for 2000 and 2003.
Country Science & Engineering (S&E) Articles per capita	The number of science and engineering publications per capita authored or coauthored by residents of a given country for 2000 and 2003.	National Science Foundation (2006), Science and Engineering Indicators 2006, Appendix Table 5-41: S&E articles, by region and country/economy: 1988-2003.
Provincial S&E Tertiary Graduates per capita	The number of science and engineering tertiary graduates per capita by province for 2000 and 2003. Degrees include bachelor's degree, master's degree and earned doctorate. Fields include physical and life sciences and technologies; mathematics, computer, and information sciences; architecture, engineering, and related technologies; agriculture, natural resources and conservation.	Statistics Canada (2006).
Country S&E Tertiary Graduates per capita	The number of science and engineering tertiary graduates per capita by country for 2000 and 2003. Degrees include bachelor's degree, master's degree and earned doctorate. Fields include science; engineering, manufacturing, and construction; agriculture.	UNESCO (United Nations Educational, Scientific, and Cultural Organization) Institute for Statistics, Total Tertiary Graduates in Science.

a: At least two of the three listed sources must have designated a language as one of a country's official languages for it to be considered an official language for that country. The official language of each province is English, except for Quebec, whose official language is French. New Brunswick is the only province that has two official languages (English and French).
b: CIPO changed their patent reporting system between the 2000-2001 and 2003-2004 Annual Reports. The patent reporting period for the 2000-2001 Annual Report as noted above is January-December, 2000. However, the patent reporting period for the 2003-2004 Annual Report is April 1, 2003 - March 31, 2004.

Appendix 2.2: Provinces and Countries included in Study

Provinces (n =10)	Developing Countries (n = 40)	Developed Countries (n=20)
Alberta	Algeria	Australia
British Columbia	Argentina	Austria
Manitoba	Bangladesh	Belgium
New Brunswick	Brazil	Denmark
Newfoundland and Labrador	Chile	Finland
Nova Scotia	China	France (incl. Monaco, French Antilles)
Ontario	Colombia	Germany
Prince Edward Island	Cuba	Greece
Quebec	Czech Republic	Ireland
Saskatchewan	Dominican Republic	Italy (includes Vatican City State)
	Ecuador	Japan
	Egypt	Netherlands
	Guatemala	New Zealand
	Hong Kong	Norway
	India	Portugal
	Indonesia (includes East Timor)	Spain
	Iran	Sweden
	Israel	Switzerland
	Jamaica	United Kingdom (U.K.)
	Korea, South	United States (U.S.)
	Malaysia	
	Mexico	
	Morocco	
	Pakistan	
	Peru	
	Philippines	
	Poland	
	Qatar	
	Romania	
	Russia	
	Saudi Arabia	
	Singapore	
	South Africa	
	Taiwan (Taipei)	
	Thailand	
	Trinidad and Tobago	
	Turkey	
	United Arab Emirates	
	Venezuela	
	Vietnam	

Appendix 3.1: Provinces/Regions

Provinces/Regions
Atlantic Canada (aggregated)
New Brunswick
Newfoundland/Labrador
Nova Scotia
Prince Edward Island
Quebec
Ontario
Manitoba
Saskatchewan
British Columbia

Appendix 3.2: Immigrant Source Countries by Region/Category

Countries by Region/Category
W. Europe/N. America (Developed)
France
Germany
United Kingdom
United States
E. Europe
Bosnia-Herzegovina
Poland
High Income Asia[a]
Hong Kong
Taiwan
Low Income Asia[b]
China
India
Philippines
Sri Lanka
Middle East/N. Africa
Kuwait
Lebanon
Morocco
All Other Countries (including Haiti)[c]

a: High Income Asia includes countries with levels of per capita GDP close to those of developed countries. For instance, Hong Kong's 2005 per capita GDP is $32,900 USD and Taiwan's 2005 per capita GDP is $27,600 USD, which is in the vicinity of the range for our subset of developed countries ($29,900 USD (for France) -$41,800 USD (for the U.S.)) (CIA World Factbook 2006).
b: Low Income Asia includes countries with much lower levels of per capita GDP than its higher income Asian cohort. In the subset of Low Income Asian countries, 2005 per capita GDP ranges from $3,300 USD (for India) to $6,800 USD (for China) (CIA World Factbook 2006).
c: I have separate data for Haiti, but combined it with all other countries since there was no obvious region/category to place it into. For example, although Haiti is in North America, it does not fit into the W. Europe/N. America category since it is a very poor developing country. According to the United Nations Statistics Division (2007), Haiti is considered a "least developed country" (with a 2005 per capita GDP of only $1,700 USD).

Appendix 3.3: Top 5 Countries of Last Permanent Residence (CLPR) by Region
Tax Year 2003*

Canada 1. India 2. China 3. Philippines 4. Hong Kong 5. Poland	**Manitoba** 1. Philippines 2. India 3. Poland 4. United Kingdom 5. China
Atlantic 1. United States 2. United Kingdom 3. China 4. Germany 5. Kuwait	**Saskatchewan** 1. Philippines 2. China 3. United States 4. United Kingdom 5. Bosnia-Herzegovina
Quebec 1. France 2. Lebanon 3. Haiti 4. China 5. Morocco	**Alberta** 1. Philippines 2. India 3. China 4. Hong Kong 5. United Kingdom
Ontario 1. India 2. China 3. Philippines 4. Hong Kong 5. Sri Lanka	**British Columbia** 1. Hong Kong 2. India 3. China 4. Philippines 5. Taiwan

Source: Statistics Canada (2007c)
* The set of countries for each region is derived from aggregating the top 5 immigrant source countries for each region for immigrants who landed in Canada between 1988 and 2002 and are residing in that region in 2003.

Appendix 3.4: Variable Definitions and Sources

Variable	Definition	Source
$PATENTS/100,000LF_{p,\ t+3}$	U.S. Utility Patent grants assigned to a given province per 100,000 provincial labor force.	Institut de la Statistique Québec (2007) Number of Inventions Patented at the USPTO and Share in Canadian Total (Utility Patents), Quebec, Other Provinces, and Territories.
$ARTICLES/100,000LF_{p,t+3}$	Science and Engineering (S&E) Journal Articles assigned to a given province per 100,000 provincial labor force.	Institut de la Statistique Québec (2007) Number of (Natural Sciences and Engineering Scientific) Publications and share of Canadian Total, Quebec, Other Provinces, and Territories.
$GDP/LF_{p,t}$	Real Gross domestic expenditures by Province in Canadian dollars (1997=100) divided by the provincial labor force.	Statistics Canada (2007b; 2007a) GDP and Labor Force data
$RSRCHRS/100,000LF_{p,t}$	The number of R&D researchers by province per 100,000 labor force.	Statistics Canada (1995; 1997; 1998)
$GERD/LF_{p,t}$	Real gross expenditures on research and development by Province in Canadian dollars (1997=100) divided by the provincial labor force.	Institut de la Statistique Québec (2007) Value of GERD, Quebec, Other Provinces, and Canada (millions of constant dollars)
$BERD/LF_{p,t}$	Real gross expenditures on research and development in the business enterprise sector by Province in Canadian dollars (1997=100) divided by the provincial labor force.	Institut de la Statistique Québec (2007) Business Enterprise Intramural Expenditure on R&D - BERD, Quebec, Other Provinces, and Canada (millions of constant dollars)
$GOVERD/LF_{p,t}$	Real gross expenditures on research and development in the government sector by Province in Canadian dollars (1997=100) divided by the provincial labor force.	Institut de la Statistique Québec (2007) Government Intramural Expenditure on R&D - GOVERD, Quebec, Other Provinces, and Canada (millions of constant dollars)
$HERD/LF_{p,t}$	Real gross expenditures on research and development in the higher education sector by Province in Canadian dollars (1997=100) divided by the provincial labor force.	Institut de la Statistique Québec (2007) Intramural Higher Education R&D Expenditure - HERD, Quebec, Other Provinces, and Canada (millions of constant dollars)
$BSPLUS/100,000LF_{p,t}$	Σ (previous 5 years of immigrants with a Bachelor's degree or higher level of education by province) per 100,000 provincial labor force	Statistics Canada (2007c) Author's calculations
$MSPLUS/100,000LF_{p,t}$	Σ (previous 5 years of immigrants with a Master's degree or higher level of education by province) per 100,000 provincial labor force	Statistics Canada (2007c) Author's calculations
$LANG/100,000LF_{p,t}$	Σ (previous 5 years of Immigrants who speak English and/or French) per 100,000 provincial labor force.	Statistics Canada (2007c) Author's calculations
$COMLANG/100,000LF_{p,t}$	Σ (previous 5 years of Immigrants who speak the province's official language) per 100,000 provincial labor force.	Statistics Canada (2007c) Author's calculations
$SKILL/100,000LF_{p,t}$ [a]	Σ (previous 5 years of Skilled Immigrants by province) per 100,000 provincial labor force.	Statistics Canada (2007c) Author's calculations
$INDEPENDENT/100,000LF_{p,t}$ [a]	Σ (previous 5 years of Independent Immigrants by province) per 100,000 provincial labor force.	Statistics Canada (2007c) Author's calculations

a Skilled Immigrants include Skilled Worker (P.A.). Independent Immigrants include Skilled Worker (P.A.), Business (P.A.) (which includes Entrepreneur P.A., Self-Employed P.A., Investor P.A., and Other Business P.A. –Abroad), and Other Economic (which includes Business Class S.D. and Skilled Workers S.D.). P.A. = Principal Applicant and S.D. = Spouse or Dependent.