TRADE POLICY, INTERNATIONAL SPILLOVERS AND INNOVATION: THEORY AND EMPIRICAL EVIDENCES

by
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Contents

The relationship between international trade and growth has been widely discussed for many years. Although the evidence is still mixed, openness and trade liberalization are generally viewed as key components of the national policy cocktail designed to stimulate economic growth and enhance aggregate economic well-being (Winters, 2001). Both Adam Smith and David Ricardo argued in their theories of absolute and comparative advantage that the general wealth level of nations entering into trade would improve due to the resulting specialization of labour. The Hekcsher-Ohlin-Samuelson model states that trade patterns will be driven by factor endowments. Factor prices will equalize internationally, with the price of the factor used relatively intensively in the importing sector decreasing and the price of the factor used relatively intensively in the exporting sector increasing. However, these predictions are based on the classical theory where production functions exhibit constant returns to scale and technology is given exogenously.

From the classical point of view, the two sides of the equation between trade and growth create problems. On the growth side, there is the problem that the level of technology is exogenous. Some authors such as Lucas (1988) and Romer (1990), have developed frameworks where human capital accumulation and technological change are engines of economic growth. The technology level is then endogenized in these models. In international economics, consistent with the work of Trefler (1993, 1995) who showed that technological differences are the main determinant of trade, new theoretical using imperfect competition and increasing return to scale to explain trade patterns. These "new trade models" were introduced into international economics by such authors as Krugman (1979, 1984, 1987), Ethier (1982), Helpman and Grossman (1991) and Young (1991) (Bransetter, 2000). These new model used technological differences and differences in innovation incentives to affect the global pattern of trade and specialization and, ultimately, the nature and the degree of the gains from trade (Bransetter, 2000).

The question I seek to address concerns the relationship between trade policies and the growth of innovation. What are the impacts of trade policy on the growth rate of innovation? Can tariffs and trade quotas, which are seen to have similar impacts according to Lerner's symmetry theorem, benefit the innovation sector in some countries? If yes, under which conditions this can work? What are the benefits of trade policy in terms of productivity, innovation and growth?

Using the endogenous growth in the open economy frameworks developed by Helpman and Grossman (1991) and Sejerstrom and Dinopoulos (1999), we can see the effects of trade policy on human capital accumulation and technological change. The latter are the engines of economic growth. By using a similar framework, I study the role played by trade policy in determining the success of different countries in attracting productive foreign capital, in diffusing technology and becoming more integrated in the world market. Under what circumstances will they benefit from globalization? Using an empirical framework developed by Helpman and Coe (1995), I estimate the relationship between trade policy, mostly tariffs, and the growth rate of innovation quantified as the Total Factor Productivity, TFP, patent number and gross expenditure on research and development, GERD.

This essay will be divided in the following way. In the first section, I present the theoretical model developed by Helpman and Grossman (1991) and by Sejerstrom and Dinopoulos (1999). In the second section, I present a review of the empirical studies that were conduct on this topic. In the third section, I discuss the empirical model along with the data used the estimate the model. The fourth section will present the empirical results and the associated analysis.

Theoretical Model

In this paper, I follow the work of Helpman and Grossman (1991), Rivera-Batiz and Romer (1991) and Dinopoulos and Segerstrom (1999) and I study the dynamic effects of trade policy, tariffs and quotas, between two similar countries. I adopt the usual notation and refer to the countries as home and foreign. I will assume a Shumpeterian growth model like Segerstrom et al. (1990) and Helpman and Grossman (1991) where, in each industry, firms engage in research activities aimed at improving the quality of existing products (Dinopoulos and Segerstrom, 1999). In that case, a firm that wins an innovative race will earn a temporary monopoly profits as a reward for its R&D investment. I will also assume complete international spillovers. That is, when there is an innovation in one country, it adds to the stock of knowledge of the other country as well as its own. Hence, the growth rate of innovation and the growth rate of the economy are endogenously determined by on the profit maximizing behavior of firms in both countries (Dinopoulos and Segerstrom, 1999).

The work force N(t) grows exogenously at the rate n and it os divided between general skill L(t) and specialized R&D skill H(t), where L(t)+H(t)=N(t). Both L(t) and H(t) are assumed to grow at the rate n. L(t) and H(t) are the only two factors of production of the economy. H(t) and L(t) can move freely between both sector as well as in the intermediate output sector.

One Country Framework

The framework I use will be the two sectors, two country framework of Grossman and Helpman (1991). The analysis here is derived from the section 7.2 and 10.4 of their book, *Innovation and Growth in the Global Economy*. I begin with the household problem where households maximize intertemporal utility subject to their budget constraints. For the moment, I consider only one country and include a second country in the next subsection. The utility function takes the form

(1) $Ut = \int_t^{\infty} e^{-\rho(\tau-t)[\sigma log Cy(\tau)+(1-\sigma)\log Cz(\tau)]d\tau}$

where σ is a number between 0 and 1 representing the share of household spending devoted to high-tech good. Cz is the consumption of the traditional good and Cy is the consumption of the high-tech good. Like Helpman and Grossman, aggregate spending, E, is normalized to 1. This allows us to derive the demands for goods Z and Y.

(2) $C_Y = \frac{\sigma}{p_Y}$

(3) $C_Z = \frac{(1-\sigma)}{p_Z}$

As the market for Y and the market for X must clear, this implies that

(4) $p_x \chi = \sigma.$

This is because the value of the consumption of Y is σ. In equilibrium, this must match the value of output, which in turn is equal to the total cost of production $p_D D$ and the aggregate cost of the component intermediates $p_x \chi$. Where D represents the index of differentiated intermediate inputs for the good Y and χ is the intermediate input that enters in the production of intermediate with quality index D.

The production function of the intermediate good D looks like

(5) $logD = \int_0^1 log[\sum_m \lambda^m x_m(j)]dj$

where λ is bigger than 1 and it is the quality index and $x(j)$ is the input of the variety j.

As the intermediate goods are produced using only one unit of labour, their marginal cost or unit cost function are $C_x(w_L, w_H)$. Therefore, we have

(6) $p_x = C_x(w_{L,} w_H)\lambda.$

The index of intermediate inputs can be expressed as

(7) $D = A_D\chi$

where χ represents the aggregate volume of intermediate output (the number of products times the quantity employed of each one), A_x represents the index of productivity of intermediates. As $p_dD=p_x\chi$, (12) implies that

(8) $p_D = \frac{p_x}{A_D}.$

We now want to have the exact form of $A_D(t)$. Since we can change equation (3) as

(9) $LogD = \int_0^1 logq(j)dj + log\chi$

Where q(j) is the quality index of product j and χ equals x from equation (3). Helpman and Grossman assume uncertainty in the R&D process. In fact, any firm that invests resources in this activity at intensity ι for a time interval dt will succeed with probability ιdt and will fail to develop new innovation with probability (1-ιdt). By investing $a\iota$ units of labour per unit of time, a firm conducts R&D with ι intensity. This process features constant return to scale in the R&D activity. The process brings no cumulative benefits of unsuccessful research efforts, it is said to be memoryless. However, the spillover places everyone at the same point, so every firm conducts their research on the quality of the current state-of-the-art product.

From (14), we can recognize that $\int_0^1 logq(j)$ is equal to *I(t)logλ*, where $I(t) = \int_0^t \iota(\tau)d\tau$ and it reflects the total "number" of research successes in all industries from τ=0 to τ=t. If we substitute for *D* in (12), we get

(10) $$A_D(t) = \lambda^{I(t)}$$

The R&D sector also uses skilled labour, H, and unskilled labour, L. The technology of the R&D sector can also be expressed by $c_\gamma(w_L, w_H)\gamma$. γ also represents the growth rate of innovation. In the case of a Schumpeterian model, γ is the arrival rate of the quality improvement ι that we saw earlier[1].

Good Z, on the other hands, is produced using unskilled labour, L, and skilled labour, H, in a competitive set-up with a constant-returns-to-scale technology. The production of good Z is more intensive in unskilled labour. In fact, is uses the most unskilled labour among the three sectors. Its technology can also be represented by a unit cost function $c_z(w_L, w_H)$. This sector also operates also under perfect competition, therefore

(11) $$p_z = c_z(w_L, w_H).$$

If we uses Sheppard's lemma on the functions $c_\gamma(w_L, w_H)\gamma$, $c_z(w_L, w_H)Z$ and $C_Y(w_{L,} w_H)Y$, we get the demands for labour by each sector. Then we can derive the labour market clearing conditions

(12) $$a_{L\gamma}(w_L, w_H)\gamma + a_{LY}(w_L, w_H)Y + a_{LZ}(w_L, w_H)Z = L$$

(13) $$a_{H\gamma}(w_L, w_H)\gamma + a_{HY}(w_L, w_H)Y + a_{HZ}(w_L, w_H)Z = H.$$

Here $a_{jZ}(w_L, w_H)Z$ is the input factor *j* per unit of output of the traditional sector. These are the factor prices and commodity prices in the steady-state. Also, γ is the rate at which the quality of the intermediates products improves in the economy. Therefore, $c_\gamma(w_L, w_H)\gamma$ represents the cost of achieving a rate of innovation γ. I now turn to the no-arbitrage condition which equates the long-run profit rate of a leader in the R&D process to the sum of the interest rate and the expected rate of capital loss in the steady-state.

[1] In the case of an expanding variety model, γ would represent the rate of new product introduction $\frac{\dot{n}}{n}$.

(14) $$\frac{(1-\frac{1}{\lambda})p_Y Y}{c_Y(w_L,w_H)} = \rho + \gamma$$

This can gives an equation for the growth rate of innovation, γ, in the steady-state for a one country setting.

Free-trade equilibrium

The previous subsection will serve as a basis for the free-trade equilibrium. In fact, both countries, Home and Foreign, have the same features as described previously. I take country *i=H,F* for Home and Foreign. Therefore, the superscript *i* denotes the country in this case.

The firm producing quality m of product j will be called the leader and the firm producing product j of quality m-1 will be the follower. As firms compete over prices, we will have a Bertrand competition model. Furthermore, I will have to make the distinction between firms from their country of origin as we have a two countries setting. The optimal strategy for both firms is then to set $p^{ij} = c_Y\left(w_L^j, w_H^j\right)$ for the follower and $p^{ij} = \lambda c_Y\left(w_L^j, w_H^j\right)$ for the leader. p^{ij} denotes the equilibrium price charged by a purveyor of a state-of-the-art product from country *i* when the follower resides in country *j*. By doing so, the follower is driven from the market and the leader captures all the market.

By doing so, the leader will sell σ/p^{ij} units, from equation (4), and the flow of profits will be

(15) $$\pi^{ij} = \sigma\left[1 - \frac{c_Y(w_L^i,w_H^i)}{\lambda c_Y\left(w_L^j,w_H^j\right)}\right]$$, *i=H,F, j=H,F.*

Since, in the steady-state, both countries will be active in the R&D sector, it should be the case that

(16) $$c_Y(w_L^H, w_H^H) = c_Y(w_L^F, w_H^F).$$

In this case, equation (20) becomes

(17) $$\pi^{ij} = \pi = \left[1 - \frac{1}{\lambda}\right]\sigma, \forall\, i,j$$

The free-entry and no-arbitrage conditions then imply that every leader located in country *i* will have a market value

(18) $$v^i = c_\gamma(w_L^i, w_H^i), i = H, F$$

If a leader faces the instantaneous probability $(\iota^{Hi} + \iota^{Fi})dt$ of winning the next race to upgrade the quality of its product under free-trade, the no-arbitrage condition becomes

(19) $$\frac{\pi}{v^i} = r^i + \iota^i,\ \iota^i = (\iota^{Hi} + \iota^{Fi})$$

From previous discussion, $\rho = r^i$. Using this and substituting (22) and (23) into (24), the no-arbitrage condition becomes

(20) $$\frac{\sigma(1-\frac{1}{\lambda})}{c_\gamma(w_L^i, w_H^i)} = \rho + \iota^i$$

As Grossman and Helpman observe, different manufacturers facing a different risk of displacement by the next-generation of product will have a different profit rate in the long-run.

I now turn to the markets-clearing conditions. The factor market clearing now becomes

(21) $$a_\gamma(w_L^i, w_H^i)(\iota^{iH} n^H + \iota^{iF} n^F) + a_Y(w_L^i, w_H^i)Y^i + a_Z(w_L^i, w_H^i)Z^i = \frac{L^i}{H^i}, i = H, F$$

where n^i measures the number of leaders in country *i* and $(\iota^{iH} n^H + \iota^{iF} n^F)$ measures the aggregate amount of R&D taken in this country.

In the steady-state, each country maintains the leadership in a constant fraction of the total number of high-technology products. It follows that,

(22) $$(\iota^{FH} n^H = \iota^{HF} n^F)$$

where $\iota^{FH} n^H$ is the flow of leading industries from Home captured by Foreign in an interval *dt.* Therefore, the inflow must equate the outflow in steady-state. In this case, the factor market clearing in the steady-state becomes

(23) $$a_\gamma(w_L^i, w_H^i)\iota^i n^i + a_Y(w_L^i, w_H^i)Y^i + a_Z(w_L^i, w_H^i)Z^i = \frac{L^i}{H^i}, i = H, F$$

Notice that equation (21) and the equilibrium price of the traditional good $p_Z^i = c_Z(w_L^i, w_H^i)$ ensure factor price equalization. Because the factor price equalization makes the unit cost in each sector equal, the cost of innovation will also be equal across countries. The no-arbitrage condition then implies $\iota^H = \iota^F$. Therefore, in a factor price equalization equilibrium, the leader in each country faces the same risk per units of time of losing their technological leads.

The patterns of trade and the relative specialization will then be driven by the endowment of each country. For example, a country with a relative abundance in human capital will specialize relatively in R&D, will have a relative greater number of successes in this sector and capture a relative larger number of leadership positions in high-technology industries. Under balanced trade in the steady-state, the human capital abundant country will import a greater number of traditional goods and export a greater number of high-technology goods. If trade is not balanced in the steady-state, one country might import both goods but the trade pattern will be biased in the same way as under balanced trade.

Trade policies

In terms of trade policies, I will present an extension of the model developed by Helpman and Grossman. However, I will also show different version of a similar model with different results. I will present these different versions at the end of this section and I will begin with a discussion of the Helpman and Grossman model. The analysis will also make uses of the Lerner symmetry (1936) which implies the equivalence of an export subsidy to a tariff on import for the same good. This will simplify greatly the analysis.

Let country H imposing a tariff τ on the import of the traditional good Z. Therefore, the price of Z, p_Z, in country A becomes $(1+\tau)p_Z$. Market clearing conditions of good Z becomes

(24) $$p_Z Z = (1-\sigma)\left[\frac{E^H}{1+\tau^H} + E^F\right]$$

where σ represents the share of expenditure made on the traditional good Z and E^H is the total expenditure of Home and E^F is the total expenditure of Foreign. Also,

(25) $$p_z = \frac{w_L^i a_{LZ} + w_H^i a_{HZ}}{1+\tau^i}\ , i = H, F$$

is the price of the traditional good. I then use (29) and (30) to get

(26) $$w_L^i a_{LZ} + w_H^i a_{HZ} = \frac{(1-\sigma)(1+\tau^i)}{\bar{Z}+b_Z\gamma}\left[\frac{E^H}{1+\tau^H} + E^F\right], i = H, F.$$

Here, $\bar{Z}$=$\bar{Z}^H + \bar{Z}^F$ and

(27) $$\bar{Z}^i = (L^i a_{HY} - H^i a_{LY})/(a_{HY}a_{LZ} - a_{LY}a_{HZ})$$

(28) $$b_Z = (a_{H\gamma}a_{LY} - a_{L\gamma}a_{HY})/(a_{HY}a_{LZ} - a_{LY}a_{HZ})$$

By a similar procedure in the market of the high-technology product, good Y, we get

(29) $$w_L^i a_{LY} + w_H^i a_{HY} = \frac{\sigma}{\lambda(\bar{Y}+b_Y\gamma)}[E^H + E^F], i = H, F.$$

Again,

(30) $$\bar{Y}^i = (H^i a_{LZ} - L^i a_{HZ})/(a_{HY}a_{LZ} - a_{LY}a_{HZ})$$

(31) $$b_Y = (a_{HZ}a_{L\gamma} - a_{LZ}a_{H\gamma})/(a_{HY}a_{LZ} - a_{LY}a_{HZ})$$

and $\bar{Y} = \bar{Y}^H + \bar{Y}^F$. Recall that, by normalization, $E^H + E^F = 1$. Combining (31) and (34) gives the cost of innovation in each country, $c_\gamma^i(E^H, E^F, \tau^H)$. As before, this cost is rising with the aggregate rate of innovation in each country. Substituting this cost function into the no-arbitrage condition to yields

(32) $$\frac{\left(1-\frac{1}{\lambda}\right)\sigma}{c_\gamma^i(E^H, E^F, \tau^H)} = \rho + \iota^i\ , i = H, F.$$

Multiply (37) by n^i, and summing over *i,* implies

(33) $$\left(1-\frac{1}{\lambda}\right)\sigma\left[\frac{n^H}{c^H(\gamma, E^H, E^F, \tau^H)} + \frac{n^F}{c^F(\gamma, E^H, E^F, \tau^H)}\right] = \rho + \gamma.$$

This last equation provides the basis for an analysis of the effects of trade policy on the growth rate of innovation at the aggregate level. However, equation (37) will be the starting point for my analysis at the country level.

If, on the one hand, the global rate of innovation rises in response of a positive increase τ^H, then $c^F(\gamma, E^H, E^F, \tau^H)$ must increase as well. If that happens, from (37) we clearly see that ι^Fmust fall. On the other hand, if the global rate of innovation declines with an increase of τ^H, $c^H(\gamma, E^H, E^F, \tau^H)$ must also decreases. Again, (37) shows that ι^H must rise.

If ι^F falls, (41) shows that n^F must increase if x falls. If ι^H rises, (42) shows n^Hmust fall if x rises. But, $\bar{Y} + b_Y\gamma = Y$ imply an inverse relationship between the innovation rate and the aggregate or per firm output of high-technology product. The implication of either case is the same. A trade policy that supports a country's traditional sector reduces the number of its leading edge industries. The opposite will be true for a policy that supports the high-technology sector.

Moreover, the trade policy will also affect the allocation of resources. If the tariff on a traditional good from country H creates an increase in the global rate of innovation, (42) implies an expansion of the country H R&D sector. The skilled-labour in coutry H will then relocate from the high-technology sector towards the R&D sector. If the global rate of innovation were to fall, then the high-technology sector of country F will expand. The skilled-labour country H will move from R&D to the more rewarding high-technology sector. Therefore, the R&D sector of country F will contract. The general results are that a trade policy which aims to protect the traditional manufacturing sector will also protect the R&D sector of this country. It will have the opposite effect abroad.

Before heading to the empirical part, I would like to talk briefly about two other papers that use similar models to analyze the same policies. It is worth mention these papers because, as Dinopoulos and Segerstrom (1999) note, this question has received surprisingly little theoretical attention in the literature. The first paper I would like to mention is Dinopoulos and Segerstrom (1999). They use a similar "quality ladders" model to that of Grossman and Helpman (1991) and Segerstrom (1990). In fact, it is similar to the one I developed previously. They used different assumptions to make their model slightly different from that of Grossman and Helpman. To begin with, trade barriers are used by both countries. In fact, tariffs are used to protect a R&D firm that falls behind in the technological race, which is a bit different than in my analysis. The conclude that when a government helps out a domestic firm that falls behind foreign firms in global technological races this will temporarily increase the global rate of innovation at the margin (Dinopoulos and Segerstrom, 1999). This helps domestic firms to charge a higher price and shift resources towards the R&D sector and out of the manufacturing sector, and improves R&D efficiency. Here, the tariff has to be large enough to offset the technological advantage of foreign rivals. However, when the tariff is small, they called it a rent-extracting tariff, it temporarily decreases the global rate of innovation and reduces the efficiency of the R&D sector in both countries, as it reallocate resources towards exporting industries in both countries.

Rivera-Batiz and Romer (1991) used a model of endogenous growth with increasing variety of products instead of "quality ladders" and they assumed that trade take place between two similar countries. They find that if tariffs are used to apply broad restrictions on all newly invented goods from Foreign, and Foreign puts the same tariff on all newly invented goods from Home, then innovation would be a less rewarding activity in both places and technological progress would slow down (Rivera-Batiz and Romer, 1991).

Empirical part

Before going into the actual empirical model that I will use for this paper, I will make a brief literature review. This will help to explain and justify the choices that I made in terms of empirical model. The first thing I have to notice is that the majority of the studies mentioned here seek to evaluate the international spillover of R&D and the channel by which these spillovers travel. In my case, I will follow the principal assumption that the majority of studies follow, even though it is controversial. The main assumption is that the spillovers channel through international trade. Numerous studies uses trade-related data to evaluate the spillover and get robust and significant results. Coe and Helpman (1995), Coe, Helpman and Hoffmaister (2009) and Bayoumi, Coe and Helpman (1999) find strong evidence of trade-related spillovers. Furthermore, Chen and Kao (1995) used the previous research from Coe and Helpman (1995) on cointegration in panel data, confirming their main result that import-weighed foreign R&D spillovers are significantly correlated with domestic productivity level (Bransetetter, 2000).

However, Keller (1996) raises the controversy when he used the Coe and Helpman data set and tried to replicate their results. He then used a Monte Carlo approach to generate randomly a matrix of bilateral trade relationship between two countries. Using this matrix to weight the foreign R&D stock, Coe and Helpman weighted the foreign R&D stock with the real bilateral trade relationship, and regressed, like Coe and Helpman, the aggregate TFP on aggregate domestic and trade-weighted R&D stock and replicate this experiment a thousand times. This approach gave larger and more precise international spillovers estimates than the ones with the true bilateral trade shares. As Keller notes in the abstract to his paper, this cast some doubt on the earlier results in the literature (Bransetetter, 2000).

Bayoumi, Coe and Helpman (1999) tried to study the same problem using a different approach. In fact, their goal is to provide a quantitative evaluation of the importance of R&D and trade in influencing TFP and output growth(Bayoumi, Coe and Helpman, 1999). They used the trade-weighted matrix of Coe and Helpman (1995) and included them in the IMF MULTIMOD econometric model to simulate changes in R&D in the industrial countries and in the exposure to trade of the developing countries in order to obtain estimates of induced changes in TFP, capital, output and consumption in 12 countries of the industrial world, as well as of developing countries (Bayoumi, Coe and Helpman, 1999). Their results are consistent with the one of Coe and Helpman (1995). An increase in domestic R&D can significantly raise the level of domestic output as well as the level of foreign output through spillovers. Furthermore, open trading policies can benefit developing nations through facilitating technology transfer from industrial nations (Bayoumi, Coe and Helpman, 1999). In fact, they believe that part of the success of the New Industrialized Economy's over the last 20 years can be attributed to productivity growth stemming from foreign R&D spillovers through trade (Bayoumi, Coe and Helpman, 1999).

Certainly the most cited and most influential studies in this field are the one from Coe and Helpman (1995) and from similar papers by Coe, Helpman and Hoffmaister (1997), (2009). I will now refer to Coe and Helpman (1995) as CH95 and to Coe, Helpman and Hoffmaister (2009) as CHH 2009. To study the extent to which a country's productivity level depends on domestic and foreign R&D capital stocks, they regress TFP on the domestic R&D stock and on a trade-weighted foreign R&D stock using a cointegration approach. The trade weights are base on bilateral trade relationship with the other countries relative to their GDP. With a sample of 21 OECD countries plus Israel from 1971-1990, they find out that both domestic and foreign R&D have a significant effect on the TFP of a country. Some of their estimates even suggest that foreign R&D capital stock have a stronger effect on TFP the larger the share of domestic imports in GDP (Coe and Helpman, 1995). This can be interpreted as implying that more open economies benefit more from the spillovers, by extracting more productivity from foreign R&D, than do closed economies.

Furthermore, Coe, Helpman and Hoffmaister (1997) use the same approach with a larger sample of countries which includes 77 developing countries and evaluate the extent to which less developed countries that hardly invest in research and development themselves benefit from R & D that is performed in the industrial countries (Coe, Helpman and Hoffmaister, 1997). As they note in their abstract, their results suggest that R&D spillovers from industrial countries are important and substantial for developing countries. CHH 2009 revisited the CH95 paper with a more extended data set in terms of countries, they got 24 countries instead of 21, and an updated data set to 2004. Applying panel cointegration techniques, they got similar results to those reported by CH95 (Coe Helpman and Hoffmaister, 2009). They also extended their analysis on various institutional variables like the ease of doing business, the quality of the education system, patent protection system and the legal system. They find that the ease of doing business and a higher quality education system are associated with higher returns on domestic and foreign R&D. Strong patent protection is associated with higher levels of TFP, higher returns on domestic R&D and larger international R&D spillovers (Coe, Helpman and Hoffmaister, 2009). Legal systems based on English or German law tend to give more benefits from domestic and foreign R&D capital.

One of the main criticisms received by the CH95 approach is that the aggregate approach used allows them no way to control for technological heterogeneity across firms, industries, and countries (Bransetetter, 2000). One alternative method would be to estimate a cost function instead of the aggregate production function. The cost function approach has the advantage of being often more flexible in functional form and of benefiting from more structure, considering the impact of R&D not only on total costs but also on the amount of labour and intermediate products used (Griliches, 1992). It also has the advantage of having the possibility of estimation even if the firm is not a price-taker in the output market. As long as the firm is a price-taker in the inputs markets, it can be estimated. This approach would also make sense in my problem as I would like to estimate equation (37) at the country level. To estimate the impact of a tariff on the growth rate of innovation, I would have to estimate the impact of the tariff on the cost function

$c^i(\gamma, E^H, E^F, \tau^H)$. I would just need to estimate $\frac{\partial}{\partial\tau} c^i(\gamma, E^H, E^F, \tau^H)$ as the rest of the equation is parameters.

Bernstein (2000) uses the cost function approach to estimate the effect of intranational and international spillovers on production cost and factor intensities for eleven industries in the United States and in Canada. He is then able to get results by industry and by country, US and Canada. He finds that international spillovers are generally cost reducing, and increase R&D and physical capital intensities. He also finds that international spillovers are generally labor and intermediate input intensity reducing (Bernstein, 2000).

However, there are numerous drawbacks to this approach. The first one, as noted by Griliches (1992), the cost function requires the use of good input price data which varies across units of observation and over time (Bransetetter, 2000). The problem is that this generally does not exist at the industry level for R&D and physical capital. Another problem is that the access to this kind of data at the firm level can be highly complicated or the data can even be non-existent in certain cases. Furthermore, as noted by Griliches, a cost function that takes into account spillovers will have the tendency to produce an unwarranted appearance of economies of scale and is likely to bias upward the own and outside R&D capital coefficients, especially in the absence of any other trend-like terms in the equations (Griliches, 1992). For these reasons and to have a greater simplicity, I will use the CH95 approach for my studies. I will keep for a later study the use of the cost function approach.

Data

For the purpose of this study, I merge two databases. The first one I use is the CHH 2009 database. They, in fact, used an expanded version of the CH95 database. The CH95 database included a set of 21 OECD countries plus Israel with annual observations over the period 1971 to 1990. In the 2009 version of their paper, Coe, Helpman and Hoffmaister add 14 more years to their sample, meaning the sample goes from 1971 to 2004. They also includ Korea and Iceland, so that the sample is then 24 countries.

The TFP measure, f, is defined as the log of output minus a weighted average of labour and capital inputs, using factor shares as weights (Coe, Helpman and Hoffmaister, 2009). It rose on average by 77 percent from 1971 to 2004 for the entire sample. It grew on average at a rate of 0.029 percents during the same period. The biggest increases came from Ireland, Korea, Finland, Iceland and Norway, while Israel, New Zealand and Switzerland exhibited the smallest increases. Furthermore, the TFP of Australia, Canada, Sweden and the United States exhibited a clear acceleration after 1990.

TFP growth is a proxy for the rate of innovation process here. In order to assess the sensitivity of my results, I also consider two other possible proxies for the rate of innovation. From the OECD, I obtained data on Gross Expenditure on R&D (GERD) and on patent applications to the Patent Cooperation Treaty, PCT, (1970)[2]. Both these variables can also be thought of as proxies for the rate of innovation. The data are available for all 24 countries of the study. Because of the tariff problem for Switzerland, data will be available for the 23 countries of the study and they span 23 years between 1981 and 2004. Data on GERD are in million US dollars of 2000 and are in constant prices and in purchasing power parity (PPP)

Both variables experience a similar upward trend to TFP from 1981 to 1984 as we can see on figure 1, 2, 3 and 4. The number of patent applications gets a correlation coefficient with TFP of 0.25 while the correlation between GERD and TFP is 0.17. These positives correlation suggest that these variables are reasonable alternatives to TFP. However, GERD has a coefficient correlation of 0.99 with S^d which is an independent variable. When considered in terms of growth rates, the correlation between the growth rate of TFP and the growth rate of GERD is 0.20 and the correlation coefficient between the growth rate of TFP and the growth rate of patent application is 0.15. However, the correlation between the growth rate of domestic R&D stock and the growth rate of GERD is 0.37. The average growth rate of the GERD from 1981 to 2004 was of 0.05 percents while the average growth rate of the patent application during the same period was at 0.19 percents.

[2] http://www.wipo.int/pct/en/treaty/about.htm

Figure 1: Average TFP Growth

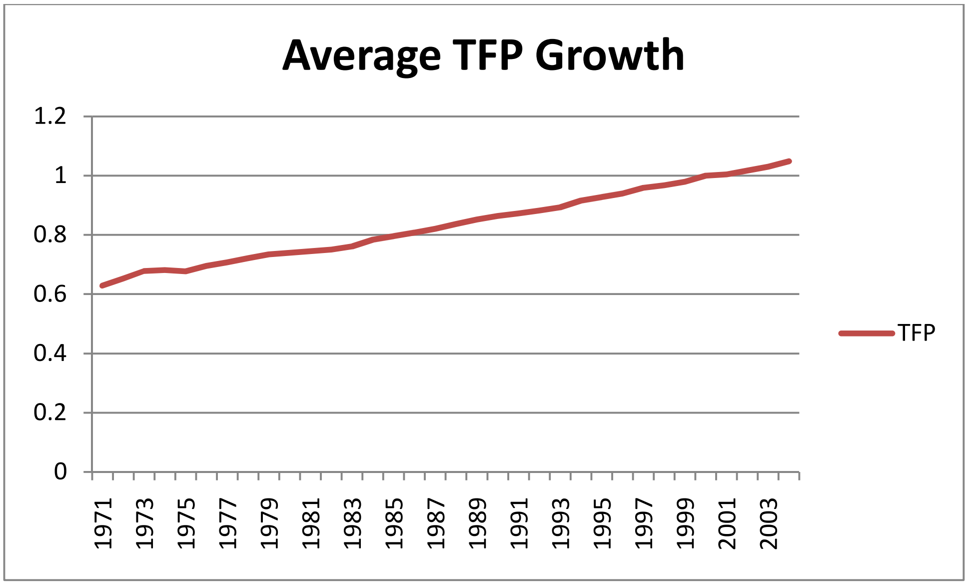


Figure 2: Growth of Patent Application

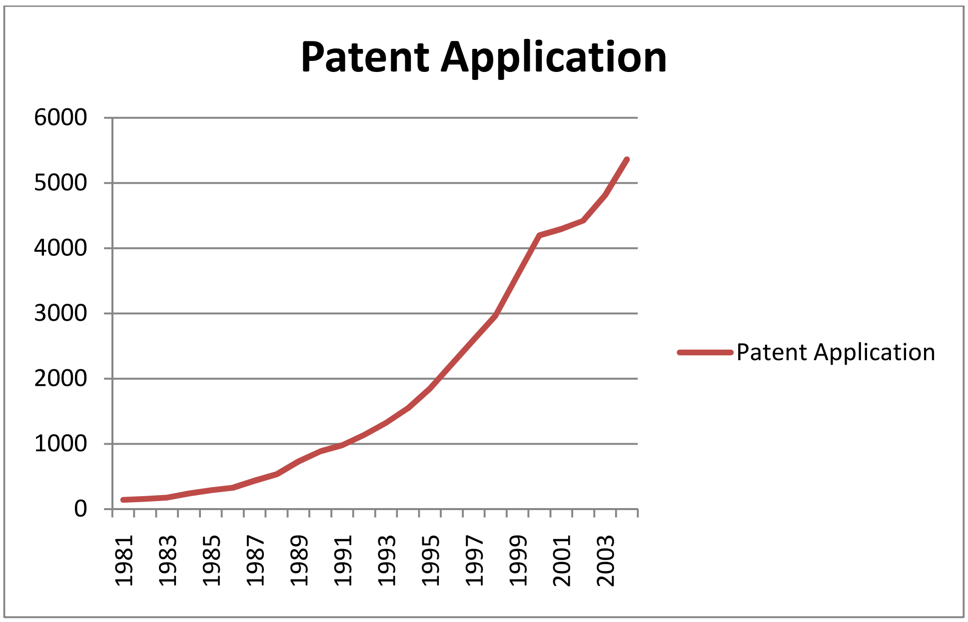
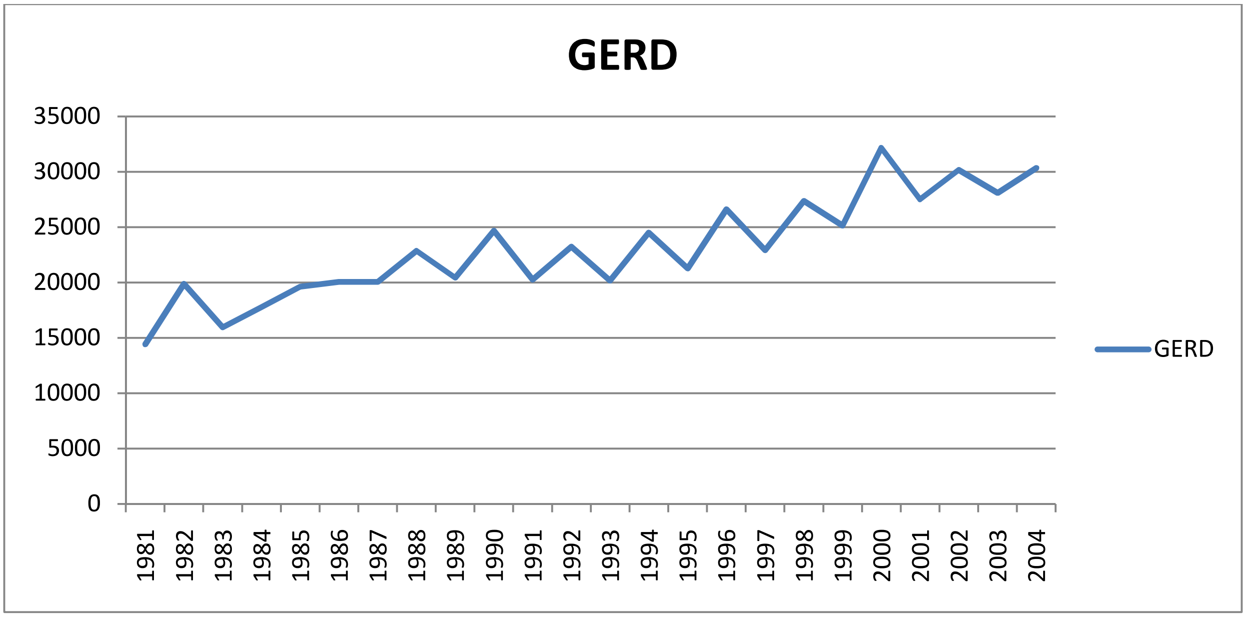


Figure 4: Growth of GERD



S^d represents the stock of domestic R&D measured in constant dollars. It shows a monotonic upward trend for all the years and all the countries displayed a clear deceleration of the rise in domestic R&D after 1990. Iceland, Korea, Greece, Israel and Spain had the fastest expansion of their R&D sector while the United Kingdom, Switzerland and the Netherlands had the slowest expansion. As CHH note, the increase in R&D tends to be smallest in the largest countries, with the notable exceptions of Canada, Japan and Spain (Coe, Helpman and Hoffmaister, 2009).

The foreign R&D capital stock, S^{f-biw}, is constructed as a weighted average of each of the 23 trading partners' domestic R&D stock. This variable increases monotonically and smoothly for most countries. The import share as a percentage of GDP, m, is really diversified across countries reflecting a diversity in openness as well as in GDP. On average it rose about 10 percentage points from 1971 to 2004, but it was really volatile and shows no trend for most countries. Human capital, H, is proxied by the average years of schooling in the country. It increased in every country during the sample period.

The second part of my database consists of the Trade, Production and Protection database developed by Niceta and Olarreaga (2007). The trade, production, and protection database includes annual data on trade flows (exports and imports), domestic production (output, value added, employment), and trade protection (tariffs and nontariff barriers) for up to 100 countries over the period 1976–2004 (Nicita and Olarreaga, 2007). The data is also disaggregated into 28 manufacturing sectors like the International Standard Industrial Classification Revision 2 (ISIC Rev. 2)[3]. From this database, I will only use the tariff variables from the Trade Protection section. The Tariff variables come from the Trade Analysis and Information System (TRAINS) of the United Nation Conference on Trade and Development (UNCTAD).

As the database includes 100 countries, I only use 24 of those in order to merge this database with the CHH 2009 dataset. In this case, I use the same countries as Coe, Helpman and Hoffmaister: the OECD countries plus Iceland and Israel. However, the tariffs recorded for Switzerland are all zero, which appears to be counterfactual, so I decided to not include this country in my investigation. Therefore, I have data on only 23 countries. The time span of the trade, production and protection database is from 1976 to 2004. However, information on tariffs is only available from 1988 for some countries and there are several missing data for at least four to five countries.

From this database, I created three variables. The first one is a general manufacturing average tariff which is built as the average tariff of the 28 manufacturing categories by country and by year. It is only an average and I will use it to estimate the general effect of a tariff on the growth rate of innovation.

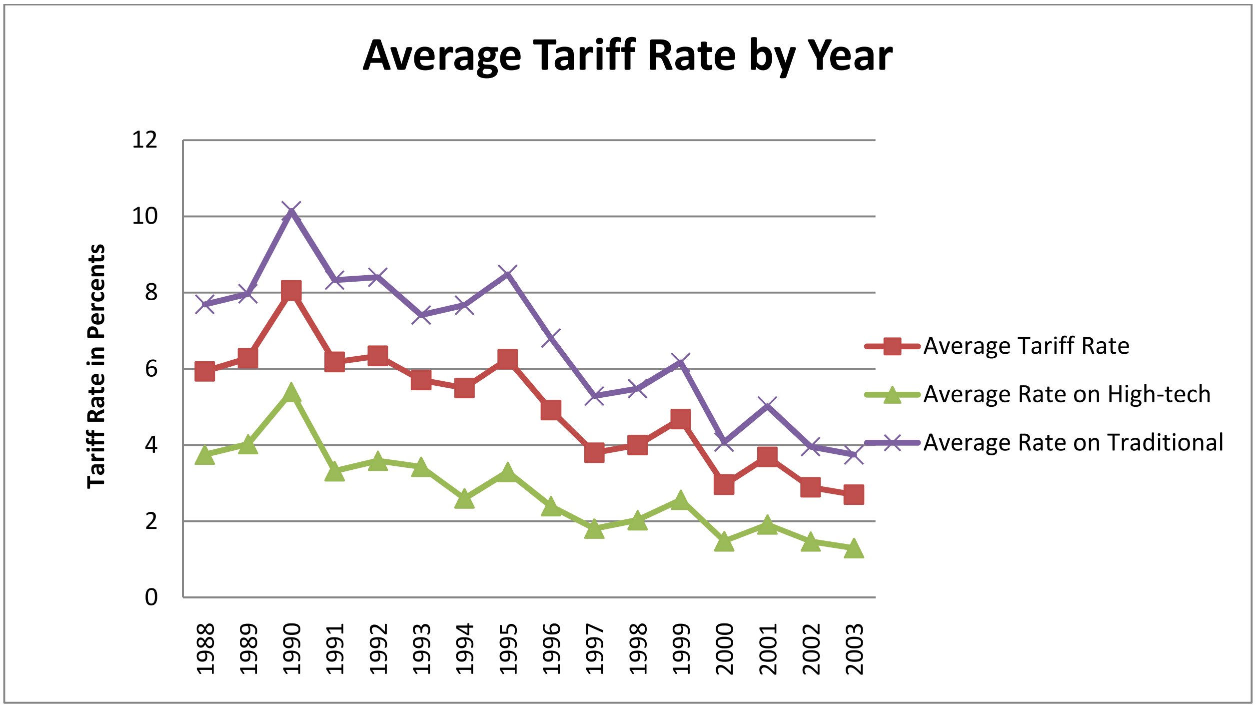
The other two variables constructed from the trade, production and protection database, are an average tariff rate for the high-tech sector and an average tariff rate for the traditional sector. Like the previous variable, I used an average tariff rate by year and by country for both sectors. I did that because the theoretical model characterized a two sector economy plus the R&D sector. It is therefore useful to study the effects of a tariff on each sector on the growth rate of innovation. To determine whether or not a sector is high-tech or traditional, I followed the guidelines of the 2009 European Union Industrial and R&D Scoreboard[4]. In the section five, they provide a measure of R&D intensity by sector. I then took the most R&D intensive sector as the high-tech sector and the other ones were classified as traditional. In this case, the subcategories

[3] http://laborsta.ilo.org/applv8/data/isic2e.html

[4] http://www.scribd.com/doc/25451234/The-2009-EU-Industrial-R-D-investment-scoreboard

35, 38 and 39 from the ISIC Rev. 2 were classified as high-tech while the subcategories 31, 32, 33, 34, 36 and 37 were classified as traditional.

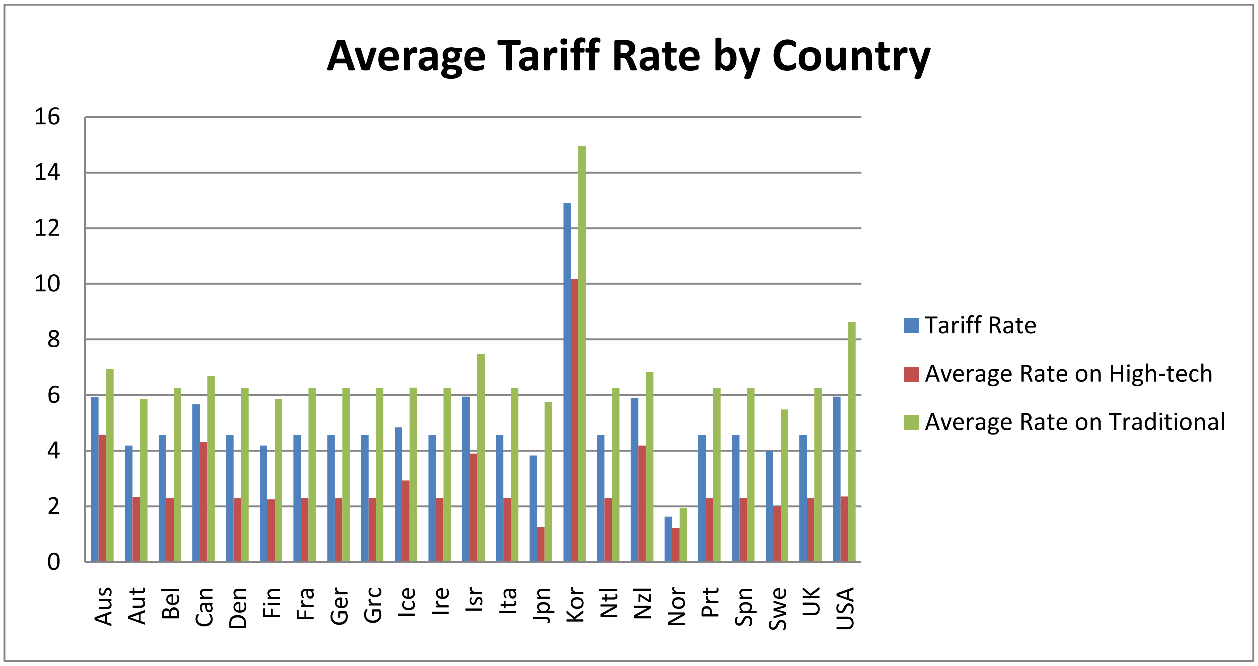
Figure 5: Average Tariff Rate by Year



As we can see from Figure 1, the average tariff rate in the OECD increased from 1988 to 1990 and then began decreasing steadily until 2003. I kept only until 2003 as the year 2004 only had 7 observations on 23 countries. The average rate is roughly around 5 percents. The other thing to notice here is that the Average rate on high-tech goods is much lower than the average rate on traditional goods. The average rate on traditional is around 6.66 percents while the average rate on high-tech goods is around 2.77 percents. Both sectors experience the same trend as the average tariff rate.

On figure 2, we can see the average tariff rate by country. All countries show the same trend, the average tariff rate on traditional goods is higher than the average tariff rate on high-tech goods. Every country seems to impose similar tariff rates on both goods although during that period the USA imposed an average tariff rate on traditional good of 8.65 percents. On the other hand**,** Japan has the lowest tariff rate on high-tech goods during the same period with a rate averaging 1.27 percents. Korea looks like it had the highest tariff rate over the period. However, I have fewer observations for this particular country which is may be why the average looks very high at 12.9 percents. However, knowing Korea has generally had stronger trade intervention since the 1960s, this seems reasonable. The same thing can be said about Norway with its particularly low tariff rate. As their rate look realistic, I only have fewer observations, I keep these countries in my study. Israel and Iceland experience the same phenomenon.

Figure 6: Average Tariff Rate by Country



Methodology

CH95 used three models to estimate the spillover effect. As part of my data comes from this study, I use the same specifications for my own study. The first one is,

(34) $$logf_{ti} = \beta^0 + \beta^1 logs_{ti}^d + \beta^2 logs_{ti}^f + \varepsilon_{ti}$$

where i is the country subscript and t is the time subscript. The variables are in logs to capture their elasticity. As the models come from panel data, the error term, ε_{ti}, is divided into an individual effect, c_i, and an idiosyncratic error term, μ_{it}. Therefore,

(35) $$\varepsilon_{ti} = c_i + \mu_{it}$$

The second model they estimated is,

(36) $$logf_{ti} = \beta^0 + \beta^1 logs_{ti}^d + \beta^2 G7logs_{ti}^d + \beta^3 logs_{ti}^f + \varepsilon_{ti}$$

G7 is a dummy variable being 1 for a G7 country and 0 otherwise. It allows the coefficient on the domestic R&D stock to differ between the seven biggest economies and the others as it is thought the effect of the R&D stock will be bigger for the G7 economies. The third specification is,

(37) $$logf_{ti} = \beta^0 + \beta^1 logs_{ti}^d + \beta^2 G7logs_{ti}^d + \beta^3 m_{ti} logs_{ti}^f + \varepsilon_{ti}$$

where m is the fraction of imports to the GDP . This interaction tries to capture the theoretical argument that a country importing more relative to its GDP may benefits more from foreign R&D whenever the countries have the same composition of imports and face the same composition of R&D stocks among trade partners (Coe and Helpman, 1995).

In their 2009 revision of the 1995 study, Coe, Helpman and Hoffmaister included a measured of human capital proxied by the average year of schooling in each country. Theoretically, human capital is an important determinant of productivity and its growth rate should be included with a longer time length as advanced countries measures of human capital tend to change slowly while a country like Korea, which is included in the study, invested heavily in human capital formation since the early 1970s (Coe, Helpman and Hoffmaister, 2009). Therefore, the models showed in equations (43), (44) and (45) will include a variable $logh_{ti}$ in it.

CHH 2009 measures the effects of the variables on the TFP so all the variables are in level. In my case, I want to estimates the effect of the tariff on the growth rate of innovation. Still, my proxy will be the logarithm of the TFP. However, I will use a method called Dynamic Ordinary Least Squares (DOLS). Besides the tariffs variables, which will stay in levels, the other variables will also be in logarithms. When I include the average tariff variable and the average tariff rate by sector and the logarithms, the models then becomes,

(38) $$logf_{ti} = \beta^0 + \beta^1 logs_{ti}^d + \beta^2 logs_{ti}^f + \beta^4 logh_{ti} + \beta^5 avetariff_{ti} + \varepsilon_{ti}$$

(39) $$logf_{ti} = \beta^0 + \beta^1 logs_{ti}^d + \beta^2 logs_{ti}^f + \beta^4 logh_{ti} + \beta^5 tradtariff_{ti} + \beta^6 hightechtariff_{ti} + \varepsilon_{ti}$$

(40) $$logf_{ti} = \beta^0 + \beta^1 logs_{ti}^d + \beta^2 G7logs_{ti}^d + \beta^3 logs_{ti}^f + \beta^4 logh_{ti} + \beta^5 avetariff_{ti} + \varepsilon_{ti}$$

(41) $$logf_{ti} = \beta^0 + \beta^1 logs_{ti}^d + \beta^2 G7logs_{ti}^d + \beta^3 logs_{ti}^f + \beta^4 logh_{ti} + \beta^5 tradtariff_{ti} + \beta^6 hightechtariff_{ti} + \varepsilon_{ti}$$

(42) $$logf_{ti} = \beta^0 + \beta^1 logs_{ti}^d + \beta^2 G7logs_{ti}^d + \beta^3 m_{ti} logs_{ti}^f + \beta^4 logh_{ti} + \beta^5 avetariff_{ti} + \varepsilon_{ti}$$

(43) $$logf_{ti} = \beta^0 + \beta^1 logs_{ti}^d + \beta^2 G7logs_{ti}^d + \beta^3 m_{ti} logs_{ti}^f + \beta^4 logh_{ti} + \beta^5 tradtariff_{it} + \beta^6 hightechtariff_{it} + \varepsilon_{ti}$$

where the tariff rates are in levels. In this case, *avetariff* is the average tariff rate on all manufacturing goods, *tradtariff* is the average tariff rate on traditional goods and *hightechtariff* is the average tariff rate on high-tech goods. As I have panel data, I provide estimates using pooled OLS, fixed effects and random effects in my results. Like CHH 2009, I use DOLS which consists in augmenting the static cointegrating regression with leads and lags of the first differences of the regressors. The idea is to remove the asymptotic inefficiency of the least squares estimate in the static regression by using the relevant information in the system to account for the correlation between the regressors and the dependent variable (Mohitosh and Perron, 2005). In that case, the DOLS model looks like

(44) $$y_{it} = \beta_i^0 + \beta x_{it} + \sum_{j=-q_1}^{q_2} c_{ij} \Delta x_{i,t+j} + v_{it}$$

Where y_{it} is the dependent variable, x_{it} is the set of independents variables, v_{it} is the error term and $\Delta x_{i,t+j}$ is the independent variables in first difference they are sum over their leads and lags.

I also use three other variables to proxy the innovation, my dependent variable. For these *logGERD* and *logapapp*, respectively, represent the logarithms of Gross Expenditure on R&D and the logarithms of the number of patent applications to the PCT. Using the results of CHH 2009, I can assume easily that all their variable are I(1) as their test all display the presence of a unit-root. Their variables are all non-stationary. In the case of the tariffs, I was unable to perform such a test as there are gaps in my dataset. As the tariff displayed a clear trend for each country, I assumed these variables were also I(1) and will be included in the lad and lead section of my specifications.

Before I get to my analysis, I should be careful with the tariff data in a regression. For one thing, simple tariff average will tend to underweight high tariff rates because the corresponding import levels tend to be low. I should also be careful with issues related to endogeneity in my empirical framework (Rodriguez and Rodrick, 2000). I believe that the tariff data on manufacturing goods only will take care of the first drawback, as tariffs tend to be particularly high in other sectors of the economy such as agriculture or services and this is especially true for the OECD countries. Still, I have to be conscious of the fact that a tariff measure might come with measurement error. For the endogeneity problem, this is one of the reasons I use other variables such as the number of patents to proxy for the growth rate of innovation. I believe that this will eliminate any endogeneity related to the growth rate and trade openness. Furthermore, the DOLS regression will also take care of the endogeneity problem.

Results:

Table 1 is used to replicate the CHH 2009 study without Switzerland. The first thing to notice is that the coefficients on the domestic and foreign R&D stock remain positive and significant. However, they are higher than CHH 2009 for both variables. When interacted with the G7 dummy, the domestic R&D stock becomes negative or insignificant meaning that being a bigger economy bring less returns, or at least virtually no more returns, on own R&D stock than smaller ones. When interacted with the share of imports in terms of GDP, the coefficient on foreign R&D stock is still significant but decreases by half. The human capital stock, on the other hand, has a positive effect and significant which is consistent with CHH 2009 and with the theory. The r-squared are also similar to CHH 2009. As for CHH 2009, human capital decreases the coefficient on the domestic and foreign R&D.

Table 2 and Table 3 show the results with the average manufacturing tariff. Table 2 present the pooled OLS results while table 3 presents the fixed effects. The hausman test on the random effect which test the validity of the of the random effect assumption always reject the null hypothesis. This means that I can-not assume strict exogeneity between the individual effects and the independent variables. In fact, the covariance between the individual effects c_i and the independent variables x_{it} is not 0. This is only allowed to happen under the random effects which has stronger assumption than the fixed effects. In that case, the fixed effects analysis will more robust than the fixed effect analysis (Wooldridge, 2002). This is also intuitive as there is a strong probability that the individual effect, for example one country's political system or legal system, will be correlated with the decision of increasing the human capital stock, the R&D stock or a tariff. In that case, I will not present the results of the random effects.

Table 1: Fixed Effects CHH 2009 without Switzerland

VARIABLES	*Fixed Effetcs* logf	logf	logf	logf	logf	logf
logsd	0.123***	0.0513***	0.126***	0.0511***	0.174***	0.0982***
	(0.0087)	(0.00935)	(0.00865)	(0.00951)	(0.00606)	(0.0081)
logsf	0.184***	0.151***	0.184***	0.166***		
	(0.0169)	(0.0153)	(0.018)	(0.0162)		
logh		0.692***		0.691***		0.656***
		(0.0512)		(0.0523)		(0.0542)
G7logsd			-0.0393**	-0.0614***	0.00545	-0.0185
			(0.0179)	(0.0161)	(0.0172)	(0.0156)
mlogsf					0.0543***	0.0433***
					(0.00585)	(0.00537)
Constant	-3.742***	-4.088***	-3.592***	-4.023***	-2.135***	-2.647***
	(0.154)	(0.143)	(0.157)	(0.149)	(0.0759)	(0.0866)
Observations	713	713	713	713	713	713
R^2: Within	0.735	0.792	0.744	0.798	0.736	0.787
:Between	0.015	0.015	0.019	0.027	0.007	0.000
:Overall	0.145	0.198	0.12	0.041	0.103	0.141
Number of cid	23	23	23	23	23	23

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

It seems that the average tariff has a negative impact on the variation of the growth rate of TFP. The coefficients on the average tariff are all negative and significant. Indeed, an increase in the tariff of one percent decreases the growth rate of the TFP by 0.03 percents on average. The human capital stock, which was positive and significant under CHH 2009, becomes insignificant after controlling for the average tariff rate. The domestic R&D stock retains similar coefficient and they are all insignificant. However, the foreign R&D stock is insignificant and becomes negative and significant only when interacting with the share of imports in GDP. The R-squareds are all between 0.45 and 0.55.

In table 3, I present the results of the fixed effects model with the average tariff. In this case, the average manufacturing tariff still has a negative effect on TFP but it is generally insignificant. Only in two of the specifications is the coefficient on tariffs significant, but only at the 5 percent level and its coefficient is really low. The growth rate of the human capital stock is still negative and significant. The interaction term of the G7 dummy with the growth rate of the domestic R&D stock is still generally insignificant meaning that there are no differences between a G7 economy and any other OECD economy in terms of the effect of R&D on their TFP. The coefficient on the domestic and foreign R&D stocks are similar and consistent with CHH 2009 but they increase when the human capital stock is included in the regression. The human capital stock is negative and significant, which is counterintuitive and inconsistent with the theory. The r-squareds are similar to CHH 2009 at more or less 0.77.

Table 2: Pooled OLS with Average Tariff Rate

	Pooled OLS					
VARIABLES	logf	logf	logf	logf	logf	logf
logsd	0.0106***	0.00843**	0.0204***	0.0232***	0.0201***	0.0237***
	(0.00314)	(0.0037)	(0.00428)	(0.00563)	(0.00405)	(0.00546)
logsf	-0.00577	-0.00493	-0.0124	-0.00676		
	(0.0101)	(0.0103)	(0.0108)	(0.0113)		
logh		0.0389		-0.000877		-0.0133
		(0.0306)		(0.0328)		(0.0304)
avemanuftariff	-0.0310***	-0.0293***	-0.0306***	-0.0285***	-0.0317***	-0.0304***
	(0.00332)	(0.00337)	(0.00333)	(0.00337)	(0.00306)	(0.0031)
G7logsd			-0.00609***	-0.00650***	-0.00825***	-0.00851***
			(0.00176)	(0.00175)	(0.00173)	(0.00175)
mlogsf					-0.00986***	-0.00879***
					(0.00225)	(0.00244)
Constant	0.0788	-0.00752	0.0793	-0.0438	-0.0243	-0.0551
	(0.123)	(0.129)	(0.143)	(0.148)	(0.0547)	(0.0703)
Observations	207	207	207	207	207	207
R-squared	0.451	0.473	0.498	0.525	0.536	0.551
Standard errors in parentheses						
*** p<0.01, ** p<0.05,	*p<0.1					

Table 3: Fixed Effects with Average Tariff Rate

	Fixed Effects					
VARIABLES	logf	logf	logf	logf	logf	logf
logsd	0.170***	0.199***	0.179***	0.207***	0.132***	0.153***
	(0.0194)	(0.0217)	(0.0196)	(0.0218)	(0.0211)	(0.024)
logsf	0.138***	0.140***	0.156***	0.150***		
	(0.0299)	(0.0294)	(0.0362)	(0.036)		
avemanuftariff	-0.00307	-0.00929**	-0.000359	-0.00676	-0.00219	-0.00820**
	(0.00367)	(0.00406)	(0.00388)	(0.00432)	(0.0035)	(0.00397)
logh		-0.531***		-0.516***		-0.459***
		(0.153)		(0.154)		(0.148)
G7logsd			-0.0692	-0.0558	0.0636	0.0787**
			(0.0489)	(0.0486)	(0.0396)	(0.0392)
mlogsf					0.0437***	0.0425***
					(0.00767)	(0.00789)
Constant	-3.662***	-2.808***	-3.645***	-2.771***	-1.996***	-1.261***
	(0.402)	(0.463)	(0.409)	(0.48)	(0.255)	(0.336)
Observations	207	207	207	207	207	207
R^2: Within	0.758	0.775	0.767	0.783	0.786	0.8
:Between	0.107	0.072	0.093	0.129	0.011	0.006
:Overall	0.120	0.120	0.084	0.195	0.040	0.036
Number of cid	19	19	19	19	19	19
Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1						

Tables 4 and 5 present the results when the average tariff is disaggregated by sectors. I have the high-tech sector and the traditional sector just like the theoretical model developed by Grossman and Helpman (1991). I also present the pooled OLS and the fixed effects. Like before, the Hausman test on the validity of the strict exogeneity assumption reject the null on every specification. The tariff applied on traditional and high-technology goods has a negative but not always significant effect on the growth rate of the TFP. This would in part validate the Grossman and Helpman hypothesis as the tariff on high-technology goods should have a negative effect on the growth rate of innovation by the reallocation of skilled-labour. However, the elasticity of both tariffs on TFP is at 0.1 or lower. On the other hand, these results are inconsistent with the theoretical part developed earlier where the general results are that a trade policy which aims to protect the traditional manufacturing sector will also protect the R&D sector of this country. The low impact of the tariff could potentially be explained by the offsetting forces of the tariffs applied abroad.

Table 4: Pooled OLS with Tariffs by Sector

	Pooled OLS					
VARIABLES	logf	logf	logf	logf	logf	logf
logsd	0.0106***	0.00817**	0.0200***	0.0225***	0.0190***	0.0221***
	(0.00346)	(0.00406)	(0.00448)	(0.00589)	(0.0042)	(0.00576)
logsf	-0.00719	-0.00623	-0.0137	-0.00814		
	(0.0109)	(0.011)	(0.0114)	(0.0118)		
logh		0.0405		0.00268		-0.0069
		(0.0313)		(0.0333)		(0.0315)
hightechavetariff	-0.0111	-0.0116	-0.0130*	-0.0128*	-0.0194***	-0.0188***
	(0.00773)	(0.00778)	(0.00753)	(0.00754)	(0.00699)	(0.00713)
traditionalavetariff	-0.0188***	-0.0176***	-0.0181***	-0.0169***	-0.0166***	-0.0158***
	(0.00346)	(0.00346)	(0.00335)	(0.00333)	(0.00302)	(0.00306)
G7logsd			-0.00620***	-0.00660***	-0.00844***	-0.00863***
			(0.00178)	(0.00177)	(0.00175)	(0.00177)
mlogsf					-0.00969***	-0.00857***
					(0.00229)	(0.00248)
Constant	0.102	0.0138	0.107	-0.0181	-0.00659	-0.0471
	(0.132)	(0.138)	(0.148)	(0.153)	(0.058)	(0.0717)
Observations	207	207	207	207	207	207
R-squared	0.456	0.476	0.504	0.53	0.54	0.554
Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1						

The coefficient on the human capital stock is sometime negative but has become closer to zero and it is never significant. An interesting thing arises here when I consider the foreign R&D stock interacted with the share of imports in terms of the GDP. This coefficient is now negative and highly significant which is counterintuitive as based on CHH 2009 theoretical model we would expect this measure to be a key long-run determinant of TFP. Furthermore, the coefficient on the foreign R&D stock is always insignificant.

Table 5: Fixed Effects with Tariffs by Sector

	Fixed Effects					
VARIABLES	logf	logf	logf	logf	logf	logf
logsd	0.175***	0.196***	0.182***	0.202***	0.113***	0.131***
	(0.0218)	(0.0227)	(0.0218)	(0.0227)	(0.0231)	(0.0246)
logsf	0.145***	0.130***	0.162***	0.141***		
	(0.0357)	(0.0361)	(0.04)	(0.0411)		
hightechavetariff	0.0029	-0.00859	0.00142	-0.00999	-0.0187**	-0.0283***
	(0.0102)	(0.0109)	(0.0101)	(0.0109)	(0.00856)	(0.00879)
traditionalavetariff	-0.00101	-0.00399	0.00147	-0.00158	0.00364	0.000456
	(0.00255)	(0.00267)	(0.00274)	(0.00288)	(0.00267)	(0.00276)
logh		-0.535***		-0.520***		-0.526***
		(0.162)		(0.164)		(0.15)
G7logsd			-0.0895*	-0.08	0.00688	0.0112
			(0.0506)	(0.0503)	(0.0439)	(0.043)
mlogsf					0.0452***	0.0431***
					(0.00768)	(0.00781)
Constant	-3.815***	-2.627***	-3.678***	-2.475***	-1.501***	-0.517
	(0.544)	(0.655)	(0.551)	(0.672)	(0.328)	(0.418)
Observations	207	207	207	207	207	207
R^2: Within	0.761	0.777	0.773	0.787	0.798	0.814
:Between	0.105	0.069	0.037	0.032	0.005	0.001
:Overall	0.119	0.121	0.031	0.057	0.090	0.081
Number of cid	19	19	19	19	19	19
Standard errors in parentheses						
*** p<0.01, ** p<0.05,	*p<0.1					

When I considered the fixed effects, the effect of a tariff applied on the traditional sector is insignificant in every specification and negative in almost every specification. On the other hand, the high-tech tariff shows a negative and sometimes significant effect on the TFP. In fact, it is only significant when the foreign stock of R&D is interacted with the share of imports in terms of GDP. In this case, an increase of the tariff applied on high-technology manufacturing goods of one percent will decrease the TFP by about 0.015 percents on average. Again, human capital stock is negative and significant. The foreign R&D stock interacted with the share of imports in terms of GDP is now positive which is more consistent with the theory. The coefficient on domestic and foreign R&D stock are still consistent with CHH 2009 but they increase when I control for human capital stock, like before. The r-squared are at the same levels as the fixed effect model with the average tariff rate.

New proxy for the Growth Rate of Innovation:

This next section will be devoted on the analysis of new variables as proxy for the growth rate of innovation. The first one I will analyze is the number of patent application to the PCT and the results are presented in tables 6 and 7. When I used this variable as the dependant variable, the specifications of CHH 2009 are still valid, of similar sign and significant, but now are much higher than before. The human capital stock is now positive and significantly higher than it previously was. An increase of one percent in the stock of human capital results in an increase of 9.5 percent in the level of patent application. The human capital stock reduces the coefficients on the domestic and foreign R&D stock as in CHH 2009. When I consider the average tariff on manufacturing goods, the effect significant is half of the time. The coefficient on the average tariff rate is positive and significant when human capital is included in the regression and negative otherwise which is quite intriguing. This means, that an average tariff increase has a positive effect on the number of patent application in the long-run when human capital is accounted for. The G7 dummy interacting with the domestic R&D stock now becomes positive and generally become significant.

Table 6: Patent Application to the PCT (Fixed Effects with average tariffs rate)

VARIABLES	*Fixed Effects*					
	logpaapp	logpaapp	logpaapp	logpaapp	logpaapp	logpaapp
logsd	1.289***	0.587***	1.322***	0.641***	1.202***	0.424**
	(0.17)	(0.155)	(0.17)	(0.155)	(0.196)	(0.189)
logsf	2.232***	2.305***	1.681***	2.028***		
	(0.263)	(0.21)	(0.314)	(0.256)		
avemanuftariff	-0.03	0.0984***	-0.0396	0.0939***	-0.105***	0.0276
	(0.0322)	(0.029)	(0.0336)	(0.0308)	(0.0324)	(0.0311)
logh		9.908***		9.596***		9.583***
		(1.091)		(1.099)		(1.165)
G7logsd			0.893**	0.379	2.178***	2.012***
			(0.423)	(0.346)	(0.367)	(0.308)
mlogsf					0.159**	0.265***
					(0.071)	(0.062)
Constant	-35.55***	-51.13***	-33.41***	-49.42***	-17.45***	-30.22***
	(3.532)	(3.31)	(3.542)	(3.416)	(2.362)	(2.637)
Observations	207	207	207	207	207	207
R^2: Within	0.82	0.889	0.832	0.894	0.824	0.881
:Between	0.780	0.659	0.626	0.806	0.531	0.604
:Overall	0.809	0.696	0.623	0.802	0.526	0.593
Number of cid	19	19	19	19	19	19

Standard errors in parentheses
*** p<0.01, ** p<0.05, *p<0.1

Table 7 presents the results when the tariff rate is divided by sector. Again, the results of the previous section remain. The G7 dummy interacting with the domestic R&D stock is half of the time insignificant. In fact, it becomes significant when the foreign R&D stock is interacted with the share of imports in terms of GDP. The tariff rate on traditional goods is generally significant and generally positive. This is consistent with my theoretical model. In fact, an increase of one percent in the tariff imposed on traditional manufacturing goods increases the number of patent application by about 0.05 percent. The tariff rate on the high-technology manufacturing goods is generally significant and negative. Again, this would be consistent with the theory.

Table 7: Patent Application to the PCT (Fixed Effects with tariffs rate by sector)

	Fixed Effects					
VARIABLES	logpaapp	logpaapp	logpaapp	logpaapp	logpaapp	logpaapp
logsd	1.042***	0.587***	1.097***	0.645***	0.808***	0.248
	(0.188)	(0.161)	(0.186)	(0.161)	(0.209)	(0.195)
logsf	1.733***	2.290***	1.272***	2.055***		
	(0.307)	(0.256)	(0.342)	(0.292)		
hightechavetariff	-0.267***	0.0406	-0.262***	0.035	-0.344***	-0.172**
	(0.0876)	(0.0775)	(0.0863)	(0.0774)	(0.0774)	(0.0696)
traditionalavetariff	0.0101	0.0697***	0.00777	0.0710***	-0.0149	0.0444**
	(0.0219)	(0.019)	(0.0234)	(0.0205)	(0.0241)	(0.0218)
logh		10.13***		9.847***		8.944***
		(1.154)		(1.164)		(1.187)
G7logsd			0.661	0.225	1.490***	1.558***
			(0.432)	(0.357)	(0.397)	(0.34)
mlogsf					0.1803***	0.2745***
					(0.0694)	(0.0618)
Constant	-26.13***	-51.51***	-24.24***	-49.68***	-9.419***	-24.44***
	(4.685)	(4.654)	(4.706)	(4.781)	(2.969)	(3.31)
Observations	207	207	207	207	207	207
R^2: Within	0.83	0.892	0.841	0.897	0.841	0.888
:Between	0.814	0.658	0.642	0.800	0.530	0.6199
:Overall	0.822	0.693	0.644	0.805	0.533	0.6132
Number of cid	19	19	19	19	19	19

Standard errors in parentheses
*** p<0.01, ** p<0.05, *p<0.1

Tables 8 and 9 consider the results of the model when the dependent variable is the growth rate of the GERD. Again here, the results are mixed. The results of CHH 2009 are generally replicated especially for the domestic R&D stock. When interacted with the G7 dummy, the domestic R&D stock becomes insignificant. Curiously, the coefficient on the foreign R&D stock is now generally insignificant and remains insignificant when interacting with the share of imports GDP. Furthermore, the coefficient on the human capital stock is now negative and insignificant. This means that human capital accumulation has virtually no impact on the GERD. As for my main explanatory variables, the tariffs, they are generally significant and all have a negative sign. The coefficients on the tariff rate are close to zero however. The R-square, on the other hands, are all high at 0.97. One interesting thing about these specifications is that the hausman test on the validity of the strict-exogeneity assumptions gave me mixed results. In some specifications, the random effects model was more valid than the fixed effects model.

Table 8: GERD (Fixed Effects with Average Tariffs)

	Fixed Effects					
VARIABLES	logGERD	logGERD	logGERD	logGERD	logGERD	logGERD
logsd	0.828***	0.827***	0.822***	0.816***	0.806***	0.793***
	(0.0235)	(0.0275)	(0.0203)	(0.0236)	(0.0238)	(0.0288)
logsf	-0.0344	-0.035	0.00877	0.0101		
	(0.0353)	(0.0371)	(0.0376)	(0.0385)		
avemanuftariff	-0.00688	-0.00918*	-0.00898**	-0.00933**	-0.00840**	-0.00823**
	(0.00429)	(0.00485)	(0.00394)	(0.00449)	(0.00357)	(0.00412)
logh		-0.18		-0.0317		-0.00717
		(0.187)		(0.164)		(0.16)
G7logsd			0.0521	0.0408	0.0601	0.0593
			(0.0484)	(0.0484)	(0.0398)	(0.0402)
mlogsf					0.00808	0.0107
					(0.00823)	(0.00887)
Constant	0.318	0.75	-0.464	-0.265	-0.261	-0.0978
	(0.474)	(0.582)	(0.419)	(0.52)	(0.276)	(0.36)
Observations	188	188	188	188	188	188
R^2: Within	0.967	0.969	0.977	0.978	0.977	0.978
:Between	0.980	0.981	0.978	0.980	0.975	0.974
:Overall	0.982	0.984	0.980	0.982	0.977	0.976
Number of cid	19	19	19	19	19	19

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

When the tariff rate is divided by sector, the same results apply. The domestic R&D is positive and significant and its coefficient is around 0.8 on average. It becomes insignificant when interacted with the G7 dummy. The foreign R&D stock is negative and significant in the first two specifications which is counterintuitive as the spillovers effects would be negative. For the tariffs, neither the tariff imposed on traditional manufacturing goods nor the tariffs imposed on the high-technology goods are significant. However, the tariff on high-technology manufacturing good is negative and significant in the first two specifications but only at the ten percent level. I can therefore conclude that they have virtually no effect on the GERD. The r-squared are still high at around 0.97.

Table 9: GERD (Fixed Effects with Tariffs by Sector)

	Fixed Effects					
VARIABLES	logGERD	logGERD	logGERD	logGERD	logGERD	logGERD
logsd	0.811***	0.816***	0.814***	0.812***	0.801***	0.791***
	(0.0263)	(0.0282)	(0.0228)	(0.0243)	(0.0265)	(0.03)
logsf	-0.0719*	-0.0780*	-0.00759	-0.00277		
	(0.0415)	(0.045)	(0.0415)	(0.0443)		
hightechavetariff	-0.0219*	-0.0237*	-0.0151	-0.0126	-0.0103	-0.00914
	(0.0116)	(0.0128)	(0.0101)	(0.0111)	(0.00893)	(0.00933)
traditionalavetariff	-0.000405	-0.00224	-0.00239	-0.00271	-0.00244	-0.00224
	(0.00285)	(0.00309)	(0.00269)	(0.00293)	(0.00273)	(0.0029)
logh		-0.241		-0.0354		0.00121
		(0.199)		(0.176)		(0.168)
G7logsd			0.031	0.0198	0.0359	0.0364
			(0.0502)	(0.0501)	(0.0451)	(0.0453)
mlogsf					0.00756	0.00941
					(0.00849)	(0.00909)
Constant	0.999	1.577*	-0.0376	0.0735	-0.072	0.0373
	0.641	0.821	0.571	0.736	0.365	0.467
Observations	188	188	188	188	188	188
R^2: Within	0.968	0.97	0.977	0.978	0.977	0.979
:Between	0.978	0.980	0.982	0.982	0.980	0.979
:Overall	0.982	0.984	0.984	0.985	0.982	0.981
Number of cid	19	19	19	19	19	19

Standard errors in parentheses
*** p<0.01, ** p<0.05, *p<0.1

Conclusion:

When considered from a purely theoretical point of view, the effect of trade policy on the growth rate of innovation should depends on the sector a country tries to promote, assuming a two sector economy. It will also depends on the stronger of two offsetting effects a tariff have on the economy. The first one is an effect on the cost of innovation at the firm level while the there also exist a reallocation effect of the labour force in the country. As mentioned earlier, a study like this one could use the cost function and firm level data to empirically study the effect of a tariff on the cost of innovation. However, I will leave that kind of study for later work.

On the empirical side, I could easily replicate the results of CHH 2009 with a sample of 23 countries instead of 24. The results of my main study were generally mixed. The effect of an average tariff rate on manufacturing goods on the growth rate of innovation is sometimes positive. Sometime, it is negative and, on other occasions, it is insignificant. There were some specifications where it was insignificant when, for example, I use the growth rate of the TFP as the dependant variable. This could be interpreted theoretically to be a result of the offsetting forces of the tariff on the cost of innovation and on the labour force. But the effect I wanted to evaluate was a general effect of trade policy on the growth rate of innovation and the results show a positive effect of the tariff on the growth rate of innovation. This could also reflect some problems of my database and mis-measurements in the tariff rate. From one thing, data on tariffs were not easy to obtain and were only available, in most cases, from 1981 to 2003. My panel was unbalanced as some countries, like Korea and Norway, had few observations and this prevent me to perform unit root test for my variables as there were gaps in their time-series. This study could also be replicate with a more up-to-date panel of data.

Even if the human capital stock always had a strong positive effect in CHH 2009, my study showed some mixed results in that regard too. It became generally negative when I controlled for the tariffs suggesting some form of multicollinarity. The growth rate of the human capital stock only became significant and had a positive effect on the growth rate of innovation when the latter is proxied by the growth rate of patent applications to the PCT. Again, it would be fruitful to extend the study in that area.

To conclude, it would probably be good to empirically evaluate the effect of a tariff, with more data on the tariff and more countries, on the human capital stock and on the spillover effect, the variable s^f in my study. I believe that there exist some extensions to this study that could empirically explain the effect of trade policy in the economy. These extensions could take the form of new empirical models, they could include more independent variables or they could evaluate the effects of trade policy on other relevant variables.

Bibliography:

Barro, Robert J. and Xavier Sala-i-Martin, **Economic Growth, Second Edition**, The MIT Press, Cambridge, 2003.

Bernstein, Jeffrey I., *"Factor Intensities, Rates of Return, and International R&D Spillovers: The Case of Canadian and U.S. Industries"*, **D. Encaoua et al., The Economics and Econometrics of Innovation**, Kluwer Academic Publishers, Netherlands, 2000, pp. 519-542.

Bayoumi, Tamim, David T. Coe and Elhanan Helpman, *"R&D spillovers and global growth",* Journal of International Economics, Vol. 47, 1999, p. 399-428.

Bransetetter, Lee G., *"Looking for International Knowledge Spillovers: AReview of the Literature with Suggestions for New Approaches"*, **D. Encaoua et al., The Economics and Econometrics of Innovation**, Kluwer Academic Publishers, Netherlands, 2000, pp. 495-518.

Coe, David T. and Elhanan Helpman, *"International R&D spillovers"*, European Economic Review, Vol. 39, 1995, pp. 859-887.

Coe, David T., Elhanan Helpman and Alexander W. Hoffmaister, *" North-South R & D Spillovers"*, The Economics Journal, Vol. 107, No. 440, 1997, pp. 134-149.

Coe, David T., Elhanan Helpman and Alexander W. Hoffmaister, *"International R&D spillovers and institutions"*, The European Economic Review, Vol. 53, 2009, pp. 723-741.

Dinopoulos, Elias and Paul Segerstrom, *"The dynamic effects of contingent tariffs",* Journal of International Economics, Vol 47, 1999, pp. 191-222.

Feenstra, Robert C., **Advanced International Trade: Theory and Evidence**, Princeton University Press, Princeton, 2004.

Grossman, Gene M. and Elhanan Helpman, **Innovation and Growth in the Global Economy**, The MIT Press, Cambridge, 1991.

Griliches, Zvi, *"The Search for R&D Spillovers",* Scandinavian Journal of Economics, Vol. 94, 1992, pp. 29-47.

Kao, Chihwa, Chiang, Min-Hsien and Bangtian Chien, *"International R&D Spillovers: An Application of Estimation and Inference in Panel Cointegration"*, Oxford Bulletin of Economics and Statistics, Special Issue, 1999, pp. 691-709.

Krugman, Paul, *"The increasing Returns Revolution in trade and Geography"*, American Economic Review, Vol. 99, No. 3, June 2009, pp. 561-571.

Krugman, Paul, *"Technology, Trade and Factor Prices"*, Journal of International Economics, Vol. 50, 2000, pp. 51-71.

Lucas, Jr., Robert E., *"On the mechanics of Economic Development"*, Journal of Monetary Economics, Vol. 22, 1988, pp. 3-42.

Mohitosh, Kejriwal and Pierre Perron, "*Data Dependent Rule for Selection of the Numbers of Leads and Lagsin the Dynamic OLS Cointegrating Regression",* Econometric Theory, Vol. 24, No. 5, October 2005, pp. 1425-1441.

Nicita, Alessandro and Marcelo Olarreaga, "*Trade, Production and Protection Database, 1976-2004",* THE WORLD BANK ECONOMIC REVIEW, VOL. 21, NO. 1, pp. 165–171

Rivera-Batiz, Luis A. and Paul M. Romer, "*International trade with endogenous technological change",* European Economic Review, Vol. 35, 1991, pp. 971-1004.

Rodriguez, Fransisco and Dani Rodrick, *"Trade Policy and Economic Growth: A Skeptic's Guide to the Cross-National Evidence"*, NBER Working Paper, No. 7081, May 2000.

Romer, Paul M., *"Endogenous Technological Change"*, Journal of Political Economy, Vol. 98, no. 5, pp. 71-102.

Segerstrom, Paul S., T. C. A. Anant and Elias Dinopoulos, *"A Schumpeterian Model of the Product Life Cycle"*, The American Economic Review, Vol. 80, No. 5, December 1990, 1077-1091.

Stock, James H. And Mark W. Watson, *"Estimator of Cointegrating Vectors in Higher Order Integrated Systems"*, Econometrica, Vol. 61, No. 4, Jul. 1993, pp. 783-820.

Winters, Alan L., "*Trade and Poverty: Is there a Connection?",* World Trade organization, Geneva, 2001.

Wooldridge, Jeffrey M., **Econometric Analysis of Cross Section and Panel Data,** MIT press, Cambridge, 2002.