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Critical Mass, Network Effect and ICT productivity – a dynamic CGE modelling approach.

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Abstract: This paper models and analyses the impact of ICT technology on productivity growth. Three characteristics of ICT which have the capacity to impact upon ICT productivity are considered: (i) general purpose technology, (ii) network technology, and (iii) spillovers of ICT knowledge stock. The paper models national productivity as a function of economy-wide ICT productivity and the sectoral allocation of ICT resources. The model is hosted within a recursive dynamic CGE environment. The specification is applied to an ICT trade liberalisation experiment, which forecasts the possible impact of ICT technology on productivity growth for 2009-2015 if trade liberalisation in ICT products were to occur between APEC economies.

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Introduction

The importance of productivity for long term economic growth is widely acknowledged. Recent literature provides formal evidence for a positive relationship between productivity growth and investment in Information Technology (IT) and Telecommunications (together, ICT) (Brynjolfsson and Hitt 2000; Park, Shin et al. 2007; Park, Shin et al. 2007).

ICT displays three characteristics that are important for productivity growth: (i) ICT is recognized as a General Purpose Technology or enabling technology, which has applicability across large parts of the economy and exhibits strong complementarities with other technologies (Helpman 1998; Lipsey, Carlaw et al. 2005). Quoting Lipsey (1998) : "*the [ICT] revolution is changing product design, production, marketing, finance, and the organization of firms. It is also creating a wide range of new products incorporating hard coded chips, computers and/or software. Computers are used to fly aeroplanes, drive trains, operate machines, run building systems, warn of unsafe driving practices, monitor health, to facilitate communication through the internet, e-mail, and desktop publishing*"; (ii) ICT is a network technology i.e. the value of ICT technology to a potential user depends on the number of other existing users of the technology as well as on the possibility to interact with them. This implies that productivity growth resulting from investment in ICT is variable and would take the form of an inverted u-shaped function with maximum representing the moment when all the isolated IT clusters integrate into a coherent network; using Greenspan's (2000) phrase: "*the full value of computing power could be realized only after ways have been devised to link computers into large-scale networks...*". Consequently, ICT would form another 'wave' of innovations impacting upon productivity among waves of innovations such as steam power or electricity (Hargroves and Smith 2005); finally, (iii) ICT is subject to strong externalities or spillover effect, which allows for diffusion of ICT innovation across sectors and national boundaries. One of the modes of diffusion of innovation is via traded products embedding new, innovative technology. The concept of externalities, neighborhood effects or spillovers was first described in 1890 by Alfred Marshall (1920). Marshall observed that innovative knowledge benefits the inventor for a rather short time: "*the most important improvements in method seldom remain secret for long after they have passed from the experimental stage*". The importance of trade as a vehicle for the international transmission of knowledge contributing to TFP growth was taken up by Coe and Helpman (1995) in 1995 and followed by a number of studies (Coe and Helpman 1997; Crespo, Martin et al. 2004; Lumenga-Neso, Olarreaga et al. 2005). Madsen (2007) estimated that 93% of the increase in TFP over the past century has been solely due to imports of knowledge. Other studies have found knowledge distributed through imports to be less important (Keller 1998).

This paper forecasts productivity growth resulting from investment in ICT and diffusion of ICT innovation for APEC economies. We construct a framework which accounts for the main characteristics of ICT impacting upon productivity in different ways. We use the developed framework to test for ICT-related productivity resulting from trade liberalization in electronic equipment between the APEC economies.

The remainder of the paper is organized as follows: section two overviews the development of the model, section three summarizes the data and variables used in the study, section four describes the experimental design, section five reports the results, and section six concludes.

Model specification

To account for the three main characteristics of ICT impacting upon productivity, we assume (i) ICT has the potential to affect the performance of all sectors in an economy (enabling technology); (ii) sectoral IT productivity depends not only on sectoral ICT resources but also on the entire economy-wide ICT environment, so that sectoral productivity cannot be considered in isolation from the rest of an economy, (network technology); (iii), productivity is affected by spillovers of knowledge stocks which accumulate as an outcome of R&D activity and/or as a result of internationally traded ICT containing embodied technological advances. The details follow.

We place our analysis in a region consisting of *i* economies connected by trade linkages. Each economy utilises IT capital stock $SJ_{i,t}$. Productivity of the economy-wide IT stock, $A^{IT}{}_{i,t}$, depends on the degree of development of the *IT economy* $N_{i,t}$, and is given by the logistic function $\tau(\bullet)$:

$$A^{IT}{}_{i,t} = \tau\left(N_{i,t}\right) = \frac{b\exp\left(c + g(b-a)N_{i,t}\right) + a}{1 + \exp\left(c + g(b-a)N_{i,t}\right)} \qquad (1.1)$$

where parameters a and b are lower and upper bound respectively, c is a constant, g is a rate of growth. By using the term 'IT economy' we seek to highlight the importance of the degree of saturation and utilisation of IT technologies within the economy, relative to the world's best practice.

Each economy i comprises $s = 1,...,S$ sectors. Each sector utilises a set of inputs $X_{i,s,t}$ and produces output $Y_{i,s,t}$ with available technology $F(\bullet)$ and resulting productivity $A_{i,s,t}$ at time t, i.e.: $Y_{i,s,t} = A_{i,s,t} F(X_{i,s,t})$. Sectoral productivity $A_{i,s,t}$ resulting from productivity of the national IT stock $A^{IT}{}_{i,t}$ is proportional to the share of national IT stock $SJ_{i,t}$ owned by a sector s:

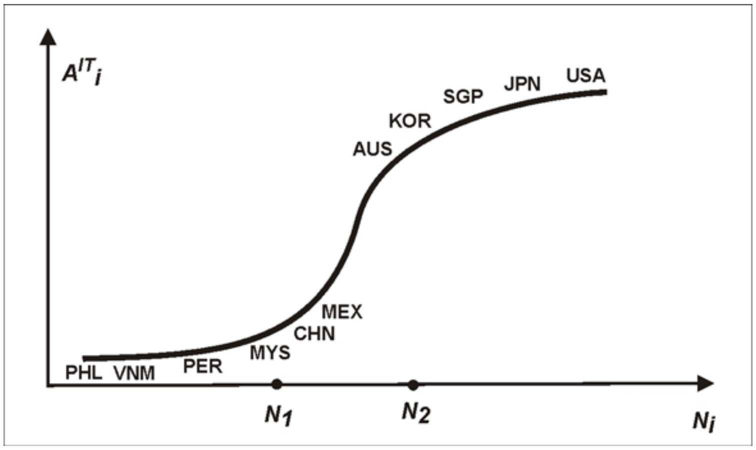
$$A_{i,s,t} = \frac{SJ_{i,s,t}}{\sum_r SJ_{i,r,t}} \cdot A^{IT}{}_{i,t} = \frac{SJ_{i,s,t}}{\sum_r SJ_{i,r,t}} \cdot \frac{b \exp\left(c + g(b-a)N_{i,t}\right) + a}{1 + \exp\left(c + g(b-a)N_{i,t}\right)} \qquad (1.2)$$

where $SJ_{i,s,t}$ represents IT stock in sector s.

The overall national productivity $A_{i,t}$ is given by a share weighted average of sectoral productivities with sectoral outputs used as weights:

$$A_{i,t} = \frac{\sum_s A_{i,s,t} Y_{i,s,t}}{\sum_r Y_{i,r,t}} \qquad (1.3)$$

Figure 1. Productivity of national IT resources



The logistic functional form (Figure 1 and equation(1.1)) reflects different productivity of aggregated IT resources for countries at different level of IT advancement N_i. Initially, as countries comprise only scarce

IT resources which form isolated clusters, the marginal productivity of IT resources is rather low. If an economy gains a *critical mass* of IT capacity, N_1, its IT begins to exhibit additional productivity benefits resulting from integration of existing stock into coherent network. This transition in which disperse IT mass merges into a coherent system improves the productivity of existing stock as well as the marginal productivity of new investment, since new IT additions bring not only their own isolated productive capacity but also benefit from the entire system they join. Once an economy saturates with IT applications and exhausts its capabilities at point N_2, the IT marginal productivity decreases again and the period of rapid IT-related growth ceases.

The IT economy is a product of many factors from across the spectrum of socio-economic development, such as: infrastructure environment, market conditions, political and regulatory environment; all those across the business, government and individual level. Our initial value of $N_{i,t}$ takes account of all these factors[1], however the factors impacting upon the dynamic development of $N_{i,t}$ are simplified to changes in total IT equipment stock, $SJ_{i,t}$, and changes in IT-related knowledge stock, $SK_{i,t}$, which is country-specific and available to all sectors. IT equipment depreciates at rate η and materialise with investment $I_{i,s,t}$:

$$SJ_{i,t} = \sum_{s}\left((1-\eta)SJ_{i,s,t-1} + I_{i,s,t-1}\right) \tag{1.4}$$

Inasmuch as IT equipment stock and investment data are collected and can be obtained, the IT knowledge component is more problematic due to intangibility of knowledge and lack of information on international flows of knowledge. To deal with this problem we assume the following framework:

Economy i can benefit not only from its own domestic stock, but also from knowledge developed elsewhere (via externalities or spillovers). Therefore we assume that the *effective* stock of knowledge impacting upon i's productivity consists of domestic stock $SK_{i,d,t}$ and foreign stock $SK_{i,f,t}$:

$$SK_{i,t} = SK_{i,d,t} + SK_{i,f,t} \tag{1.5}$$

Domestic stock of knowledge is an output of domestic R&D process and is a subject to depreciation:

$$SK_{i,d,t} = (1-\varepsilon)SK_{i,d,t-1} + R_{i,d,t-1} \tag{1.6}$$

[1] We use the Networked Readiness of Nations Index (NRI) which is an international assessment of countries' capacity to exploit opportunities offered by ICT. NRI is a single score index developed by the Centre for International Development at Harvard University. For details see Dutta (2004).

where the stock of domestic knowledge of economy i in time t, $SK_{i,d,t}$,is given as the previous period's stock depreciated by rate ε and enhanced by new knowledge resulting from expenditure on R&D in *t-1*, $R_{i,d,t-1}$.

The mechanism of foreign stocks complementing domestic stock is represented by the function $\phi(\bullet) \equiv \mu \cdot E^{\alpha(1-\gamma)+(1-\alpha)(1-\delta)}$ in the formula:

$$SK_{i,f,t} = \phi(\bullet) SK_{j,d,t} = \mu_{i,j,t} \cdot E_{i,j,t}{}^{\alpha(1-\gamma_{i,j,t})+(1-\alpha)(1-\delta_{i,j,t})} SK_{j,d,t} \qquad i \neq j \qquad (1.7)$$

where

- $E_{i,j,t}$ - amount of knowledge developed at economy *j* and available to *i*. Because the knowledge is embedded in the exported commodity, $E_{i,j,t}$ is an export share of a commodity embedding the knowledge from *j* to *i*:

$$E_{i,j,t} = \frac{X_{j,i,t}}{\sum_k X_{j,k,t}} \qquad (1.8)$$

- $\mu_{i,j,t}$ - importance of imports from source country *j* to the destination country *i*. $\mu_{i,j,t}$ is a share of imports from *j* in total imports by *i*:

$$\mu_{i,j,t} = \frac{M_{i,j,t}}{\sum_k M_{i,k,t}} \qquad (1.9)$$

- $\delta_{i,j,t}$ - the potential for economy *i* to benefit from economy *j*'s stock of knowledge, or the extent of the knowledge gap between *j* and *i*. $\delta_{i,j,t}$ is a function of the difference between $SK_{j,d,t}$ and $SK_{i,d,t}$:

$$\delta_{i,j,t} = \max\left[0, \frac{SK_{j,d,t} - SK_{i,d,t}}{SK_{\max,d,t}}\right] \qquad (1.10)$$

  the maximum of zero and the difference between the stocks ensures that $\delta_{i,j,t}$ will not take negative values, i.e. the specification prevents 'negative spillovers'.

- $\gamma_{i,j,t}$ - absorption capacity – a parameter specific to each pair of countries, which represents country *i*'s ability to assimilate and utilize the knowledge developed in country *j*. $\gamma_{i,j,t}$ is calculated according to (1.11), where *N* is the nation's degree of preparation to benefit from ICT developments.

$$\gamma_{i,j,t} = \exp(-\max[0, N_{j,t} - N_{i,t}]) \qquad (1.11)$$

- $\alpha_{i,j}$ – a parameter which weights $\delta_{i,j}$ and $\gamma_{i,j}$ according to their relative importance between any pair of countries. $\alpha_{i,j}$ reflects social characteristics such as common history or same language.

The total knowledge stock $SK_{i,t}$ available to economy *i* is given by sum of the *i*'s domestic stock $SK_{i,d,t}$ and a foreign component which is a share weighted sum of the domestic stocks of *i*'s trading partners, *j*s:

$$SK_{i,t} = SK_{i,d,t} + \sum_j \left(\mu_{i,j,t} \cdot E_{i,j,t}{}^{\alpha(1-\gamma_{i,j,t})+(1-\alpha)(1-\delta_{i,j,t})} \cdot SK_{j,d,t} \right), \quad i \neq j \qquad (1.12)$$

In order to define a linear relation between productivity change and change in the stocks of IT equipment and knowledge we differentiate (1.2) wrt $N_{i,t}$:

$$\frac{dA_{i,s,t}}{dN_{i,t}} = \frac{SJ_{i,s,t}}{\sum_r SJ_{i,r,t}} \cdot g\left(\tau(N_{i,t}) - a\right)\left(b - \tau(N_{i,t})\right) \qquad (1.13)$$

Since the equipment and knowledge are complementary and hence combine to yield the complete IT environment, advancement of the IT economy is an average of changes in $SJ_{i,t}$ and $SK_{i,t}$:

$$\Delta N_{i,t} = (\Delta SJ_{i,t} \bullet \Delta SK_{i,t})^{1/2} \qquad (1.14)$$

where:

$$\Delta SJ_{i,t} = I_{i,t-1} - \eta SJ_{i,t-1}, \quad and$$
$$\Delta SK_{i,t} = (R_{i,d,t-1} - \varepsilon SK_{i,d,t-1}) + \sum_j \left(\mu_{i,j,t} \cdot E_{i,j,t}{}^{\alpha(1-\gamma_{i,j,t})+(1-\alpha)(1-\delta_{i,j,t})} \cdot \left(R_{j,d,t-1} - \varepsilon SK_{j,d,t-1} \right) \right)$$

substituting (1.14) into (1.13), we obtain an equation representing the change in sector *s* contribution to economy-wide productivity change:

$$a_{i,s,t} = \frac{SJ_{i,s,t}}{\sum_r SJ_{i,r,t}} \cdot g\left(\tau(N_{i,t}) - a\right)\left(b - \tau(N_{i,t})\right) \cdot$$
$$[(I_{i,t-1} - \eta SJ_{i,t-1}) \cdot$$
$$(R_{i,d,t-1} - \varepsilon SK_{i,d,t-1} + \tag{1.15}$$
$$\sum_j \left(\mu_{i,j,t} \cdot E_{i,j,t}{}^{\alpha(1-\gamma_{i,j,t})+(1-\alpha)(1-\delta_{i,j,t})} \cdot \left(R_{j,d,t-1} - \varepsilon SK_{j,d,t-1}\right)\right))]^{\frac{1}{2}}$$

Equation (1.15) consists of four components, each on a separate line: (i) the logistic function governs the productivity of sector *s* with respect to the degree of advancement of the IT economy represented by $N_{i,t}$, (ii) change in stock of IT equipment, (iii) change in the stock of domestic IT knowledge, and (iv) change in the stock of foreign IT knowledge.

Additional assumptions employed for the modelling are: cost minimizing producers are subject to CES production technology, country-specific national income comprises all income generated in the economy and net tax income revenue. Expenditures from national income are governed by an aggregate Cobb Douglas utility function across three broad categories: private consumption, government consumption and savings. Producers supply the goods that are purchased by private and government consumption and saved for future consumption. Domestic production can be substituted with imports differentiated by country of origin (Armington assumption). Private consumption is governed by a non-homothetic Constant Difference of Elasticities utility function. Government consumption is governed by a Cobb Douglas function. The firms rent endowments, which are the source of national income. Investment in the model is savings driven. The total savings from all countries are collected in a 'global fund' and than allocated across countries according to each economy's elasticity of rate of return on capital with respect to change in capital stock. Investment does not change the current period's production capacity, but it does affect total activity in the economy.

Data and variables

Updating the data Base

The Data Base we start with (Dimaranan 2006) is constructed on the base of Input-Output tables representing the world economy in year 2001. To make the forecast accurate we have to begin with the picture of economy as up-to-date as possible, hence the need for updating the data base. We update the database by simulating the period end-2001 to end-2007 with a number of macroeconomic variables exogenous and equal to their historical values. The variables we “force” into the simulation are: change in real GDP, in capital, in labour and in population. In effect we create a database which represents the world economy at the end of 2007. Additionally we observe movements in endogenous variables such as technical change and total factor productivity. The implied growth rates between the 2001 data from the database and the 2007 data collected[2] are presented in Table 3 in the Appendix.

Research and Development expenditure and Knowledge Stocks

R&D expenditure on ICT for Australia, Canada, Japan and the USA are taken from the ANBERD database (OECD 2006).For other APEC economies total R&D expenditure was retrieved from the R&D Internationalisation Database (DCITA 2008), and their respective share of R&D expenditure on ICT was assumed to be proportional to the share of ICT investment (relative to the total investment for each economy).

Accumulated R&D expenditure, and hence ICT knowledge stocks are calculated from R&D expenditure using the perpetual inventory method applied to equation(1.6).
The stock in the first year for which data is available is calculated using the method suggested by Griliches (1979):

$$SK_0 = \frac{R_0}{\varphi + \lambda}$$

where φ is average growth of R&D expenditure over the period for which data is available, λ is a depreciation rate, and R_0 is an estimated figure for expenditure in an initial year.

[2] Data for end-2007 is mostly based on the World Bank data. For details see the Appendix.

Absorption capacity

Absorption capacity γ_{ij} is calculated according to equation(1.11). Each country's degree of preparation to perceive and utilise ICT developments is proxied by the Network Readiness Index (NRI)(Dutta, Lanvin et al. 2004). NRI is an international assessment of countries' capacity to exploit opportunities offered by ICT. For the purpose of this study we adopt a specific sub-index (Table 4 in the Appendix), which describes the ICT readiness capability of the business sector. Focusing on the business sector is motivated by externalities being more fertile on a business level than on an individual or government level.

Baseline Forecast

We develop a baseline scenario which forecasts the most likely movement of the global economy from 2008 to 2015. This baseline scenario utilises forecasts of population, capital stocks, real GDP and changes in the labour force from Walmsley *et al.* (2000) and Walmsley (2006), and which are consistent with World Bank's Global Economic Prospects publications.

Parameters

The parameters for the logistic function specified in equation (1.1) are based on the initial estimation from a pooled cross-economy time-series analysis of historical data (ANBERD, OECD 2006) for OECD economies, and set for: a=3.35, b=6.55, g=1 and c=-15.

Experimental Design

The model

We place the model developed in the previous section within the dynamic Computable General Equilibrium (CGE) environment. A CGE model allows an accounting for complicated relationships between economic agent involved in the analysis. Complementing this with non-linear recursive dynamics provides insight into the long-term impact of ICT on economies.

The starting point for the model used in this study is GTAP version 6.2 (Hertel 1997). The model is supported by a version 6 database for 87 regions and 57 sectors. We modify the model by adding two extensions: (i) in order to allow for multi-period simulations the model is extended to take account for changing capital stocks; this modification allows the subsequent period's simulation to take account of the changes in the previous period, and therefore all simulation periods can be linked into the consequent cause-effect series of results, and (ii) to model the impact of ICT on an economy we integrate the module which incorporates the ICT productivity process described in the previous section.

The experiment

The experiment implemented liberalizes ICT trade within the APEC region, and involves the complete removal of import tariffs and tariff equivalents of bilateral nontariff barriers on ICT among the APEC economies (see Table 5 in the Appendix for details on removed import tariffs on ICT).

The experiment consists of two series of simulations: baseline (business-as-usual) and policy (tariff removal) scenario. Our analysis will look at the *deviations* between the two series of simulations. Development of the baseline forecast, and then a benchmark policy forecast against the baseline forecast allows elimination from the analysis of changes in the economy that would occur over time anyway, and focuses on the impact of the policy *cateris paribus.*

Results

It is important to note that, unless specified otherwise, the reported results are *cumulative deviations between* the baseline simulation (business-as-usual) and the policy simulation (ICT tariff removal).

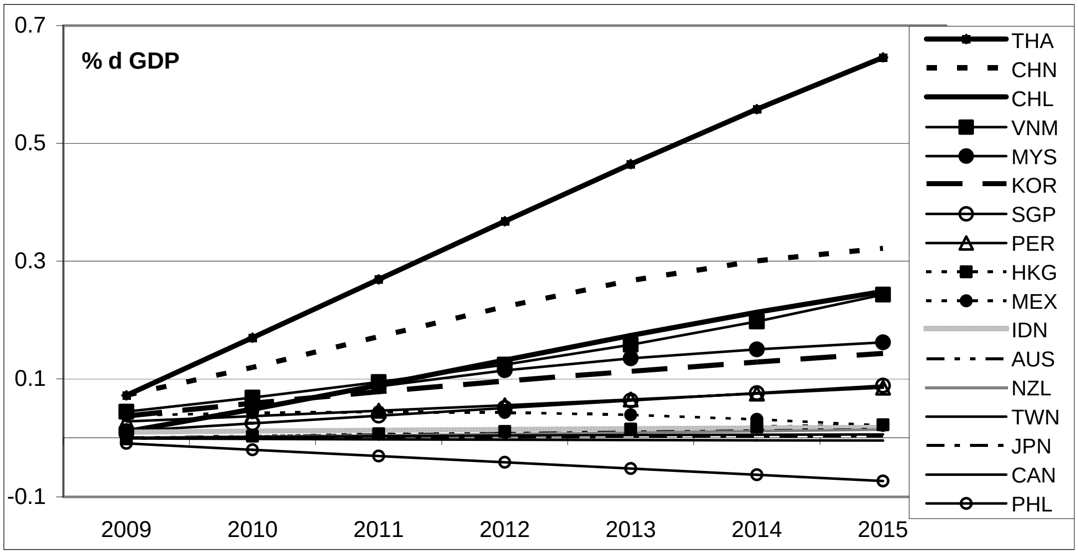
This section is organized as follows: firstly we look at the changes in real GDP resulting from ICT trade liberalization. Secondly we analyse changes in fixed capital accumulation, indirect tax payments and technological change as the main drivers of change in real GDP. Than we turn to analysis of technical change and the role of ICT technology for productivity.

Regional overview

In this section we look at the changes in real GDP for APEC member economies, and then at the main factors impacting upon those changes.

Figure 2 below provides an overview of the changes in real GDP for the APEC economies. The highest increase in GDP experienced Thailand (0.65 percent) followed by China (0.32 percent) and Vietnam (0.24 percent). The GDP of the Philippines, the USA and Canada declined by 0.073, 0.007 and 0.005 percent respectively.

Figure 2. Cumulative percentage change in real GDP for the APEC economies.



In order to explain different magnitudes of changes in GDP we will look closer at the sources of those changes. In Table 1 below we decompose the change in real GDP into the change in accumulated capital, change in indirect tax payments and technical change in the economy. Results in Table 1 are presented for the final year (2015). The results for all the years are depicted in Figure 9 in the Appendix.

Table 1. Decomposition of the cumulative percentage change in real GDP and sectoral outputs

Region	*GDP=*	*Capital+*	*Taxes+*	*Technology*	*Sectoral output*					
					Food	*Mnfcs*	*Svces*	*ICT*	*Mvh*	*Ofi*
AUS	0.015	0.013	0.000	0.002	0.00	0.05	0.01	-1.46	-0.03	0.00
NZL	0.014	0.011	-0.001	0.005	0.03	0.12	0.01	-2.79	0.09	0.00
CHN	0.322	0.195	0.027	0.106	-0.09	-0.31	0.27	7.08	0.04	0.11
HKG	0.022	0.029	-0.001	-0.006	-0.05	-0.05	-0.02	7.41	-0.13	-0.13
JPN	0.003	0.003	0.001	0.000	-0.02	-0.09	0.00	0.62	-0.29	-0.01
KOR	0.144	0.097	0.043	0.006	-0.07	-0.40	0.12	3.35	-0.55	0.13
IDN	0.018	0.012	0.003	0.002	-0.05	-0.25	0.02	3.00	0.02	0.00
MYS	0.162	0.116	-0.002	0.058	-0.41	-0.66	-0.17	1.32	-0.11	-0.07
PHL	-0.073	-0.033	-0.041	-0.003	0.01	0.26	-0.09	-0.94	0.20	-0.09
SGP	0.089	0.064	0.021	0.007	-0.27	-0.16	-0.01	1.21	-0.30	0.12
THA	0.646	0.447	-0.003	0.215	-0.80	-1.89	0.24	12.53	0.44	0.35
VNM	0.243	0.138	0.033	0.077	-0.05	0.37	0.23	-6.20	0.45	-0.23
CAN	-0.005	-0.002	-0.002	-0.001	0.02	0.08	0.00	-2.17	0.05	0.00
USA	-0.007	-0.004	-0.003	0.000	0.05	0.14	0.00	-1.91	0.08	-0.01
MEX	0.021	0.051	0.024	-0.056	-0.01	0.11	0.02	-1.01	0.07	0.02
PER	0.085	0.043	0.024	0.017	0.07	0.21	0.11	-9.05	0.19	0.09
CHL	0.249	0.097	0.015	0.140	0.02	0.29	0.21	-13.35	0.13	0.10
TWN	0.006	0.009	-0.003	0.000	-0.02	0.09	-0.01	-0.06	-0.04	0.00

From Table 1 above and Figure 9 in the Appendix we see that the changes in GDP are mainly due to change in stock of capital and technological change and, surprisingly for a tariff reform, the changes in indirect taxes have only a mild impact on real GDP. The changes in cumulative sectoral outputs from Table 1 will be commented upon in the later section.

Now we turn to analysis of the changes in capital accumulation and, most interestingly, sources and diffusion of technological change.

Fixed capital accumulation

In our specification regional investments are determined by the current rate of return (CRR) to existing capital and the expected rate of return (ERR). The CRR is a function of the difference between the price of new capital goods and rental on existing capital, hence the higher CRR the greater investment. The ERR declines with current additions to capital stock, and level of investment is set to equalize change in ERR across regions.

The removal of import tariffs on ICT, including tariffs on investment goods, has its greatest impact on markets which were protected by high tariffs, such as China (8.3 percent)[3], Vietnam (7.6 percent), Thailand (4 percent) and Chile (4.8 percent). For countries which do not set tariffs on ICT (Hong Kong, Japan or Singapore) the policy reform does not directly impact upon the local price of ICT.

[3] Average tariff share weighted by the import volumes is used here for the illustrative purpose only. The model utilises bilateral tariffs data.

Table 2. Tariffs, local price and shares of imported use of ICT by sector for 2009

Region	Average Tariff [%]	Local price of ICT d[%]	Share of imported intermediate ICT					capital intensity of ICT sector [%]	Rental d[%]	Current rate of return d[%]	Investment d[%]
			Total	Mnfct	Services	ICT	Invest				
AUS	0.66	-0.22	86	4	24	9	48	44	0.03	0.09	0.08
NZL	0.82	-0.05	81	4	30	5	39	38	0.01	0.09	0.06
CHN	8.25	-2.39	95	15	12	52	10	52	0.52	0.53	0.69
HKG	0.00	-0.40	53	4	29	8	12	48	0.14	0.13	0.13
JPN	0.00	0.03	87	5	2	42	38	41	0.11	0.06	0.02
KOR	1.01	-0.16	91	1	3	50	35	62	0.27	0.33	0.52
IDN	1.62	-0.17	61	1	9	37	13	70	0.12	0.07	0.03
MYS	0.26	-0.07	95	2	1	75	16	46	0.18	0.44	0.90
PHL	0.12	-0.26	96	4	9	75	6	88	-0.13	-0.07	-0.23
SGP	0.00	-0.28	96	3	6	78	8	70	0.19	0.22	0.27
THA	3.99	-1.90	93	1	3	76	10	80	0.94	1.13	2.13
VNM	7.61	-1.19	81	3	28	16	35	35	0.03	0.42	0.48
CAN	0.05	-0.13	64	15	7	23	17	30	-0.01	0.04	-0.02
USA	0.20	-0.18	84	7	13	23	38	32	-0.07	0.04	-0.03
MEX	2.73	-0.65	71	13	5	33	20	67	-0.08	0.11	0.16
PER	8.76	-0.68	85	24	34	9	16	92	-0.02	0.16	0.22
CHL	4.83	-0.37	62	11	12	3	34	38	0.14	0.40	0.54
TWN	0.28	-0.23	95	4	1	81	9	53	0.04	0.06	0.02
RUS	1.71	-0.42	51	20	21	4	3	31	0.01	0.04	-0.02

In Table 2 we present 2009 (a year after the tariff reform) values for the main variables which determine regional investment and capital accumulation. The greatest increase in investment occurs in Thailand (2.13 percent), even though Thailand had only the fifth highest average tariff on ICT before liberalization. This is mainly because of (i) the high share of intermediate inputs being imported (93 percent), so greater is the impact of the decrease in the price of imports on the local price of ICT, and (ii) a very high share of imported ICT being utilised by the sector producing ICT (76 percent), which stimulates expansion of this sector and inflates the rental price of capital. China's local price of ICT declines by 2.4 percent which is more than Thailand, however there are two factors which make China less attractive for investing than Thailand: (i) local production of ICT uses only a half of its intermediate ICT inputs from imports, hence there is less impact on the output price, and (ii) capital intensity of the ICT sector in China is lower than in Thailand (50 and 80 percent respectively). In effect, increasing ICT production raises the rental on capital and CRR in Thailand more than in China.

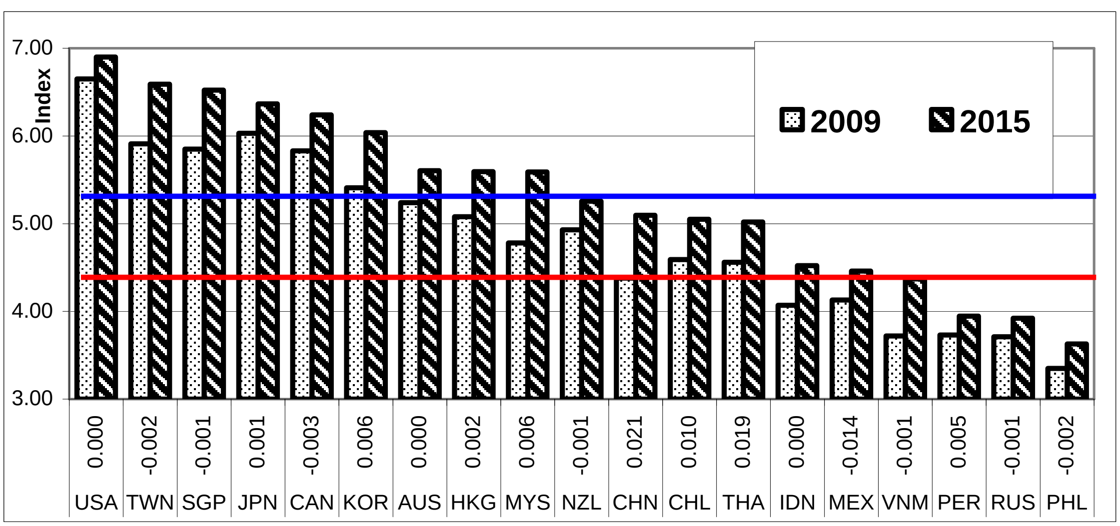
The greatest deterioration in investment is experienced in the Philippines (0.23 percent). The mechanism causing the decline in the Philippine's investment is analogous to the mechanism which benefits Thailand and China, working in the other direction though. The Philippines, being an important importer and exporter of ICT products, does not have an advantage of a lower local price of ICT resulting from the removed import tariff because its tariff is already very low. In effect, the Philippines loses some share of the market to Thailand, China and Vietnam and, consequently, its contracting ICT sector releases capital triggering a decline in rental price (and CRR) and discouraging investment.

Impact of ICT technology

IT environment

In our model sectoral productivity depends on the IT environment within which the sector operates, and on the sector-specific capability to benefit from advancement in the IT environment (equation(1.2)). The development of the IT economy in different countries for the baseline scenario between 2008 and 2014 is pictured in Figure 3. The numbers at the base of the chart represent the change in the IT economy index for the policy scenario (see Table 6 in the Appendix for time series data).

Figure 3. IT Economy Index development between 2008 and 2014, baseline



The ICT productivity level is governed by a logistic function (equation(1.2)) with variable productivity returns on IT investment for different levels of the IT economy. The period of greatest growth is schematically depicted between upper (blue) and lower (red) lines superimposed on Figure 3. Between years 2008-2014 the greatest returns on ICT investments were experienced by China, Chile and Thailand.

Countries above the blue line experienced slowdown of productivity returns to ICT investments due to saturation of the economy with ICT, whereas countries below the red line have not yet approached the critical mass of ICT allowing full utilization of potential of ICT stock. The returns to the economy-wide IT investment (differentiated logistic function aggregated across sectors) over time are graphed in Figure 4, and the change in total IT stock for each country is depicted on Figure 5 below.

Figure 4. Returns to the economy-wide IT investments over time

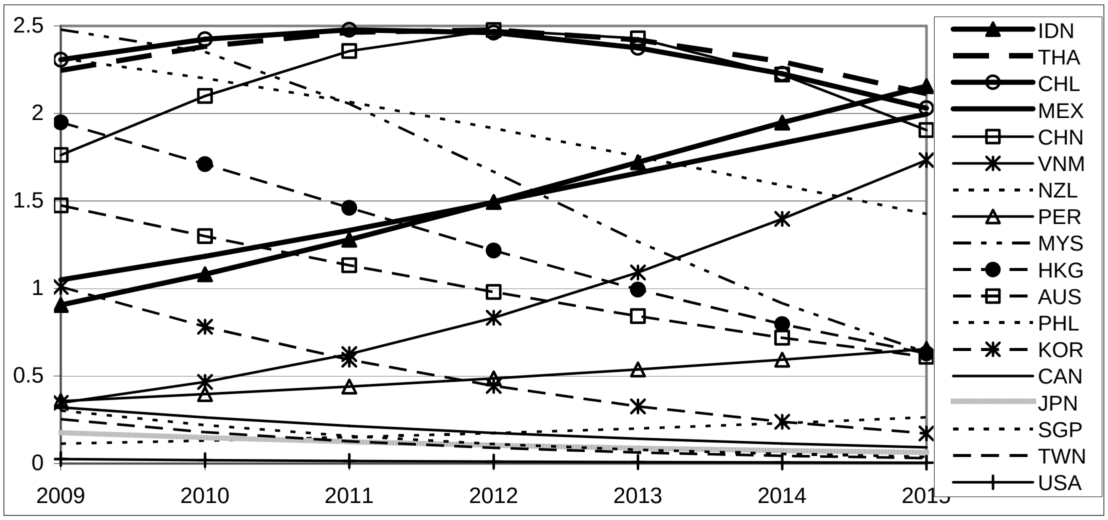


Figure 5. Cumulative change in total IT stock by country.

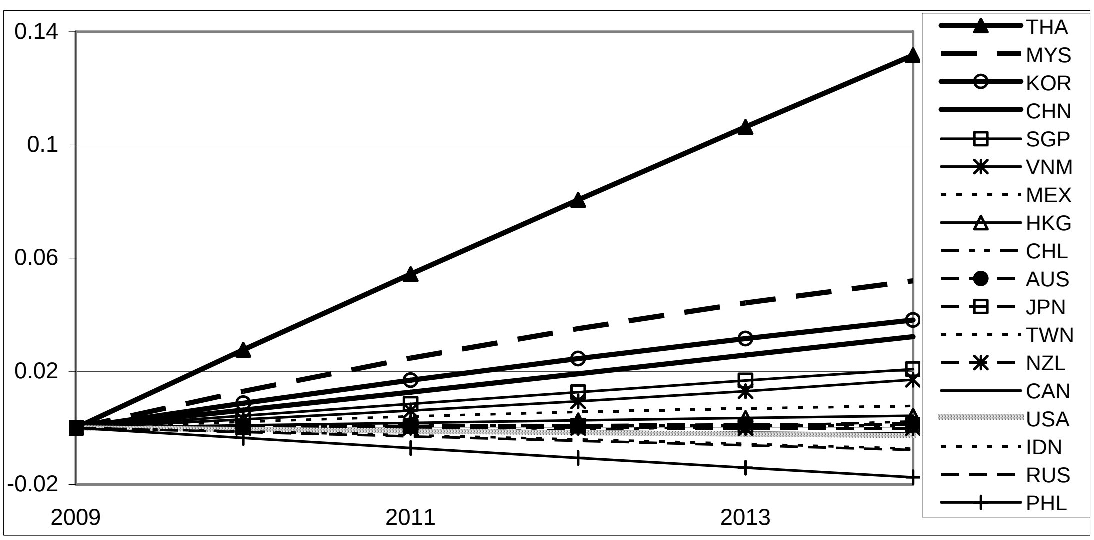
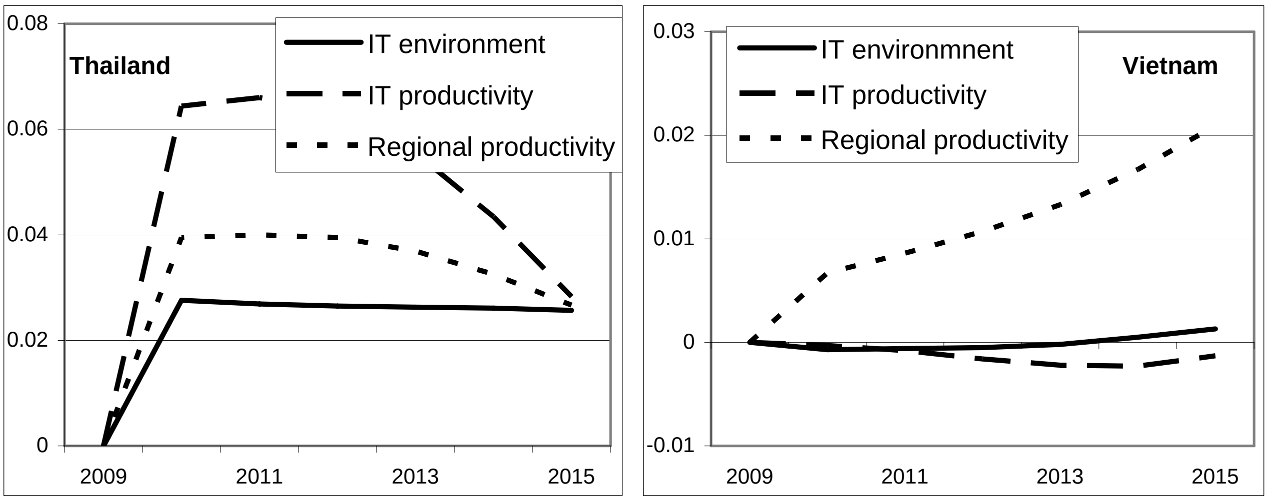


Figure 6 illustrates the changing IT environment, IT productivity and national productivity for Thailand and Vietnam over 2009-2015.

Figure 6. Year-on-year percentage change in IT environment (N_i), IT productivity (A^{IT}_i) and national productivity ($A_{i,t}$) for Thailand and Vietnam.



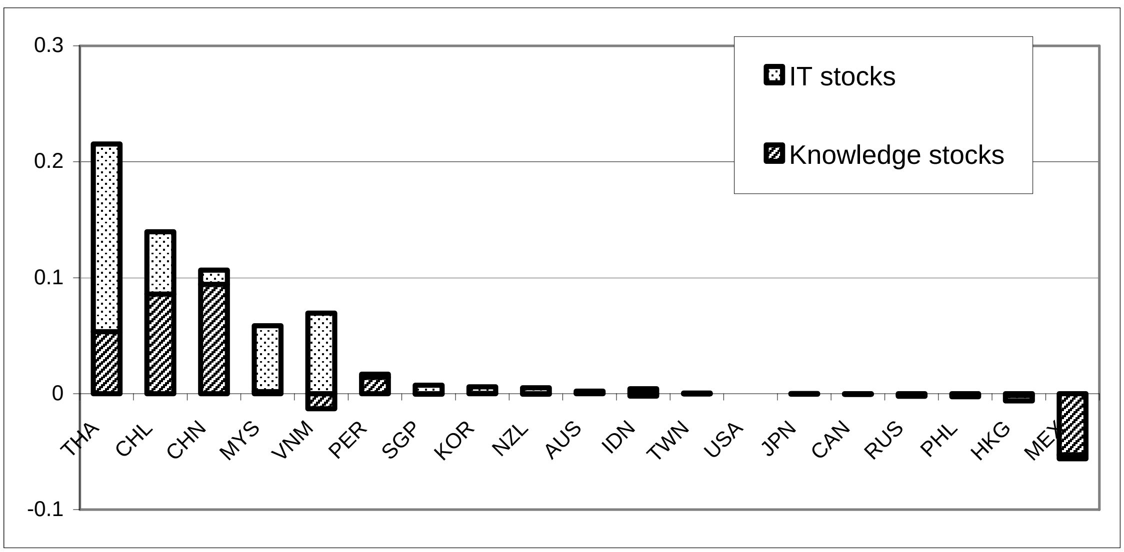
Thailand, as a beneficiary of trade liberalization, takes in more ICT investment (as a share of total investment - Table 2), and absorbs more knowledge spillovers (discussed in the next section). Those two components, according to equation (1.14) contribute to advancement of the IT environment immediately after implementing the new trade policy, and the level of the IT environment does not change significantly afterwards. Thailand in 2009 experiences very high returns on ICT investment; therefore productivity of ICT resources grows dramatically. However, because the main driver of technological change is the sector that manufactures ICT equipment (see Table 1 earlier in the paper) which comprises most of Thailand's IT resources, overall national productivity is lowered by other sectors which do not embrace significant shares of productivity-boosting IT resources. Over time the Thai economy saturates with ICT and exhibits decreasing returns to scale, a decline in productivity growth of IT resources and, consequently, a decline in the growth rate of national productivity.

Vietnam (Figure 6) does not benefit from trade liberalization initially. The economy experiences a decline in ICT investment leading to a downgrade of its IT environment and deterioration in productivity of IT resources. However, this is accompanied by a sharp decline in the size of the ICT manufacturing sector (Table 1) which comprises a large share of national IT stock. As a result of the ICT sector becoming less important in the Vietnamese economy, its overall national productivity improves by receiving more weight from other sectors in which productivity does not decline. Over time, as Vietnam recovers its IT capabilities, the productivity of IT increases, positively impacting upon national productivity. By the 2015 Vietnam is just approaching the period of fastest productivity growth.

Knowledge stocks

Economy-wide technical change is a function of the overall change in an IT environment within which all sectors of an economy operate. The IT environment evolves with changes in IT fixed capital and IT knowledge stocks (1.14). The two kinds of stocks are of different importance for different countries. For example Thailand's productivity change (0.22 percent) is mostly due to an increase in the fixed IT capital stock (0.16 percent) and partially to an improved IT knowledge stock (0.05 percent). Chinese productivity change (0.11 percent) is mainly due to a gain in the knowledge stock (0.10 percent) and marginally due to fixed IT capital accumulation (0.01 percent). Vietnam experiences a negative impact of decreased IT knowledge stock on productivity.

Figure 7. Cumulative change in regional productivity and its contributions of IT stocks and Knowledge stocks



Because in the implemented specification we do not allow for changes in R&D expenditure, all domestic R&D activity and domestic creation of ICT-related knowledge do not change. However, there is a change in foreign stocks of ICT-knowledge (equation(1.7)) resulting from changing trade patterns and various characteristics which determine national capacity to utilise knowledge created elsewhere.

Figure 8. Decomposition the cumulative change of IT knowledge stock by source and mechanism for Thailand and Vietnam

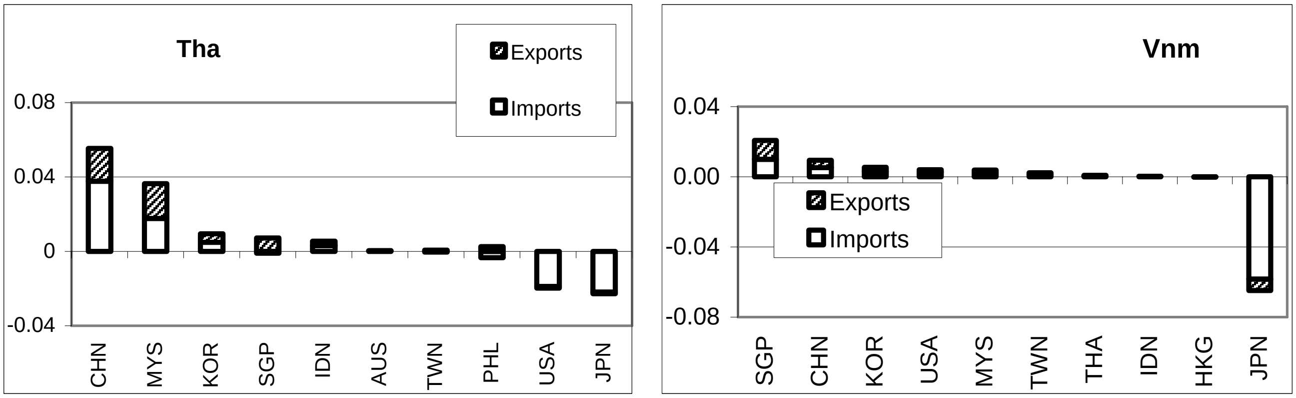


Figure 8 above provides a decomposition of the change in the foreign knowledge stock for Thailand according to equation (1.7). Owning to the change in tariffs, Thailand shifts part of its imports from the USA and Japan (for which Thailand had low tariffs before liberalization) to China, Malaysia, Korea and Singapore, whose tariffs were far greater. In effect there is a loss of embedded knowledge being imported with ICT equipment from the USA and Japan; however there is an increase in spillovers from intensified trade with China and Malaysia. Also, Thailand becomes more important in terms of export shares for China, Malaysia and Korea. Hence a larger share of the total knowledge embedded in the product is exported to Thailand. The Philippines increases its share of ICT exported to Thailand. However imports from the Philippines become less important for Thailand, and those two contrary effects net themselves out.

Vietnam experiences a large loss in innovative knowledge being imported with ICT from Japan (0.07 percent). This negative effect is not overweighed by more externalities being provided with imports from Singapore, China and Korea. Thus the overall net effect is negative and it is decisive in producing the decline in productivity of Vietnamese IT resources discussed in the previous section.

Summary and Conclusions

In this paper we analysed a possible future impact of ICT technology on productivity growth if trade liberalization in ICT products were to occur. The analysis was set up in a model representing 19 APEC economies trading six commodities. Three characteristics of ICT which have the capacity to impact upon national productivity were considered: applicability across large parts of the economy i.e. ICT's potential to affect the performance of all sectors; networking of ICT components reflected in variable productivity returns on ICT investment dependent on critical mass; and ICT-related innovative knowledge which is a key component of national IT capability and which can be created domestically or transferred from elsewhere by means of spillovers embedded in a product.

The experiment consisted of two series of dynamically linked simulations: baseline (business-as-usual) and a policy simulation. The policy simulation involved the complete removal of import tariffs and tariff equivalents of bilateral nontariff barriers on ICT among the APEC economies. By analysing the changes between the results for the two series of the simulations, we obtained measures of the tariff liberalization impact upon the economies, including productivity changes resulting from investment in ICT and diffusion of spillovers.

We found that the removal of import tariffs on ICT has its greatest impact on markets which are initially protected by high tariffs (Thailand, China). For those countries the local price of ICT depends on the level of the tariff removed as well as on the share of imported ICT in use in the economy. For countries which do not initially have high tariffs on ICT the policy reform does not have a significant impact upon their economies (Singapore, Japan).

Productivity of IT resources depends on the level of advancement of the IT economy. The largest potential for productivity growth based on IT occurs in countries whose IT resources are merging into an economy-wide network (Thailand, China, Chile). Developed countries, which have already passed through this phase face decreasing returns to IT scale (USA, Japan), whereas less developed countries are approaching a phase of rapidly increasing returns to IT scale (Vietnam, Indonesia).

The benefits from the potential for high productivity growth are realised by investment in IT physical stocks and an IT-related knowledge stock, which together advance the degree of sophistication of the IT economy. Countries, which (as a result of trade liberalization policy) attract more IT investment, experience rapid growth (Thailand). Countries which do not absorb more investment in IT after the policy implementation cope with stagnant or even decreasing productivity of IT.

Economy-wide productivity depends on the sectoral composition of IT resources and on the sizes of all the sectors. For economies where the driver of national productivity is a growing sector(s) comprising improving IT resources, the productivity of IT would be higher than national productivity (Thailand). Countries which experience a decline in IT productivity can have positive national productivity growth if the sector(s) comprising a significant share of IT stock declines fast enough to outweigh the decline in IT productivity with its diminishing sectoral importance in an economy (Vietnam).

Finally we looked at the knowledge stocks available to an economy. Because in our specification we do not allow for changes in R&D expenditure, all domestic knowledge stocks do not change. However there is a possible change in foreign stocks of ICT knowledge resulting from the changing trade patterns. In the example of Vietnam and Thailand we showed how a shift in trade composition impacts upon spillovers absorbed by an economy, and how this could improve national productivity or diminish the ability to utilise existing resources.

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Appendix

Details on the aggregation of the growth rates for the database update from 2001 to 2007.

Estimates for end-2007 GDP were obtained from the World Bank's World Development Indicators (2008) database. The growth rates were calculated between values for 2001 (old database) and 2007 (World Bank).

From World Development Indicators (2008) we obtained population sizes for years 2001 to 2006. In 2007 we assumed population growth rate equal to the average of growth rates for 2001-2006. The rates of growth between 2001 and 2007 were calculated between values for 2001 and 2007.

The total labour force values were obtained from World Development Indicators database (2008) for years 2001 to 2006. The growth rates of total labour force in 2007 were obtained from country specific statistical agencies, which allowed us to calculate total labour force in 2007.

From the base database we had values for capital and investment in 2001. Growth rates for gross fixed capital formation were obtained from World Development Indicators database (2008) for years 2002-2005, and from country-specific statistical agencies for year 2006. We also assumed model consistent depreciation rate of capital at the level of 4 percent. Having the above information we could deduce the value of capital in 2007 and determine its growth between 2001 (the database) and 2007 (historical values).

Table 3. Major macro variables change between 2001 and 2007 for updating the database.

Country	***GDP %***	***Capital %***	***Labour %***	***Population %***
Australia	27.09	34.59	9.38	8.30
Canada	15.91	29.34	9.83	6.62
Chile	33.38	48.48	7.78	7.65
China	105.25	94.12	5.94	4.44
Hong Kong	43.07	37.32	9.29	6.22
Indonesia	50.48	24.09	11.69	9.27
Japan	9.22	13.56	-2.83	0.29
Korea	49.36	30.62	8.08	3.15
Malaysia	38.23	8.42	15.99	13.61
Mexico	19.27	16.27	9.67	7.49
New Zealand	24.41	31.62	13.18	7.43
Peru	41.82	21.94	17.90	10.75
Philippines	36.41	18.90	20.39	13.59
Russia	45.54	21.27	1.43	-3.20
Singapore	45.42	36.07	8.64	9.84
Thailand	38.24	20.94	7.24	6.06
United States	18.46	32.43	6.35	6.77
Vietnam	56.19	82.30	13.39	9.58
Taiwan	30.45	39.97	5.10	3.30

Table 4. Network Readiness Index (NRI)

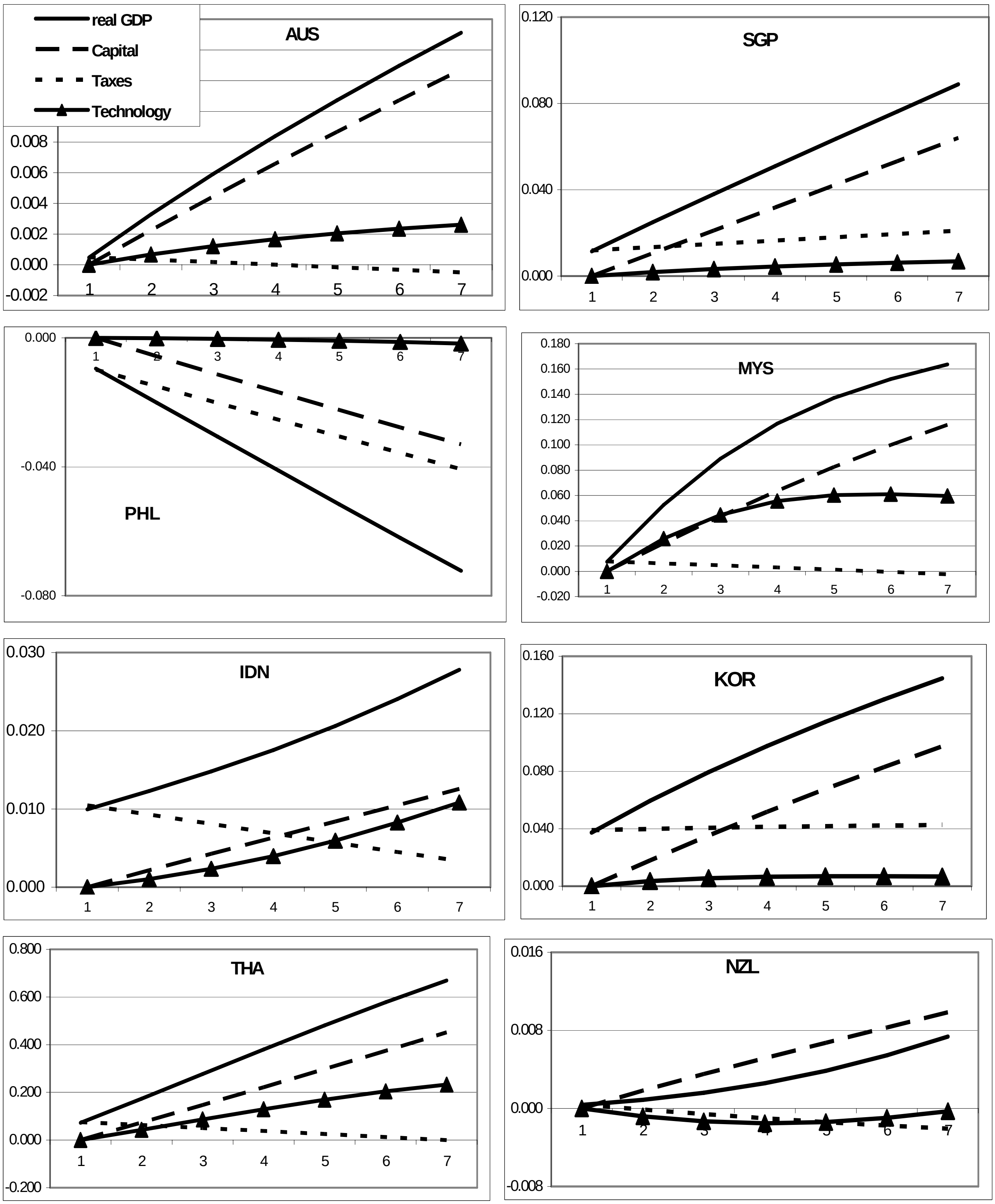
Country	*NRI*	*Country*	*NRI*
AUS	5.24	***THA***	4.56
NZL	4.93	***VNM***	3.72
CHN	4.38	***CAN***	5.83
HKG	5.08	***USA***	6.65
JPN	6.03	***MEX***	4.13
KOR	5.41	***PER***	3.73
IDN	4.07	***CHL***	4.59
MYS	4.78	***TWN***	5.91
PHL	3.35	***RUS***	3.71
SGP	5.85		

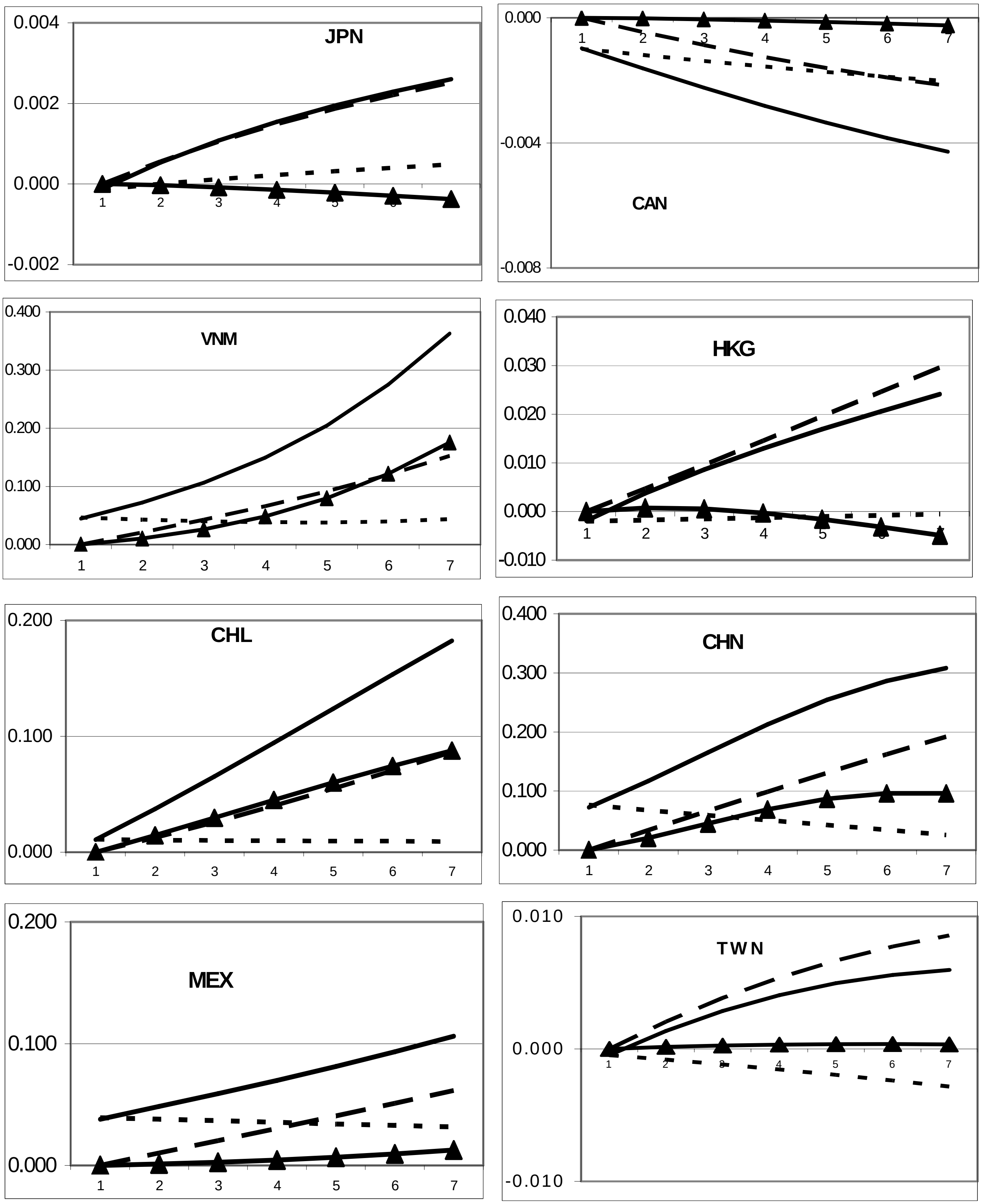
Table 5. Bilateral import tariffs on ICT

M / X	*AUS*	*NZL*	*CHN*	*HKG*	*JPN*	*KOR*	*IDN*	*MYS*	*PHL*	*SGP*	*THA*	*VNM*	*CAN*	*USA*	*MEX*	*PER*	*CHL*	*TWN*	*RUS*
AUS	0.0	0.0	11.6	0.0	0.0	1.3	2.7	1.9	0.3	0.0	6.5	9.3	0.0	0.2	6.6	12.0	7.0	1.3	7.2
NZL	0.6	0.0	10.9	0.0	0.0	1.7	1.6	0.6	0.1	0.0	3.7	6.6	0.1	0.5	16.5	12.0	7.0	0.4	8.1
CHN	1.3	1.3	0.0	0.0	0.0	2.5	5.9	1.3	1.7	0.0	7.1	19.1	0.0	0.4	10.6	12.0	7.0	0.9	9.2
HKG	0.8	1.0	9.9	0.0	0.0	1.2	3.7	0.7	0.4	0.0	3.4	3.4	0.0	0.2	4.7	12.0	7.0	0.2	7.8
JPN	1.4	1.0	10.5	0.0	0.0	1.7	0.7	0.1	0.1	0.0	2.9	2.6	0.3	0.5	7.9	12.0	7.0	0.6	8.0
KOR	0.8	1.7	11.3	0.0	0.0	0.0	1.4	0.6	0.2	0.0	6.0	13.2	0.1	0.2	9.3	12.0	7.0	0.2	9.8
IDN	1.7	1.9	12.0	0.0	0.0	4.8	0.0	0.8	1.0	0.0	11.5	13.4	0.1	0.2	12.7	12.0	7.0	1.3	9.4
MYS	1.0	0.9	8.9	0.0	0.0	1.2	0.9	0.0	0.3	0.0	6.9	13.5	0.1	0.3	6.8	12.0	7.0	0.3	10.3
PHL	1.2	1.0	7.7	0.0	0.0	0.2	0.4	0.0	0.0	0.0	3.6	7.3	0.1	0.0	3.8	12.0	7.0	0.1	6.6
SGP	0.3	0.7	8.9	0.0	0.0	0.4	1.1	0.2	0.2	0.0	4.2	10.8	0.0	0.1	6.3	12.0	7.0	0.1	8.2
THA	1.8	0.9	9.5	0.0	0.0	0.9	2.1	0.5	0.0	0.0	0.0	17.6	0.4	0.3	7.9	12.0	7.0	0.2	7.3
VNM	2.9	2.9	11.3	0.0	0.0	2.9	0.7	0.1	0.0	0.0	8.3	0.0	0.0	0.1	9.1	0.0	0.0	3.8	12.3
CAN	0.3	0.0	11.4	0.0	0.0	0.6	2.7	1.1	0.2	0.0	5.5	9.7	0.0	0.0	0.1	12.0	7.0	0.4	7.1
USA	0.4	1.5	10.2	0.0	0.0	0.6	1.9	0.1	0.0	0.0	1.7	10.2	0.0	0.0	0.1	12.0	7.0	0.2	6.0
MEX	0.6	2.0	9.2	0.0	0.0	2.6	1.3	0.0	0.5	0.0	3.9	5.0	0.0	0.0	0.0	12.0	0.0	0.1	5.9
PER	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	0.0	7.0	0.0	0.0
CHL	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.2	0.0	12.0	0.0	0.0	0.0
TWN	0.2	0.7	8.2	0.0	0.0	0.3	2.1	0.1	0.0	0.0	3.9	14.1	0.3	0.2	6.2	12.0	7.0	0.0	6.5
RUS	1.4	1.5	12.8	0.0	0.0	2.4	4.1	0.5	0.0	0.0	5.5	8.6	0.0	0.8	14.3	12.0	7.0	0.2	0.0
AVE [*]	***0.66***	***0.82***	***8.25***	***0.00***	***0.00***	***1.01***	***1.62***	***0.26***	***0.12***	***0.00***	***3.99***	***7.61***	***0.05***	***0.20***	***2.73***	***8.76***	***4.83***	***0.28***	***1.71***

[*] Average tariffs share weighted by import volumes

Figure 9. Cumulative changes in real GDP and its substituents for all countries.




JPN
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CAN
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1 2 3 4 5 6 7
VNM
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0.100
0.000
1 2 3 4 5 6 7
HKG
0.040
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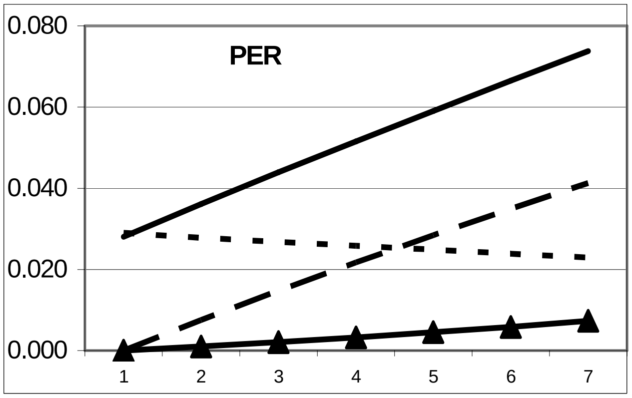

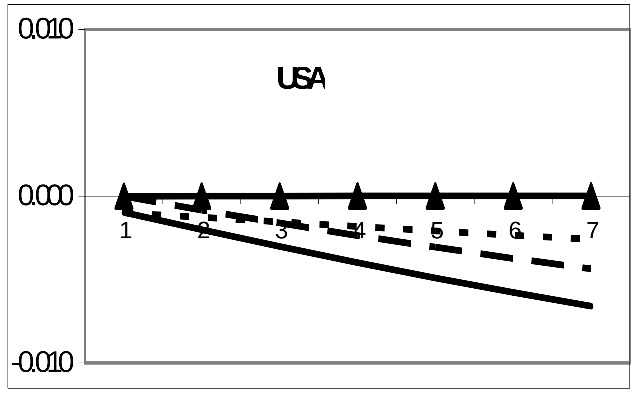

Table 6. Cumulative change in IT Economy index

	2009	***2010***	***2011***	***2012***	***2013***	***2014***	***2015***
AUS	0	0	0	0.0001	0.0001	0.0002	0.0003
NZL	0	0	-0.0002	-0.0005	-0.0009	-0.0015	-0.0023
CHN	0	0	0.0011	0.0034	0.0069	0.0117	0.0178
HKG	0	0	0.0002	0.0006	0.0011	0.0018	0.0027
JPN	0	0	0.0001	0.0002	0.0004	0.0007	0.001
KOR	0	0	0.0005	0.0015	0.003	0.005	0.0075
IDN	0	0	0.0001	0.0004	0.0008	0.0013	0.002
MYS	0	0	0.0005	0.0013	0.0026	0.0043	0.0063
PHL	0	0	-0.0001	-0.0002	-0.0004	-0.0007	-0.0011
SGP	0	0	0	0.0001	0.0002	0.0002	0.0003
THA	0	0	0.0015	0.0045	0.0091	0.0153	0.0231
VNM	0	0	0.0007	0.0022	0.0046	0.0077	0.0118
CAN	0	0	0	0	0.0001	0.0001	0.0002
USA	0	0	0	0	0	0.0001	0.0002
MEX	0	0	0.0001	0.0004	0.0009	0.0015	0.0023
PER	0	0	0	0	0.0001	0.0001	0.0002
CHL	0	0	0	-0.0001	-0.0001	-0.0001	-0.0001
TWN	0	0	0	-0.0001	-0.0003	-0.0006	-0.0009
RUS	0	0	0	0	0	-0.0001	0

Table 7. Change in regional technology its contributions of IT stock and IT knowledge

	Technology	***Knowledge stocks***	***IT stocks***
AUS	0.002	0.000	0.002
NZL	0.005	-0.001	0.005
CHN	0.107	0.094	0.012
HKG	-0.006	-0.002	-0.005
JPN	0.000	0.000	-0.001
KOR	0.006	0.000	0.006
IDN	0.002	0.004	-0.002
MYS	0.059	0.002	0.057
PHL	-0.003	-0.001	-0.002
SGP	0.007	-0.001	0.007
THA	0.215	0.054	0.162
VNM	0.057	-0.013	0.070
CAN	-0.001	0.000	0.000
USA	0.000	0.000	0.000
MEX	-0.056	-0.053	-0.003
PER	0.017	0.014	0.003
CHL	0.140	0.086	0.054
TWN	0.000	0.000	0.001
RUS	-0.002	-0.001	-0.001