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ICT in CGE models – Modifying the Typical CGE Theoretical Structure.

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Abstract: This paper proposes a holistic approach to modelling of ICT technology within a CGE model. Accurate conceptual representation of ICT technology requires a multi-perspective approach which accounts for a dynamic nature of networked ICT at the broad economy-wide level, as well as for its sectoral-level enabling characteristics. The ICT-related technical change is a logistic function of the level of advancement of ICT economy to account for a network effect; the IT economy in turn builds on IT capital, IT-related knowledge, and other supportive and infrastructure measures. The IT-related knowledge can be sourced domestically or from trading partners as embedded in imported goods. Efficiency of the knowledge spillover depends on the quantity of the goods imported, potential to learn and ability to absorb knowledge from a specific trading partner. A simple numerical example is provided for selected APEC economies.

Introduction

The recent widespread adoption of Information Technology (IT) and its synergy with Telecommunication infrastructure to form Information and Communication Technology (ICT) has affected almost every kind of business process within an economy. The enabling role of ICT that allows for improved performance at all levels and sectors of an economy, and complexity in the adaptation of ICT technology together imply that the manner and degree of impact of ICT depends on economy-specific characteristics and on level of economic development, so the magnitude of the 'enabling effect' would vary between countries.

The ubiquitousness and complexity in the adaptation of ICT technology imply that the effect of every economic policy depends, to an extent, on the degree and mode of utilization of ICT in the related area. Furthermore, if the impact of ICT is not taken into account by policy makers, the actual outcomes of the policy can be amplified, counterbalanced or even opposed to the planned results. In economic strategy development, the lack of a carefully articulated ICT dimension, backed by evidence-based modelling, constitutes a significant gap in both the policy advising and policy making processes.

Computable General Equilibrium (CGE) appears as a platform suitable for modelling the enabling role of ICT technology in economy. CGE is recognized as a class of models with a high level of detail of economy and a highly disaggregated structure. For example, the MONASH model of Australia accounts for 140 industries, 56 regions and 340 occupations, and USAGE model of the US resembles a 500-industries economy. Another key feature of CGE models is their attention to trade linkages, both domestic and international. The typical CGE model's database contains information on all intra- and inter-national trade at the given level of aggregation. For example the GTAP model database provides consistent bilateral international trade figures for 57 sectors of 113 countries.

A holistic treatment of a new, general purpose technology such as ICT is not, however, widely discussed in CGE literature. CGE models usually incorporate technology variables which allow for accounting for different sorts of technical changes: these could be an improved efficiency of intermediate inputs or factors of production, or output augmenting technical change. These technical change variables are not, however, integrated into the structure of the standard CGE model, i.e. there is no theory in the model which would determine how they should respond to changes in other variables within the model, therefore they have to be shocked exogenously for their values to change and for a technical change to occur. There are limited applications where a number of technical change variables are linked together, mostly to simulate intra- and inter-regional technological spillovers[1]. Those applications, although introducing additional theory about how the technologies of different economic agents are interlinked, still require an exogenous, usually arbitrary, shock to trigger initial technical change which then propagates throughout the economy. This theory was take a step further by Lejour and Nahuis (2005) who made, within a CGE model, the technology variables dependent on the, additionally incorporated, Research and Development (R&D) expenditure. In the reviewed CGE literature the technology was assumed to be a linear function of R&D expenditure or R&D intensity. This assumption appears plausible for overall aggregated R&D and technology and/or short-run analysis. However, when looking at a single technology in the longer term we should recognize a technology lifecycle or, in case of network technologies – a network effect, which introduces non-linearities between technical change and factors impacting upon them.

The successful utilisation of ICT technology within an economy requires not only physical, tangible ICT equipment, but also the *know-how* component – the knowledge how to use the technology in the most productive modes. The relevant knowledge can either come from associated R&D activity, or can come from other parties which already possess the relevant knowledge. The transfer of knowledge from the other parties can take many forms. In this paper we are particularly interested in transfer by *knowledge spillovers via trade linkages*, as the important channel for diffusion of knowledge in general (Coe and Helpman, 1995; Madsen, 2007), and for ICT-related knowledge in particular (Lopez-Pueyo et al., 2009; OECD, 2003).

In this paper we attempt a holistic consideration of ICT technology within a CGE model. We do so by modelling the relation between technical change and the key characteristics of ICT technology: enabling effect at the disaggregated, sectoral level; network effect at the aggregated, national level; diffusion of ICT-related knowledge via international spillovers.

[1] One of the first extensions added to a standard CGE model to simulate international technological spillovers in the agricultural sector was developed by Van Meijl & Van Tongeren (1999, 2004). See also Das & Powell (2000)

Theory and development

Key characteristics of ICT technology

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.

Throughout the paper we operate with three different kinds of productivity: (i) sectoral IT productivity, $A_{i,r}^{IT}$, which accounts for productivity if IT resources owned by the sector *i* in region *r*, (ii) productivity of economy-wide IT stock , A_{r}^{IT}, which accounts for productivity of IT resources aggregated at the national level in region *r*, (iii) national productivity, A_r, which is a share weighted average of sectoral productivities. The details follow.

Accounting for ICT technology in the model

We place our analysis in a multi-country region consisting of *R* economies, *r*=1,…,*R*, connected by trade linkages. Each economy *r* comprises $i = 1,...,I$ sectors. Each sector utilises a set of inputs $X_{r,i,t}$ and produces output $Y_{r,i,t}$ with available technology $F(\bullet)$ and productivity $A_{r,i,t}$ at time *t*, i.e.: $Y_{r,i,t} = A_{r,i,t} F(X_{r,i,t})$. We assume that $A_{r,i,t}$ comprises *IT*- and *Non-IT*-related productivities $A_{r,i,t}^{IT}$ and $A_{r,i,t}^{Non-IT}$, in such a way that $A_{r,i,t} = A_{r,i,t}^{IT} \cdot A_{r,i,t}^{Non-IT}$. The $A_{r,i,t}^{Non-IT}$ term is needed to account for other explanatory factors of MFP growth such as microeconomic reform.[2]

[2] In fact some studies have found microeconomic reform as a major driver of MFP growth (Parham, 2002; Parham et al., 2001). Our broader specification allows for comprehensive accommodation of explanatory factors.

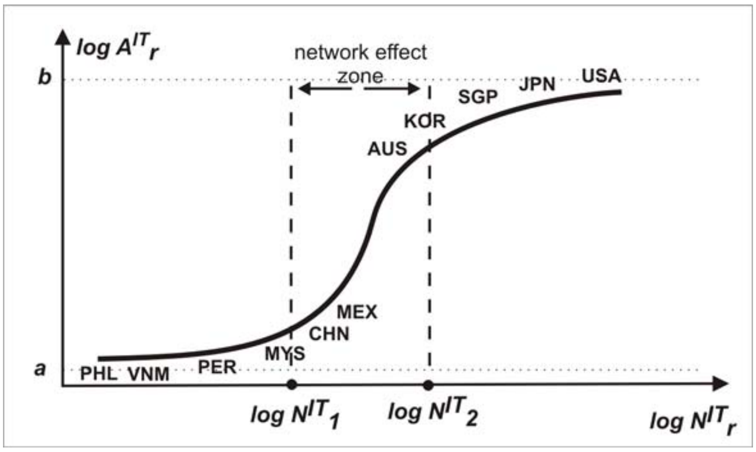
Productivity of the economy-wide IT stock, $A^{IT}_{r,t}$, depends on the degree of development of the *IT economy* $N^{IT}_{r,t}$, and is modelled in this paper by the 'transcendental logarithmic' logistic (or logistic in logs) function $\tau(\bullet)$:

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

where parameters *a* and *b* are lower and upper bounds 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.

The function given in equation (1.1) allows in a specific manner for a *network* or *critical mass effect*. The network effect is a phenomenon whereby the productivity of ICT resources increases sharply as they reach a critical quantity within an economy (Economides, 1996; Lim et al., 2003):

Figure 1. Productivity and the Network Effect for ICT technology



The logistic curve on the above Figure 1 reflects different productivity of aggregated IT resources for countries at alternative levels of ICT infrastructure. Initially, when countries have available only scarce IT infrastructure which form isolated clusters, the marginal productivity of IT resources is rather low. If an economy gains a *critical mass* of IT capacity, $N^{IT}{}_{1}$, its IT begins to exhibit additional productivity benefits resulting from integration of existing stock into a 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 $N^{IT}{}_2$, the IT marginal productivity decreases again and the period of rapid IT-related growth ceases.

Sectoral productivity $A^{IT}_{r,i,t}$ resulting from productivity of the national IT stock $A^{IT}_{r,t}$ is proportional to the share of sectoral IT investment in national IT investment I [3]:

$$\log A^{IT}_{r,i,t} = \frac{I_{r,i,t}}{\sum_j I_{r,j,t}} \cdot \frac{b\exp\left(c + g(b-a)\log N^{IT}_{r,t}\right) + a}{1 + \exp\left(c + g(b-a)\log N^{IT}_{r,t}\right)} \qquad (1.2)$$

where $I_{r,i,t}$ represents IT investment in sector *i*.

The (1.2) specification which shares out the change in productivity of national IT stock to sectors based on their relative IT investment clearly links productivity to new technology. We employ sectoral ICT investment shares as an indicator of sectoral ability to utilise national advancements in the IT economy. This specification is motivated by the very high pace of ICT-related innovation and fast rate of obsolesce of IT capital that suggests a higher proportion of national productivity would arise in those sectors that are investing more highly in ICT products. It derives from the assumption that the change in productivity of IT has to be considered at the aggregated, national level due to the technology's 'network effect' characteristic, i.e. only looking at the whole[4] of the IT stock we can comprehend productivity change resulting from the network effect. Then, given the change in productivity of IT at the national level, we share it out to sectors in economy relative to their investments in new technology, so only the investing sectors can benefit from the new technology[5].

[3] It is possible that some sectors are better adapted to the use of IT than others. For example some studies (Gretton et al., 2003; Productivity Commission, 2004) consider business services, banking and finance as being able to make better use of IT innovations. Our proportionality assumption, which does not account for variable productivity returns to IT investment across sectors, is an initial proposal to develop a working model.

[4] For this specification we treat a country as a separable entity with constituent and separable IT network. More elaborate treatment could include cross-country networked linkages.

[5] For case studies and examples of how new ICT facilitates improvement in efficiency of all stages of the firm's internal business or production processes see Bartel et al. (2007) or Sung (2007).

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

$$A_{r,t} = \frac{\sum_i (A_{r,i,t}^{IT} \cdot A_{r,i,t}^{Non-IT}) Y_{r,i,t}}{\sum_j Y_{r,j,t}} \qquad (1.3)$$

We can summarise the above approach in three steps: firstly we look at the whole of IT investment in a country and the resulting change in productivity of IT stock (1.1). Secondly, we share out the aggregated IT productivity change to sectors in proportion to their investment in IT (1.2). Thirdly, we calculate change in national productivity as a share weighted average which takes into account relative size of each sector (1.3).

IT Economy

The IT economy is a product of many factors from across the spectrum of socio-economic development, such as: IT-equipment, IT-knowledge, non-IT supporting infrastructure, and also of less tangible market conditions, political and regulatory environment; each of these across the business, government and individual levels. Our initial value of $N_{r,t}^{IT}$ takes account of all these factors[6]. To endogenise further, dynamic development of $N_{r,t}^{IT}$ we adopt a framework which builds on IT capital stock and IT related knowledge as two critical building blocks of the IT economy. We express the IT economy index, $N_{r,t}^{IT}$, as the following:

$$N_{r,t}^{IT} = \bar{N}_r \cdot SJ_{r,t}^{*\,\rho} \cdot SK_{r,t}^{(1-\rho)} \qquad (1.4)$$

where $\bar{N}_r$ is a constant that equates $N_{r,t}^{IT}$ to the value of NRI in the initial year, $SJ_{r,t}^{*}$ represents an adjusted measure of IT capital stock[7], $SK_{r,t}$ is the stock of IT-related knowledge which is *r*-country-specific and available to all sectors, and ρ is a relative weighting parameter. The (1.4) specification which assumes complementarity between new, technologically advanced capital and the related knowledge (the new knowledge can be embodied in skilled labour), builds on the

[6] 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).

[7] We explain the adjustment mechanism and rationale for adjustment in a later section.

evidence that only skilled workers with new innovative knowledge are able to fully implement new technology (Pianta, 2004; Piva et al., 2005).

We write Equation (1.4) in percentage change form as a weighted average of percentage changes in $SJ^{*}_{r,t}$ and $SK_{r,t}$:

$$n^{IT}_{r,t} = \bar{n}_r + \rho \cdot sj^{*}_{r,t} + (1-\rho) sk_{r,t} \qquad (1.5)$$

In the next two sections we explain how the stock of knowledge, *SK*, and the adjusted stock of IT capital, *SJ**, are determined.

IT-related knowledge

Whereas IT equipment stock and investment data are collected by statistical agencies and can therefore be obtained from these sources, the IT knowledge component is more problematic due to the intangibility of knowledge and lack of information on international flows of knowledge. To deal with this problem we assume the following framework:

Economy *r* can benefit not only from its own domestic stock, but also from knowledge developed elsewhere and transferred across national borders as embedded within the traded goods. The concept of traded goods being a vehicle for knowledge transfer was introduced by Griliches (1979) and gained much attention after emergence of theories of endogenous technological change (Aghion and Howitt, 1992; Romer, 1990) conceiving substantial body of research on relations between technical change, trade and growth. The related literature corroborates initial presumption about the positive statistical effect between import of innovative goods and TFP (Coe and Helpman, 1995; Frantzen, 2000; Grossman and Helpman, 1991; Lopez-Pueyo et al., 2009).

It should be stressed that the stock of knowledge, $SK_{r,t}$, due to its non-rivalry and (possibly) non-excludability character (Romer, 1990) is a type of (regional) public good and so is region-specific, unlike the stock of physical IT equipment, $SJ_{r,i,t}$, which is rival and excludable hence sector-specific (can profit only the owner).

Total stock of knowledge

We assume that the *effective* stock of knowledge impacting upon *r*'s productivity consists of domestic stock $SK_{r,d,t}$ and foreign stock $SK_{r,f,t}$:

$$SK_{r,t} = SK_{r,d,t}{}^{\omega_d} \cdot SK_{r,f,t}{}^{\omega_f} \tag{1.6}$$

which we write in percentage change form as:

$$sk_{r,t} = \omega_d \cdot sk_{r,d,t} + \omega_f \cdot sk_{r,f,t} \tag{1.7}$$

where ω_d and ω_f are constant parameters. To interpret this equation the nature of the foreign knowledge stock needs to be understood. In particular, it needs to be noted that the foreign knowledge stock does not mean the knowledge stock in foreign countries but rather means the stock of knowledge from foreign sources available to a particular country. As will be shown in the theoretical development to follow, this quantity will be much lower than the actual stock of knowledge in foreign countries. Indeed, it is possible (see the formulations to follow) for $SK_{r,f,t}$ to be only slightly higher than unity. In fact this is the base case where a country's economy is closed. It follows that $\omega_d = 1$ is a suitable parameter value to allow for this base case. Another extreme case would be that in which no or very little domestic R&D takes place and so the domestic stock of knowledge is extremely low. In the multiplicative formulation we can regard $SK_{r,d,t}$ as unity in this case. Since all knowledge then comes from foreign sources, we set $\omega_f = 1$ to allow for this case. While this specification may appear to represent a rather extreme degree of increasing returns to scale, since the two power parameters sum to 2, it should be noted in interpreting this specification that an equal expansion of domestic and foreign knowledge stocks is not a realistic option to examine here. A back-of-the envelope calculation suggests that a 10% increase in all domestic knowledge stocks APEC-wide will lead to an increase of about 11% in the knowledge stock of a typical APEC economy, with the extra increase coming from the modelled spillover effect. Precise results for any given economy depend on individual country characteristics as will be apparent from the detailed specifications developed below.

Domestic knowledge stocks

The domestic stock of knowledge is an output of domestic R&D processes and is subject to depreciation:

$$SK_{r,d,t} = (1-\varepsilon)SK_{r,d,t-1} + R_{r,d,t-1} \tag{1.8}$$

where the stock of domestic knowledge of economy *r* in time *t*, $SK_{r,d,t}$,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*, $R_{r,d,t-1}$.

Foreign knowledge stocks

For any given economy, say denoted by region *r*, its foreign knowledge stock actually comes (with some modification) from the domestic knowledge stocks of all of its trading partners. In a specification that will be explained term by term below, the domestic knowledge stock of any given trading partner, say region *s*, is modified by a factor that represents the passing on of knowledge through the trading interaction. The modified knowledge stock is[8]:

$$SK_{r,f,t} = \prod_{s \neq r} SK_{s,d,t}{}^{\phi(\bullet)}, \; where \;\; \phi(\bullet) = IMP\_SHR_{r,s,t} \cdot EXP\_SHR_{s,r,t}{}^{\alpha_{r,s,t}} \tag{1.9}$$

To explain and justify the properties of formula (1.9), we simplify it to a two-country example: recipient country *r* and source country *s*. We also, for now, drop the time index and write equation (1.9) in differentiated form – the way it will be used in a model:

$$sk_{r,f} = \phi(\bullet) \cdot sk_{s,d} = IMP\_SHR_{r,s} \cdot EXP\_SHR_{s,r}{}^{\alpha_{r,s}} \cdot sk_{s,d} \tag{1.10}$$

In the above term, a change in stock of domestic knowledge in country *s*, $sk_{s,d}$, provides the initial impetus for a change in foreign stock of knowledge in country *r*, $sk_{r,f}$. The magnitude of this impact depends on the value of the three main components of (1.10), which are (i) import share, $IMP\_SHR_{r,s}$, (ii) export share, $EXP\_SHR_{s,r}$, and (iii) the exponent $\alpha_{r,s}$ containing a set of environmental variables which determine country *r* ability to benefit form knowledge transferred from country *s*. Below we explain and analyse the three components term by term.

[8] The general functional form used in the knowledge transmission equation, i.e. the fractional trade index raised to the power of a set of environmental variables, is credited to Van Meijl and Van Tongeren (1999).

Then we will provide a detailed, numerical example to show how the components interact within the (1.10) formula, and we will follow with a graphical interpretation.

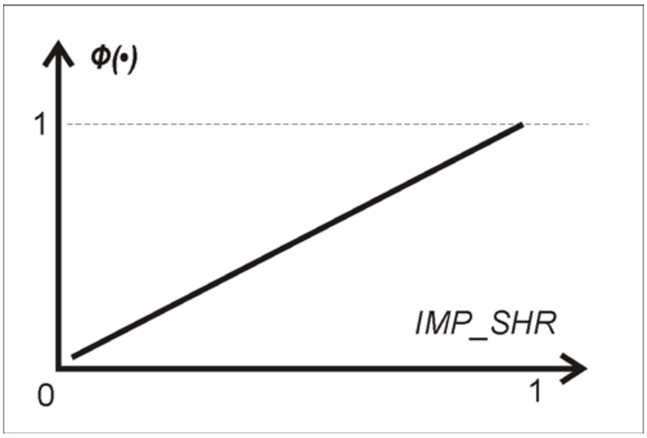
Import shares

$IMP\_SHR_{r,s}$ represents importance of imports of ICT to the destination country – ie this is actually measured as exports of ICT from source country s to the destination country r as a proportion of world-wide exports of ICT to r :

$$IMP\_SHR_{r,s} = \frac{VXMD_{s,r}}{\sum_k VXMD_{k,r}} \tag{1.11}$$

The value of IMP_SHR provides information on the amount of embodied knowledge which flows into a country, or in other words, the exposure of a country to innovative knowledge. The impact of IMP_SHR on $\phi(\bullet)$ is of a linear character, which we schematically graph in Figure 2 below:

Figure 2. Impact of IMP_SHR on the value of $\phi(\bullet)$



Use of the share of imports of goods embedding innovative knowledge as one of the measures of inter-national flow of knowledge is an intuitively satisfactory and empirically tested approach (Bayoumi et al., 1996; Madsen, 2007; World Bank, 1987).

The approach using import-weighted fractions which add up to unity has been, however, criticised as not adequately reflecting the level of imports, since for two countries which have the same share composition but different levels of imports and face the same foreign knowledge stocks, the country with higher import levels would be expected to benefit more from its trading partners (Lichtenberg and Potterie, 1998). We account for the differentiated import levels by incorporating the export shares into our specification, so higher import levels will be reflected in greater export shares in the exporting country[9].

Export shares

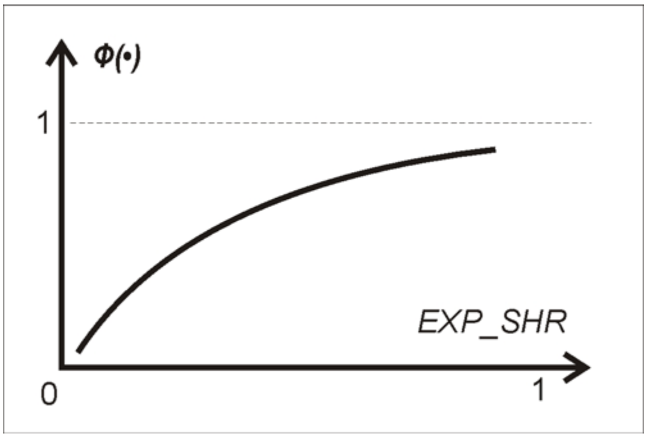
*A*s we stated above, the import share on its own does not carry information about the level of trade, so we integrate export shares, $EXP\_SHR_{s,r}$, into the knowledge-flow specification. $EXP\_SHR_{s,r}$ depicts importance of the destination country *r* in the exports of the ICT from country *s*. This represents the amount of knowledge developed at economy *s* and available to *r*:

$$EXP\_SHR_{s,r} = \frac{VXMD_{s,r}}{\sum_k VXMD_{s,k}} \qquad (1.12)$$

where $VXMD_{s,r}$ is export of IT equipment from *s* to *r*.

The specification implies that the benefits for the recipient country increase with the share of exports of ICT to this country. The benefits (i.e. ϕ) increase at the highest rate for small EXP_SHR viz. when the trade is first initiated, and from that point they increase at a decreasing rate. We schematically depict the impact of the export share defined in Equation (1.12) on $\phi(\bullet)$ in Figure 3 below.

Figure 3. Behaviour of $\phi(\bullet)$ as a function of EXP_SHR



[9] Another possible solution is to express the imports level as a share in the country's GDP, which would account for the size of the country.

Environmental variables

The embedded knowledge which flows from *s* to *r* is not necessarily utilised by the recipient country in full. It is easy to picture two countries which import the same quantity of innovative IT products (i.e. have the same value of $IMP\_SHR_{s,r} \times EXP\_SHR_{s,r}$) but differ in the extent they actually benefit from the imported embedded knowledge. The differences in success in using the inflow of knowledge may be due to differences in a recipient country's characteristics, such as the relevance of the new knowledge for a particular country, ability of a country to disembody / reverse engineer and understand the new knowledge, or a country's ability to use the new information for its own benefit. To capture those characteristics we modify the export share (*EXP_SHR*) by exponent $\alpha_{r,s}$, which provides a measure of a country's ability to benefit from the embodied knowledge which flows into a country. In other words, $\alpha_{r,s}$ determines what fraction of potential benefit a country will actually exploit. Accordingly, we construct $\alpha_{r,s}$ as a function of (i) the potential benefit a country has available to it when exposed to new knowledge through international trade, and (ii) the country's ability to absorb the new knowledge. Specifically, the exponent is given by a function:

$$\alpha_{r,s} = \mu \cdot (1-\delta_{r,s}) + (1-\mu)\gamma_{r,s} \qquad (1.13)$$

where $\delta_{r,s}$ is country *r*'s potential to benefit through knowledge flows from trade with country *s*; and $\gamma_{r,s}$ is country *r*'s ability to understand and use the new knowledge for its own benefit; and μ is a parameter which weights $\delta_{r,s}$ and $\gamma_{r,s}$ according to their relative importance between any pair of countries. We discuss details of the modelling of the exponent and its components below.

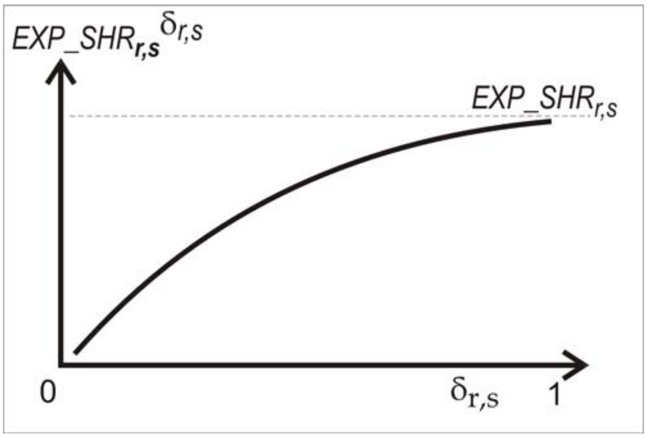
Potential to benefit from knowledge flows through trade

We measure the potential for country *s* from trade with country *r* as a difference in their stocks of knowledge. We assume that the greater is the knowledge stock of an importing country's trading partner, the greater would be the benefit for the importing country from the trade. This specification builds on the technological-gap theory (e.g. Fagerberg (1994)), where the catching-up country's potential to increase own technological capability from interaction with a more technologically advanced country is greater if the gap between the catching-up country and the technologically advanced country is bigger. For the purpose of the IT knowledge spillover we measure the extent of the knowledge gap between *r* and *s* as a difference in respective IT-related knowledge stocks $SK_{s,d}$ and $SK_{r,d}$. We denote the gap measure by $\delta_{r,s}$ and specify it as:

$$\delta_{r,s} = \max\left[0, \frac{SK_{s,d} - SK_{r,d}}{SK_{\max,d}}\right] \qquad (1.14)$$

In this specification the maximum of zero and the (scaled) difference between the stocks ensures that $\delta_{r,s}$ will not take negative values, i.e. the specification prevents 'negative spillovers'. We graph a value of $EXP\_SHR_{s,r}{}^{\alpha_{r,s}}$ as a function of $\delta_{r,s}$, in Figure 4 below:

Figure 4. Value of $EXP\_SHR_{s,r}{}^{\alpha_{r,s}}$ **as a function of** $\delta_{r,s}$



The larger the positive gap in stocks of knowledge between region *s* and region *r*, the larger the value of $\delta_{r,s}$ (hence lower value of $\alpha_{r,s}$ - equation (1.13)) and, consequently, since $EXP\_SHR_{s,r}$ is a fraction, the greater potential for region *r* to benefit from region's *s* knowledge via the term $EXP\_SHR_{s,r}{}^{\alpha_{r,s}}$.

Absorption capacity or, conversely, forgone benefit of knowledge 'lost in translation'

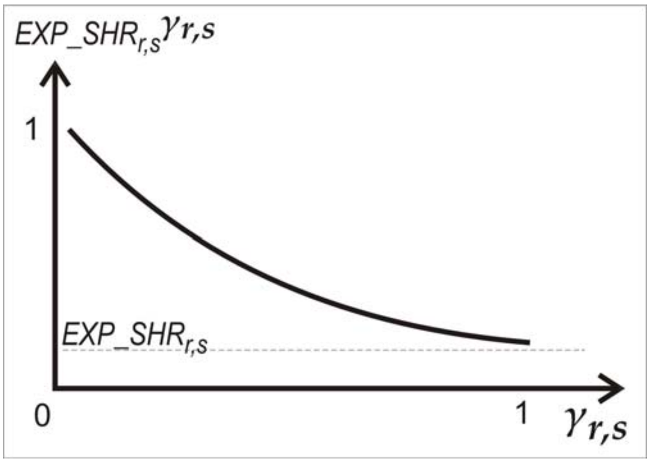
By *absorption capacity* we indicate the extent into which a country is able to exploit its potential to benefit from trade. Conversely, by *forgone benefit* we denote the unrealised potential or inability to benefit from trade. The variable $\gamma_{r,s}$ measures country's *r* foregone benefit from trade with country *s*. For example, if $\gamma_{r,s} = 0$ there is no forgone benefit so *s* realises full potential from trade with *r*. Then, the larger the value of $\gamma_{r,s}$ the greater will be forgone benefit for *r* from trade with *s* and the lower the actual benefit experienced by *r*.

In general, higher *foregone benefit* results from lower human capital available in the recipient country (Abramovitz, 1994). In case of the IT-related knowledge a set of measures required to effectively understand and absorb such new knowledge is more specific and includes both skills and, since IT is an applied science, capital equipment. The measure we use, N^{IT}, accounts for all those factors categorised in four broad categories: readiness, access and availability, use, and impact[10]. Finally, since the ability to understand new knowledge transferred from another country is relative to the level of knowledge represented by this country, we measure the recipient country's absorption capacity relative to the donor country knowledge level. Specifically, $\gamma_{r,s}$ is calculated in a form of a lack of absorption capacity according to (1.15), where N^{IT} is the nation's degree of preparation to benefit from ICT developments.

$$\gamma_{r,s} = \max\left[0, \frac{N_s^{IT} - N_r^{IT}}{N_{\max}^{IT}}\right] \tag{1.15}$$

Given (1.13) and the fact that $EXP\_SHR_{s,r}$ is a fraction, the value of $EXP\_SHR_{s,r}{}^{\alpha_{r,s}}$ decreases along with economy *r*'s inability to exploit opportunities offered by ICT (measured by *r*'s NRI relative to *s*'s) (Figure 5)

Figure 5. Value of $EXP\_SHR_{s,r}{}^{\alpha_{r,s}}$ as a function of $\gamma_{r,s}$



[10] For more details on the range of measures included in our network readiness index (N^{IT}) see Dutta et al. (2004)

The larger the positive difference between the two countries advancements in the IT-Economy, the higher is the catching-up (*r*) country's foregone benefit from a source country's (*s*) knowledge, which increases the value of $\gamma_{r,s}$ (and $\alpha_{r,s}$) and, consequently, decreases the value of $EXP\_SHR_{s,r}{}^{\alpha_{r,s}}$.

To illustrate behaviour for the above specification of the inter-country transmission of knowledge, we analyse a numerical example of the knowledge spillover flow from Japan to Indonesia and contrast it with the flow from Japan to Taiwan. The table below provides the values for all the variables used in the spillover equation:

Table 1. Numerical example of the spillover flow from Japan to Indonesia and Taiwan

Raw number	**Variable/ parameter**	**Description**	**Variable values for pair of countries**	
			Japan (*s*) to Indonesia (*r*)	**Japan (*s*) to Taiwan (*r*)**
1	$IMP\_SHR_{r,s}$	Share of imports by *r* from *s* in all imports by *r*	0.29	0.17
2	$EXP\_SHR_{s,r}$	Share of exports from *s* to *r* in al exports from *s*	0.01	0.04
3	$\delta_{r,s}$	Potential for *r* to learn from *s* (the higher the better for *r*)	0.99	0.91
4	$\gamma_{r,s}$	Foregone benefit for *r* from *s* (the higher the worse for *r*)	0.30	0.02
5	μ	Weighting parameter	0.5	0.5
6	$\alpha_{r,s} = \mu \cdot (1-\delta_{r,s}) + (1-\mu)\gamma_{r,s}$	Value of the exponent (the lower the better for *r*)	0.15	0.05
7	$EXP\_SHR_{s,r}{}^{\alpha_{r,s}}$	Share of exports from *s* to *r* raised to the power of the exponent	0.50	0.84
8	$\phi(\bullet) = IMP\_SHR \bullet EXP\_SHR_{s,r}{}^{\alpha_{r,s}}$	*IMP_SHR* (column 1) modified by the value of row 7	0.14	0.15

We divide the spillover equation into three components indicated on the equation below, and analyse them term by term. Term 3 is an exponent on term 2. Terms 2 and 3 together modify the importance of the import share (Term 1) and intensities of the spillovers.

$$\phi(\bullet) = \underbrace{IMP\_SHR_{r,s}}_{\text{term 1}} \cdot \underbrace{EXP\_SHR_{s,r}}_{\text{term 2}}{}^{\overbrace{\alpha_{r,s}}^{\text{term 3}}} , \qquad \overbrace{\alpha_{r,s} = \mu \cdot (1-\delta_{r,s}) + (1-\mu)\gamma_{r,s}}^{\text{term 3}}$$

To elaborate on this view, we begin with the exponent of the above equation (term 3), then we will analyse the interaction between the exponent and the export shares (terms 2 and 3), and finally we will show how the terms 2 and 3 together affect the inflow of knowledge (term 1) to yield the value of the spillover (ϕ).

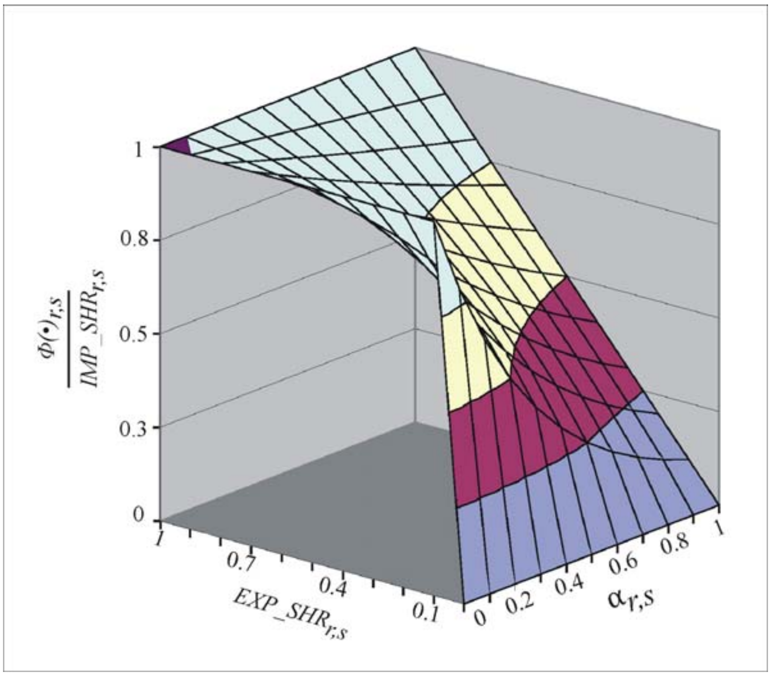
The two environmental variables in term 3 are potential to learn (δ) and foregone benefits (γ). Currently the weighting parameter μ is set to 0.5 so the two effects are given equal weights in the undertaken experiment. The *potential to learn*, variable δ , reflects the difference in stocks of knowledge between a pair of trading partners. The bigger the difference the more unexplored innovative knowledge is available for the importing country for use, or in other words, the bigger the difference the greater δ and larger EXP_SHR^{α} . In our example, the knowledge gap is greater between Indonesia and Japan (0.99), than between Taiwan and Japan (0.91), therefore Indonesia potentially benefits more from trade with Japan. The second variable in the exponent, *foregone benefit,* γ , determines the fraction of the transferred knowledge which the importing country fails to capture and to put into productive use. The ability to capture knowledge from a specific trading partner would be related to the difference in relative development levels of the IT-Economy between the pair of countries. So the bigger the difference, the more difficult it is for an importing country to understand and implement new knowledge and hence the larger the size of the *forgone* benefit. The value of variable γ for imports from Japan to Indonesia is 0.30, which is greater than the value of γ=0.02 for imports from Japan to Taiwan. Therefore Indonesia's forgone benefit is greater than Taiwan's forgone benefit, or put conversely, Indonesia's actual benefit is lower than Taiwan's actual benefit. Column 6 in Table 1 gives the value of the entire exponent, $\alpha_{r,s}$, which is 0.15 for Indonesia and 0.05 for Taiwan. Because the base (*EXP_SHR*) is a fraction, a lower value of an exponent generates greater benefits for the receipient country. So the value of 0.05 for Taiwan indicates that it is able to capture more innovation flowing with trade from Japan than Indonesia with its exponent value of 0.15.

The exponent (term 3) interacts with export shares to the importing country (*EXP_SHR*, term 2). The export share from Japan to Taiwan (4 percent) is greater than export shares to Indonesia (1 percent). Adjusted for the potential to learn (δ) and (in)ability to extract and use the knowledge (γ), the value of modified export shares are 0.50 for exports form Japan to Indonesia, and 0.84 for exports from Japan to Taiwan.

The main component of the spillover equation, term 3: *IMP_SHR*, reflects the importance of the imports from a particular trading partner. It is larger for Indonesia, whose 29 percent of imports come form Japan, compared to 17 percent in case of Taiwan. However, when the import shares are modified by adjusted export shares, the final spillover equation takes value of 0.15 for Taiwan and only 0.14 for Indonesia.

A diagrammatic representation of the entire function governing international embodied knowledge spillovers (Equation (1.10)) is provided in Figure 6 below. Because we cannot draw a four-dimensional diagram to include all variables of (1.10) separately, we graph the equation in the following way: we move IMP_SHR to the LHS ($\phi(\bullet)$ is homogenous of degree one in IMP_SHR) and depict the value of $\phi(\bullet)/IMP\_SHR$ on the vertical axis ($\phi(\bullet)_{r,s} / IMP\_SHR_{r,s} = EXP\_SHR_{s,r}{}^{\alpha_{r,s}}$). We can interpret the vertical distance as a multiplier which modifies the import share. The value of the multiplier is equal to export share adjusted for knowledge capture parameter, α, which reflects the effect of the combination of two effects for each pair of countries: potential to learn (δ) and foregone benefits (γ).

Figure 6. Simplified graphical interpretation of the spillover function



From Figure 6 above we see that the destination country *r* can fully benefit from a source country *s* stock of knowledge only if either *EXP_SHR=1* and *IMP_SHR=1*, or if the value of the exponent is equal to zero, i.e. $\delta = 1$ (there exists significant difference between two countries' levels of knowledge stocks so there is potential for one country to learn from another one), and $\gamma = 0$ (the two countries are the same level of development of IT-Economy and there is no knowledge that will be left uncaptured – the importing country realised the full potential) and *IMP_SHR=1*. None of these extreme cases is likely to occur, and most of the interactions take place on the inner part of the surface.

Adjusted measure of IT capital stock

Jorgenson and Griliches (1967) introduced the theory of variable services provided by capital of different vintages. For example, 'the services provided by a truck built in 1968 differ from a truck of vintage 1998' (Jalava and Pohjola, 2007). This change in capital service flow with respect to the capital's vintage is of particular importance for ICT capital, where rapid advances in IT make old stock less valuable relatively faster than other types of capital (see e.g. Yorukoglu (1998)). Further, ICT should be considered within a broader supporting set of labour skills and infrastructure. If such a 'complete cluster of associate complements' do not improve together it is unlikely to make a bigger contribution to output than it costs (Atzeni and Carboni, 2006; Bresnahan et al., 2002; Brynjolfsson and Yang, 1997). We take account of these supporting, complementary, factors and fast obsolesce of IT capital in two instances in our specification: the first is to allocate the change in national IT productivity to sectors proportional to their IT investment shares (see Equation (1.2)) so only the sectors actively seeking innovation are assumed to benefit from advances in ICT; secondly we use an *adjusted* measure of IT capital stock, SJ^*, rather than the stock itself. On the second point we elaborate and explain below.

We define SJ^* as a quality adjusted modified measure of the change in ICT capital stock, which indicates its network readiness modified by ICT investment. SJ^* is linked to level of total capital *KB* by a constant[11] parameter η and additional characteristic *U*.

$$SJ_{r,t}^{*} = KB_{r,t}^{\eta_{r,t}} \cdot U_r \tag{1.16}$$

where:

[11] Parameter η is time varying however is not directly affected by the measure of *SJ**, therefore we treat it as constant.

$$\eta_{r,t} = \log_{ITOT_{r,t}} I_{r,t} \tag{1.17}$$

We specify parameter η as the logarithm of ICT investment, *I*, with base of total investment, *ITOT*. SJ^* is linked to the percentage change in total (ICT and non-ICT) capital in the economy, *KB*, to account for the supportive role of non-ICT capital in development of the networked economy and to differentiate between stand alone and networked ICT. Because *I* is a share of *ITOT* and $\frac{I}{ITOT} \leq 1$, the expression $\log_{ITOT} I \leq 1$ is increasing in accordance with the value of the ratio $\frac{I}{ITOT}$, but also it is increasing at a decreasing rate in the level of $ITOT$ (and I) for a constant ratio $\frac{I}{ITOT}$ (see Figure 7 below). So the SJ^* component of the IT economy is greater the greater is investment in ICT relative to the overall investment in an economy. Also, the impact of ICT investment is higher at low levels of *I* as SJ^* increases rapidly with small increases in *I* [12]. Countries whose level of ICT investment is high relative to the level of the overall investment ($\frac{I}{ITOT}$) are likely to have ICT supportive and effective political and regulatory standards, which increase the efficiency of utilisation of the components of the IT economy required to construct networked economic structure. The property of SJ^* increasing with level of *ITOT* (and *I*) for a constant ration of $\frac{I}{ITOT}$ implies increasing returns to scale for larger economies which invest more.

The parameter *U* in Equation (1.16) is aimed to capture effects other than those related to SJ^* and *SK* characteristics, which can affect growth of the networked economy. It also can be used in calibration of the model if advancement in SJ^* is greater than advancement in overall capital growth *KB*[13].

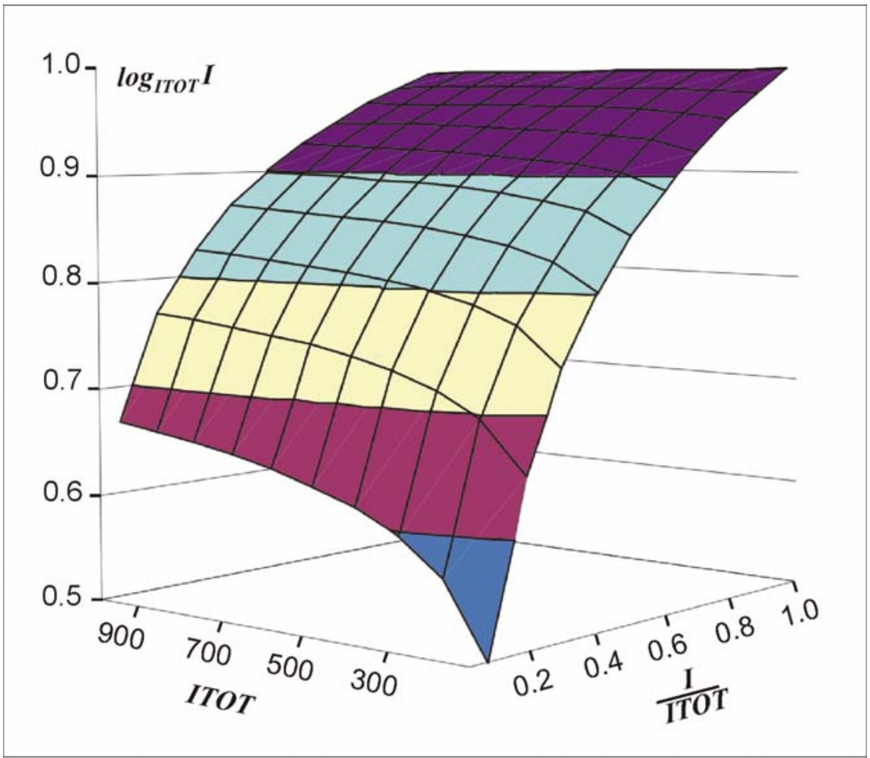
The characteristics represented by parameter *u* include a range of demographic or sociological factors such as: density of a population (denser population is easier to network); average age

[12] This specification is consistent with findings of INSEAD (Européen d'Administration des Affaires) reported in Dutta (2004). This report also provides the country-specific initial values for the NRI (Networked Readiness Index) used in this study.

[13] The case when $sj^*>kb$ could in principle be captured by parameter ρ in equation (1.5), however introduction of parameter *u* allows for a more flexible specification.

(ICT diffuses better among younger population), attitude towards new technologies or extent of ICT education in various educational institutions.

Figure 7. Value of $\log_{ITOT} I$ as function of ICT investment, *I*, and ratio of *ICT* investment to total investment *I/ITOT*.



Sectoral IT productivity change

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

$$\frac{d\log A_{r,i,t}^{IT}}{d\log N_{r,t}^{IT}} = \frac{I_{r,i,t}}{\sum_{j} I_{r,j,t}} \cdot g\left(\tau(\log N_{r,t}^{IT}) - a\right)\left(b - \tau(\log N_{r,t}^{IT})\right) \qquad (1.18)$$

Important to notice at this stage is that although investment shares are time dependent, they do not directly depend upon the economy-wide level of ICT readiness, N^{IT}. Thus in (1.18) the derivative with respect to $\log N^{IT}$ is taken treating investment shares as constant. Consequently, (1.18) may be though of as defining the sectoral sensitivity of IT productivity to economy-wide network readiness. Of course, the time evolution of this sensitivity is dependent on the time evolution of investment shares, as specified in (1.18), but at any given instance the main influence on the sensitivity of IT productivity to network readiness is the slope of the 'translog logistic' function. Equation (1.18) takes a measure of the economy wide sensitivity of productivity to network readiness and allocates it across sectors, thus defining sectoral-specific measures of

the productivity sensitivity of individual sectors to economy-wide network readiness. Given the importance of new ICT investment in realising IT productivity gains, the sectoral allocation is based on current (time varying) investment shares.

The percentage change form of adjusted measure of ICT capital stock implied by equations (1.16) and (1.17) is:

$$sj^{*}_{r,t} = \log_{ITOT_{r,t}} I_{r,t} \cdot kb_{r,t} + u_{r,t} \tag{1.19}$$

Substituting (1.5) into (1.18), we obtain an equation representing the percentage change in sector *s* contribution to economy-wide productivity change:

$$\begin{aligned} a^{IT}_{r,i,t} = \frac{I_{r,i,t}}{\sum_j I_{r,j,t}} \cdot g\left(\tau(\log N^{IT}_{r,t}) - a\right)\left(b - \tau(\log N^{IT}_{r,t})\right) \cdot \{\overline{n}_r + \\ \rho \cdot sj^{*}_{r,t} + \\ (1-\rho) \cdot [\omega_d \cdot sk_{r,d,t} + \\ \omega_f \sum_{s \neq r}\left(IMP\_SHR_{r,s,t} \cdot EXP\_SHR_{r,s,t}{}^{\mu(1-\gamma_{r,s,t})+(1-\mu)(1-\delta_{r,s,t})} \cdot sk_{s,d,t}\right)]\} \end{aligned} \tag{1.20}$$

Equation (1.20) consists of four components, each on a separate line: (i) the logistic function governs the productivity of sector *i* with respect to the degree of advancement of the IT economy represented by $\log N_{r,t}$, (ii) change in stock of network-adjusted IT equipment, (iii) change in the stock of domestic IT knowledge, and (iv) change in the stock of foreign IT knowledge.

Illustrative application

In this section we provide an overview of illustrative application of the new theory incorporated into the standard GTAP[14] model. The illustrative application is aimed to provide further insight into the model mechanisms. For this purpose, we simulate economic development of several APEC countries for the period 2008-2012 with particular attention to the role of ICT technology.

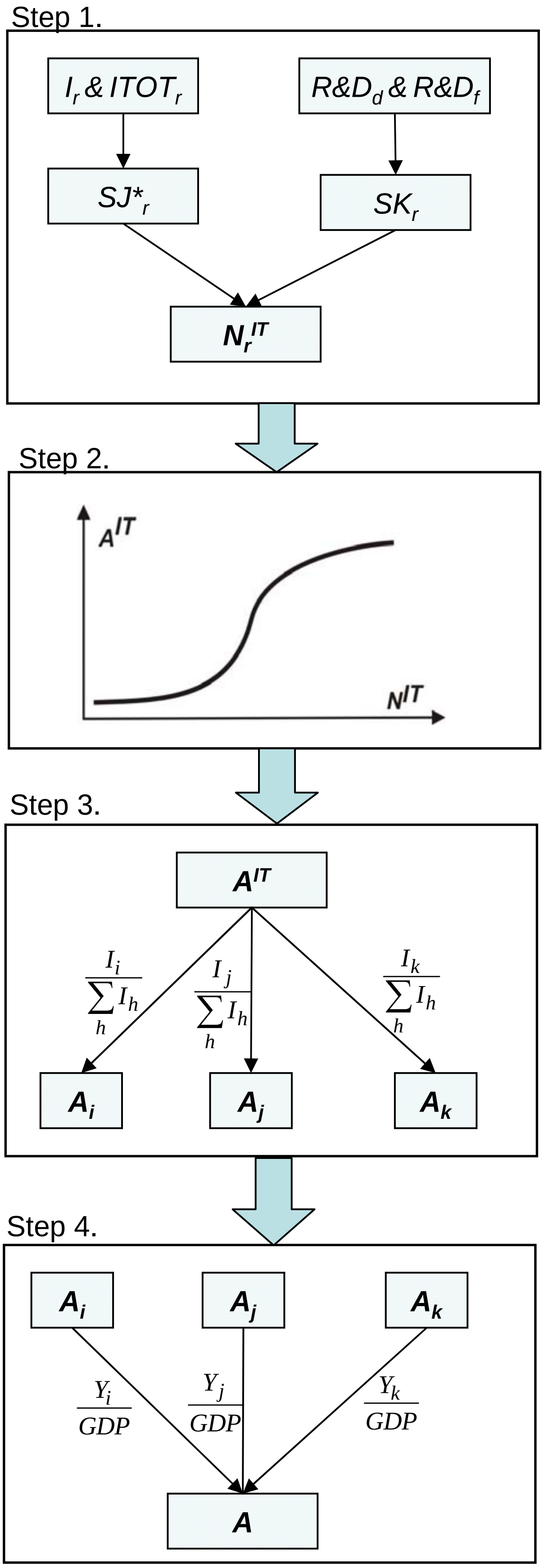
Note that at the time of writing, the world economy was in an acknowledged recession and official macroeconomic forecasts were subject to frequent revisions undermining their reliability. Our primary aim is, though, not to forecast economic development but rather to illustrate the impact of ICT technology on development of selected economies and for a given macroeconomic outlook.

The main component of the data used is the GTAP 6 Data Base (Dimaranan, 2006) with reference year 2001. To begin our forecast with more recent picture of an economy we update the database using the GTAP[15] model itself by simulating the period end-2001 to end-2007 with a number of macroeconomic variables exogenous (real GDP and population) and equal to their historical values. In effect we use the model to create a model consistent database which represents the world economy at the end of 2007. The supplementary data required by our ICT extension is information related to: (i) initial value of the IT economy development index, N_r^{IT}, and (ii) IT knowledge stocks, SK_r. More detailed information on data sources, construction and assumptions is provided in the Appendix.

Results

We begin with overview of the main mechanisms of the IT extension to the model. This overview will serve as a roadmap for the results to follow.

[14] Global Trade Analysis Project's (GTAP) model is a multi-country CGE model based on GEMPACK and developed at Purdue University (Hertel, 1997).
[15] For the updating and simulation purpose we use the GTAP model supplemented with an intertemporal, capital accumulation extension. The extension equals end of period capital stock to the beginning of the next period capital stock allowing for a change in productive capacity.



IT-Economy, N^{IT}, reflects the degree of saturation and utilisation of IT technologies within an economy. N^{IT} advances with two components (eq.(1.4)): (1) adjusted measure of IT capital stock, SJ^*, which depends on fixed IT investment and investment in other supportive non-IT capital (eq.(1.16)), and (2) IT related stock of knowledge, SK, which is a function of domestic and foreign R&D expenditure; the value of the foreign IT-related knowledge to the recipient country is modified via spillover function (eq.(1.9)).

The change in aggregate productivity of IT resources, A^{IT}, resulting from advancement in IT-Economy, N^{IT}, is of non-linear character to account for a network effect when a county reaches a critical mass of IT resources (eq.(1.1)).

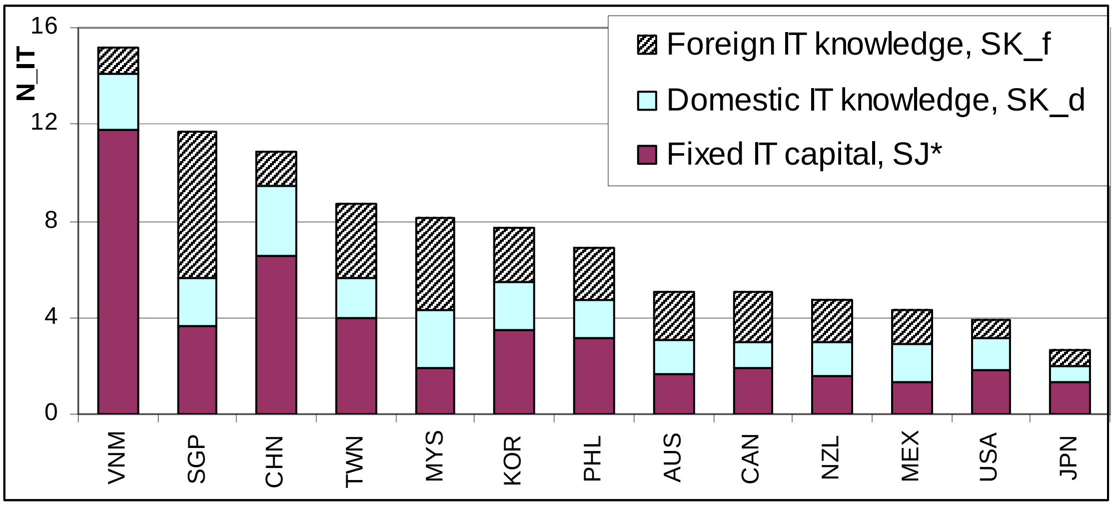
Sectoral productivity resulting from the productivity in aggregate IT resources depends on the sector's share in overall IT investment, $I_j / \sum_h I_h$. Only the investing sectors can benefit from the new technology (eq.(1.2)).

Finally, the change in national productivity, A, is calculated as a share weighted average which takes into account relative size of each sector, Y_j / GDP (eq.(1.3)).

Step 1. Advancement in IT-Economy index, N^{IT}

The following Figure 8 shows percentage cumulative change in the measure of IT-Economy, N^{IT}, which is determined by changes in (1) measure of adjusted fixed IT capital, SJ^*, (2) change in domestic stock of IT-related knowledge, SK_d, and (3) change in foreign knowledge used within an economy, i.e. change in foreign stocks of knowledge, change in rate of transfer of knowledge between countries, and potential and efficiency of use of this knowledge by a recipient country. The greatest proportional advancement in IT-Economy has taken place in Vietnam (15 percent), with largest contribution from accumulation of fixed IT capital (12 percent). Second greatest improvement in N^{IT} experienced Singapore (11 percent) where the advancement was due to increased impact of foreign IT knowledge (8 percent), SK_f and to fixed IT capital formation (6 percent). At the other end, the lowest proportional progress in IT-Economy occurred in USA and Japan (4 and 3 percent respectively); for both countries bulk of advancement is due to fixed IT capital investment.

Figure 8. Cumulative proportional advancement in IT Economy index, N^{IT}, and changes in its constituents, SJ^*, SK_d and SK_f.



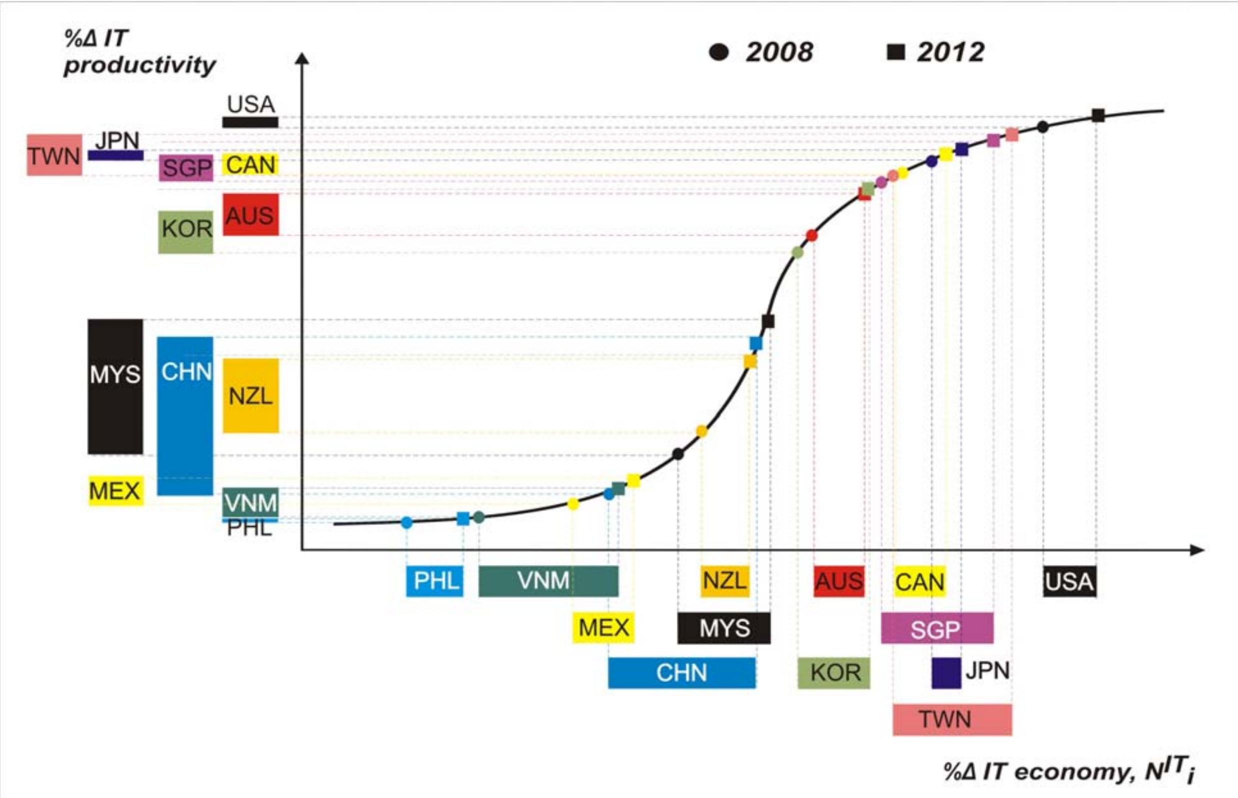
Step 2. IT-economy index and aggregated IT productivity

Now we analyse how these advancements in the IT economy translate into a change in IT productivity. Productivity of the IT stock, A^{IT}, is governed by a logistic function with variable productivity returns on IT investment for different levels of the IT economy and depends on the degree of development of the IT environment, N^{IT}, according to Equation (1.1), which we rewrite below:

$$\log A_{r,t}^{IT} = \tau\left(\log N_{r,t}^{IT}\right) = \frac{b\exp\left(c + g(b-a)\log N_{r,t}^{IT}\right) + a}{1 + \exp\left(c + g(b-a)\log N_{r,t}^{IT}\right)} \qquad (1.21)$$

We depict the relationship between advancement in the IT economy and change in productivity for the baseline simulation in Figure 9, where the length of the rectangles at the bottom of the figure reflect advancement in the IT economy index between 2008 and 2012 for the baseline scenario, and the height of the rectangles on the left side of the graph represent the magnitude of the change in IT productivity over the same time period as measured by the model.

Figure 9. Change in IT economy and resulting change in IT productivity, 2008-2012



The horizontal axis in Figure 9 reflects the scenario discussed above with respect to Figure 8. To partially re-iterate, we see that the greatest IT-economy advancement between 2008 and 2012 (horizontal axis) is expected to be experienced by Vietnam, Singapore, China and Taiwan, while a lower rate of IT development is projected for New Zealand, Japan and the Philippines. The resulting change in productivity of IT (vertical axis), however, is not strictly proportional to the development in the IT economy. For example Vietnam advances significantly with the IT economy, but its resulting IT productivity change is very small. New Zealand, Australia and Canada experience similarly equal changes in their IT economies, but the resulting IT productivity change is several times higher for New Zealand than for Canada. Overall, the greatest beneficiaries of increasing IT productivity are China and Malaysia, and the least are the Philippines, Mexico, Japan and the USA. Countries at the upper part of the logistic curve experience a slowdown of productivity returns to ICT investments due to saturation of the economy with ICT, whereas countries at the lower part of the curve have not yet approached the critical mass of ICT, allowing fuller utilization of the potential of the ICT stock.

Step 3. Change in sectoral productivity due to change in productivity of IT resources.

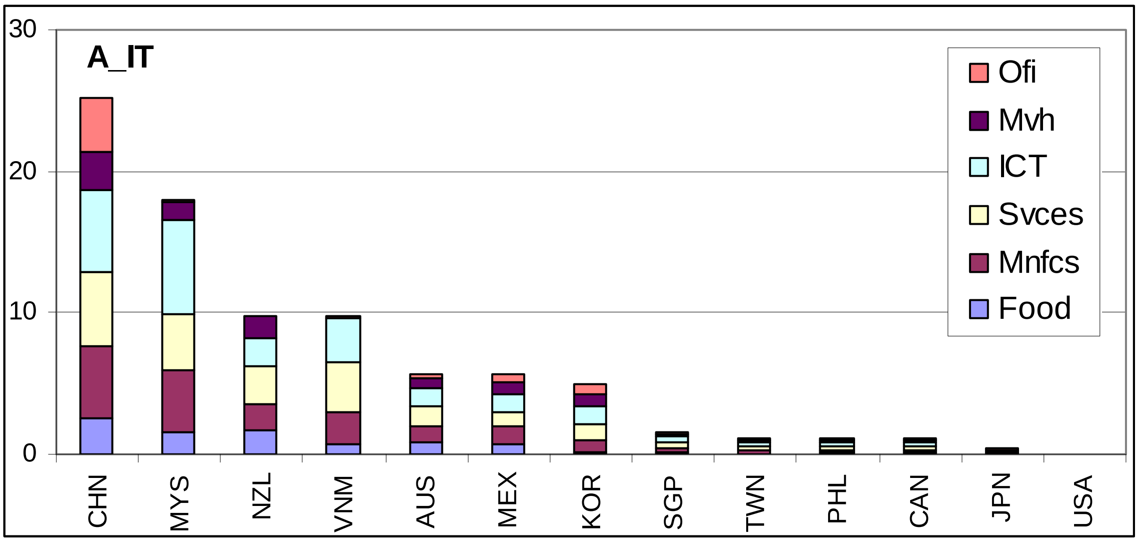
Sectoral productivity $A_{r,i,t}^{IT}$ resulting from productivity of the national IT stock $A_{r,t}^{IT}$ is proportional to the share of sectoral IT investment in national IT investment $I_j \Big/ \sum_h I_h$ (see equation (1.2)).

Table 2. Percentage cumulative change in sectoral productivity, A_j, and average (for 2009-2012) share of sectoral IT investment in national IT investment, $I_j \Big/ \sum_h I_h$.

	A^{IT}	Food		Mnfcs		Svces		ICT		Mvh		Ofi	
		$\frac{I_f}{\sum_h I_h}$	A_f	$\frac{I_m}{\sum_h I_h}$	A_m	$\frac{I_s}{\sum_h I_h}$	A_s	$\frac{I_I}{\sum_h I_h}$	A_I	$\frac{I_{mv}}{\sum_h I_h}$	A_{mv}	$\frac{I_o}{\sum_h I_h}$	A_o
CHN	**25.0**	0.10	2.24	0.20	4.79	0.21	4.83	0.23	5.52	0.11	2.57	0.15	3.48
MYS	**18.0**	0.09	1.58	0.24	4.14	0.22	3.70	0.37	6.38	0.07	1.17	0.01	0.18
NZL	**9.8**	0.17	1.60	0.19	1.83	0.28	2.72	0.20	1.94	0.15	1.40	0.01	0.07
VNM	**9.8**	0.08	0.71	0.23	2.22	0.36	3.40	0.33	3.10	0.01	0.07	0.00	0.04
AUS	**5.7**	0.14	0.78	0.20	1.13	0.26	1.47	0.22	1.24	0.11	0.59	0.07	0.41
MEX	**5.6**	0.13	0.70	0.21	1.16	0.19	1.06	0.23	1.29	0.15	0.81	0.09	0.52
KOR	**4.9**	0.04	0.21	0.17	0.81	0.21	1.04	0.27	1.33	0.18	0.87	0.13	0.61
SGP	**1.6**	0.05	0.08	0.22	0.34	0.23	0.36	0.31	0.48	0.07	0.11	0.13	0.20
TWN	**1.2**	0.03	0.03	0.22	0.26	0.20	0.24	0.30	0.35	0.12	0.14	0.13	0.15
PHL	**1.1**	0.07	0.08	0.22	0.23	0.24	0.26	0.31	0.33	0.08	0.08	0.09	0.10
CAN	**1.1**	0.11	0.12	0.21	0.23	0.20	0.22	0.23	0.24	0.16	0.18	0.10	0.11
JPN	**0.4**	0.07	0.03	0.20	0.08	0.21	0.08	0.24	0.09	0.20	0.08	0.08	0.03
USA	**0.1**	0.05	0.00	0.20	0.01	0.21	0.01	0.22	0.02	0.18	0.01	0.14	0.01

The employed specification implies that the change in sectoral productivity resulting from increasing productivity of aggregate IT resources is proportional to the share of investment in IT undertaken be each sector. From Table 2 we see that, for example, China IT resources' productivity improves by 25 percent and the sectors which invested relatively the most in IT are ICT manufacturing (23 percent of IT investment) and Services (21 percent of IT investment), hence the resulting sectoral productivity improvement is 5.5 percent for ICT sector and 4.8 percent for Services sector. Figure 10 provides graphical interpretation of Table 2. We see that the most IT investing sectors are, on average, ICT manufacturing and Services sectors, whereas broad Food sector invests relatively the least in IT.

Figure 10. Percentage cumulative change in productivity if IT resources and allocation of IT national investments across sectors.



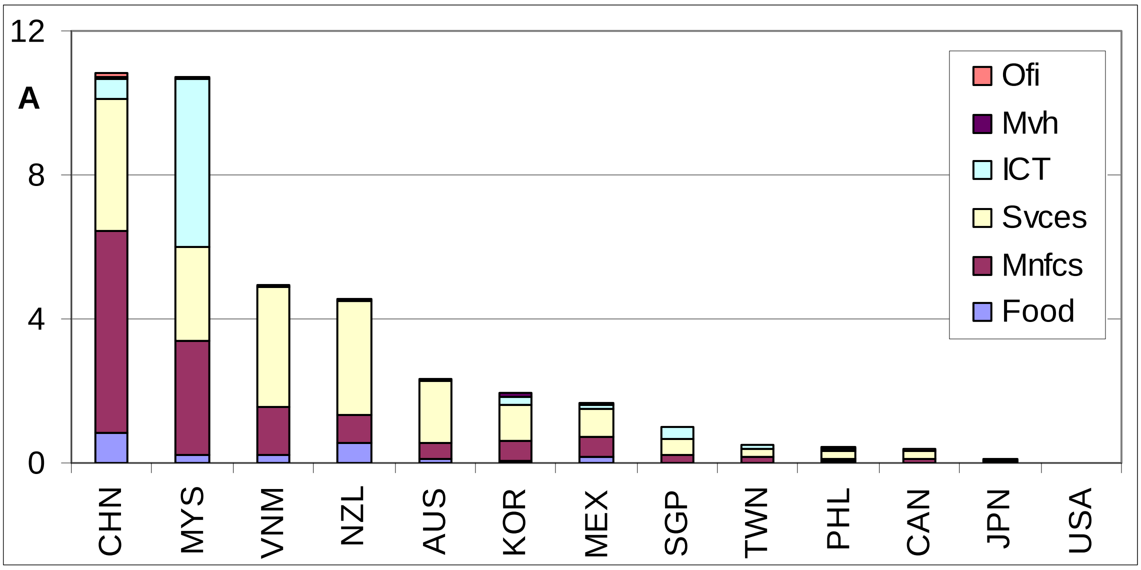
Step 4. Determination of national productivity

The overall national productivity A_r is given by a weighted average of sectoral productivities with sectoral outputs used as weights (see equation (1.3)) (note that sectoral contributions to the GDP add to more that unity because we include intermediate inputs in the measure of sectoral output). Table 3 and Figure 11 provide an overview of data on change in sectoral productivities, and on sectoral contributions to GDP which are used as weights for aggregating sectoral productivities into nation ional productivity.

Table 3. Percentage cumulative changes in sectoral productivity and their contributions to the national productivity change.

	A	Food		Mnfcs		Svces		ICT		Mvh		Ofi	
		$\frac{Y_f}{GDP}$	A_f	$\frac{Y_m}{GDP}$	A_m	$\frac{Y_s}{GDP}$	A_s	$\frac{Y_I}{GDP}$	A_I	$\frac{Y_{mv}}{GDP}$	A_{mv}	$\frac{Y_o}{GDP}$	A_o
CHN	10.95	0.36	2.24	1.18	4.79	0.76	4.83	0.10	5.52	0.04	2.57	0.03	3.48
MYS	10.91	0.15	1.58	0.77	4.14	0.70	3.70	0.73	6.38	0.04	1.17	0.06	0.18
VNM	5.01	0.33	0.71	0.60	2.22	0.98	3.40	0.03	3.10	0.00	0.07	0.01	0.04
NZL	4.58	0.35	1.60	0.41	1.83	1.17	2.72	0.02	1.94	0.02	1.40	0.05	0.07
AUS	2.34	0.16	0.78	0.39	1.13	1.18	1.47	0.01	1.24	0.03	0.59	0.05	0.41
KOR	1.97	0.15	0.21	0.70	0.81	1.00	1.04	0.15	1.33	0.10	0.87	0.07	0.61
MEX	1.68	0.23	0.70	0.51	1.16	0.73	1.06	0.07	1.29	0.07	0.81	0.02	0.52
SGP	1.00	0.06	0.08	0.63	0.34	1.31	0.36	0.61	0.48	0.01	0.11	0.09	0.20
TWN	0.50	0.10	0.03	0.65	0.26	0.93	0.24	0.24	0.35	0.03	0.14	0.08	0.15
PHL	0.42	0.49	0.08	0.37	0.23	0.77	0.26	0.28	0.33	0.01	0.08	0.02	0.10
CAN	0.36	0.11	0.12	0.48	0.23	0.96	0.22	0.03	0.24	0.09	0.18	0.03	0.11
JPN	0.13	0.09	0.03	0.37	0.08	1.03	0.08	0.09	0.09	0.08	0.08	0.05	0.03
USA	0.02	0.10	0.00	0.37	0.01	1.15	0.01	0.04	0.02	0.05	0.01	0.11	0.01

Figure 11. Percentage cumulative change in national productivity, *A*, and sectoral contributions to *A*.



From Table 3 and Figure 11 we see that the greatest overall national productivity improvement experienced China and Malaysia at the similar level of 11 percent. The two countries, however, had different sectors contribution to this productivity increase. In China national productivity was mostly due to growth of two sectors: Manufacturing and Services. Both sectors' productivity improves significantly (4.8 percent) and both sectors are relatively important in determining the level of GDP (1.18 and 0.76 respectively). In Malaysia, however, national productivity grew mostly due to increased productivity of ICT manufacturing sector (4.14) which, in Malaysian economy, is large enough (0.73) to significantly impact upon aggregated output.

Conclusions

In this paper we proposed how to account for ICT technology within a CGE model. We argued that an accurate representation of ICT technology requires a multi-perspective approach which accounts for a dynamic nature of networked ICT at the broad economy-wide level, as well as for its sectoral-level enabling characteristics.

The CGE framework, and the GTAP model in particular, are flexible enough to incorporate new theory which embeds the function of ICT technology in an economy. The structure of an economy, which absorbs ICT technology, is reflected in the GTAP model at a sufficiently detailed level to support a model capable of providing relevant results, and the cross-economy trade linkages successfully proxy flows of knowledge between the economies. When the model is extended to a dynamic version, it allows an accounting for the transformative nature of new technology, its temporal diffusion and the changing overall socio-economic environment within which the ICT technology operates.

We employed the developed model to provide an illustrative application, which considers development of several APEC economies between 2008 and 2012. We illustrated that the productivity of IT resources depends on the level of advancement of the IT economy. The largest potential for IT-based productivity growth occurs in countries whose IT resources are merging into an economy-wide network (China, Malaysia). In those countries IT resources are just gaining their critical mass which triggers the network effect and, which in turn, improves productivity of the entire, economy-wide ICT system. 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, the Philippines). The sectoral resulting from productivity of the national IT stock depended on sectoral intensity of investment in IT, so the sectors which invest more will experience greater productivity improvement. Finally, the national productivity is a weighted average of spectral productivities, with sectoral shares of sectoral outputs in GDP used as weights.

Further developments:

Intertemporal optimisation – although our model is equipped with dynamics in the form of capital accumulation and E-economy development, embedding intertemporal optimisation of, for example, consumption and investment decisions, would more accurately reflect economic agents' behaviour. Of particular relevance for the study of enabling technologies would be extension of the theory to incorporate insights of endogenous growth theory. For example, the intertemporal model would ideally endogenize the R&D investment decision.

In addition to endogenisation of the R&D decision, there is also scope for more elaborate linkages between R&D activity and the rest of economy on both the demand and supply sides, i.e. consumption of resources by the R&D sector as well as provision of the R&D output impacting upon performance of the rest of economy.

Although our model provides a measure of advancement of the IT economy in the form of a single compound indicator, having a more detailed specification of the environment related to

ICT adoption and utilization would allow the researcher to identify and hierarchically categorise factors which are important for IT adoption for a particular economy or region. The indicators to be taken into account could include human capital measures such as skills composition and skills level, other demographic factors such as age and share of population living within urban areas, and measures of any kinds of restriction, regulation or constraint that limit the set of choices of an economic agent.

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Appendix

Updating the database 2001-2007

The implied growth rates between the 2001 data from the GTAP database and the data observed empirically for 2007 are presented below in Table 4 below.

Table 4. Major macro variables changes 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

Estimates for end-2007 GDP were obtained from the World Development Indicators (World Bank, 2008) database (hereafter, WDI). The growth rates were calculated between values for 2001 (GTAP database) and 2007 (actual data).

From WDI 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 WDI 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 GTAP v6 database we had values for capital and investment in 2001. Growth rates for gross fixed capital formation were obtained from World Development Indicators database (World Bank, 2008) for years 2002-2005, and from country-specific statistical agencies for year 2006. We also assumed a constant annual 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).

Real GDP for 2008 to 2012.

For the economic growth forecast we use data provided by Business Monitor International (2009), listed in the Table 5 below.

Table 5. Projections of annual rowth rates of real GDP for 2008 to 2013

Real GDP	2008	2009	2010	2011	2012
AUS	1.9	-1.4	1.2	3.0	3.4
NZL	-0.6	0.2	1.3	2.1	1.9
CHN	9.0	5.6	6.8	7.9	7.6
HKG	3.1	-3.6	2.2	4.3	4.9
JPN	-0.3	-2.6	0.6	1.2	1.5
KOR	4.1	3.0	3.4	3.6	4.2
IDN	6.1	5.0	5.2	5.0	5.1
MYS	5.5	1.4	3.2	4.4	4.5
PHL	4.4	4.3	5.9	6.6	5.9
SGP	1.5	-2.8	2.3	4.5	4.4
THA	3.6	-2.5	2.2	3.3	4.1
VNM	6.3	2.9	5.0	8.3	7.9
CAN	0.6	-1.4	3.0	3.8	3.6
USA	1.3	-2.0	0.8	2.6	3.8
MEX	0.0	-1.3	1.9	4.4	5.0
PER	8.5	4.3	4.7	4.4	3.5
CHL	3.7	0.9	2.1	3.2	3.0
TWN	1.5	-0.2	3.5	4.0	5.4
RUS	5.6	-4.0	1.1	3.5	5.1

Knowledge stocks

We estimate stocks of ICT-related knowledge, SK, as accumulated expenditure on ICT-related R&D. To overcome a lack of long time-series data on respective R&D expenditures, we use the perpetual inventory method suggested by Griliches (1979) to evaluate SK. The stock in the first year for which data is available, SK_0, is calculated as:

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

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 a figure for expenditure in an initial year. Stocks for further periods are calculated as:

$$SK_t = SK_{t-1} \cdot (1 - \lambda) + R_{t-1}$$

Table 6 presents estimated stocks, SK, for year 2007.

Table 6. Stocks of ICT-related knowledge for APEC economies in 2007, (US$m PPP)

Country	SK	Country	SK
AUS	1842.9	**THA**	136.3
NZL	178.8	**VNM**	7.6
CHN	19482.7	**CAN**	24082.8
HKG	602.1	**USA**	246215.4
JPN	191551.4	**MEX**	548.7
KOR	17865.5	**PER**	18.4
IND	69.6	**CHL**	75.2
MYS	426.5	**TWN**	21585.8
PHL	19.7	**RUS**	1223.4
SGP	2246.9		

Initial values for Network Readiness Index

A numerical value for $\alpha_{r,s}$ is proxied by the Network Readiness Index (NRI) (Dutta et al. 2004). NRI is an international assessment of countries' capacities to exploit opportunities offered by ICT. For the purpose of this study we adopt a specific sub-index (Table 7), which describes the ICT readiness capability of the business sector. The focus on the business sector is motivated by the assumption that externalities are likely to be more fertile on a business level than on an individual or government level.

Table 7. Values for Business Readiness sub-index of the Network Readiness Index.

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***		

Parameters

The parameters used for calibration of the model are drawn from research using a pooled cross-economy time-series statistical analysis of historical data (ANBERD, OECD 2006) for OECD economies. Based on this research, the relevant parameters are set as: $a = 3.35,\ b = 6.55,\ g = 1,\ c = -15,\ \omega_d = 1,\ \omega_f = 1,\ \rho = 0.5$ and $\mu = 0.5$.