A Dynamic Global CGE Model with a GVAR-based Baseline

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Abstract

With one crisis every 58 months on average, statistically speaking the beginning of the next crisis would be around April 2015 and would end by March 2016. This paper documents the theoretical structure of a dynamic global CGE model, as well as illustrates the potential economic consequences of another global crisis on the world economy.

The two main reasons for developing a dynamic model is (1) to identify transition paths of variables between the initial equilibrium and the post-simulation equilibrium; and (2) to incorporate the convergence speed of out-of-steady state growth paths for specific variables. The first – transition paths – are particularly useful when the study has an explicit interest in inter-temporal aspects of exogenous variables (e.g. investment phase-in) or endogenous variables (e.g. inflation pattern). The second – convergence speed – helps improve the credibility of predictions by allowing lagged adjustments to be introduced into the model (e.g. in investment and/or in the labour market).

The calibration of the global dynamic model involves developing baseline growth paths for each of the regional economies that are globally consistent. Development of a world baseline include currently introducing demographic as well as real GDP projections in each region. The paper analyses the policy scenario applying interval-differentiated shocks in both the baseline and in the counterfactual simulations. This allows taking full advantage of quarterly GDP forecasts produced by our in-house global VAR model that is consistent with our set of countries.

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1 Introduction

Two key features of extending a static global CGE model to a dynamic version are around stock-flow accumulation relations and investment theory.

As capital is assumed to be internationally mobile, the first key feature includes the distinction between physical capital stocks and financial assets. In the dynamic model, this results that international financial capital flows does add to capital stock available for productive use, contrary to the static version where the behaviour of investment can only influence output through changes in the composition of final demand. In addition, international income receipts and payments are now part of the calculation of the current account balance.

The second key feature of the dynamic model is a lagged adjustment, adaptive expectations theory of investment. Investment levels and rates of return derived from the benchmark data are often inconsistent with values based on the theory of investment behaviour embedded in the model. These disequilibria are accommodated by letting investors react to expected rather than actual rates of return. Furthermore, these disparities are not eliminated instantaneously, but progressively through time, such that expected rates of return converge in the long-run toward actual rates of return.

The calibration of a global dynamic model involves developing baseline growth paths for each of the regional economies that are consistent globally. As it has been recognised for more than a decade, the choice of a baseline can affect the results of the policy simulation. Therefore particular emphasis is place on developing a baseline by relying on both recent literature-based projections and on in-house projections derived from a global vector autoregressive model.

Development of a world baseline involves introducing to the dynamic model demographic, macroeconomic and sectoral productivity forecasts for each region as well as expected policy changes in each region. Projections on real GDP are estimated using a global vector autoregressive model, while the remaining projections are based on the literature. The developed baseline is then used to assess the potential economic impacts of a collapse of the world economy on agents in each region worldwide.

2 Model Theoretical Structure

The dynamic global CGE model developed in this paper is an extension of a previously developed static global CGE model (Cretegny, 2014). It is Walrasian in spirit and along the lines of models used for applied international trade policy (Shoven & Whalley, 1984). The core theoretical specification of the static model at the regional level draws upon the long Johansen/MONASH tradition in CGE modelling (Dixon, Koopman, & Rimmer, 2013). The macroeconomic closure at the global level is based on the well-known GTAP model (Hertel & Tsigas, 1997). The particularities of the static global CGE model are twofold. The first particularity lies in the representation of the regional demand for a given commodity from a specific region that is differentiated for each of these users. The second particularity is the specification of investment at the industry level rather than at the aggregate level. This allows the determination of industry-specific rates of return and the reallocation of investment across industries to be affected by relative rates of return.

Introducing dynamics in computable general equilibrium models allows the calculation of the transition path from the initial equilibrium to the new equilibrium. There are two types of dynamic models. On the one hand, recursive dynamic models characterized by myopic agents and on the other hand, forward-looking models, which assume that agents anticipate future changes in making their choices today.

In the context of our work, which focus essentially on financial consequences of the materialization of potential systemic risks, the assumption of investors' perfect foresight of returns to capital is not appropriate. During the Asian financial crisis at the end of last century, investors massively withdrew their investment in the region following downward adjustment in the expectations. This acknowledgment of errors in their expectations suggests that they have not foreseen perfectly returns to capital and shows the importance of modelling errors in investors' expectations. Therefore our model assumes myopic agents and introduce adaptive expectations about rates of return on installed capital in each region equalizing across regions in the long run (Ianchovichina & McDougall, 2012).

The dynamic global CGE model consists of four theoretical modules: core theory, sectoral investment theory, stock-flow accumulation relations and regional investment theory.

2.1 Core theory

The core theory of the dynamic CGE model is primarily the static version of the model. This model consists of two components. The first component is a set of equations describing agents' behaviour, markets clearance and income balance within a region and comprises Equations R-1 to R-18 of our previously-developed stylized static CGE model (Cretegny, 2014). The second component of the global static CGE model provides the linkages between regions in terms of both physical flows (e.g. goods and services) and financial flows (e.g. investment) and is discussed in section 2.6.

Each region consists of industries and investors, households, foreigners and a national government. The particularity of this model lies in the representation of the regional demand for a given commodity from a specific region that is differentiated for each of these users.

For any activity of the global economy, marginal cost is assumed to equal marginal revenue which makes pure profits impossible to earn. In addition agents are assumed to produce under constant returns to scale and face markets that are perfectly competitive with free entry and exit.

Market-clearing conditions imply that, at equilibrium prices and activity levels, supply equals demand for every individual commodity represented in the model. This has to hold for both margin and non-margin domestically produced commodities, as well as for imported commodities. In the case of the former, the demand includes the model's five users (industries, investors, households, the government, and the foreigners), whereas it excludes the foreigners for the latter as exports always involve some domestic value added[1].

Market demand for primary factors of production also has to equal the supply of endowments. In the model, capital stock is assumed to be specific to each sector and to each region, which means that, in equilibrium, capital sustains differential returns across sectors in each region. In contrast, labour is assumed to be mobile between sectors but not across regions, which results in a single regional wage rate across industries in equilibrium.

Welfare in each region depends on private consumption, government spending and savings, which are determined as part of a single Cobb-Douglas utility maximization problem. Regional income is thus allocated in fixed shares to current consumption, government services and investment. This implies a fixed savings rate and resulting regional savings are assumed to finance domestic and/or foreign investment. Taxes accrue to the region as a whole so government revenue is currently not linked to government spending. The third equilibrium condition ensures that, in each region, the value of households' income equals the value of factor endowments.

2.2 Sectoral investment theory

In each region, aggregate investment is endogenous to the model as well as the allocation of investment across industries. Investment in each industry is determined by expected rates of return required by investors to advance additional investment and the rate of return in that industry results from the interaction of demand for capital with given capital supply. Although capital is specific to each industry, capital formation is mobile across sectors with high-profitable industries increasing their shares of investment at the expense of low-profitable sectors. However, if an industry has already attracted considerable investment funds giving it a high rate of capital growth, then it must have a higher expected rate of return to attract the marginal investor. This specification may be written in linearized percentage-change form equation as follows:

$$\widehat{ror}_{i,r} - ror_r = \varepsilon_{i,r} \cdot \left[\hat{\imath}_{i,r} - i_r\right] \qquad \text{(I-1)}$$

where $\widehat{ror}_{i,r}$ and ror_r are, respectively, the regional rate of return in industry i and the economy-wide rate of return in region r, $\hat{\imath}_{i,r}$ and i_r are, respectively, the real level of investment in industry i of region r and aggregate real investment in region r, and $\varepsilon_{i,r}$ is a positive parameter defining the sensitivity of regional investment allocation across sectors. The regional rate of return in industry i and is determined as part of the regional sub-system of equations for capital and investment at the industry level.

Equation I-1 can be interpreted as the risk-return trade-off in Markowitz's portfolio theory, where relatively fast growing industries calling for risk premia and relatively slow growing industries accepting discounts on their rates of return. Industries reporting relatively strong growth in capital stock in a particular region require relatively large increases in rates of return in comparison to the average rate of return in the region. Conversely relative small or negative increases in rates of return

[1] Note that the stylized CGE model assumes that the volume of net trade has to adjust to reconcile changes in real GDP with changes in real domestic absorption via the real exchange rate, as real GDP is determined from the income side and domestic absorption depends on real GDP. This assumption is however not part of the standard closure in our global dynamic model.

compared to the economy-wide rate of return result for industries with relatively weak growth in capital stock.

2.3 Stock-flow accumulation relations

Capital is an important issue in dynamic general equilibrium modelling since it may refer to two different notions including different assumptions regarding its mobility. The two notions are on the one hand, the value of physical capital stocks and, on the other hand, the position of financial assets for private households. The former is related to the domestic rental market of capital services while the latter takes the form of claims on earnings from domestic physical capital as well as from foreign capital stocks.

Specification of capital mobility revolves around three dimensions:

1 Sectoral dimension: mobility of capital across sectors;
2 Spatial dimension: mobility of capital across borders; and
3 Temporal dimension: mobility of capital across periods.

A variety of contexts may arise from different combinations of the above-listed situations. The issues of capital mobility thus differ depending on the particular context considered, and so do the set of possible treatments.

In our model, capital stock is assumed to be specific to each sector as well as to each region. Across border mobility of physical capital is not realistic as it fails to capture important aspects of foreign investments (Goulder, Shoven, & Whalley, 1983). In addition actual trade statistics do not show much evidence of movement of old machines, equipment, and structures (Bovenberg & Goulder, 1991). With this specification of capital mobility, capital stock sustains differential rates of return in equilibrium across sectors as well as across regions.

In a closed economy, regional saving equals regional investment. In a global economy, regions are linked not only through trade in goods and services but also through financial capital flows representing claims on earnings to the ownership of physical capital. As a consequence, regional saving may diverge from regional investment due to international capital mobility. Financial assets are assumed to be perfect substitutes and may move freely across regions. Mobility of financial capital across borders has to be viewed mainly in the form of movement of funds[2], which then get translated into movement of capital goods through external trade. In this view, physical capital does not change location. Instead, it gets run down through depreciation. Funds coming from depreciation finance capital formation in the economy of destination. In this way, physical capital becomes fungible and can take whatever concrete form is necessary in the new economy.

As a starting point, we do not intend to represent bilateral ownerships of physical capital stocks in our model, but assume a single market for financial assets. All the regional saving not allocated to domestic investment forms foreign investment and thus distributed across regions to capital formation. The allocation of savings between domestic and foreign investment respects the

[2] Foreign direct investment is a very important form of savings moving across borders. They represent acquisition or construction of physical capital by foreigners in one country providing an immediate financial inflow. Foreigners accumulate then a claim on the future earnings of their acquired capital.

observed home bias in equity portfolios (French & Poterba, 1991). Specifically, it is assumed that the initial share of each regional household's wealth in domestic and foreign firms and the initial share of each region's capital stocks owned by domestic and foreign residents are held constant, subject to the regional saving and investment accounting constraints (Ianchovichina & McDougall, 2012).

In the real world, firms cannot instantaneously adjust physical capital. They face building lags and delivery lags. To reflect this reality, discrete-time models typically follow the time-to-build approach, which assumes that it takes time to change the capital stock. Particularly, they assume a one period lag for investment to come on line. As capital stock depreciates at a constant geometric rate, it means that the net increase in the stock of physical capital between any two adjacent time periods equals gross investment less depreciation. For reasons exposed in section 3.1, we adopt however a continuous-time approach, which means that, in the stylised model, the linearized percentage-change form of the stock-flow accumulation is given by the following equation:

$$k = 100 \cdot \frac{I}{K} \cdot dt \qquad \text{(R-19)}$$

where K and I are the current values of capital stock and net investment, respectively, and dt the length of the time interval. As a consequence, our model does not incorporate explicit representation of gestation lags, as typically is the case in discrete-time models.

2.4 Regional investment theory

As mentioned at the beginning of this section, we introduce to our global model adaptive expectations or lagged adjustment in investment. This treatment of investment has two important consequences. First, it will soften investment volatility as a response to price changes due to the lack of any gestation lags or adjustment costs mechanism in the model. Second, it will allow reconciling the theory of investment with observed reality.

In many cases, the level of investment in the benchmark data (resulting from the national statistics) is inconsistent with the level calculated with the equations of the model using the rate of return. In particular, observed levels of investment in some regions may be very low, while observed rates of return may be very high in these regions. This suggests that investment does not move across regions according to the theory on capital mobility. As we acknowledge that empirical reality is more important than theory, the model incorporates errors in investors' expectations about actual rates of return, so that observed investment levels are now consistent with theoretical predictions.

The investment theory of adaptive expectations comprises the following four equations:

Adaptive expected rate of return, $eror$

$$eror = -\varepsilon_{ROR} \cdot [k - 100 \cdot KGR \cdot dt] - 100 \cdot \kappa_{EROR} \cdot \ln \frac{EROR}{ROR} \cdot dt \qquad \text{(R-20)}$$

Target rate of return, $tror$

$$d\_roregr = \kappa_{ROREGR} \cdot [tror - eror] \qquad \text{(R-21)}$$

Long-run rate of growth in capital stock, d_kgr

$$d\_kgr = \kappa_{KGR} \cdot \left[k + \frac{ror}{\varepsilon_{ROR}} - 100 \cdot KGR \cdot dt\right] \tag{R-22}$$

Expected rate of growth in rate of return, d_roregr

$$d\_roregr = -\varepsilon_{ROR} \cdot \frac{I}{K} \cdot [i - k] + \varepsilon_{ROR} \cdot d\_kgr \tag{R-23}$$

This system of equation determines the forward-sloping regional supply of investment funds and allows perfect capital mobility only over the long run as regional rates of return gradually adjust towards a world-wide common target rate.

2.5 Macroeconomic closure

Comparative-static single- and multi-region models face the issue of explaining aggregate investment (Robinson, 2006). Dynamic models are no exception to the rule and the approach adopted in this model is to assume a neoclassical closure along the lines of the GTAP model (Hertel & Tsigas, 1997). In this closure, global investment is driven by savings, which means that, at the global level, investment adjusts to accommodate savings.

Under the disequilibrium approach for modelling international capital mobility, the allocation of investment across regions do not implies equalisation of rates of return across regions instantaneously, but only in the very long run, which translates into the following condition:

$$tror_r = tror\_r \tag{G-1}$$

where $tror_r$ and $tror\_r$ are, respectively, the target gross rate of return to capital stock in region r and the world-wide common target gross rate of return to capital stock.

Another set of international equilibrium conditions in the model is related to international shipping services. As described previously, each region contributes to a global transportation sector in fixed shares. The zero-profit condition ensures that the value of inputs per unit activity is equal to the value of output in the production of each of the international margins. Aggregate demand for each international transport service is the sum of all bilateral demands for moving commodities between regions and is required to meet aggregate supply for the market-clearing condition to be satisfied.

3 Empirical Implementation

3.1 Formulation

The model is formulated as a system of linearized equalities derived from a highly nonlinear system of equations representing behavioural and definitional relationships exposed in the previous section. For each year the model may be expressed in the levels as:

$$F(X,Y) = 0 \tag{F-1}$$

where F is a vector of m twice differentiable functions of the l vector X of exogenous variables and the n vector Y of endogenous variables, $X \in \mathbb{R}_+^l$, $Y \in \mathbb{R}_+^n$, and $l + n > m$. The linear, or first-order, approximation can be written in the following compact form (Johansen, 1960):

$$y = -[F_Y \cdot Y]^{-1} \cdot [F_X \cdot X] \cdot x \tag{F-2}$$

where F_X and F_Y are matrices of the derivatives of F with respect to X and Y, respectively, and x and y are vectors of percentage changes in exogenous and endogenous variables. Using the GEMPACK economic modelling software (Harrison & Pearson, 1996), the exact solution for the vector of endogenous can be extrapolated through a multistep computation process (Dixon, Parmenter, Sutton, & Vincent, 1982).

In terms of dynamics, the model assumes that time is not a discrete index but a continuous variable for two major reasons. The first reason is that it involves the use of the same capital accumulation equation for any time interval as it includes no parameters that depend on the length of the time step for the simulation. The second reason is the specification of the time period length at run time rather than in the data base. The separation of the model theory from the length of the time period allows the model to be applied at run time either in comparative static mode or dynamic mode, and in the latter case to include time intervals of different lengths (e.g. years, quarters, etc.). Our model is typically run with three different interval lengths. The first time period comprises several years and is intended to bring the 2011 base year database to the initial period of interest, which is the year 2014 in this study. The second length of time intervals involves quarters of years as the objective is to produce detailed industry forecasts. The last type of interval length is the year for medium-term time horizon and could be increased to five-year time periods for long-term time horizon.

3.2 Closures

Any calibration of a general equilibrium model starts with the specification of the set of naturally exogenous variables so that there are as many independent equations as endogenous variables left in the system. Naturally exogenous variables are normally not explained in a CGE model. These are usually observable variables such as tax rates and unobservable variables such as technology and preference variables.

Our global economic model can be configured to run in one of two modes:

1 Comparative static mode; or
2 Recursive-dynamic (period-to-period) mode.

Table 1: Equation summary of the stylized model

<table>
<tr><th></th><th>Closure type</th><th>Structural closure</th><th>Static SR closure</th><th>Static LR closure</th><th>Dynamic closure</th></tr>
<tr><td></td><td>Exogenous variables</td><td>k, l
$d\bar{t} = 0$</td><td>k, rw
$d\bar{t} = 0$</td><td>$l, \psi_{I/K}$
$d\bar{t} = 0$</td><td>l, f_K
$d\bar{t} = 1$</td></tr>
<tr><td></td><td>Equations</td><td colspan="4">Endogenous variables for the specified closure</td></tr>
<tr><td>R-1</td><td>$k - l = \sigma_{KL}(p_L - p_K)$</td><td>$p_L$</td><td>$l$</td><td>$p_L$</td><td>$p_L$</td></tr>
<tr><td>R-2</td><td>$p_K = ror - S_X \cdot tot + S_T \cdot \bar{t}$</td><td>$ror$</td><td>$ror$</td><td>$ror$</td><td>$ror$</td></tr>
<tr><td>R-3</td><td>$p_L = rw - S_X \cdot tot + S_T \cdot \bar{t}$</td><td>$rw$</td><td>$p_L$</td><td>$rw$</td><td>$rw$</td></tr>
<tr><td>R-4</td><td>$S_K \cdot p_K = -S_L \cdot p_L + \bar{a}$</td><td>$p_K$</td><td>$p_K$</td><td>$p_K$</td><td>$p_K$</td></tr>
<tr><td>R-5</td><td>$p_{MP} = p_{FC} + S_T \cdot \bar{t}$</td><td colspan="4">$y_{FC}$</td></tr>
<tr><td>R-6</td><td>$i - k = \psi_{I/K}$</td><td colspan="2">$\psi_{I/K}$</td><td>k</td><td>$\psi_{I/K}$</td></tr>
<tr><td>R-7</td><td>$p_C = p_{MP} - S_X \cdot tot$</td><td colspan="4">$c$</td></tr>
<tr><td>R-8</td><td>$c = \bar{y}_C + (y_{MP} + p_{MP}) - p_C$</td><td colspan="4">$p_C$</td></tr>
<tr><td>R-9</td><td>$p_G = p_C + \bar{f}_G$</td><td colspan="4">g</td></tr>
<tr><td>R-10</td><td>$g = \bar{y}_G + (y_{MP} + p_{MP}) - p_G$</td><td colspan="4">$p_G$</td></tr>
<tr><td>R-11</td><td>$rer = e + \bar{p}_W - p_{MP}$</td><td colspan="4">$rer$</td></tr>
<tr><td>R-12</td><td>$m = y_{MP} - \sigma_M \cdot rer$</td><td colspan="4">$m$</td></tr>
<tr><td>R-13</td><td>$x = \bar{y}_W - \varepsilon_X \cdot rer$</td><td colspan="4">$x$</td></tr>
<tr><td>R-14</td><td>$tot = {}^{x}/_{\varepsilon_X} - \bar{p}_W + \bar{f}_X$</td><td colspan="4">$tot$</td></tr>
<tr><td>R-15</td><td>$y_{MP} = S_C \cdot c + S_G \cdot g + S_I \cdot i + (S_X \cdot x - S_M \cdot m)$</td><td colspan="2">$e$</td><td colspan="2">$p_{MP}$</td></tr>
<tr><td>R-16</td><td>$y_{FC} = S_L \cdot l + S_K \cdot k - \bar{a}$</td><td colspan="4">$p_{FC}$</td></tr>
<tr><td>R-17</td><td>$y_{MP} = S_{FC} \cdot y_{FC} + S_T \cdot \bar{y}_T$</td><td colspan="4">$y_{MP}$</td></tr>
<tr><td>R-18</td><td>$y_{MP} + p_{MP} = S_{FC} \cdot y_{FC} + p_{FC} + S_T \cdot (\bar{t} + \bar{y}_T)$</td><td colspan="2">$p_{MP}$</td><td colspan="2">$e$</td></tr>
<tr><td>R-19</td><td>$k = 100 \cdot \frac{I}{K} \cdot d\bar{t} + f_K$</td><td colspan="3">$f_K$</td><td>$k$</td></tr>
<tr><td>R-20</td><td>$eror = -\varepsilon_{ROR} \cdot [k - 100 \cdot KGR \cdot d\bar{t}]$
$-100 \cdot \kappa_{EROR} \cdot \ln \frac{EROR}{ROR} \cdot d\bar{t} + f_{EROR}$</td><td colspan="4">$eror$</td></tr>
<tr><td>R-21</td><td>$d\_roregr = \kappa_{ROREGR} \cdot [tror - eror]$</td><td colspan="4">$tror$</td></tr>
<tr><td>R-22</td><td>$d\_kgr = \kappa_{KGR} \cdot \left[k + \frac{ror}{\varepsilon_{ROR}} - 100 \cdot KGR \cdot d\bar{t}\right]$</td><td colspan="4">$d\_kgr$</td></tr>
<tr><td>R-23</td><td>$d\_roregr = -\varepsilon_{ROR} \cdot \frac{I}{K} \cdot [i - k] + \varepsilon_{ROR} \cdot d\_kgr$</td><td colspan="4">$d\_roregr$</td></tr>
<tr><td>G-1</td><td>$tror_r = tror\_r$</td><td colspan="4">i_r</td></tr>
<tr><td>G-2</td><td>$i_r = f_{I,r} + \bar{f}_I\_r$</td><td colspan="4">$f_{I,r}$</td></tr>
</table>

Note that all variables (except $d\bar{t}$) in equations R-1 to R-23 are indexed by region.

The stylized dynamic model developed in this paper comprises 23 equations and 36 variables at the regional level (Equations R-1 to R-23 in Table 1). Ten variables are regarded as naturally exogenous in this model and are denoted with a bar on top of the symbol[3], which leaves 26 variables to be determined. As the model satisfies Walras Law and so can't determine the general price level, one equation is redundant and one variable has to act as the numeraire. The equation is the definition of the regional nominal income (Equation R-18) and the numeraire is the nominal exchange rate. Therefore the equation is omitted and the nominal exchange rate is exogenized. This leaves three more variables to be made exogenous.

The allocation of regional investment is assumed to be determined at the global level and thus the level of investment in each region can be thought of as exogenous (Equation G-1[4]). The last two exogenous variables are the supply of labour, which is primarily determined by demographic factors and technological change and the arbitrary shift variable in capital stock.

In comparative static mode, the model indicates the effects of specified policy changes over a time span of between 1 and 10 years, depending on the closure chosen. However, only the assumptions about which variables are fixed and the interpretation of the results bear on the timing of changes since the model itself is atemporal.

Compared to the dynamic model, the shift variable in capital stock is endogenous in the stylized static model so that capital stock can be either exogenous or endogenous (Equation R-19). Therefore there are again two last variables that need to be exogenous and the choice is associated with the time that would be needed for economic variables to adjust to a new equilibrium.

Typical comparative-static closures have one endowment endogenous between labour and capital. In short-run comparative-static simulations, the capital stock ($\bar{k}$) and real wage rate ($\overline{rw}$) are typically exogenous, allowing the model to determine values for employment (l) and the ratio of investment to capital ($\psi_{I/K}$). In long-run comparative-static simulations, employment ($\bar{l}$) and the ratio of investment to capital ($\bar{\psi}_{I/K}$) are exogenous, allowing the model to determine values for capital (k) and the real wage rate (rw).

It is worthwhile to note that in the static mode, the system of Equations R-20 to R-23 simplifies and may be expressed in the following form:

$$tror = ror - \varepsilon_{ROR} \cdot \frac{I}{K}(i - k)$$

where ε_{ROR} is the sensitivity of investment to target rate of return reflecting assumptions made on the mobility of international investment flows. In this equation the expected rate of return on capital at the regional level depends positively on the current rate of return and negatively on future investment, which can be shown to be similar to Equation G-2 in our static CGE model (Cretegny, 2014).

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[3] Variables denoted in capital letters and variables denoted in Greek letters are exogenous as they represent, respectively, coefficients and parameters.

[4] To be precise, Equation G-1 determines investment in all regions except one as it is constrained by the equilibrium condition between global investment and global savings. This one degree of freedom of investment allows the determination of the common world risk-adjusted rate of return, $tror\_r$.

3.3 Calibration of the model

The model is calibrated to the newly-developed GTAP 9 database data (Narayanan, Aguiar, & McDougall, 2015) and uses the state of the world economy in 2011 as a starting point of our simulations.

The full database includes three years (2004, 2007 and 2011) and covers 140 countries/regions and 57 commodities/sectors, as well as eight endowments. For the purpose of our work, the database is aggregated to the 51 largest countries in terms of nominal GDP and 9 regions (see Appendix A-1 for the list of countries/regions). World GDP in 2011 is equal to $US 71,477,147 million and the 50 largest countries account for approximately 94 per cent of world GDP. Within the 57 sectors, the original database features sub-industries in agriculture, livestock, food processing, and a few in manufacturing. As these are not relevant to our analysis, they are aggregated to finally distinguish between 35 sectors (see Appendix A-2 for the list of sectors). Finally primary factors include land, natural resources, capital and two types of labour, unskilled and skilled labour.

The model relies primarily on three type of substitution/transformation elasticity parameters: the elasticity of substitution between primary factors in production, the elasticity of substitution in the Armington nesting structure, and the elasticity of transformation between sectors for sluggish primary factors. Values for these parameters are also based on the GTAP 9 database.

In addition we assume a unitary elasticity for the sensitivity of regional investment allocation across sectors in Equation I-1. Values of the remaining parameters and coefficients for the dynamic equations are derived similarly to the dynamic GTAP model (McDougall, Walmsley, Golub, Ianchovichina, & Itakura, 2012).

4 Illustrative Application

The main purpose of this section is to present an illustrative application of the developed model.

The potential economic consequences of the collapse of the world economy make use of two sets of results from the global economic model, namely:

- baseline results that forecast how the world economy might be expected to change over the forecast horizon; and
- counterfactual results that forecast the world economy if it collapses similarly to the GFC in 2009, and are compared against the baseline results to determine the incremental economic impact.

The development of baselines and the description of the experiment design are provided in the next two sections, while the results of the baseline and counterfactual simulations are reported in the two subsequent sections.

4.1 Development of baselines

Quarters throughout a year can vary, showing seasonal fluctuations or changes in ordering activity, which means that quarterly forecasting is essential for corporate valuation models (e.g. market capitalisation forecasting) or for comparing the current quarter's performance to that of the previous year. In addition policy analysis can also be sensitive to the future trajectory of the world economy. In order to assess the consequences on the forecasted variable of different time interval we develop three different baselines:

1 Baseline with interval length of one year;
2 Baseline with interval length of one quarter between the years 2015 to 2017, but applying yearly shocks spread uniformly across quarters; and
3 Baseline with interval length of one quarter between the years 2015 to 2017, and applying quarterly shocks.

The development of the baselines builds upon the work from GTAP (Walmsley, Dimaranan , & McDougall, 2012). The macroeconomic variables in the database include projections for GDP, gross domestic investment, government and private consumption, imports and exports, skilled and unskilled labour, and population by age groups. These projected values were obtained for 226 countries starting in 2005 up to different end years depending on the type of data and on the data provider. As a starting point, only projections of labour force (skilled and unskilled labour) and population are drawn from this work to develop the baselines.

Projections for real GDP are derived directly from our in-house global VAR (GVAR) model[5]. Our quarterly global VAR model links individual country vector error-correcting models in which domestic variables are related to corresponding trade-weighted foreign variables (Dées, di Mauro, Pesaran, & Smith, 2007). Our GVAR model is estimated for the 50 largest countries in the world. The set of country-specific variables in our GVAR model include real GDP, inflation, real equity prices, real exchange rate, and short-term and long-term interest rates. The model also takes account of global variables including oil price and commodity price indices.

Projections for capital stocks are endogenous to the model as they results from the accumulation of projected investment. Changes in endowments that don't explained changes in real GDP are attributed to technical changes in all primary factors except capital. In terms of our stylized model, this means that the technology shift variable a is endogenous whereas GDP at market price y_{MP} is exogenous.

4.2 Experimental design

The design of experiments considers five simulations, as shown in Table 2. All simulations apply the same policy scenario but use a combination of different time intervals in the baseline as well as in the counterfactual. In both the baseline and the counterfactual, shocks can be specified on a quarterly basis or on a yearly basis and spread uniformly across the quarters[6] (lower-right corner in Table 2). Finally, in addition to running the model at quarterly periodicity, the last simulation uses the standard assumption of yearly periodicity (upper-left corner in Table 2).

[5] Special thanks go to my colleague Yong Jortzik-Yan for developing the GVAR model and being able to produce these forecasts in due course.

[6] Results are however only reported for simulations that specify the baseline and the counterfactual with the same length of time interval, as the two remaining specifications do not bring much to the discussion (e.g. policy analysis is not significantly sensitive to the length of the period in the baseline).

Table 2: Simulations considered in the illustrative application

	Baseline specification		
Counterfactual specification	Yearly shocks	Quarterly-applied yearly shocks	Quarterly shocks
Yearly shocks	BYRS_PYRS		
Quarterly-applied yearly shocks		BQYR_PQYR	BQYR_PQTR
Quarterly shocks		BQTR_PQYR	BQTR_PQTR

The underlying story of the hypothetical policy scenario is a serious downturn of the world economy similarly to the Global Financial Crisis. Today the world economy is more interconnected than ever. Crisis becomes contagious as it is shown by the crisis in Thailand that spread across Asia at the end of the last century or more recently the crisis in Greece that contaminated Europe.

According to Arturo Bris, Professor of finance at IMD, Switzerland (Bris, 2014), there is, on average, one crisis every 58 months (using data from the US National Bureau of Economic Research between 1945 and 2008). In other words, statistically speaking the beginning of the next crisis would be around April 2015 and would end by March 2016.

In this hypothetical scenario, it is assumed that the world economy contracts considerably in 2015 along the same magnitude to the severe recession in 2009 resulting from the global financial and economic crisis. This world-wide downturn is simulated by targeting changes in real GDP and investment in 2015 to those changes that occurred in 2009. Similarly to the baseline, these shocks are imposed either on a yearly basis, or uniformly across quarters, or within the first quarter only. Using the data and the program from the Center for Global Trade Analysis (Walmsley, Dimaranan , & McDougall, 2012), the 2009 changes in real GDP and gross domestic investment are aggregated to our model aggregation and are reported in Table 3.

Table 3: Policy shocks considered in the illustrative application (annual percent change)

	Investment			Real GDP		
Regions	2015	2015:Q1-Q4	2015:Q1	2015	2015:Q1-Q4	2015:Q1
ASPAC	-17.23	-4.62	-17.23	-4.04	-1.03	-4.04
BRICS	8.83	2.14	8.83	4.45	1.10	4.45
EFTA	-9.01	-2.33	-9.01	-1.72	-0.43	-1.72
Euro Zone	-16.96	-4.54	-16.96	-4.09	-1.04	-4.09
Latin America	-13.60	-3.59	-13.60	0.38	0.10	0.38
Middle East	-29.35	-8.32	-29.35	-2.68	-0.68	-2.68
NAFTA	-19.03	-5.14	-19.03	-2.81	-0.71	-2.81
NEZEU	-22.00	-6.02	-22.00	-4.34	-1.10	-4.34
OPEC	6.08	1.49	6.08	2.14	0.53	2.14
ROW	-5.68	-1.45	-5.68	-0.13	-0.03	-0.13

The imposition of investment targets to the global model is undertaken in two steps. The first involves the adjustment of expected rates of return to meet specified changes in investment by introducing errors in expectations. Since global investment is savings-driven, the second step needs to adjust regional investment levels to accommodate global savings. In other words, investment targets are only imposed on regional shares in world investment. In terms of our stylized model, the investment targets $\overline{f}_{I,r}$ are now exogenous and shifts in expected rate of return f_{EROR} are endogenous. The global level of savings is accommodated by letting f_I_r vary and making exogenous, $tror\_r$, the world-wide common target gross rate of return to capital stock.

In the counterfactual real GDP is imposed to the model by assuming that the 2015 hypothetical crisis causes an immediate but temporary decrease in efficiency and return to capital. Similarly to the baseline case, this means that, in our stylized model, the technology shift variable a is endogenous and GDP at market price y_{MP} is exogenous.

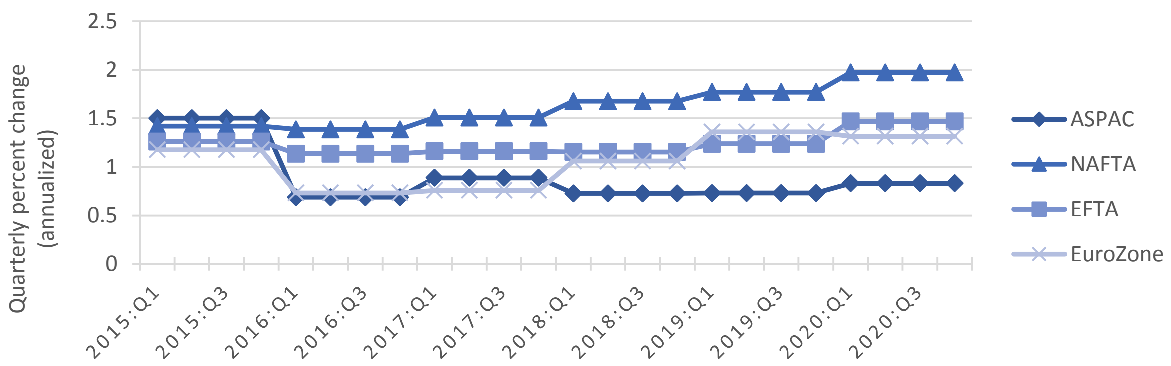
As mentioned earlier, both shocks are temporary and happen only in 2015 or part of 2015. From 2016 it is assumed that the investment theory drives again the investment allocation across regions. Similarly capital efficiency returns to baseline levels by 2016.

4.3 Baseline simulation results

Projections for only selected regions and variables are presented in this section. We focus particularly on the first three years as they are built on forecasts derived from different length of time interval.

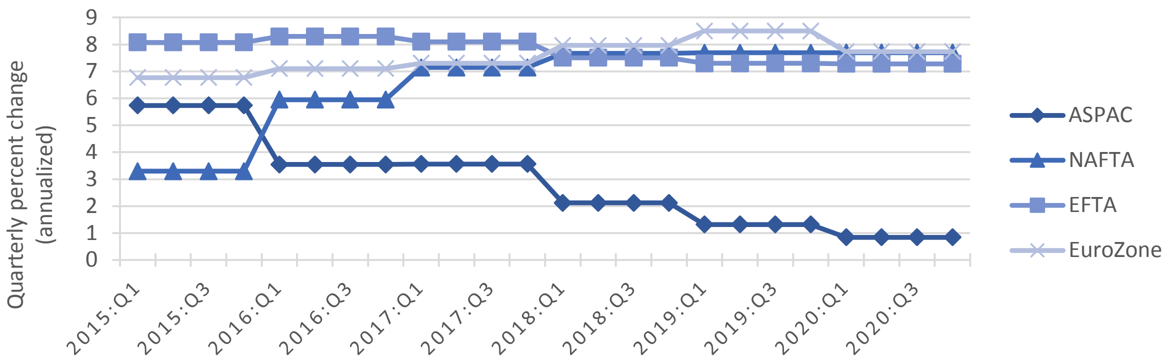
Real GDP forecasts produced by our global VAR model and imposed to the global CGE model are presented in Figure 1. The increase in 2015 is supported by the decline in oil prices, which once internalized will reduce marginally GDP growth in 2016. Regional growth is forecast to increase slightly beyond 2016 with the United States playing the most important role. These forecasts are broadly in line with those published in the World Economic Outlook (International Monetary Fund, 2015) or in the OECD Economic Outlook (OECD, 2015) which are the most easily accessible and by far the most frequently analysed in the literature.

Figure 1: Quarterly real GDP growth, forecasts from 2015 to 2020



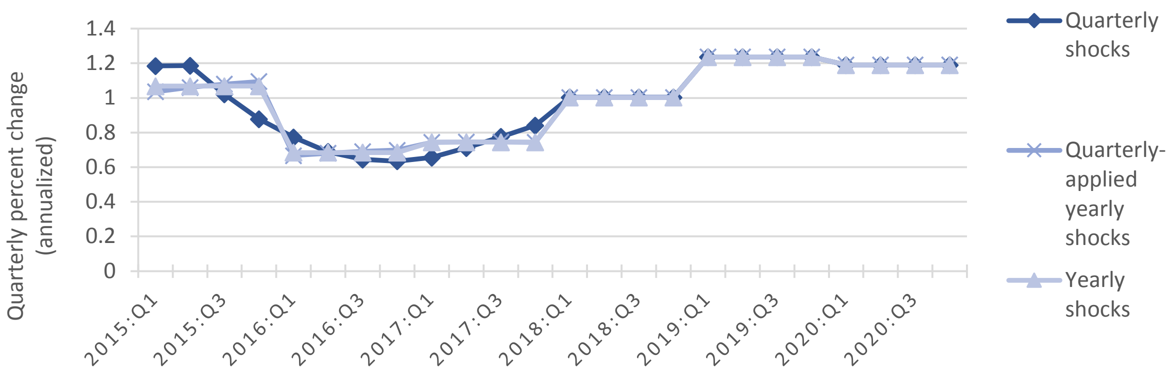
At the global level, the rise of real GDP growth around the world pushes both investment and the cost of buying capital goods up, which translates into an increase in capital stock and thus lower rental price. As investment is more costly and rental rate on capital is lower, rate of return on capital stock drops significantly worldwide, but not uniformly across all regions. Global saving is allocated across regions to those investments with the relative highest rate of return. Declines in rate of return in NAFTA and in the Euro Zone are least pronounced, which explains the significant level of investment for these two regions, as shown in Figure 2. In the case of ASPAC, the decline in investment is more likely to be the result of a significant amelioration of the trade balance.

Figure 2: Quarterly real investment growth, forecasts from 2015 to 2020



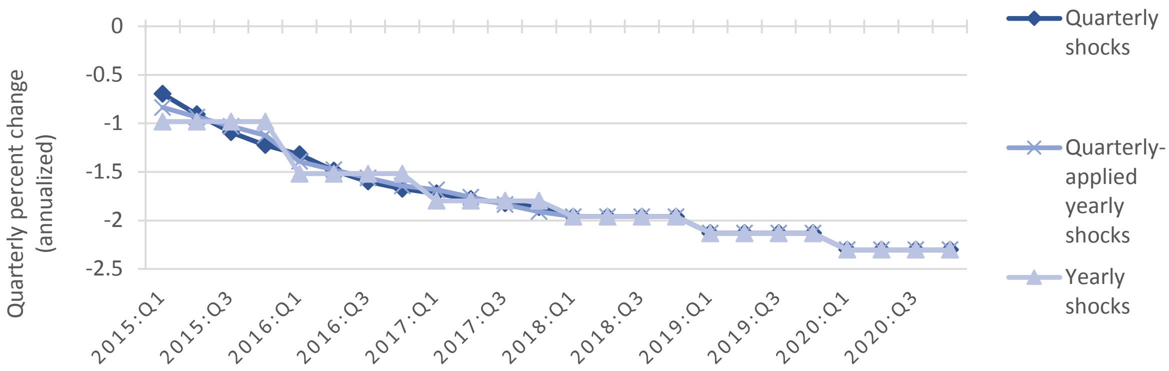
Drilling down at the regional level, Figure 3 depicts the projected impact on output for the insurance sector in the Euro Zone. It follows quite closely forecasts of real GDP in that region. In terms of interval-differentiated profile, projections based on yearly shocks or quarterly-applied yearly shocks are not significantly different, as yearly shocks are distributed uniformly across quarters. However, when quarter-specific shocks are applied, the difference can be quite significant, in particular when there are rapid changes as illustrated over the year 2015 in Figure 3.

Figure 3: Quarterly insurance output growth in the Euro Zone, forecasts from 2015 to 2020



As mentioned earlier, quarterly forecasting is essential for corporate valuation models, in particular when these models use inputs derived from economic models. Specifically this is the case for market capitalisation forecasting, where one of the input is the regional rate of return of our global economic model. Using the rate of return for the insurance sector in the Euro Zone, Figure 4 shows the different time profiles when applying interval-differentiated shocks. Similarly to the output in that sector, the rate of return can be significantly different when applying quarter-specific shocks. In the first quarter of 2015, the difference in the rate of return can be as much as 30 percentage points when using yearly shocks but can be reduced by half when applying these shocks on a quarterly basis.

Figure 4: Quarterly insurance rate of return growth in the Euro Zone, forecasts from 2015 to 2020



The implication for market capitalisation forecasting can be estimated using the simple constant dividend growth rate model (Gordon & Shapiro, 1956). For a stock that moves similarly to the market, it can results in a difference of approximately 6 to 12 cents per dollar of book value.

4.4 Counterfactual simulation results

In this section, the results of a hypothetical downturn of the world economy in 2015 are discussed. Again we focus particularly on the first three years as the results are compared to their corresponding baselines that are developed with projections derived from different length of time interval.

A direct consequence of the shock specification in the counterfactual is the drop in real investment during the year 2015. In Figure 5 however, regional investment is higher than the shock specification as global savings does not fall as much as global investment. As a consequence, the downward shift in actual rates of return is compensated by a shift upwards of expected rates of return as shown in Figure 6. After 2015 the crisis is over and the relative attractiveness of investment depends again on expected rates of return moving gradually towards equality across regions in the long run.

Figure 5: Quarterly real investment, from 2015 to 2020

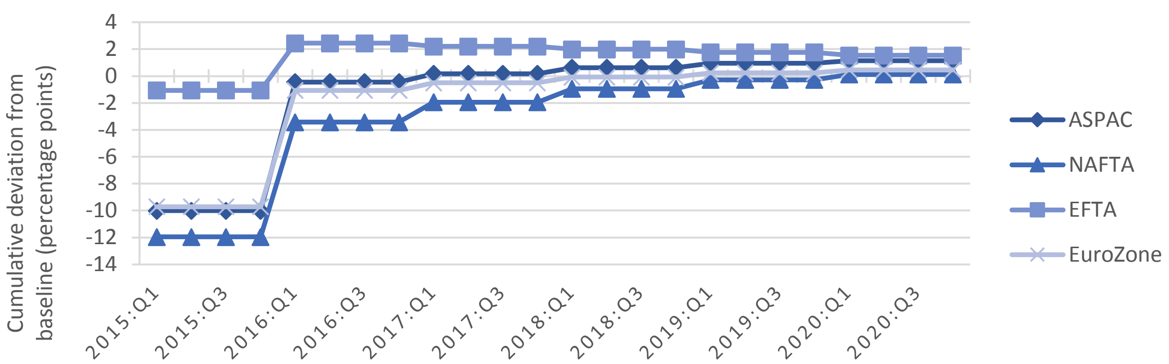
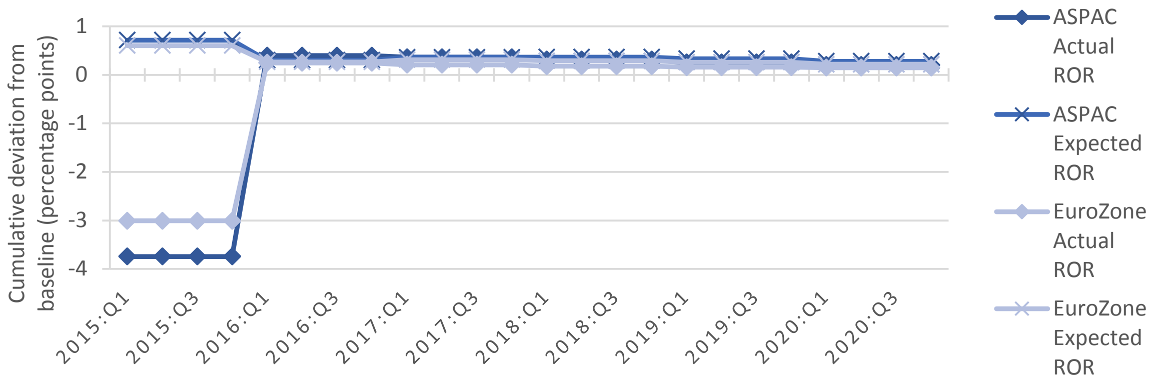
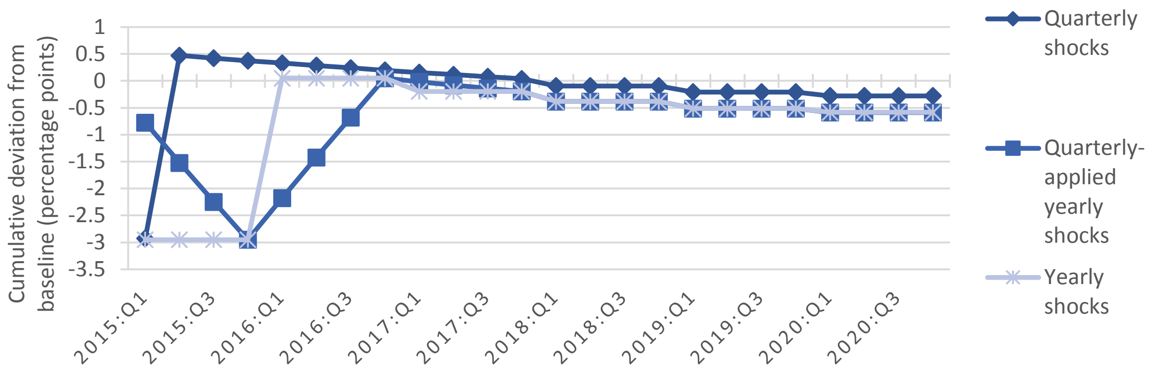


Figure 6: Quarterly expected and actual rates of return in ASPAC, from 2015 to 2020



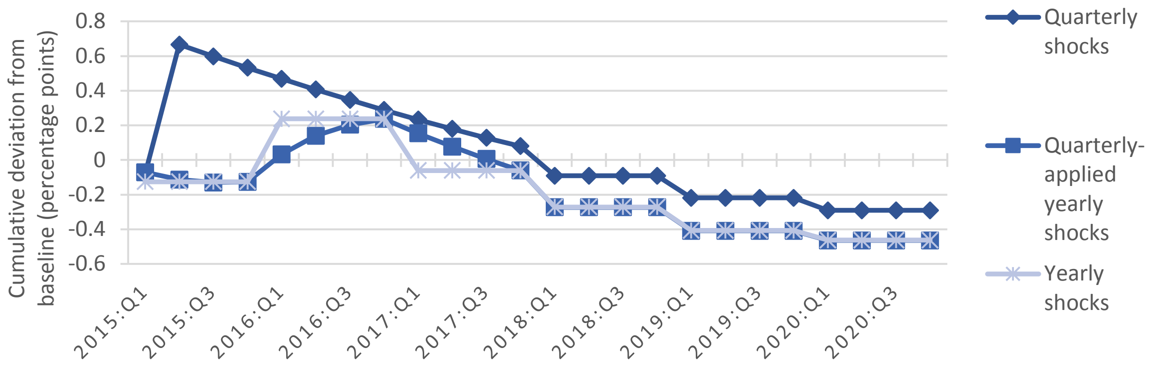
The contraction of the global economy in 2015 has naturally adverse consequences in all sectors. However, depending on the length of time interval in the model, the timing of the shocks is different and so is the adjustment path of the different variables. When the model is specified with annually periodicity, the transition path is relatively abrupt, as shown in Figure 7 for the light manufacturing industry. If the timing of the shocks is undefined, this can still be improved by applying uniform shocks to a model with quarterly periodicity. The time path of both shock and recovery phases is much smoother in that case. When the timing of the shocks is known, the adjustment path can be determined more accurately, and consequently can decrease the underestimation or the overestimation of the impacts.

Figure 7: Quarterly light manufacturing output in the Euro Zone, from 2015 to 2020



In terms of consequences for a company's market capitalisation, the timing of the shocks can lead to different impacts on rates of return as illustrated in Figure 8. However the differences are not significant compared to the differences resulting from interval-differentiated baselines.

Figure 8: Quarterly light manufacturing rate of return in the Euro Zone, from 2015 to 2020



5 Further Developments

5.1 Baseline improvement

Structural change is important to economic growth. Structural change is influenced by many factors, including technological changes and shifts in consumer preferences. These factors have an important impact on economic performance through the reallocation of resources from one economic activity to another and should complement the macroeconomic forecasts in developing the baseline.

The difficulty in the estimation is that household preferences and industry technologies are naturally exogenous variables and are not observable. This difficulty can be overcome by first conducting an historical simulation. In this simulation, variables that can be observed across the period 2001 to 2007 are exogenous and shock with their actual movements. On the other hand, naturally exogenous but unobservable variables are made endogenous. Once the historical simulation has been completed, a decomposition simulation can be conducted. In this simulation, estimates of unobservable exogenous variables are used to explain structural change in the economy across the period in consideration. Due to the considerable amount of data required to undertake the estimation, the application of historical and decomposition simulations to the world economy is very limited (Walmsley & Strutt, 2009).

Another development in the baseline is the specification of investment. Projection data for gross domestic investment are key in determining regional rates of return on capital stock so that investment forecasts produced by our global VAR model are imposed to the global economic model.

5.2 Theoretical extensions

The first developments in the global CGE model is to represent lagged adjustment in the labour market. Avoiding extreme assumptions in the labour market, we assume that real wages can be stick in the short-run and flexible in the long-run (Dixon & Rimmer, 2002). In each region, the labour market is assumed to be consistent with an exogenous level of regional unemployment below which inflation rises. In the long-run, the underlying labour supply is not influenced by policy changes, but is primarily determined by demographic factors and technological changes. However, in the short-run, favourable shocks may generate a change in unemployment at the regional level, but real wage rates will eventually respond to take unemployment back to its initial level, which results in long-run changes in real wages.

Another extension very appropriate when dealing with large private corporations is related to increasing returns to scale. For a small number of firms within a market, company's decisions may influence one another so that market power may vary between them. These oligopolistic interactions between firms lead to more sensitive variation of their rates of return to capital.

Further development may also consider the treatment of capital supply to allow differentiation of rates of return between equities and bonds so that bilateral ownership of capital can be determined.

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Appendix

A-1. List of Countries in the GTAP Database

The global CGE model is calibrated using the GTAP 9 Release Candidate 2 database for the 2011 reference year. The original database covers 140 countries/regions and 57 commodities. For the purpose of our work, the database is aggregated to the 50 largest countries in terms of nominal GDP and 10 regions, as well as to 35 industries. The countries are grouped then into ten geo-politico-economic regions. World GDP in 2011 is equal to $US 71,477,147 million and the 50 largest countries account for approximately 94 per cent of world GDP.

Region Categories	Countries	GDP	GWP Share	Rank
ASPAC – Asia-Pacific	Australia	1,387,013	1.94%	13
(15.0%)	Hong Kong	248,516	0.35%	42
	Japan	5,905,634	8.26%	3
	Korea	1,202,463	1.68%	14
	Malaysia	289,260	0.40%	37
	New Zealand	163,841	0.23%	53
	Pakistan	213,686	0.30%	48
	Philippines	224,095	0.31%	46
	Singapore	274,065	0.38%	38
	Taiwan	464,009	0.65%	27
	Thailand	345,670	0.48%	32
BRICS	Brazil	2,476,695	3.47%	6
(19.6%)	China	7,321,875	10.24%	2
	India	1,880,100	2.63%	10
	Russian Federation	1,904,794	2.66%	9
	South Africa	403,891	0.57%	30
EFTA – European Free Trade	Norway	490,812	0.69%	26
Association (1.6%)	Switzerland	658,867	0.92%	20
Euro Zone	Austria	415,983	0.58%	28
(17.9%)	Belgium	513,316	0.72%	25
	Finland	262,378	0.37%	39
	France	2,777,493	3.89%	5
	Germany	3,628,099	5.08%	4
	Greece	289,886	0.41%	36
	Ireland	226,034	0.32%	45
	Italy	2,196,334	3.07%	8
	Netherlands	832,751	1.17%	17
	Portugal	237,888	0.33%	43
	Spain	1,454,530	2.03%	12
Latin America	Argentina	557,727	0.78%	21
(1.6%)	Chile	251,162	0.35%	41
	Colombia	335,416	0.47%	33
Middle East	Egypt	236,001	0.33%	44
(1.8%)	Israel	258,216	0.36%	40
	Turkey	774,754	1.08%	18
NAFTA – North American Free	Canada	1,778,629	2.49%	11
Trade Agreement	Mexico	1,170,083	1.64%	15
(25.9%)	United States of America	15,533,787	21.73%	1
NEZEU – Non-Eurozone	Czech Republic	216,060	0.30%	47
European Union	Denmark	333,743	0.47%	34

(5.9%)	Poland	515,771	0.72%	24
	Romania	182,611	0.26%	50
	Sweden	535,997	0.75%	22
	United Kingdom	2,462,479	3.45%	7
OPEC – Organization of Petroleum Exporting Countries (4.4%)	Indonesia	845,925	1.18%	16
	Iran Islamic Republic of	528,425	0.74%	23
	Nigeria	411,744	0.58%	29
	Saudi Arabia	669,509	0.94%	19
	United Arab Emirates	348,596	0.49%	31
	Venezuela	316,482	0.44%	35
Rest of the world (6.3%)	ECCAS – Economic Community of Central African States	216,975	0.30%	
	Rest of Latin America and Caribbean	756,178	1.06%	
	Rest of European Union	584,911	0.82%	
	Rest Western Asia	552,896	0.77%	
	Rest of Asia and Oceania	450,562	0.63%	
	Rest of North Africa	379,859	0.53%	
	Rest of Africa	428,040	0.60%	
	Rest of OPEC	407,175	0.57%	
	Rest of ASPAC	372,010	0.52%	
	Rest of Europe	367,249	0.51%	

Source: GTAP 9 Data Base Release Candidate 2

A-2. List of Sectors in the GTAP Database

The following table shows the sectoral aggregation in the current CGE model. The original database includes 57 sectors, which features sub-industries in agriculture, food processing, and a few in manufacturing. As these are not relevant to our study, they have been aggregated to finally distinguish between 35 sectors. For comparison with other database, the mapping to the internationally recognised ISIC Rev. 3 classification[1] is reported but remains an approximation in some sectors (Huff, McDougall, & Walmsley, 2000). The economic measure used to represent the size of each sector is gross value added as it is the best proxy to breakdown GDP by industry.

Sector Categories	No	ISIC Rev. 3	Description	GVA	World Share
Agriculture	1	011, 02, 05	Agriculture, forestry and fishing	2,174,440	3.22%
(4.2%)	2	012-015	Live stock	641,519	0.95%
Extraction	3	10	Extraction of coal	246,344	0.37%
industries	4	11	Extraction of crude oil	2,009,731	2.98%
(4.5%)	5	11	Extraction of natural gas	297,609	0.44%
	6	12-14	Extraction of minerals n.e.c.	508,952	0.75%
Manufacturing	7	151	Production, processing and preservation of meat products	285,280	0.42%
(21%)	8	152	Manufacture of fats and dairy products	279,900	0.42%
	9	153-154	Manufacture of food products	936,164	1.39%
	10	155-16	Manufacture of beverages and tobacco	492,553	0.73%
	11	17-18	Manufacture of textiles and wearing apparel	737,069	1.09%

[1] International Standard Industrial Classification of All Economic Activities (ISIC) developed under the auspices of the United Nations.

	12	19-20	Manufacture of leather and wood products	501,895	0.74%
	13	21-22	Manufacture of pulp, paper and paper products; publishing and printing	877,696	1.30%
	14	23	Manufacture of coke, refined petroleum products and nuclear fuel	563,527	0.84%
	15	24-26	Manufacture of chemical, plastic and other non-metallic mineral products	2,742,754	4.07%
	16	27-28	Manufacture of basic metals and fabricated metal products	1,837,903	2.73%
	17	34-35	Manufacture of transport equipment	1,283,999	1.90%
	18	30, 32	Manufacture of electronic equipment	795,446	1.18%
	19	29, 31, 33	Manufacture of machinery and precision instruments	2,287,989	3.39%
	20	36-37	Manufacturing n.e.c. and recycling	512,679	0.76%
Services (70.3%)	21	401	Production, collection and distribution of electricity	991,541	1.47%
	22	402-403	Manufacture and distribution of gas	157,457	0.23%
	23	41	Collection, purification and distribution of water	261,561	0.39%
	24	45	Construction	4,306,388	6.39%
	25	50-55	Wholesale and retail trade; hotels and restaurant	7,496,609	11.12%
	26	60, 63	Land transport and auxiliary activities	2,404,303	3.57%
	27	61	Water transport	384,559	0.57%
	28	62	Air transport	338,061	0.50%
	29	64	Post and telecommunications	1,495,777	2.22%
	30	65, 67	Financial intermediation and auxiliary activities	3,332,816	4.94%
	31	66	Insurance and pension funding	848,393	1.26%
	32	70-74	Real estate, renting and business activities	6,728,587	9.98%
	33	n.a.	Dwelling	4,509,500	6.69%
	34	92-95	Recreational and other services	1,931,469	2.86%
	35	75-91, 99	Public administration, defence; compulsory social security; education, health	12,240,632	18.15%

Source: GTAP 9 Data Base Release Candidate 2