# Sector-Specific Investment in a MRIO CGE Model

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## Abstract

Concerns with the measurement of systemic risk are heightened in today's interconnected, post-GFC world. However, as it is recognised by the academic community, empirical analyses quantifying the impact of shocks to the world economy on agent risk are scarce if not inexistent. A widely used framework for performing such analysis is computable general equilibrium (CGE) modelling. This paper documents work in progress on developing a global CGE model.

A key challenge in the development of the global model lies in the combining of the strengths of the GTAP and WIOD databases. Contrary to the GTAP database, the World Input-Output Database (WIOD) does not rely on the common sourcing assumption but recognises that demand in a region for a given commodity from another region may differ across users. On the other hand, limited data are available in WIOD on taxes, tariffs and international transport margins, while the GTAP database has all the necessary data to incorporate a realistic structure of these variables into the model.

The main purpose of the simulations in this paper is to illustrate the usefulness of applying a multi-region input-output database to a CGE model. The analysis shows that, at the macroeconomic level, the advantage of a real sourcing-differentiated database is relatively insignificant. However, at the industry level, it can result in significant differences in prices that are relevant in analysing policy reforms in the global supply chain.

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# 1 Introduction

It is now widely accepted that the substantial decline in interaction costs globally has led to a widespread de-verticalization of corporate business structures. As a result large multinational corporations (MNCs) are more dependent on international supply chains, infrastructure and markets which poses a systemic threat to business as usual. Failing to manage these risks globally exposes them to increasingly massive financial losses. They need therefore to understand the full range of their activities, from the conception of the good or service through the different phases of production to delivery to final consumers. Drawing on the well-known study of the Apple iPod (Dedrick, Kraemer, & Linden, 2009), it means that the corporate should identify the value for each of the different components of the iPod flowing from an industry in a region to an industry in another region. At a macroeconomic level, it translates into tracing out trade flows between producers, consumers and investors within a region as well as bilateral trade flows between producers, consumers and investors across regions globally.

Up until recently only databases with harmonized national input–output tables (IOTs) and bilateral trade information existed for a large number of countries and for several years. The best known examples are GTAP and OECD. The GTAP database was set up in the 1990s as the result of collaboration among numerous individuals in the GTAP network and recently saw its eighth release (Narayanan, Aguiar, & McDougall, 2012). The OECD database was first developed in 1995 and updated several times and has been disseminated freely (Yamano & Ahmad, 2006).

Today global multiregional input–output (GMRIO) databases have been developed in response to increasing demand for analytical tools from policy makers and MNCs. Several projects have been formed with the goal of producing true GMRIO data bases, including EXIOBASE (Tukker, et al., 2013), WIOD (Dietzenbacher, Los, Stehrer, Timmer, & de Vries, 2013), EORA (Lenzen, Moran, Kanemoto, & Geschke, 2013) and OECD-TiVA (OECD, 2013). Work on already existing databases includes GTAP-MRIO (Walmsley, Hertel, & Hummels, 2013) and GTAP-ICIO (Koopman, Powers, Wang, & Wei, 2010).

EORA does not include the additional MRIO detail on sourcing by agent, while EXIOBASE has developed MRIO variants using the proportionality method. On the other hand, WIOD, OECD-TiVA and GTAP-MRIO/ICIO are examples of global data bases where the BEC concordance has been used to improve the sourcing splits.

This paper documents work in progress on developing a global CGE model to be used with a global MRIO database. The particularities of this model are twofold. The first particularity lies in the specification of the sourcing assumption, which is at the user level rather than at the aggregate level of users. While the common sourcing assumption has been widely used for reducing solution time in simulations, it is however not appropriate for analysing interactions between agents in international supply chains. In the Apple iPod case for example, China exports final products to final consumers while Japan exports storage devices to intermediate firms. As a consequence, under the common sourcing assumption, all users in a particular region would source the aggregated category of electronics from these two regions in common proportions, even though the sourcing share of final good would be higher.

The second particularity is the specification of investment at the industry level rather than at the aggregate level. The simulation of the impacts on industrial activity and the balance of trade of changes in foreign direct investment, for example, requires that each industry has an individual investment behaviour. 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.

An illustrative application is provided to show how additional sourcing information can change results when changes in foreign direct investment occur in a particular region. As a starting point, this application uses the WIOD database as it already includes the required sourcing assumptions.

# 2 Model Description

The global CGE model developed in this paper is along the lines of models used for applied international trade policy (Shoven & Whalley, 1984). The core theoretical specification of the 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). For the sake of clarity the model is formally described as a linearised system of equations using a stylized representation of the global economy (Adams, 2003). In this macro model, representation of inter-regional linkages is only through investment flows and not though trade in goods and services. Nevertheless, it will be useful for interpreting macroeconomic results, before providing more detailed results at the sectoral level and more comprehensive interpretations of policy simulations.

The comparative-static model consists of two components. The first component is a set of equations describing agents' behaviour, markets clearance and income balance within a region (sections 2.1 to 2.3). The second component of the global CGE model provides the linkages between the regions (section 2.4) in terms of both physical flows (e.g. goods and services) and financial flows (e.g. investment).

## 2.1 Regional behaviours

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.

### 2.1.1 Industries

Producers are assumed to maximize their profits subject to a production technology represented by a three-stage production function. The top level is a Leontief combination of intermediate inputs and value-added. Value-added is a combination of labour and capital using a constant elasticity of substitution (CES) function. With regard to intermediate demand, each individual input is represented as a composite of imported and domestic goods at the second level of the nested structure. The bottom level applies the Armington specification and allow thus differentiation of goods and services by its region of origin (Armington, 1969).

Wedges between prices paid by purchasers and prices received by producers exist in the different commodities markets. Given the limited availability of taxes in WIOD, the model currently includes only ad valorem production taxes on output and on domestic and imported intermediate inputs.

In the stylised model, the firm behaviour starts with the derivation of the relationship of the factor-intensity ratio to relative factor prices from the cost-minimization programme. The linearised percentage-change form of this relationship is given by the following equation[1]:

$$k - l = \sigma_{\mathrm{KL}}(rp_L - rp_K) \tag{R-1}$$

where $k$ and $l$ are capital stock and employment, respectively, $rp_K$ and $rp_L$ are their corresponding real price at factor cost and $\sigma_{\mathrm{KL}}$ the elasticity of substitution between capital and labour. In this perfect competition environment, the real price of capital is equal to the marginal product of capital and the real price of labour is equal to the marginal product of labour.

The real rental rate of capital at factor cost may be expressed as the product of the three following ratios:

- Ratio of the price of capital to the price of investment;
- Ratio of the price of investment to the price of GDP at market price; and
- Ratio of the price of GDP at market price to the price of GDP at factor price.

The first ratio can be interpreted as a rate of return ($ror$ in percentage change). The second ratio may be viewed as a function of the inverse of the terms of trade ($tot$ in percentage change) since the investment price includes import prices but not export prices whereas the GDP deflator includes export prices but not import prices. The final ratio is equivalent to the power of the tax rate ($t$ is an *ad valorem* average rate of indirect taxes net of subsidies in percentage change and is the only form of indirect taxation imposed in each region). The linearised percentage-change form of the real price of capital at factor cost may be then written as follows:

$$rp_K = ror - \mathrm{S_X} \cdot tot + \mathrm{S_T} \cdot \bar{t} \tag{R-2}$$

where $\mathrm{S_X}$ and $\mathrm{S_T}$ are the share of exports in GDP at market prices and the share of indirect taxes net of subsidies in market-price GDP, respectively.

Similarly, the real price of labour at factor cost may be expressed as the product of the three following ratios:

- Ratio of the price of labour to the price of private consumption;
- Ratio of the consumption price to the market-price GDP deflator; and
- Ratio of the market-price GDP deflator to the factor-cost GDP deflator.

The first ratio defines the real wage, $rw$, which is faced by households. The second and third ratios have an analogous interpretation as in the derivation for the real price of capital. The linearised

[1] For the sake of brevity, the regional dimension is omitted in section 2.1 to 2.3.

percentage-change form of the real price of labour at factor cost is then the sum of these three ratios as follows:

$$rp_L = rw - \mathrm{S_X} \cdot tot + \mathrm{S_T} \cdot \bar{t} \tag{R-3}$$

The relationship between real factor prices comes from the derivation of the unit cost of the value added bundle (at factor cost), which can be thought of as a geometric-average of factor prices. Redefining in terms of real prices at factor cost, this equation may be written in linearised percentage-change form as follows:

$$\mathrm{S_K} \cdot rp_K = -\mathrm{S_L} \cdot rp_L + \bar{a} \tag{R-4}$$

where $\mathrm{S_K}$ and $\mathrm{S_L}$ are the share of the cost of capital in GDP at factor cost and the share of the cost of labour in GDP at factor cost, respectively (see section 2.2 for the explanation of $a$).

The final equation of the stylized model for the firm behaviour is the zero-profit condition in the production of a commodity. As there is no intermediate demand in this stylized model, the price of GDP at market prices, $p_{MP}$, depends on the price of GDP at factor cost, $p_{FC}$, which is the unit cost of the value added composite, and the average rate of tax, net of subsidy. The linearised percentage-change form of this equation is expressed as follows:

$$p_{MP} = p_{FC} + \mathrm{S_T} \cdot \bar{t} \tag{R-5}$$

### 2.1.2 Investors

Investors are assumed to behave in the same way as producers except for one difference. They do not directly use primary factors as inputs to capital formation. In other words, the nested structure of investment production is a particular case of the general production structure described above. This implies that, similarly to producers, investors for each regional industry may choose their own imported intermediates from different regions of origin. The composition of capital goods created in each industry responds to relative prices that investors are facing in each sector. These relative prices are subject to ad valorem taxes on the use of domestic and imported commodities.

The allocation of regional investment expenditure across industries in comparative static models makes no fixed relationship between capital and investment and thus depends on the requirements of the specific simulation. The model distinguishes between three alternative specifications.

The first specification assumes the creation of new capital stock in each industry $i$ of a particular region $r$ is related to profitability in that industry:

$$ror_{i,r} - ror\_i_r = \varepsilon_{\mathrm{i,r}} \cdot (ke_{i,r} - kb_{i,r}) \tag{I-1}$$

where $ror\_i_r$ is the economy-wide rate of return in region $r$, $kb_{i,r}$ and $ke_{i,r}$ are capital stocks at the beginning and at the end of the period, respectively, and $\varepsilon_{i,r}$ is a positive parameter defining the sensitivity of the investment allocation.

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

The second specification assumes that investment in a particular industry follows the national trend:

$$i_{i,r} = i\_i_r \qquad \text{(I-2)}$$

where $i_{i,r}$ and $i\_i_r$ are the real level of investment in industry $i$ of region $r$ and the aggregate level of real investment in region $r$, respectively.

The allocation of investment according to this specification may be appropriate for industries in which investment is determined by government policy.

The third specification assumes that investment follows the industry capital stock:

$$i_{i,r} = k_{0,i,r} \qquad \text{(I-3)}$$

In long-run comparative-static simulations, it is often assumed a fixed ratio of investment to capital stock for a given industry in a particular region. In other words, the percentage changes in capital and investment are equal, and this can be specific to the industry and region, or specific to the region only, or specific to the industry only, or not specific to any industry or region.

In the stylized model, it is assumed a fixed ratio of aggregate investment to aggregate capital stock only, which translates as follows:

$$i - k = \psi_{I/K} \qquad \text{(R-6)}$$

where $\psi_{I/K}$ is the ratio of aggregate investment to aggregate capital.

### 2.1.3 Households

Private households in each region are assumed to maximize a Cobb-Douglas utility subject to the fixed share of regional income that has been allocated for private consumption. As for producers and investors, households' preferences for each commodity is first between domestic and imported goods, and then for the imported composite between the different regions of origin. Households are subject to consumption taxes on their purchases of domestic and imported commodities.

The stylized representation of the households' behaviour is the relationship between the price of private consumption, $p_C$, and the market-price GDP deflator adjusted for the terms of trade effects, which can be expressed in linearised percentage-change form by the following equation[2]:

$$p_C = p_{MP} - \mathrm{S_X} \cdot tot \qquad \text{(R-7)}$$

[2] The derivation of the equation comes from the linearised percentage-change form of the market-price GDP deflator from the expenditure side which can be written as follows:

$$p_{MP} = \mathrm{S_C} \cdot p_C + \mathrm{S_G} \cdot p_G + \mathrm{S_I} \cdot p_I + (\mathrm{S_X} \cdot p_X - \mathrm{S_M} \cdot p_M)$$

and assuming that the prices of private consumption, government spending and investment move together ($p_C = p_G = p_I$) as well as assuming that the balance of trade is initially in equilibrium ($\mathrm{S_X} = \mathrm{S_M}$).

An improvement in the terms of trade reduces the unit cost of gross national expenditure (which includes import prices but not export prices) relative to the market-price GDP deflator (which includes export prices but not import prices).

The consumption function for households relates the value of private consumption to the value of GDP at market prices via the average propensity to consume. This equation takes the following linearised percentage-change form:

$$c = \bar{\gamma}_{\mathrm{C}} + (y_{MP} + p_{MP}) - p_C \qquad \text{(R-8)}$$

where $c$ and $y_{MP}$ are the real private consumption and the real GDP at market prices, respectively, and $\gamma_{\mathrm{C}}$ is the marginal propensity to consume for households.

### 2.1.4 National government

Public consumption is characterized by the same structure as private consumption except that there is no possibility of substitution between commodities as they enter on a proportional basis in public spending. The commodity composition of government consumption is thus exogenously determined.

This assumption reflects that the government allocates its budget between sectors independently from prices. However, substitution is introduced at the sourcing level, between imported and domestically produced goods and services first and then between regions of origin for imported commodities. As for private households, the national government is subject to a consumption tax on their purchases of domestic and imported commodities.

In the stylized model, the government's behaviour is represented in a similar way to the households' behaviour. In addition, based on the assumptions described in footnote 2, it can be described by the following relationship:

$$p_G = p_C + \bar{f}_G \qquad \text{(R-9)}$$

where $f_G$ is an exogenous shift variable allowing for changes in the ratio of public consumption price to private consumption price.

The consumption function for the government  is also analogous to the consumption function of households and may be expressed by the following equation in linearised percentage-change form:

$$g = \bar{\gamma}_{\mathrm{G}} + (y_{MP} + p_{MP}) - p_G \qquad \text{(R-10)}$$

where $g$ is the real public consumption and $\gamma_{\mathrm{G}}$ is the government's marginal propensity to consume.

### 2.1.5 International trade

The whole idea behind the Armington approach to modelling import demand is to recognize different trading partners and thus regionally differentiated products (Armington, 1969). The assumption of product differentiation permits the model to match bilateral trade with cross-hauling of trade (imports and exports of identical products) and avoids unrealistically strong specialization effects in response to exogenous changes in economic policy.

Up until recently, the Armington assumption has been represented in CGE models at the aggregate level, which means that the sourcing split between the different regions of origin was known only for total demand for imports. The development of recent databases allows on the other hand to specify demand for imports at the agent level. In our case, the Armington assumption is specified for each industry and for capital creation in each industry, as well as for private and public consumption.

In each region, demand for imports at the user level from a region of origin comes from supply of exports from a given industry in that source region. These bilateral flows of commodities are shipped along a particular route and thus are combined, in fixed proportions, with international transportation services. These services reflect both the activity of moving goods from one region to another region and related transaction costs. International shipping services are a Leontief aggregation of international trade margin services. Each of these international transport services is a combination of transport service exports from all regions throughout the world. They are aggregated using a Cobb-Douglas technology which means that the share of each region in the global transportation sector is constant.

The representation of international trade in the stylized model starts with the definition of the real exchange rate, $rer$, as the nominal exchange rate adjusted for inflation, which can be written in linearised percentage-change form as follows:

$$rer = e + \bar{p}_W - p_{MP} \tag{R-11}$$

where $e$ and $p_W$ are the nominal domestic-currency price of foreign currency and the average price of GDP of its trading partners.

The volume of imports, $m$, depends positively on the real GDP at market prices and negatively on the real exchange rate, which can be translated in linearised percentage-change form by the following equation:

$$m = y_{MP} - \sigma_{\mathrm{M}} \cdot rer \tag{R-12}$$

where $\sigma_{\mathrm{M}}$ is the elasticity of substitution between imported and domestic commodities. Symmetrically, the volume of exports, $x$, is positively related to the real GDP of its trading partners and to the real exchange rate, which can be written in linearised percentage-change form by the following equation:

$$x = \bar{y}_W - \varepsilon_{\mathrm{X}} \cdot rer \tag{R-13}$$

where $\varepsilon_{\mathrm{X}}$ is the price elasticity of world demand for a given region's exports and thus has a negative value. All else being equal, it follows that an increase in the real exchange rate (i.e. real depreciation of the domestic currency) improves the competitiveness of domestic production, which leads to a reduction in the volume of imports and to an increase in the volume of exports.

The last equation for international trade in the stylized model is the definition of the terms of trade which affects the prices of commodities as well as the prices of primary factors. The terms of trade are defined as the relative price of the country's exports compared to its imports and are negatively related to the volume of exports and to the average foreign-currency price of imports. This relationship may be formalized in linearised percentage-change form by the following equation:

$$tot = {}^{x}/_{\varepsilon_X} - \bar{p}_W + \bar{f}_X \quad \text{(R-14)}$$

where $f_X$ is an exogenous shift in foreign-currency price of exports. This derivation of the terms of trade assumes that the country is a price-taker with respect to imports but has some market power for its exports as it faces a downward-sloping demand curve. In addition this definition of the terms of trade is consistent with the real exchange rate as the latter is equal to the reciprocal of the former.

## 2.2 Regional markets clearance

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. However, the demand for the former 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.

Market demand for the primary factors of production also has to equal the supply of endowments. As mentioned in Goulder, Shoven and Whalley (1983), across-border mobility of physical capital is not realistic as it fails to capture important aspects of foreign investments. In addition actual trade statistics do not show much evidence of movement of old machines, equipment, and structures (Bovenberg & Goulder, 1991). In the model, capital stock is assumed then 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.

In the stylized model, the representation of the market-clearing condition for good and services may be represented by the expenditure side of real GDP at market prices and written in linearised percentage-change form as follows:

$$y_{MP} = \mathrm{S_C} \cdot c + \mathrm{S_G} \cdot g + \mathrm{S_I} \cdot i + (\mathrm{S_X} \cdot x - \mathrm{S_M} \cdot m) \quad \text{(R-15)}$$

where $\mathrm{S}_\bullet$ is the share of the macroeconomic aggregate (private consumption, public spending, investment, exports, and imports) in GDP at market prices.

The market-clearing condition for primary factors is characterized by the income side of real GDP at factor cost, which takes the following linearised percentage-change form:

$$y_{FC} = \mathrm{S_L} \cdot l + \mathrm{S_K} \cdot k - \bar{a} \quad \text{(R-16)}$$

where $a$ is an exogenous technology shift variable in all-factor inputs. An improvement (deterioration) in all-factor technical efficiency is introduced to the model with a decrease (increase) in the technology shift variable.

## 2.3 Regional welfare

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 is that, in each region, the value of households' income must equal the value of factor endowments. In real terms, this can be represented in the stylized model by the following equation in linearised percentage-change form:

$$y_{MP} = \mathrm{S}_{\mathrm{FC}} \cdot y_{FC} + \mathrm{S}_{\mathrm{T}} \cdot \bar{y}_{T} \qquad \text{(R-17)}$$

where $y_{FC}$ is the real GDP at factor cost and $y_T$ is a quantity index on which indirect taxes are applied.

## 2.4 Macroeconomic closure

Comparative-static single-region models are in-essence atemporal and face the issue of explaining aggregate investment (Robinson, 2006). Multi-region 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.

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 claim on future earnings. As a consequence, regional saving may diverge from regional investment due to changes in international financial capital flows induced by trade policy changes for instance.

Mobility of financial capital across borders has to be viewed mainly in the form of movement of funds, which then get translated into movement of capital goods through external trade. In this view, physical capital does not change its 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.

Financial assets are assumed to be perfect substitutes. In the model, they may move freely across regions or international capital mobility may be limited. The former case implies that the interest rate is determined in the international financial market, while the latter case leads to differences in real rates of return to capital. In the case of a perfect mobility of capital flows, capital markets are complete and, unrestricted borrowing and lending permit to close the balance of payment gap along with equalization of rates of return across regions. However, when international capital flows are not freely mobile, capital markets are incomplete and only expected rates of returns are equalised between regions:

$$eror\_i_r = eror\_ir \qquad \text{(G-1)}$$

At the regional level, the expected rate of return on capital depends positively on the current rate of return and negatively on future investment. The underlying assumption of the latter is derived from investors being cautious in assessing the effects of expanding the capital stock in the region. Therefore they offer lower expected rates of return in the following period with positive additions to current capital stock (i.e. increase in investment). The sensitivity of investment to expected rate of return is controlled by a parameter, $\varepsilon\_i_r$, that reflects assumptions made on the mobility of international investment flows:

$$eror\_i_r = ror\_i_r - \varepsilon\_i_r \cdot (ke\_i_r - kb\_i_r) \qquad \text{(G-2)}$$

where $ke\_i_r$ and $kb\_i_r$ are the end-of-period capital stock and the beginning-of-period capital stock, respectively.

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 Closures

A comparative-static closure includes two sets of exogenous variables. In the first set are all naturally exogenous variables, which are variables not normally explained in a CGE model. These are usually observable variables such as tax rates and unobservable variables such as technology and preference variables. In the second set of exogenous variables are all naturally endogenous variables in a dynamic model, but which are naturally exogenous in a static model.

The stylized model developed in this paper comprises 18 equations and 30 variables at the regional level. Nine variables are regarded as naturally exogenous in a CGE model and are denoted with a bar on top of the symbol, which leaves 21 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 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. The choice of the last two exogenous variables 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 rate of return on capital ($ror$). 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 ($rw$).

**Table 1: Equation summary of the stylized model**

<table>
<tr><th></th><th></th><th colspan="3">Closure specification</th></tr>
<tr><th></th><th>Equations</th><th>Structural closure</th><th>Short-run closure</th><th>Long-run closure</th></tr>
<tr><td>R-1</td><td>$k - l = \sigma_{\mathrm{KL}}(rp_L - rp_K)$</td><td>$rp_L$</td><td>$l$</td><td>$rp_L$</td></tr>
<tr><td>R-2</td><td>$rp_K = ror - \mathrm{S_X} \cdot tot + \mathrm{S_T} \cdot \bar{t}$</td><td>$ror$</td><td>$ror$</td><td>$ror$</td></tr>
<tr><td>R-3</td><td>$rp_L = rw - \mathrm{S_X} \cdot tot + \mathrm{S_T} \cdot \bar{t}$</td><td>$rw$</td><td>$rp_L$</td><td>$rw$</td></tr>
<tr><td>R-4</td><td>$\mathrm{S_K} \cdot rp_K = -\mathrm{S_L} \cdot rp_L + \bar{a}$</td><td>$rp_K$</td><td>$rp_K$</td><td>$rp_K$</td></tr>
<tr><td>R-5</td><td>$p_{MP} = p_{FC} + \mathrm{S_T} \cdot \bar{t}$</td><td></td><td>$y_{FC}$</td><td></td></tr>
<tr><td>R-6</td><td>$i - k = \psi_{I/K}$</td><td colspan="2">$\psi_{I/K}$</td><td>$k$</td></tr>
<tr><td>R-7</td><td>$p_C = p_{MP} - \mathrm{S_X} \cdot tot$</td><td></td><td>$c$</td><td></td></tr>
<tr><td>R-8</td><td>$c = \bar{\gamma}_{\mathrm{C}} + (y_{MP} + p_{MP}) - p_C$</td><td></td><td>$p_C$</td><td></td></tr>
<tr><td>R-9</td><td>$p_G = p_C + \bar{f}_G$</td><td></td><td>$g$</td><td></td></tr>
<tr><td>R-10</td><td>$g = \bar{\gamma}_{\mathrm{G}} + (y_{MP} + p_{MP}) - p_G$</td><td></td><td>$p_G$</td><td></td></tr>
<tr><td>R-11</td><td>$rer = e + \bar{p}_W - p_{MP}$</td><td></td><td>$rer$</td><td></td></tr>
<tr><td>R-12</td><td>$m = y_{MP} - \sigma_{\mathrm{M}} \cdot rer$</td><td></td><td>$m$</td><td></td></tr>
<tr><td>R-13</td><td>$x = \bar{y}_W - \varepsilon_{\mathrm{X}} \cdot rer$</td><td></td><td>$x$</td><td></td></tr>
<tr><td>R-14</td><td>$tot = {}^{x}/_{\varepsilon_{\mathrm{X}}} - \bar{p}_W + \bar{f}_X$</td><td></td><td>$tot$</td><td></td></tr>
<tr><td>R-15</td><td>$y_{MP} = \mathrm{S_C} \cdot c + \mathrm{S_G} \cdot g + \mathrm{S_I} \cdot i + (\mathrm{S_X} \cdot x - \mathrm{S_M} \cdot m)$</td><td>$e$</td><td colspan="2">$p_{MP}$</td></tr>
<tr><td>R-16</td><td>$y_{FC} = \mathrm{S_L} \cdot l + \mathrm{S_K} \cdot k - \bar{a}$</td><td></td><td>$p_{FC}$</td><td></td></tr>
<tr><td>R-17</td><td>$y_{MP} = \mathrm{S_{FC}} \cdot y_{FC} + \mathrm{S_T} \cdot \bar{y}_T$</td><td></td><td>$y_{MP}$</td><td></td></tr>
<tr><td>R-18</td><td>$y_{MP} + p_{MP} = \mathrm{S_{FC}} \cdot y_{FC} + p_{FC} + \mathrm{S_T} \cdot (\bar{t} + \bar{y}_T)$</td><td>$p_{MP}$</td><td colspan="2">$e$</td></tr>
<tr><td>G-1/2</td><td>$eror = ror_r - \varepsilon_r \cdot (ke_r - kb_r)$</td><td></td><td>$i_r$</td><td></td></tr>
</table>

# 4 Calibration

The model is calibrated to the newly-developed World Input-Output Database (WIOD) and uses 2001 as the benchmark year for the simulation.

The full WIOD time series database includes seventeen years from 1995 to 2011 and covers 40 countries, 35 industries and 59 commodities, and four endowments (Capital and low-, medium-, and high-skilled labour). There is also an industry by industry variant comprising 35 industries. Although it was funded under the European Commission 7th framework program, the database consists of the 27 countries of the European Union and the thirteen largest countries in the world. It represents 84.4 per cent of world GDP in 2012. For the purpose of model development, it has been aggregated to five regions and the rest of the world as reported in Table 2. A full detail of the countries in each region is given in Appendix A-1.

**Table 2: List of regions in the model**

| Regions | GDP (million of $US) | Share in world GDP |
|---|---|---|
| NAFTA | 19,243,418 | 26.6% |
| European Union | 16,616,415 | 23.0% |
| BRIIAT | 9,333,155 | 12.9% |
| China | 8,221,015 | 11.4% |
| East Asia | 7,563,954 | 10.5% |
| Rest of the world | 11,238,416 | 15.6% |
| Total | 72,216,373 | 100.0% |

*Source: IMF GDP 2012*

In terms of sectors the database differentiates between 35 industries, which have been aggregated into four sectors in the current model. An overview of the production structure in the benchmark year 2001 is shown in Table 4.

**Table 3: List of sectors in the model**

| Sectors | Value added (million of $US) | Share in total value added | Output (million of $US) | Share in total output |
|---|---|---|---|---|
| Primary sector | 1,901,964 | 6.2% | 3,244,612 | 5.4% |
| Manufacturing | 5,364,535 | 17.5% | 17,427,591 | 28.9% |
| Transportation | 1,339,775 | 4.4% | 2,743,176 | 4.5% |
| Services | 22,088,957 | 72.0% | 36,946,971 | 61.2% |
| Total | 30,695,231 | 100.0% | 60,362,351 | 100.0% |

*Source: WIOD 2001*

The underlying country data in WIOD draws on publicly available data from National Statistical Offices and special attention was paid to keeping with SNA methodology (UN et al., 2009) and limiting the number of changes made. Imports by intermediate and final demanders are estimated using bilateral trade data. Allocation across intermediate sectors and final demand types (private and public consumption, and investment) is based on the proportionality assumption. Given the high priority to the country data, the global database is balanced to benchmark to the country data, which results in adjustment in international trade flows.

The model relies on three types of substitution elasticities: the elasticity of substitution between labour and capital, the elasticity of substitution between domestic and imported commodities, and the elasticity of substitution between imports from different regions. Values for these parameters are based on the GTAP database (Narayanan, Aguiar, & McDougall, 2012).

# 5 Illustrative Application

The main purpose of this section is to present an illustrative application of the developed model. The description of the scenario design is provided in the next section, while the results of the simulation are reported in the subsequent section.

## 5.1 Scenario design

The design of the scenario considers four simulations, as shown in Table 1. They involve one scenario that is simulated under two different closures with two alternative assumptions regarding sourcing shares. All simulations apply the same shocks but use two different datasets to allow for the introduction of the different sourcing assumptions.

**Table 4: Simulations considered in the analysis**

| | **Closure specification** | |
|---|---|---|
| **Sourcing assumptions** | Short-run closure | Long-run closure |
| Proportional sourcing shares | PROP-SR | PROP-LR |
| WIOD sourcing shares | WIOD-SR | WIOD-LR |

The first sourcing assumption is the proportional sourcing assumption, which is frequently used in the MRIO literature, and assumes that all uses of a good are sourced in the same way. The second sourcing assumption acknowledges the different sourcing by agent using sourcing shares from WIOD.

The scenario in this analysis is not intended to reflect reality but is designed to illustrate the sourcing assumption and the modelling of sector-specific investment. It starts with the idea that risk can be systemic in nature, causing breakdowns of entire economies and not only individual industries or part of economies. As such the greater the interdependencies between countries and industries, the greater the potential for events to bring about unforeseen, cascading consequences.

As described in section 2.4, the underlying assumption for allocating global investment between regions is that, in equilibrium, expected rates of return on investments are the same across regions and equal to the global expected rate of return. Any discrepancy between the expected regional rates and the global expected rate of return can be viewed as a measure of investment-related risk in the regions (Malcolm, 1998). For relative high-risk countries, this measure of risk is above one, and for relatively safe countries below unity. Therefore reallocation of global investment among the regions depends on the global expected rate of return and a measure of risk/attractiveness of individual regions. An increase in investment-related risk in a particular region requires an increase in the expected rate of return in that region. The linearised percentage-change form of this equation replaces Equation G-1 as follows:

$$eror\_i_r = eror\_ir + \psi_r^{risk} \qquad \text{(G-3)}$$

where $\psi_r^{risk}$ represents the ratio of equilibrium rates of return in region to the global average rate of return.

The underlying story of the scenario is a reduction in China's country risk in the first decade of this century together with partial liberalization of non-tariff barriers against foreign direct investment (FDI) in services.

Country risk is a broad measure encompassing political risk, credit risk, economic performances, and other factors. In China, economic reforms started in the last decade of the 20th century have probably been a key driver for reducing China's country risk at the beginning of this century. Price regulation was essentially dismantled by 2000 and this, along with China's accession to WTO in 2001, also contributed to reinforce China's attractiveness to foreign investors. This confidence increase in China for doing business is thus represented in the model by a decrease in the risk ratio in Equation G-3.

At the end of the last century China experimented with opening up its markets to attract FDI to export-oriented manufacturing industries. Then China shifted its objective from an emphasis on GDP growth towards a more harmonious balanced development, and made a radical commitment to services liberalization in its accession to WTO. This has triggered a shift of FDI to service industries. By 2009, FDI in services increased 3 times from that in 2000, while manufacturing FDI in China increased 81 percent.

According to Petri (1997), *ad valorem* equivalents of FDI barriers in China were 21.6 per cent in the primary sector, 61.1 per cent in manufacturing and 77 per cent in services. In this illustrative application, barriers to FDI are represented by an *ad valorem* tax on capital earnings that is returned to households without absorbing productive resources. In this context, the policy experiment involves lowering FDI barriers in services in China, which will lead to international capital being attracted to this sector as its rate of return will be relatively higher compared to other countries and industries.

The last component in this hypothetical scenario is the assumption that China further liberalises its manufacturing market but only with East Asia. The underlying idea is similar to the Apple iPod case. Demand for imports of manufactured products in China is primarily directed to intermediate industries and not to final consumers, and approximately half of them come from East Asia.

## 5.2 Simulation

In this hypothetical policy experiment, it is assumed the following shocks for the three components of the scenario:

1. The investment-related risk ratio for China decreases by five per cent;
2. Barriers against foreign direct investment in services in China are reduced by ten per cent (formally the tax rate on capital earnings in this sector); and
3. The tariff rate on manufacturing goods entering China from East Asia is lowered by twenty per cent.

Table 5 presents the long-run impacts on world variables for the two alternative sourcing assumptions. At a macro level, the sourcing assumption does not significantly affect the results. As a result of investment in China being less risky, there is an inflow of capital coming from other regions leading to an increase in their rates of return (Table 6). As risk-adjusted expected rates of return equalize across regions, the global expected rate of return increases. The flow of capital and the impact on the global expected rate of return depend positively on both the size of the country and the change in the risk ratio.

**Table 5: Long-run impacts on world variables (in percent changes)**

| | Sourcing assumptions | |
|---|---|---|
| | Proportional sourcing shares | WIOD sourcing shares |
| Expected rate of return | 1.51 | 1.51 |
| Real investment | 0.40 | 0.35 |
| Price index of primary factors | 0.34 | 0.30 |
| Volume of world trade | 2.09 | 2.09 |
| Price index of world trade | 0.14 | 0.11 |

In the short run, capital stock does not adjust to changes in demand for capital, which implies a lower inflow of investment in China than in the long run. As a consequence the adjustment in the expected rates of return for the other regions is smaller. Current rates of return are also lower in the short run than in the long run. In addition, they differ across regions as investment does not add to availability of capital for production. In the long run, the mobility of capital together with the endogenous determination of capital stock implies the equalization of rates of return across time (i.e. expected and current rates of return are identical).

**Table 6: Impacts on regional rates of return and regional investment based on WIOD (in percent changes)**

| | Closure specification | |
|---|---|---|
| | Short-run closure | Long-run closure |
| *Expected rates of return* | | |
| China | -4.30 | -3.56 |
| All other regions | 0.74 | 1.51 |
| *Current rates of return* | | |
| China | 3.03 | -3.56 |
| East Asia | 1.17 | 1.51 |
| BRIIAT | 0.26 | 1.51 |
| NAFTA | 0.12 | 1.51 |
| Europe | 0.25 | 1.51 |
| Rest of the world | 0.11 | 1.51 |
| *Investment* | | |
| China | 13.40 | 19.35 |
| East Asia | 0.90 | -1.24 |
| BRIIAT | -1.21 | -2.09 |
| NAFTA | -1.55 | -2.19 |
| Europe | -0.91 | -1.97 |
| Rest of the world | -1.07 | -1.33 |

At the sectoral level, rates of return for services in China are positive both in the short and long run as barriers against FDI are lowered (Table 7). On the other hand, rates of return in other industries are negative in the long run as economy-wide rate of return for China is negative. This requires then a lower rate of return for China in the long-run than in the short-run.

**Table 7: Impacts on current rates of return by sector in China based on WIOD (in percent changes)**

| | **Closure specification** | |
|---|---|---|
| | Short-run closure | Long-run closure |
| Primary sectors | 5.16 | -31.61 |
| Manufacturing | 0.48 | -10.02 |
| Transportation | 1.95 | -3.51 |
| Services | 24.00 | 10.27 |

The impact of the simulations on real GDP worldwide is reported in Table 8. As expected, the unilateral partial liberalization of trade together with a decline in investment-related risk in China is significantly beneficial for China but not for the other regions.

**Table 8: Impact on real GDP in the long run (in percent changes)**

| | **Sourcing assumptions** | |
|---|---|---|
| | Proportional sourcing shares | WIOD sourcing shares |
| China | 8.25 | 8.23 |
| East Asia | -0.49 | -0.50 |
| BRIIAT | -0.98 | -1.01 |
| NAFTA | -0.86 | -0.89 |
| Europe | -0.68 | -0.69 |
| Rest of the world | -0.39 | -0.40 |

The comparison of the alternative sourcing assumptions shows that differences at the macro level are quite small and vanish at the second-decimal under a short-run closure (Table 9).

**Table 9: Impact on real GDP in China (in percent changes)**

| | **Closure specification** | |
|---|---|---|
| **Sourcing assumptions** | Short-run closure | Long-run closure |
| Proportional sourcing shares | 0.72 | 8.25 |
| WIOD sourcing shares | 0.72 | 8.23 |

Nevertheless at the sector level, differences between the two sourcing assumptions are quite significant. In particular, because of the lowering of the border protection in manufacturing, the price of imports falls and this decline is more pronounced for private consumption under the proportionality assumption than under the use of the WIOD sourcing shares. Conversely, the price for imports in intermediate demand decrease more with WIOD sourcing shares than with proportional sourcing shares. The reason lies in the imports share of 43.2 per cent entering China from East Asia being equal for all users under the proportionality assumption. In WIOD on the other hand, the share of imports for intermediate demand is 47 per cent while it is only 25 per cent for private consumption.

**Table 10: Long-run impacts on the demand for manufacturing in China (in percent changes)**

| | **Sourcing assumptions** | |
|---|---|---|
| | Proportional sourcing shares | WIOD sourcing shares |
| *Intermediate demand in the manufacturing sector* | | |
| Price of imports | -10.48 | -11.37 |
| Price of domestic/imported composite | -4.70 | -4.91 |
| Real imports | 33.97 | 37.44 |
| Real intermediate consumption | 8.97 | 8.97 |
| *Private consumption* | | |
| Price of imports | -10.48 | -7.04 |
| Price of domestic/imported composite | -4.21 | -3.99 |
| Real imports | 34.44 | 19.41 |
| Real household consumption | 7.51 | 7.35 |

As a result of the decline in price for imports, the demand for real imports rises and both of these effects cascade to the next level in the demand nest structure (i.e. composite commodity). However, differences are less significant as bases in intermediate/final are larger.

# 6 Further Developments

As it has been said at the beginning, WIOD do not include the richness of GTAP in terms of taxes, tariffs and international transport margins. As a consequence, a rather critical development of the model is to incorporate a realistic structure of these variables into the model, as well as in the current database. A subsequent step is to add other important countries such that the database includes at least the 50 largest economies in the world.

A major extension of the model is then the introduction of dynamics. In this context, households are assumed to form expectations of the future based on history that are adjusted over time. 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 (formally, expected rates of return are positively related to growth rate of capital stock using an inverse logistic function). 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.

Capital is an important issue in a general equilibrium model since capital may refer to two different notions including different assumptions regarding its mobility. The two notions are on the one hand, the value of capital goods and, on the other hand, the net asset position for private households. The former is related to the rental market of capital services while the latter takes the form of outright purchase and sale of capital goods. The model needs therefore to distinguish between asset ownership and asset location. The assets located in a particular region needn't be owned by agents in that region. Similarly, households in a given region needn't receive the whole income generated by the assets in that region.

A further modelling development will be to assume that, in each region, the labour market is 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 change. However, in the short-run, favourable shocks may generate a decline in unemployment at the regional level, but real wage rates will eventually respond to take unemployment back to its initial level, which will result in long-run gains in real wages.

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# Appendix

## A.1 List of countries in WIOD

GDP are in 2012 millions of $US. World GDP is equal to $72,216 billion and the 40 countries GDP in WIOD equals $60,978 billion, which makes approximately 84.4 per cent of world GDP.

| Regions | Countries | GDP | Rank |
|---|---|---|---|
| NAFTA | United States | 16,244,575 | 1 |
| (26.6%) | Canada | 1,821,445 | 11 |
| | Mexico | 1,177,398 | 14 |
| BRIIAT | Brazil | 2,253,090 | 7 |
| (12.9%) | Russia | 2,029,813 | 8 |
| | India | 1,841,717 | 10 |
| | Australia | 1,541,700 | 12 |
| | Indonesia | 878,536 | 16 |
| | Turkey | 788,299 | 17 |
| European Union | Germany | 3,429,519 | 4 |
| (23.0%) | France | 2,613,936 | 5 |
| | United Kingdom | 2,476,665 | 6 |
| | Italy | 2,014,078 | 9 |
| | Spain | 1,323,500 | 13 |
| | Netherlands | 770,867 | 18 |
| | Sweden | 523,804 | 22 |
| | Poland | 489,795 | 24 |
| | Belgium | 483,904 | 25 |
| | Austria | 394,868 | 28 |
| | Denmark | 314,889 | 34 |
| | Greece | 249,199 | 43 |
| | Finland | 247,646 | 44 |
| | Portugal | 212,446 | 47 |
| | Ireland | 210,416 | 48 |
| | Czech Republic | 195,657 | 52 |
| | Romania | 169,394 | 57 |
| | Hungary | 125,660 | 59 |
| | Slovakia | 91,915 | 63 |
| | Luxembourg | 57,140 | 72 |
| | Bulgaria | 51,020 | 76 |
| | Slovenia | 45,427 | 79 |
| | Lithuania | 42,136 | 83 |
| | Latvia | 28,380 | 92 |
| | Cyprus | 23,005 | 101 |
| | Estonia | 22,399 | 102 |
| | Malta | 8,750 | 136 |
| China (11.4%) | China | 8,221,015 | 2 |
| East Asia | Japan | 5,960,269 | 3 |
| (10.5%) | South Korea | 1,129,536 | 15 |
| | Taiwan | 474,149 | 27 |

*Source: IMF GDP 2012 in millions of $US*