

Introducing more flexible modelling of regional household consumption and saving decisions into the dynamic GTAP model

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A dynamic version of the GTAP model of the global economy became available in 2012. The dynamic version known as GDyn, introduced partial adjustment mechanisms for capital accumulation and a dynamic accounting of capital-finance and related income flows between regional households and firms, and a global trust. This paper builds on this original work by including a revised modelling of investment and capital-finance flows to reach a long-run equilibrium in which model required rates of return are equal and stable over time. This paper then further adds to the capabilities of the GDyn model by: (i) relaxing the assumption of fixed shares in the consumption-saving decisions of national households; and (ii) providing for the inclusion of exogenously determined changes in national consumption-saving choices. The revised model – termed GDyn-FS – is used to: infuse projected reductions in saving as a proportion of domestic income for China in a model base line; and, against this base line, simulate a decline in the willingness to invest in a medium-sized open economy modelled as a permanent increase in the risk adjusted required rate of return on capital.

JEL codes: C68, E17, E21, F11, F21, F43.

Keywords: Economic Growth, Dynamic Base Lines, Trade Policy Analysis.

1. Introduction

This paper describes new features included in the GDyn dynamic computable general equilibrium model of the global economy. These features provide for model stability over the long run and enhance its usefulness as a tool for the analysis of policy and other economic developments affecting the real economy.

The GDyn model is a dynamic version of the widely used Global Trade Analysis Project (GTAP) model (Hertel and Tsigas 1997, Hertel 2013, Corong *et al.* 2017). It became available in 2012 as an accessible public domain general purpose

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modelling technology (Ianchovichina and Walmsley 2012). The GDyn model built on the GTAP model through the introduction of partial adjustment mechanisms for capital accumulation and a dynamic accounting of capital-finance and related income flows between regional households and firms via a global clearing mechanism (termed the 'global trust'). The objectives of the development were to 'provide a better treatment of the long-run within a GTAP framework and provide a way of tracing the evolution of the global economy through time' (p, 12). The applicability of the model was demonstrated in Ianchovichina and Walmsley 2012 through a series of simulations on topics as diverse as trade reform, growth and investment, climate change, natural resource use, technological change and demography benchmarked using a 1995 database.

An important advantage of the GTAP and the GDyn models for economic research and policy analysis is that they are fully documented, accessible and in the public domain, and that they utilize a general purpose modelling technology based on the widely available and used GEMPACK modelling software (Horridge et al. 2018).

GDyn is a recursive dynamic model in which, in a long-run neo-classical equilibrium, model rates of return on capital by region adjust adaptively to be equal and constant over time, either with respect to regional-specific rates or a common global rate, depending on user specification. In practice, illustrative results presented with the release of GDyn show those equilibrium conditions are not satisfied with the rates of return on capital falling across regions without bounds (Ianchovichina and McDougall (2012), Golub and McDougall (2012) and Gretton (2018)). This precludes the use of the model to meaningfully investigate implications of permanent changes in required returns on capital in the real economy. It also adds to the operational burden of using the model as users seek to manage the modelling and interpretative implications of falling rates of return on capital and model instability — factors that act as a disincentive to its wider use.

Golub and McDougall (2012) and Walmsley and McDougall (2012) introduced 'saving' and 'complementarity' versions of GDyn to stabilize net foreign investment positions and returns in GDyn through endogenising saving and placing a lower bound on gross investment, respectively. The methods sought to bound variation in target variables. The methods, however, worked within the partial adjustment mechanisms for rate of return determination, capital accumulation and capital financing of the basic model without overcoming the underlying source of instability of the standard model.

This paper builds on the original work by: (i) including a revised modelling of regional investment so that in a long-run equilibrium model rates of return adaptively adjust to be equal and stable over time, either with respect to region-specific rates or a common global target rate of return; (ii) recognizing non-convex adjustment costs between the time of investment and the time capital enters

production as new capacity; and then (iii) allocating saving between regions according to relative returns on real capital investment. It then adds to the capabilities of the GDyn model by: (i) relaxing the Cobb-Douglas assumption of fixed shares in the consumption-saving decisions of national households; and (ii) providing for the inclusion of exogenously determined changes in national consumption-saving choices via a ‘twist’ methodology.

A full description of each of the new components to the model – named GDyn-FS – is provided in the next section. The following section provides illustrative results in respect of key stability tests, an illustrative baseline and a policy-related scenario that directly utilizes the exogenous treatment of capital returns in a stable environment. The illustrative baseline is extended out to 2050 based on projections of value added, population, and employment of skilled and unskilled workers. In addition to these growth determinants, the saving rate for China is projected to gradually decline from an historically high of around 50 percent of GDP in the database year of 2011, to levels comparable to other economic regions and the historical average for China. Against this baseline, the policy simulation projects the impact of a decline in the willingness of investors to invest in a medium-sized open economy (Australia). This policy is modelled as an increase in the required rate of return on investment on account of higher country risk.

The stability tests, baseline and policy simulations use a database with 6 diverse regions – Australia, China, Japan, the United States, EU-28 and the Rest-of-the-World – and 13 industry sectors – two agriculture, one mining, four manufacturing, five services plus ownership of dwellings. Five primary factor inputs are modelled – land, natural resources, skilled labour, unskilled labour and (produced) physical capital (appendix A). The database reference year is 2011. Tests of stability are simulated for 200 years and reported to 100 years. The reference case and policy simulation are reported to 2050.

A final section summarizes the contribution and findings of the paper.

2. Methods

Within the broad theoretical architecture of the GDyn model, the introduction of more flexible modelling of regional household consumption and saving choices is advanced in two steps. In the first step two elements are introduced to achieve long-run equilibrium in model simulations, namely:

- extend the GDyn investment rule to ensure that capital gradually adjusts to eliminate any differences between regional firms expected rate of return and an exogenously determined target rate; and
- modify the treatment of international capital flows to include optimizing behaviour by regional firms and households, respectively, in domestic-foreign real-asset investment choices.

In the second step, and within the stable environment afforded by the first two elements a further element is added to enable the Cobb-Douglas fixed expenditure shares assumption between consumption and saving choices to be relaxed and provide for the inclusion of exogenously determined changes in national consumption-saving mixes through a flexible consumption-saving 'twist' method.

2.1 Rates of return to capital and the investment rule

2.1.1 Returns to capital

GDyn applies three concepts of rates of return to real capital: the actual rate of return earned on capital employed in a region (*RORGROSS*); the *ex ante* returns expected by agents on installed capital (*RORGEXP*); and a required rate of return determined by factors outside of the model (*RORGTARG*). In the recursive dynamic framework with adaptive expectations, as applied in GDyn, the actual and expected returns draw towards the target rate through production and investment decisions of regional firms.²

The first of the measures is the actual rate of return per unit of capital employed as implied by the data for each region. Omitting time subscripts, the gross return for each region, *RORGROSS_r*, is calculated as:

$$RORGROSS_r = EK_r / VK_r \quad (1)$$

where *EK_r* is the gross earnings on capital during the year (net returns plus depreciation) and *VK_r* is the value of capital at the beginning of the year. The actual rate of return can vary from year-to-year with current economic conditions.

In a long-run equilibrium, the steady state value of the gross rate of return for a region, *RORGROSS_r^{*}*, would reflect a common risk neutral entrepreneurial income component (*RNETCOMM*), a regional institutions and risk component (*RRISK_r*) and a depreciation on region capital (*RDEPN_r*) component, that can be depicted as:

$$RORGROSS_r^* = RNETCOMM + RRISK_r + RDEPN_r \quad (2)$$

Following GDyn terminology, the equilibrium rate is referred to as the target rate of return (*RORGTARG*). It assumed that the model target rate is equal to what the actual rate of return would tend to in the longer-run, so that,

² The focus of attention in the investment theory is on real economy effects. The theory therefore abstracts from capital gains or losses on installed capital that may occur over time. This convention is reflected in the indexing of the global price of saving to the price of real capital and the treatment of the price of global saving as the model price numeraire. While the price of capital by region could vary in the short run and in transition to a long run equilibrium, in a long-run equilibrium, capital gains (losses) by region would be zero.

$$RORTARG_r = RORGROSS_r^* \quad (3)$$

For an individual period, the rate of return expected by investors may differ from the actual rate of return or the target rate. The expected rate is defined to depend on the level of capital stocks relative to a reference level, the actual rate of return and a parameter of adaptive expectations, that is:

$$RORGEXP_r = RORGROSS_r * \left(\frac{QK_r}{QKF_r} \right)^{-RORGflex_r} \quad (4)$$

where, $RORGEXP_r$ is expected rate of return in each region, QKF_r is a reference capital stocks reflecting normal growth in capital while $rorgflex_r$ is the region-specific model parameter of adaptive expectations. In this environment, if actual capital (QK_r) for a region r is aligned with the reference capital, QKF_r , the expected rate of return would align with the actual return. If the actual capital is above reference capital, the expected return would be lower than the base rate of return by the (negative) power of the parameter $rorgflex_r$ (set at 10 in each region GDyn).

In a long-run equilibrium, the actual, target and expected rates of return would be equal and constant over time, that is,

$$RORGROSS_r = RORTARG_r = RORGEXP_r \quad (5)$$

The equilibrium growth of the reference capital stock would be sensitive to assumptions of the average propensity to save, the rate of depreciation and the growth of effective labour inputs. In the special case of zero growth in output, effective labour and a constant saving share, the growth of the reference and actual capital stocks would be zero, that is:

$$KHAT_r = 0 = qk_r \quad (6)$$

where, $KHAT_r$ is the rate of growth in reference capital stock and qk_r is the rate of growth in the actual capital stock.

The GDyn model specifies processes for the gradual adjustment of expectations to align expected, actual and target returns through capital adjustments based on a rule for investment. The next section focuses on this rule and provides a new treatment to hold the target rate of return as a control variable not available in the standard model. The new treatment (i) enables the modelling of a long-run equilibrium in which model rates of return are equal and stable over time (Gretton 2018); and (ii) supports policy-oriented simulations of the effects of changes required returns arising from changes in country risk or institutional arrangements.

2.1.2 The investment rule

Investors are modelled in GDyn as reacting in their investment decisions to the expected gross rates of return on capital. This modelling is central to a convex

adjustment mechanism that draws the expected rate of return towards a target rate, such that in equilibrium, the expected and target rates are equal for each region,

$$RORGEXP_r = RORGTARG_r \quad (7)$$

Defining the required rate of growth in expected returns by region in a lagged adjustment process, this equality is replaced by:

$$ER_RORGE_r = \left(\frac{RORGTARG_r}{RORGEXP_r} \right)^{LAMBORGE_r} \quad (8)$$

where ER_RORGE_r denotes the required proportional change in the expected gross return in each region to align it adaptively with target rate and $LAMBORGE_r$ denotes a coefficient of partial adjustment. In natural logarithms, this expression becomes:

$$ERG_RORE_r = LAMBORGE_r * \log \left(\frac{RORGTARG_r}{RORGEXP_r} \right) \quad (9)$$

where ERG_RORE_r now denotes a required rate of growth in expected returns. Totally differentiating this expression gives:

$$erg_rorg_r = LAMBORGE_r * (rorgt_r - rorge_r) + dLAMBORGE_r * \log \left(\frac{RORGTARG_r}{RORGEXP_r} \right) * 100 \quad (10)^3$$

where erg_rorg_r denotes the absolute percentage points change in the rate of growth in the expected rate of return, $rorgt_r$ denotes the percentage change in the target rate of return, $rorge_r$ denotes the percentage change in the expected rate of return, and $dLAMBORGE_r$ denotes a within-period parameter adjustment. This expression provides a rule for investment that brings about a compression of both the difference in the rate of change of the expected relative to the target rates of return and the levels of the respective return measures. In the present implementation, the within period parameter is set at the square of the underlying parameter value, that is: $dLAMBORGE_r = LAMBORGE_r^2$.

The original implementation of this theory simplified the expression by omitting the within period term and in so doing, omitted a mechanism for drawing the actual expected rate of return to the target level. Without a theory in the model to explain the target rate of return, this omission led to the target rate declining without bound (Golub and McDougall 2012) and provides the central source of model instability (Gretton 2018).

A value for the target rate of return for each region is included as an item of data in the model database. The database value for each region is assumed equal

³ In simplified mathematical notation:

$$d \left(b \log \left(\frac{c}{d} \right) \right) = \log \left(\frac{c}{d} \right) db + \frac{b}{c} dc - \frac{b}{d} dd$$

to the simple average across regions. The value can be changed via a database amendment or in model simulations, through a shift term. From above,

$$\begin{aligned} RORGROSS_r^* &= RORGARG_r \\ &= RNETCOMM + RRISK_r + RDEPN_r \end{aligned} \quad (11)$$

Expressing the component changes in ordinary change form as percentage points contribution, the percentage change in a regional target rate can be expressed as a combination of region-specific shift terms to capture the effects of changes in the effective discount rate on account of country risk, institutional factors and regional-specific time preference ($srorc_r$) and a global shift term ($srorc_r$) to capture uniform changes across regions and any change in the rate of depreciation on regional capital ($srdepn_r$). That is:

$$rorgt_r = srorc_r + srorc_r + srdepn_r \quad (12)$$

In this set up, $srorc_r$ is naturally exogenous. An exogenous treatment of $srorc_r$ requires further consideration of the capital accumulation process. This implementation follows the GTAP convention of treating the rate of depreciation as fixed and as such the term $srdepn_r$ is not modelled.

The region-specific shift term is useful for considering issues of financial market policy or institutional changes that affect required returns. This setting is applied below to consider the economic effects of a decline in willingness by firms to invest in a medium-sized open economy (Australia) modelled through an exogenous permanent increase in the required returns on investments in real capital.

The common global shift term $srorc_r$ is not naturally exogenous. In order to implement the assumption that long-term required returns (represented by the model variable $RORGARG_r$) are determined by factors outside of the model and obtain a valid model closure, it is necessary to swap the global shift term on the target rate of return — $srorc_r$ — with another global variable. This matter is addressed in the next section.

2.1.3 Recognizing non-convex adjustment costs and model closure

The variable chosen is a region-generic shift term on capital, $sqkworld$, in the expression linking capital formation with the provision of capital services.

In each region, effective real capital stocks change according to the rate of fixed capital accumulation net of non-convex adjustment costs as a proportion of the level of installed capital. Capital services available to productive activities are then modelled to move in proportion to the change in effective capital.

$$\begin{aligned} VK_r * qk_r &= 100 * NETINV_r * time + \\ &\quad VK_r * [sqk_r + sqkworld] \end{aligned} \quad (13)$$

with

$$\begin{aligned} NETINV(r) &= GROSSINV(r) - VDEP(r) \\ qk(r) &= ksvces(r) \end{aligned}$$

where VK_r is the value of regional real capital in region r at the beginning of the period t , qk_r is the estimated growth of regional real capital stocks ascribed to period t , $NETINV_r$ is net investment, $GROSSINV_r$ is the value of gross investment in period $t - 1$, $VDEP_r$ is the value of depreciation of capital stocks at the beginning of period t . Non-convex adjustment costs (and other changes in capital available to productive activities) are represented by sqk_r a region specific shift term, and a region-generic shift term $sqkworld$. Assuming that capital becomes productive instantaneously, growth in capital services in each region, $ksvces_r$, would be just equal to the growth in the quantity of capital stocks, qk_r for each region (Hertel and Tsigas 1997, p.56, eqn 56). Any adjustment cost is an 'implicit cost of forgone output' (Khan and Thomas 2008).

Earlier consideration of adjustment costs in the capital accumulation process concluded that: the nature of a long-run equilibrium can depend on the costs of approaching and maintaining it, including adjustments of work routines and tasks (Lucas 1967, Hamermesh and Pfann 1996); the nature of adjustment can also be influenced by managerial and administrative abilities of firms as well as physical capital (Usawa 1969); and that adjustment can include internal costs where some output is expended in the process of expanding scale of firms productive processes (Treadaway 1969). In addition, period-to-period variations in capital spending and output can be influenced by the cross sectional distribution of firm responses to economic change as well as cyclical factors (for example, Caballero 1996). In later assessments, it was recognized that the presence of non-convex adjustment costs mean that some capital is expended in the process of maintaining or expanding the scale of firms' productive capabilities (for example, see reviews by Cabarelllo 1999 and Khan and Thomas 2008 and empirical studies by Cooper and Haltiwanger 2006 and Wang and Wen 2012). Cooper and Haltiwanger (2006) in a balanced-panel analysis of 7000 large US manufacturing plants in operation over the period 1972 to 1988, estimated the fixed cost of adjustment to be almost 4 percent of the value of plant level capital. McKibbin and Wilcoxon (1999) in the multi-country, multi-sector global computable general equilibrium model (G-Cubed) assume that in the installation of a unit of effective capital firms must buy a larger quantity of the investment good.

In the present application, the variable $sqkworld$ is treated as endogenous to recognize that: (i) capital does not necessarily become instantaneously productive upon installation; and (ii) the presence of non-convex adjustment costs by which some capital is expended in the process of maintaining or expanding the scale of firms' productive capabilities. The treatment is achieved via a closure swap with the variable $srorc_r$ from equation 12 above, thus completing the closure of the model.

The endogenous treatment of *sqkworld* also recognizes the very real potential for there to be data inconsistencies and from this perspective can be a measure of ignorance. One area of uncertainty is in the area of depreciation of fixed capital. GDyn (and GTAP) assume a uniform diminishing balance of 4 percent of the value of fixed capital with no retirement through final sale or scrapping. Gretton and Fisher (1997) on the basis of Australian input-output data, suggested that the average value of fixed assets at time of final sale or scrapping could be about 7.5 percent of acquisition costs. Leamer (1988) suggested the value could be around 13 percent while Cooper and Haltiwanger (2016) adopted a retirement rate of 3.2 percent. GDyn does not include a theory to account for the retirement or scrapping of assets short of the effective working life of assets implied by the diminishing balance depreciation method. Other global models adopt different depreciation rates, for example the MIRAGE model adopts a depreciation rate of 6 percent (Decreux and Valin (2007), Fontagne *et al.* (2013)). Cooper and Haltiwanger (2016) adopted a depreciation rate of 6.9 percent (inclusive of retirements of 3.2 percent). These considerations would suggest a permanent retirement or erosion of capital greater than implied by the GDyn (and GTAP) diminishing balance depreciation rate of 4 percent.

To the extent that there is an adjustment cost wedge between investment and the realization of that investment in capital accumulation and capital services or the depreciation rates in the database understate actual rates, it is conjectured that as economies move towards steady state growth, the projected value of *sqkworld* should converge to a small negative — possibly between zero and 2 percent, being in the range of the difference between the CEPII and GTAP rates, all else being equal. Other (larger or smaller) year-to-year differences could be interpreted as: (i) leads and lags in investment cycles, and real costs associated lags between investment and asset utilization;⁴ (ii) inconsistencies between projections of output, employment and saving rates; and inconsistencies between elements of a growth scenario and between projections and the initial database.⁵ Importantly, in any one period, it would only be by coincidence that the nexus between saving,

⁴ For example, McKibbin and Vines 2000 argue that adjustment costs are likely to vary with the scale of new investment and are important in economic models used for policy analysis of the effects of economic change.

⁵ For example, in the capital accumulation equation, the change in the quantity of capital by region (i.e., $VK_r * qk_r$) in period t is assumed to increase with the value of investment in period $t - 1$ (i.e. $NETINV_r$). This assumes that capital-good price changes across periods are zero in each region. While this assumption is enforced at the global level by setting the change in the price of global saving to be the model price numeraire and equal to zero and equating this to the change in the global capital-goods price index, projected changes at the regional level do not necessarily meet this condition. The regional between-period differences would have real effects at the regional level that may not net out globally.

depreciation and factor-cost shares in the database are consistent with a long-run equilibrium with such tensions flowing through to the projected adjustment cost term for that period.

If steady-state output growth were to be assumed to be zero with no recalibration of database saving rates (that is, with saving rates calibrated to ongoing growth), it would be expected that the projected value for *sqkworld* could converge to a value higher than 2 percent. This matter is tested below.

The endogenous adjustment cost term therefore: (i) recognises that investment does not become productive instantaneously, and that there are year-on-year adjustment costs in either a steady state, in transition to a steady state or in a regular baseline; and (ii) provides a measure of data inconsistency. Further, it would be inappropriate to model such costs as accumulating in structural coefficients such as rates of return or saving rates. Such a treatment would cause these coefficients to decline without bound (evident in test simulations) and be inconsistent with a long-run equilibrium.

Listing 1: GEMPACK equations and model closure for modified investment rule

```
Equation E_RORGT # identity for change in target rate of return # (all,r,REG)
rorgt(r) = srorc(r) + srorc_r ;
Equation INVESTMENT
# rule for investment # (all,r,REG)
erg_rorg(r) = LAMBRORG(r) * [rorgt(r) - rorge(r)] + [100.0 * LAMBRORGE(r)^2 *
ERRRORGT(r)*time] ;
Equation KBEGINNING # associates change in cap. services with change in cap. stock
(HT 56) # (all,r,REG)
VK(r) * qk(r) = 100 * NETINV(r) * time + VK(r) * [sqk(r) + sqkworld];

Exogenous
srorc
sqk
sqkworld

Swap sqkworld = srorc_r ; !en=ex
```

2.2 Relaxing the fixed consumption-saving share assumption

Saving and investment across regions in a base year database would only coincidentally be consistent with a long-run steady state growth path. For example, in the 2011 database adopted in this study, the gross saving rate for China is estimated to be around 50 percent, materially higher than historic savings rates for that economy, higher than comparator economies and higher than projections.

In the GTAP and GDyn family of models, households are typically modelled as disposing of total regional income according to a top-level Cobb-Douglas per capita utility function specified over three forms of final uses — private household consumption expenditure, government consumption expenditure and saving in

which the subsistence budget shares are equal to zero (Hertel and Tsigas 1997, p. 47, Corong et al. 2017, p. 22). The implementation includes slack variables which enables the user to specify the level of saving or government consumption exogenously with private consumption being calculated as a residual. This approach is relaxed in this paper in two respects: (i) the assumption of fixed shares in consumption and saving decisions of national households is relaxed to enable households to substitute between consumption and saving adaptively on the basis of relative price (Weitzman 1976); and (ii) using a 'twist' methodology (Dixon and Rimmer 2015), provision is made for the inclusion of exogenously determined changes in the consumption-saving share over time by region.

The 'income disposition tree' provides a visual representation of the disposition of regional income by regional households (figure 1).

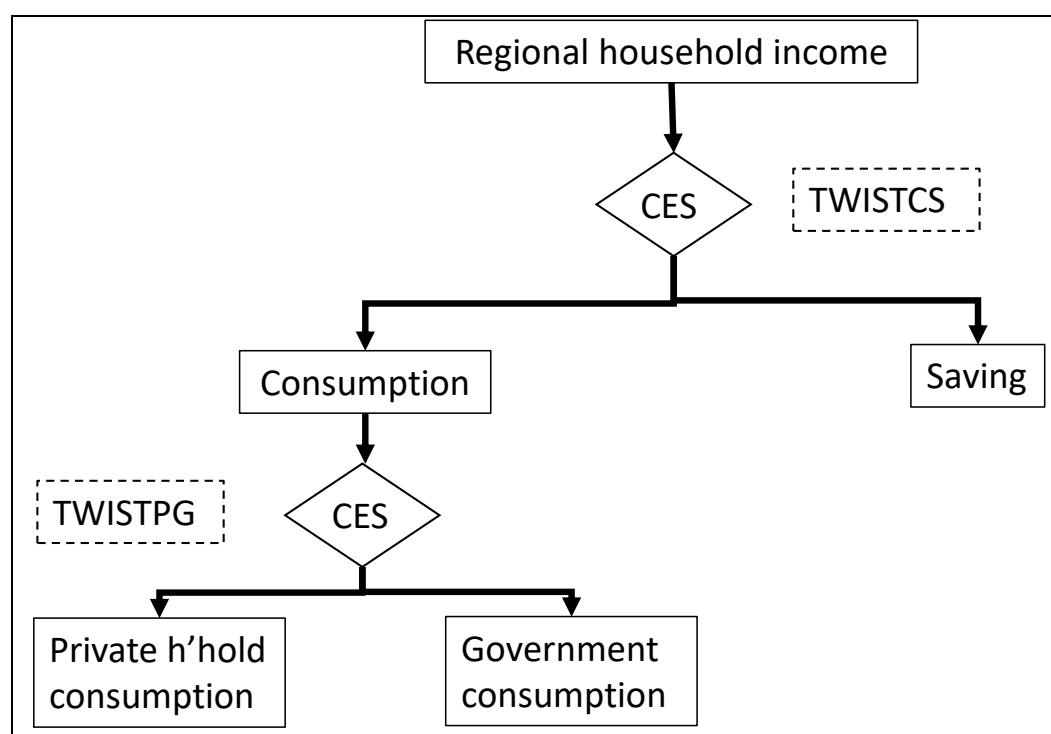


Figure 1: Regional household top level utility nest

Source: Author's representation.

At the top of the (inverted) tree is household income equal to total regional household expenditure. This is used for consumption and saving and total consumption is divided between private household consumption and government consumption. A constant elasticity of intertemporal substitution is used to mediate the consumption-saving choice and a constant elasticity of substitution is used to mediate private household-government mix. Twist terms permit exogenous shifts

in spending shares between categories. Although theory allows for the household-government shares to vary according to relative price, the present implementation retains the Cobb-Douglas assumption of fixed shares.

2.2.1 Consumption-saving expenditure choices

The above approach is implemented for the consumption-saving choices of regional households through the indirect utility function:

$$V(PC, PS, Y) = (PC^\varphi + PS^\varphi)^{-1/\varphi} * Y \quad (14)$$

such that

$$Y = PC * XC + PS * XS$$

where (without regional subscripts), Y is disposable income of the regional household, PC is the price of consumption goods, PS is the price of saving, XC and XS are the respective quantities, while $\varphi = \frac{\rho}{\rho-1}$ is a region-specific parameter representing the constant elasticity of substitution between consumption and saving in the indirect utility function (Varian 1992, p. 112). Because saving represents the present value of region households' future consumption stream, the elasticity represents a constant intertemporal elasticity of substitution (Weitzman 1976, p.160). An elasticity value of zero in the indirect utility function represents the Cobb-Douglas case adopted in the original model. (If the utility function were expressed in the direct form, the Cobb-Douglas case would be represented by a parameter value of one.)

The regional demand functions for aggregate consumption and saving can be found by Roy's identity as:

$$XC(PC, PS, Y) = \frac{-\partial V(PC, PS, M)/\partial P_s}{\partial V(PC, PS, M)/\partial Y} = \frac{PC^{\varphi-1}Y}{(PC^\varphi + PS^\varphi)}$$

Multiplying both sides by P_c gives the value of consumption spending: (15)

$$PC * XC = C = \frac{PC^\varphi M}{(PC^\varphi + PS^\varphi)}$$

Taking the logarithms and differentiating, the percentage change in consumption spending is:

$$c = y - \varphi \left(pc - \sum_i S_i p_i \right) \quad (16)$$

where $\sum_i S_i = 1$ $c, s \in i$.

Similarly, the percentage change form for saving demand function adopted is:

$$s = y - \varphi \left(ps - \sum_i S_i p_i \right) \quad (17)$$

Added to this basic set up is provision for exogenous changes in the consumption-saving mix to take into account changes in preferences, and disequilibria in a reference database and in baseline projections. For example, in

2011, the year of the reference database used in this study, gross saving as a proportion of GDP for China is around 50 percent, a level much higher than the historical average and higher than projected values. To incorporate such changes, a ‘twist’ methodology is adopted. This methodology was adopted by Dixon and Rimmer (2015, eg p. 149) to explain changes in import and domestic demand in favour of imports, and changes in technology in the use of labour and capital in favour of labour. In this paper, the twist method is used to introduce exogenously determined changes in regional household consumption and saving choices and changes in the private and government consumption mix. Those exogenously determined values may be estimated from historical data or from independent estimates of how the consumption-saving mix may evolve in the model baseline for an individual region or across regions.

The twist method is introduced by the addition of share weighted twist terms to the consumption and saving equations, so that for each region r :

$$c_r = y_r - \varphi_r \left(pc_r - \sum_i S_{i,r} p_{i,r} \right) + (SS_r * twistcs_r) + scon_r + scon_r \quad (18)$$

and

$$s_r = y_r - \varphi_r \left(ps_r - \sum_i S_{i,r} p_{i,r} \right) - (SC_r * twistcs_r) + ssave_r + ssave_r \quad (19)$$

where $twistcs_r$ is the consumption-saving twist term, SS_r and SC_r are the regional saving and consumption shares in income, respectively. The positively signed twist term in the consumption equation (and negatively signed term in the saving equation) represents the case of a twist in favour of consumption over saving. The modelling of consumption and saving in value terms, allows the twist terms to be interpreted directly against aggregate data on consumption and saving shares in regional income or regional GDP. The shift terms against the value of saving allow for exogenous changes in the value of saving where $ssave_r$ represents region-specific changes and $ssav_r$ represent region-generic changes.

Listing 2: GEMPACK equations for top-level consumption-saving choices

```
Equation E_regcons # regional household demand for private and government
consumption, combined # (all,r,REG)
yc(r) = y(r) - CESCS(r) * (pcons(r) - p(r)) + (XSHRSVE(r) * twistcs(r)) + scon(r)
+ scon_r ;
```

```
Equation E_regsave # regional household demand for saving # (all,r,REG)
ys(r) = y(r) - CESCS(r) * (psave(r) - p(r)) - (XSHRCON(r) * twistcs(r)) + ssave(r)
+ ssave_r ;
```

Exogenous

```
twistcs
scon
scon_r
ssave_r
```

2.2.2 Private, government expenditure choices

The consumption-saving tree disaggregates consumption for each region into private household and government components. Following the approach above for the consumption-saving choice, the indirect utility function is

$$V(PP, PG, YC) = (PP^\omega + PG^\omega)^{-1/\omega} * YC$$

such that (20)

$$C = PP * XP + PG * XG$$

where $YC = C$ is disposable income of the regional household entering regional consumption expenditure, PP is the price of private household consumption goods, PG is the price of regional government consumption, while $\omega = \frac{\rho}{\rho-1}$ is a parameter representing the constant elasticity of substitution between private and government consumption in the indirect utility function. With household-government twist and consumption shift terms, the percentage change in household and government consumption is:

$$yp_r = yc_r - \omega_r \left(pp_r - \sum_i S_{i,r} p_{i,r} \right) + (SG_r * twistpg_r) + syp_r \quad (21)$$

and

$$yg_r = yc_r - \omega_r \left(pg_r - \sum_i S_{i,r} p_{i,r} \right) - (SP_r * twistpg_r) + syg_r \quad (22)$$

where $twistpg_r$ is the consumption-saving twist term, SP_r and SG_r are the regional household private and government consumption shares in regional consumption spending, respectively. A positively signed twist term in the private household consumption equation (and negatively signed term in the government consumption spending equation) would imply a twist in favour of private household consumption over government consumption. Analogously with the modelling of the consumption-saving choice, the modelling of private and government consumption in value terms, allows the twist terms to be interpreted directly against aggregate data on private and government shares in regional aggregate consumption expenditure. The shift terms, syp_r and syg_r , allow for exogenous region-specific changes in the value of private and government consumption expenditure. These would be transmitted to private spending through the twist term.

Listing 3: GEMPACK equations for top-level private-government consumption choices

```

Equation E_regpriv # regional household demand for private consumption #
(all,r,REG)
yp(r) = yc(r) - CESPG(r) * (ppriv(r) - pcons(r)) + (XSHRCGOV(r) * twistpg(r)) +
syp(r);
Equation E_reggov # regional household demand for government consumption #
(all,r,REG)
yg(r) = yc(r) - CESPG(r) * (pgov(r) - pcons(r)) - (XSHRCPRIV(r) * twistpg(r)) +
syg(r);

Exogenous
twistpg
syp

```

2.2.3 Consumption-saving parameter choices

The revised theory requires two additional parameters — φ and ω termed CESCS and CESPG in the model code — to mediate regional household consumption-saving and private-government consumption choices, respectively, in response to relative price changes. The long standing literature on an elasticity of intertemporal substitution to measure the responsiveness of real household consumption spending to a change in real interest rates suggests that this elasticity is low (Hall 1988, Havranek 2014 and Best *et al.* 2017). These findings, suggest that sometimes substantial year-to-year variations and structural changes in the consumption saving mix are due to other factors. McKibbin and Wilcoxon (1999) adopt a set up in GCubed whereby the value of private consumption is treated separately from government consumption and varies in proportion to the share-weighted sum of wealth income and other household income. They base this approach on evidence that private households are liquidity constrained and consume a fixed portion of (after tax) household income. They note that the assumption of regional household private consumption being determined by fixed income shares could also be interpreted as myopic permanent income behavior. In calibrating a long-run baseline in the general equilibrium MIRAGE model, Fontagne and Foure (2018) project country saving rates based on a life cycle hypothesis and balance of payments current account balances while imposing constraints in terms of global saving and investment.

Noting that income from private real wealth as well as labour is included in the GDyn measure of regional household income, it would seem that there is not strong evidence to drift substantially from the Cobb-Douglas assumption. In the present application, a (indirect utility function) parameter value of 0.1 is therefore adopted. This value is equivalent to a value of about 1.13 when evaluated in respect of the direct utility function (see table 1). With this setting, a 1 percent increase in the *real* price of consumer goods would be projected to result in a 0.1 percent decrease in the value of consumption spending, and a 1.13 percent decrease in real consumption.

Table 1. Comparison of direct and indirect utility function CES intertemporal substitution elasticity parameter settings

	Elasticity values considered			
	Cobb-Douglas	Case 1	Case 2	Case 3
Indirect utility (value) function	0.00	0.10	0.25	0.33
Implied CES parameter ρ	$\rightarrow 0.00$	-0.12	-0.25	-0.50
Direct utility function	1.00	1.13	1.50	2.00

Source: Author conjectures.

Changes in the consumption-saving mix beyond those suggested by model parameterization and projected real price changes, such as short to medium run deviations from long-term averages (for example, on account of variations in the current account balances), and long-term factors such as changes in consumer preferences and changes in the demographic structure would be introduced through the twist method in GDyn-FS.

Modelling of the regional household private-government mix assumes constant value shares, that is, the Cobb-Douglas assumption. In this case, changes in value shares between private and government consumption would be introduced exogenously using the twist method. By comparison, government spending is modelled as exogenous with a complementary government finance account in GCubed (McKibbin and Wilcoxon 1999). In the MIRAGE model, private and government consumption expenditure are combined in a composite final consumption expenditure category (Fontagne and Foure 2018). Golub and McDougall (2012) introduced an extension to GDyn that uses resistance parameters enabling regional saving rates to vary from year-to-year within bounds indicated by historical data. This author found the application of the method can lead to unintended projections of negative saving rates in the longer run,⁶ and suggests that the CES-based methodology with twist terms is a more fruitful way of proceeding within the GDyn architecture.

2.3 Modelling of international capital flows

Current account imbalances are financed by financial flows between countries with net lending matching net borrowing across regions. Within the real economy, the ownership of reproducible fixed capital in a region consists of two components: that owned by domestic residents and that owned by foreign residents while regional household real-capital wealth can be in local firms or foreign firms.

⁶ For example, the current writer using the six region database of this study found that with standard region-specific resistance parameter setting, the model failed with error after only one period with only Time shocked. Ad hoc parameter adjustments extended the simulation period but did not resolve the stability issue.

One approach to modelling of capital-finance flows is to assume savings accumulates globally and this saving is allocated to regional investment on the basis of relative returns. The current account balance for each region, its net lending/borrowing, would represent the gap between a regions saving and investment as represented by the national accounting identity $S - I = BoT + R$ where S is regional saving, I regional investment, BoT the balance of trade and R is *net* income transfers and other foreign remittances. Such an approach is adopted in the comparative static GTAP model (Hertel and Tsigas 1997, p. 54). A similar approach is adopted in the GCubed model which assumes free mobility of financial capital across regions (McKibbin and Wilcoxon 1999, p. 134) and in the MIRAGE model (Decreux and Valin (2007), Fontagne *et al.* (2013)).

Another approach and that introduced in GDyn, is to divide net lending/borrowing of a region into strictly positive capital inflow and outflow components (Ianchovichina and McDougall 2012). Under this approach, regional household wealth holds its wealth in a two asset portfolio composed holdings in local firms and in the global trust. Firms then source finance for real capital accumulation directly from the regional household or from global savings via the model's global trust – the model's notional clearing house for cross border financial transactions. Under market clearing conditions, the total across regions of firms' drawings on global capital (whether domestic or foreign) remains equal to the total across regions of regional households' holdings. Entrepreneurial income is then distributed to regional households and the global trust in proportion to wealth holdings.

The approach was implemented in GDyn using two atheoretic resistance parameters that mediated changes in regional wealth into positive inflow and outflow components calibrated to stay as close as possible to the initial capital ownership shares (Golub and McDougall 2012, pp. 100-101).⁷

This paper maintains the separate recording of capital inflows and outflows but moves to a theory-based approach to mediate changes in regional wealth. A constant elasticity of transformation (CET) function is used to mediate between domestic and foreign portfolio holdings by regional households on the basis of relative returns while a constant elasticity of substitution (CES) function is used to mediate between domestically and foreign sourced finance by regional firms on the basis of the relative expected cost of finance (figure 2).⁸

⁷ It is found, however, that with the use of the resistance parameter method firm income remittances abroad typically turn negative during a simulation causing the simulation to terminate with a data error (as the flows must be positive). While the rigidity parameters can be recalibrated to dampen variation and extend the time horizon of a simulation, such an approach is ad hoc and not robust.

⁸ This is similar to the approach adopted in Productivity Commission (2010) in which a CET | CES formulation was introduced to the GTAP model to examine the impact of

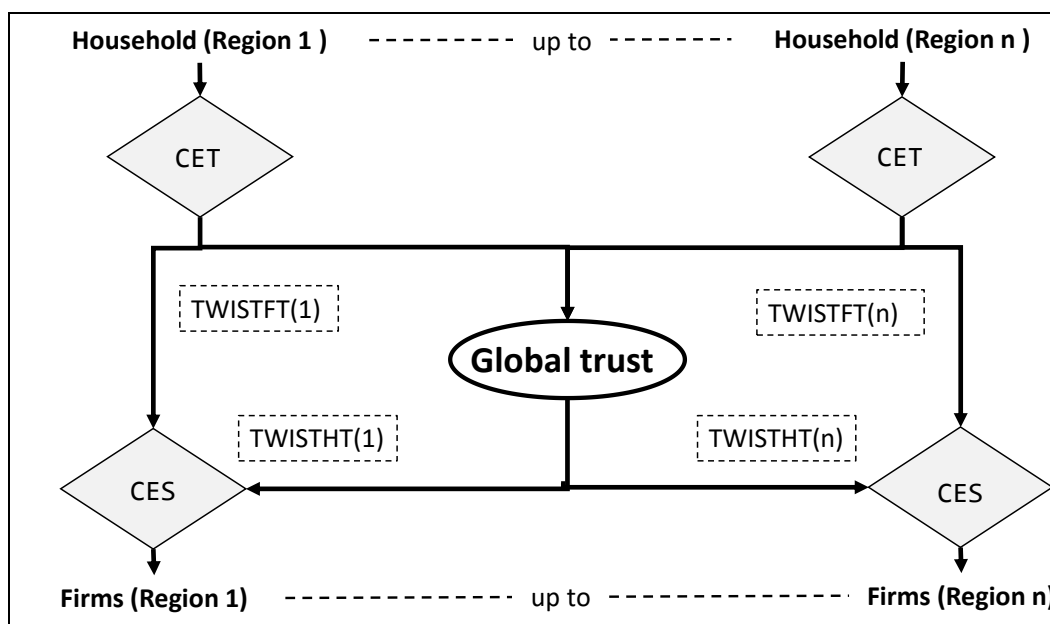


Figure 2: Regional household and firm optimizing behaviour with a CET | CES approach to modelling capital-finance

Source: Author's representation.

Twist components are added to model the effects of exogenous changes in the mix of household wealth holdings between domestic firms and the global trust (via *twistft*), and for the mix of firms funding decisions between regional households and the global trust (via *twistht*). Such changes could arise from institutional or regulatory changes, changes in taste between domestic and foreign investment or financing, or changes in economic conditions.

It should be noted that the capital-finance flows so modelled combine direct, portfolio and other investment flows which in GDyn, are assumed to be fungible and to adjust as a composite across regions. As a real economy model, financial balances are equated to real capital holdings. Financial derivatives and monetary assets are omitted.

The separation of inward and outward flows as in GDyn affords the possibility of explicitly delineating home-country biases in capital-finance inflow and outflow decisions of regional households and industries. Combined with the exogenous setting of the required return (*RORGTARG*), it also affords possibilities

polices affecting the relative cost of bilateral investments. That implementation differs from the GDyn application in this paper in that: substitution/transformation possibilities were mediated by real capital-good prices; it was applied in a comparative static and not dynamic framework; and it implemented a disaggregation of the global trust into a 25 region by 25 region flow of funds account.

for more directly modelling the impact of changes in regional institutions on inflows and outflows — of importance, for example, in modelling the impacts linkages between the operation of country/regional financial markets and growth and country convergence in returns on capital.

Sensitivity testing using the six-region, thirteen sector database of this study, indicates that the method affords a level of model stability not available with the atheoretic approach.

2.3.1 Implementing the framework for regional households investment decisions

Regional households' CET decisions for allocating regional wealth to the global trust are characterized for each region as an income maximization problem through the indirect revenue function:

$$\begin{aligned}
 YH_r^*(RF_r, RT_r, W_r) &= (RF_r^{\tau_{CS_r}} + RT_r^{\tau_{CS_r}})^{-1/\tau_{CS_r}} * YH_r^* \\
 \text{such that} \\
 YH_r^* &= YHF_r^* + YHT_r^* = RF_r \cdot WF_r + RT_r \cdot WT_r \\
 \text{and} \\
 WHF_r &= VKHF_r \\
 WHT_r &= VKHT_r
 \end{aligned} \tag{23}$$

where, YH_r^* is income from the ownership of real capital at home or abroad by households in each region r . The income would accrue either from firms at home, YHF_r^* , or abroad distributed to the regional household via the global trust, YHT_r^* . RF_r and RT_r represent the rates of return from real wealth holdings of regional households in regional firms, WHF_r and in foreign firms via the global trust, WHT_r , respectively. The unit returns on investment is represented by the actual gross rate of return for each region (that is, $RORGROSS_r$)⁹ on the basis that households would make financing decisions on the basis of the actual returns they observe in the market. VKF_r is the value of real fixed assets of resident firms owned by residents in region r , while VKT_r is the value of real fixed assets of foreign firms consolidated in the global trust and owned by residents in r . The region-specific parameter $\tau_{CS_r} = \frac{\rho}{\rho-1}$ represents the constant elasticity of transformation between ownership of local and foreign capital by regional households. An elasticity value of zero in the indirect revenue function represents the Cobb-Douglas case.

The revenue functions for aggregate income from the wealth holdings in the global trust can be found for each region, as above, by Roy's law as:

⁹ This set up follows the GDyn convention of recording returns in gross terms to avoid negative value problems. With the rate of depreciation assumed constant across regions, the direction of change measured in gross terms across sectional relativities are consistent with measures in net terms.

$$\frac{YHF_r^*}{RF_r}(RF_r, RT_r, W_r) = \frac{-\partial V(RF_r, RT_r, W_r)/\partial RT_r}{\partial V(RF_r, RT_r, W_r)/\partial W_r} = \frac{RF_r^{\tau cf_r - 1} * W_r}{(RF_r^{\tau cf_r} + RT_r^{\tau cf_r})}$$

Multiplying both sides by RF_r gives the value function for each region: (24)

$$YHF_r^* = \frac{RF_r^{\tau cf_r} W}{(RF_r^{\tau cf_r} + RT_r^{\tau cf_r})}$$

In percentage change form and assuming that household wealth and income from capital increases proportionately, this can be written for each region r as:

$$whf_r = yhf_r^* = wqh_r + \tau cf_r \left(rf_r - \sum_i S_{r,i} r_{r,i} \right) \quad (25)$$

where wqh_r is the percentage change in wealth of regional households, W_r , $\sum_i S_{r,i} = 1$, $hf, ht \in i$. $S_{r,hf}$ and $S_{r,ht}$ being the shares of regional household wealth held in regional firms, hf , and the global trust, ht , respectively.

Similarly, in percentage changes, wealth and income from holdings of foreign capital are depicted as:

$$wht_r = yht_r^* = wqh_r + \tau cf_r \left(rt_r - \sum_i S_{r,i} r_{r,i} \right) \quad (26)$$

The percentage change in investment income from the global trust is estimated as the share weighted sum of trust holdings in regional firms, so that: $rt_r = \sum_r ST_r r_r$ where ST_r is the share of global trust wealth holdings in firms in region, r .

The relationships in (26) are augmented for reach region, with possible twists between share-weighted wealth shares via the region-specific variables, $twistft_r$, and exogenous region-specific shifts in holdings of foreign capital via the variable $swht_r$, so that the final system can be depicted as:¹⁰

$$wht_r = wqh_r + \tau cf_r \left(rt_r - \sum_i S_{r,i} r_{r,i} \right) - (S_{r,hf} * twistft_r) + swht_r \quad (27)$$

and

$$WQH_r * wqh_r = WHF_r * whf_r + WHT_r * wht_r$$

2.3.2 Implementing the framework for regional firms funding decisions

As noted, regional firms' CES decisions for sourcing finance from regional and foreign sources are characterized as a cost minimization problem through the indirect cost function:

¹⁰ This depiction follows the original design of Gdyn. Another approach would be to follow the design of the consumption-saving saving module, whereby equation (25) would be included and the explicit market clearing condition omitted.

$$\begin{aligned}
 YF_r^*(RHF_r, RTF_r, WF_r) &= (RHF_r^{\sigma_{csr}} + RTF_r^{\sigma_{csr}})^{-1/\sigma_{csr}} * YF_r^* \\
 \text{such that} \\
 YF_r^* &= YHF_r^* + YTF_r^* = RHF_r \cdot WHF_r + RTF_r \cdot WTF_r \\
 \text{where} \\
 WHF_r &= VKHF_r \\
 WTF_r &= VKTF_r \\
 WF_r &= VK_r = VKHF_r + VKTF_r
 \end{aligned} \tag{29}$$

where, YF_r^* is the cost to regional firms of access to finance from the regional household and foreign owners of real capital, in each region r . The costs would be incurred on finance from regional households, YHF_r^* , or from abroad via the global trust, YTF_r^* . RHF_r , and RTF_r represent the unit cost of funding sourced to regional households by regional firms, WHF_r , and by foreign households via the global trust, WTF_r , respectively. The unit cost of funding is represented by the expected gross rate of return for each region (that is, $RORGEXP_r$) on the basis that firms would make financing decisions on the basis of the returns they expect to be realized. $VKHF_r$ is the value of real fixed assets VK owned by resident households, H , in regional resident firms, F , in region r , while $VKTF_r$ is the foreign ownership of the value of real fixed assets of resident firms via the global trust, T , in firms, F , in region r . The parameter $\sigma_{csr} = \frac{\rho}{\rho-1}$ represents the constant elasticity of substitution between funding sourced to local and foreign capital by regional firms. As before, an elasticity value of zero in the indirect revenue function would represent the Cobb-Douglas case.

From above, this leads to the value function for firm costs in sourcing finance directly from domestic saving:

$$YHF_r^* = \frac{RHF_r \cdot WF_r}{(RHF_r^{\sigma_{cfr}} + RTF_r^{\sigma_{cfr}})}$$

In percentage changes, augmented with twist and shift terms, the change in funds sourced domestically and from the trust can be depicted as:

$$\begin{aligned}
 whf_r = yhf_r^* = wf_r + \sigma_{cfr} \left(rh_r - \sum_i S_{r,i} r_{r,i} \right) - (S_{r,t} * twist_{tr}) \\
 + swhf_r
 \end{aligned} \tag{30}$$

so that:

$$wtf_r = wf_r + swtfr$$

where $swhf_r$ is an endogenous shift term with values constrained by the estimates of firms sourcing decisions and households investing decision.

These relationships provide a means of indexing the allocation of the cost of finance to the finance providers in proportion to wealth holdings, which are assumed to move in line over the longer term (depicted by a “*” against the variable yhf_r). As above, in periods of adjustment when projected firm income and

hence funding for payments to capital, may not be moving in line with capital accumulation, projected remittance to capital owners and capital growth may deviate. It should be noted, though, the income accounting and market clearing conditions of the model ensure total remittances = total receipts in all periods.

Listing 4: GEMPACK equations for the capital-finance module

```

Equation EQYHOLDHDFND # eq'n determines equity holdings of the regional hhld in
the global trust # (all,r,REG)
wqht(r) = wqt + CETCF(r) * (rorga_r - rorga_h(r)) - (WQ_HFIRMSHR(r)*twistft(r))
+ swqht(r) ;
Equation EQYHOLDWLTH # eq'n determines shift variable for wealth of the regional
hhld # (all,r,REG)
WQHHLDR(r) * wqh(r) = WQHFRM(r) * wqhfr(r) + WQHTRUST(r) * wqht(r) ;

Equation EQYHOLDHDLCL # eq'n determines the local equity holdings of the regional
hhld # (all,r,REG)
wqhfr(r) = wq_f(r) - CESCF(r) * (rorge(r) - rorge_r) - (WQ_FTRUSTSHR(r)*twistht(r))
+ swqhfr(r) ;
Equation EQYHOLDFNDLCL # eq'n determines shift variable for value of domestic
capital # (all,r,REG)
WQ_FIRM(r) * wq_f(r) = WQHFRM(r) * wqhfr(r) + WQTFIRM(r) * wqtf(r) ;

Exogenous
twistft
swqht
twistht
swqhfr

```

2.3.3 Capital-finance CET and CES parameter choices

To put the theory into effect, it is necessary to assign values to the model CET and CES parameters. With the application of the firm and household funding and investment behaviour expressed in nominal terms, as noted, the Cobb-Douglas case would be represented by CES and CET parameter values of zero. This setting is a reasonable reference setting as it aligns with the standard GDyn (and GTAP) regional household aggregate utility function which specifies that total regional income is spread over private household expenditures, government expenditure and saving according to constant shares. However, this case is likely to be too restrictive over time for modelling global capital flows as it does not take account of the changing regional composition of the global economy. This shortcoming would be of particular concern for the analyses of periods over which the comparative attractiveness of regions as investment destinations varies or for analyses with a particularly long time horizon where substantial changes in the regional distribution of economic activity, income and wealth can occur gradually. These considerations suggest non-zero values are appropriate.

In an early paper on the theme of the supply of international capital from domestic saving Feldstein and Horioka (1980) suggested four reasons why long-term arbitrage would not equalize yields across regions: (i) risk aversion

considerations become increasingly important for longer term, less liquid investments (the focus of GDyn capital flows); (ii) the full mobility of capital can be impeded by official restrictions; (iii) institutional rigidities (to which can be added cultural norms) will tend to keep a large segment of saving at home; and (iv) indirect evidence on the pattern of investment suggests that capital does not move purely out of portfolio considerations to maximize net after-tax return¹¹.

Gordon and Bovenburg (1996) argued that asymmetric information between investors in different countries is the most convincing argument for long-term immobility of long-term capital between regions. Tesar and Werner (1995) examined, for a sample of developed countries, whether increased activity on international finance markets and the large volume of cross-border equity and bond capital flows reflects an increase in the fraction of portfolios allocated to foreign securities. They found, amongst other things: (i) a strong bias towards domestic securities despite apparent risk reduction from diversification; and (ii) that high transactions rates on foreign investments suggest investors frequently adjust holdings even though this has little long-term impact on net positions. Lewis (1999) in a review of the literature on the nature of equity (and consumption) home bias found that: (i) there is no single explanation of the equity bias; (ii) trading costs for acquiring foreign equities do not appear large compared to potential diversification gains; and (iii) variability of regional equity markets significantly affects measurement and decision making rules. Kraay *et al.* (2005) demonstrated that, under reasonable assumptions, in a world that experiences recurrent episodes of systemic default, sovereign risk can lower predicted capital flows to observable levels (that is, with a home bias in investments). They also demonstrated that renegotiation costs during default episodes can introduce a bias against foreign (direct and portfolio equity) investments in favour of loans.

Consistent with the home-country bias effect identified in the literature and underpinning the setting of the atheoretic parameters in GDyn (Golub and McDougall 2012, p. 100-101), possible CES and CET parameter settings in this implementation have been set relatively close to the Cobb-Douglas case (table 2).

¹¹ For example, much of direct investment in foreign markets appears to be associated with resource seeking, market seeking, efficiency seeking or strategic asset seeking motives (for a discussion of these motivations see for example Dunning and Lundan 2008, pp. 66-72). Returns from such investments may be less than perfectly correlated with returns from passive investments motivated by considerations of maximizing (risk adjusted) net after-tax return, alone, lowering the responsiveness of capital flows to pure rate of return differences.

Table 2: Possible CES | CET parameter settings considered

		Elasticity values considered				
		Cobb-Douglas	Case 1	Case 2	Case 3	Case 4
Indirect cost/revenue (value) function	CESCF	0	0.02	0.05	0.10	0.20
	CETCF	0	0.01	0.03	0.05	0.10
Direct cost/revenue function equivalents	CESCF	1	1.02	1.05	1.13	1.34
	CETCF	1	1.01	1.03	1.05	1.13

Source: Author conjectures.

Also consistent with the relativities adopted by Golub and McDougall (2012, pp. 126, 7), the CET parameter is set at half the value of the CES parameter. This reflects the notion that regional households have a greater bias towards investing at home than regional firms have in sourcing funding for new investment from local sources. The higher settings on the CES parameters provide local firms with greater opportunity to shift to offshore funding sources if local investment opportunities exceed domestic saving (for example, during a period of capital deepening or an economic growth spurt).

Testing across the range of parameter values presented in table 2 indicated case 3 afforded model stability with some limited re-direction of flows in response to changes in relative returns between regions (at the level of aggregation reported). Those values are used in all illustrative simulations reported in this paper.

In applying the methodology in economic analysis, it would be prudent to simulate the Cobb-Douglas case together with other cases to test the sensitivity of results to alternative assumptions about the flexibility of funding and portfolio investment decisions.

3. Results with the capital-finance and consumption-saving specifications included

3.1 Model stability and achieving a long-run equilibrium

Long-run stability of a recursive dynamic model such as the GDyn and its variants can be tested by simulating changes in economies occurring only on account of the passage of time and the elimination of region risk premiums. That is, with no change in the growth variables of technology, population and labour inputs, and with all twist and shift terms on consumption and wealth assumed zero. All market clearing conditions should be satisfied and the model should be homogeneous of degree 1 in prices.

In GDyn investment theory, the model expected, target and actual rates of return on capital are conceptually all equal and constant over time in a long-run equilibrium (Ianchovichina and McDougall 2012, p.68). In equilibrium, the change in the normal rate of growth of capital for each region ($KHAT(r)$) is also constant over time and equal to zero with changes only occurring in periods of transition to a long-run equilibrium (figure 3).

$$ROREXP(r) = RORTARG(r) = RORGROSS(r), \forall r \quad (2.104)$$

$$ROREXP(r) = RORTARG(r) = RORGROSS(r) = 0, \forall r \quad (2.105)$$

$$KHAT(r) = 0, DKHAT(r) = 0, \forall r \quad (2.106)$$

Figure 3: Long-run equilibrium conditions posited for the GDyn model

Source: Ianchovichina and McDougall 2012, pp. 68-69.

These conditions imply a constant gross investment to capital ratio for each region. With a common depreciation rate assumed across regions, the long run equilibrium gross investment to capital ratio will also be common across regions. This long-run equilibrium is reached through a partial adjustment process whereby gross investment adjusts to equate the expected rate of return with the target rate, with capital simultaneously adjusting to equate the expected and actual rates of return. With the expected rate of return of each region determined by the ratio of projected capital in the next period relative to the current period and the actual rate of return, long-run equilibrium in GDyn can be likened to equilibrium in a multi-region q-investment theory model.

Following this approach and for comparison with earlier work, the test simulation was undertaken for the GDyn-FS model and for the GDyn and the GDyn-S models. As noted, GDyn-S differs from the standard GDyn model through the introduction of an endogenous treatment of saving. With only the passage of time and the elimination of region risk premiums, the first thing to notice is that in GDyn-FS simulations, the model measure of the gross rate of return is projected to converge to 0.104, that is, the standard database value given for the common constant target rate of return (figure 4, top left hand panel). With

the six region, thirteen industry aggregation, deviations of the actual rate of return from the target rate are largely eliminated within 60 years, given standard GDyn adjustment parameters. This occurs after a series of oscillating and diminishing adjustments by the regional economies as each region adjusts gradually through investment responses to adjustments in the expected rate of return relative to the actual and the (fixed) target rates. The model measure of the normal rate of growth of capital also converges towards zero for all regions over the same period (figure 4, top right hand panel). These results demonstrate that the GDyn-FS model as specified meets the stability conditions for a long-run equilibrium.

These test results contrasts with the original models. GDyn-2012 does not reach a long-run equilibrium and terminates with error when the rates of return approach the model depreciation rate of 0.04 (figure 4, second panels). Testing ascribes this instability to three factors: (i) the endogenous treatment of the region-specific target rate of return; (ii) the elimination of the theoretical requirement that investment adjusts to align the target rate; and (iii) the atheoretic treatment of capital flows (Gretton 2018). GDynS-2012 also does not reach a long-run equilibrium and terminates with error within a shorter period as compared to the standard model (figure 4, third panels). In this set up, the instability of the standard model is channeled to savings through an endogenous treatment of the saving rate. In testing, the model terminated with error when the projected index of utility from saving turns negative (for the USA). Testing also revealed that GDynS is not homogeneous in prices, a factor potentially contributing to model instability.

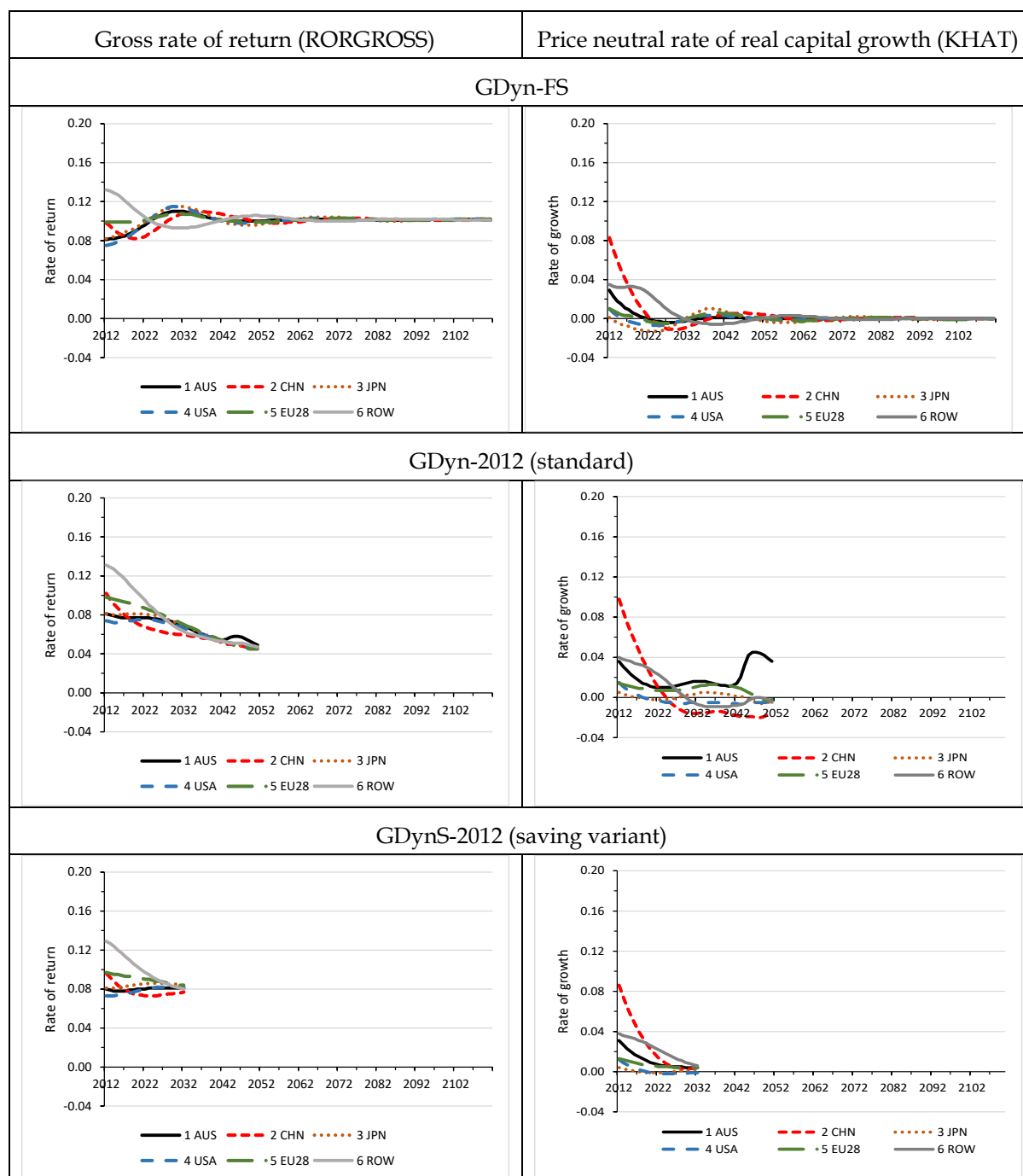


Figure 4: Model stability conditions achieved through GDyn-FS,
100-year simulation with only Time shocked

Source: Author estimates based on GDyn-2012, GDynS-2012, and GDyn-FS models.

3.2 Model stability with a steady-state saving rate with zero long-run growth

The above test of long-run stability can be extended to include the simulation of the elimination of regional differences in savings rates, simultaneously with the elimination of regional differences in risk premia.

For this test, a target global steady state gross saving rate, s^* with zero growth assumptions, is calculated for the global economy for the Cobb-Douglas case according to:

$$s^* = \alpha * (x + n + \delta) / (\delta + \rho + \theta x) \quad (31)$$

where α is the capital input share of global gross value added, $x + n$ are technological and population growth, respectively, assumed zero, δ is the depreciation rate, ρ is the rate of time preference and θ is the inverse of the intertemporal elasticity of substitution (Barro and Sala-i-Martin 1995, p.78). With zero assumed growth and the assumption that ρ is equal to net returns to capital, r ,¹² a back-of-the-envelope (BOTE) approximation of a steady-state saving rate derived from 2011 GTAP data falls in the range 0.14 to 0.15 (that is, 14 to 15 percent) of global gross product.¹³

The region-specific consumption-saving twist term ($twistcs_r$ in eqns 18 and 19, above) are calibrated so that projections of regional saving rates gradually adjust to the neighbourhood of the global BOTE steady-state value (figure 5, top left hand panel). The projections are conducted in two phases. First, rates for Australia, China, Japan, the USA and EU28 are phased to the neighbourhood of the target rate over 20 years, with one degree of freedom provided by the rest of the world. The rest of the world rate is then phased to the target gross saving rate.

The most marked projected reduction is for China which exhibited historically very high saving rates in the database year of 2011. For regions Australia, China, Japan, the EU28 and the ROW a net downward adjustment to the gross saving rate is projected, while the rate is roughly steady for the USA. Consistent with the model reaching a long-run equilibrium with zero growth, the planned rate of growth of capital stocks converges to zero for all regions (figure 5, top right hand panel).

¹² The BOTE analysis assumes that the consumption marginal rate of interest is equal to the social investment rate. Harrison (2010, pp. 32, 33) finds considerable variability in estimates of time preference ranging from theoretically based estimates of zero to direct estimates of at least 18 percent.

¹³ That is: $s^* = 0.14 \text{ to } 0.15 \approx 0.35 * (0.04) / (0.04 + 0.06)$

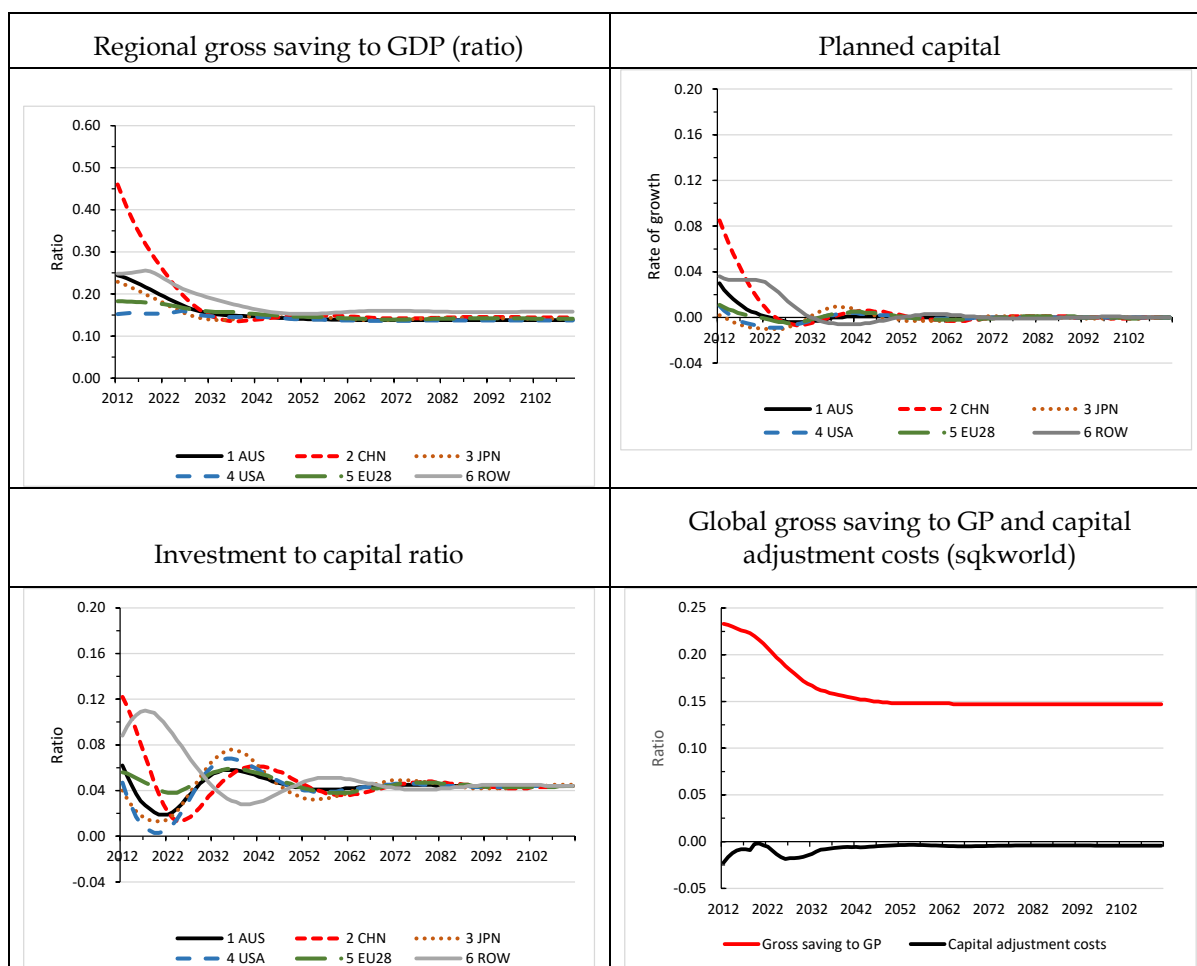


Figure 5: Projecting a steady-state saving rate consistent with zero long-run growth globally and by region over 100-years, ratio, percent

Source: Author estimates based on GDyn-FS model.

The gross investment to capital ratio is projected to converge to around 0.045 (4.5 percent) across regions and towards the model rate of depreciation, of 0.04 (4 percent) (figure 5, bottom left hand panel). However, given the saving rate assumptions, the projection does not fully converge to that rate. This leaves an implicit non-convex adjustment cost of close to 0.005 (0.5 percent) (figure 5, bottom right hand panel). This panel also shows the gradual reduction of the global gross saving rate to the neighbourhood of the BOTE estimate.

The projections, although of a BOTE kind, illustrate a conundrum with the model data. For example, if it is considered that the depreciation rate is realistically higher than current in GTAP (eg at 6 percent), the steady-state saving (and

investment) rate would also be higher and the projected adjustment cost gap would be expected to widen.

3.3 A stylized baseline incorporating exogenous saving rates

3.3.1 Baseline assumptions and flow on effects on the external account

The focus of the illustrative simulations reported in this and the next section shifts to a stylized baseline that incorporates projections of GDP, population, skilled labour and unskilled labour for each of the six regions modelled. The CEPII projections provided with the standard GDyn database are used (GTAP 2016). These projections start from 2004 and cover the 39-year period of interest in this paper from 2011, the database year for this study, out to 2050.

The projections reflect an expectation that GDP growth in China and the regions covered by the Rest-of-the-World grouping will continue at rates above those for Australia, Japan, the United States, and the EU28 economies, with projected growth rates for China and Japan, in particular, tapering off (figure 6, top left panel). Population growth rates for all regional groups are projected to decline, while growth rates for Japan are projected to be negative through the period and to turn negative for China and the EU28 economies (figure 6, top right panel). Growth rates for Skilled labour and Unskilled labour inputs are also projected to decline, more so for the Unskilled group (figure 6, bottom left and right panels). For this latter group, growth rates are projected to be negative for all regions except the Rest-of-the-World (figure 6, bottom left panel).

In GDyn, growth in regional populations and labour inputs are naturally exogenous.¹⁴ With GDP usually determined by the model, that is, naturally determined endogenously, it is necessary to swap this activity variable with another in baseline simulations. Following Walmsley *et al.* (2012), GDP by region is swapped with the region-specific technological change variable for ‘non-accumulable endowment commodities’, that is, land, natural resources and labour.¹⁵ Under this treatment, technological change is determined endogenously while gross investment is also determined endogenously by the investment theory of the model whereby regional firms vary gross regional investment to: eliminate errors in expectations; align actual and target rates of return; and gradually align the actual with the normal rate of capital growth.

¹⁴ Through model variables: *pop*, *qfactsup[SkLab]* and *qfactsup[UnskLab]*.

¹⁵ Technological change in non-accumulable endowment commodities is represented by the model variable *afereg(r)*. The model closure swap is therefore: **Swap** *afereg* = *qgdp* ; *!en* = *ex*.

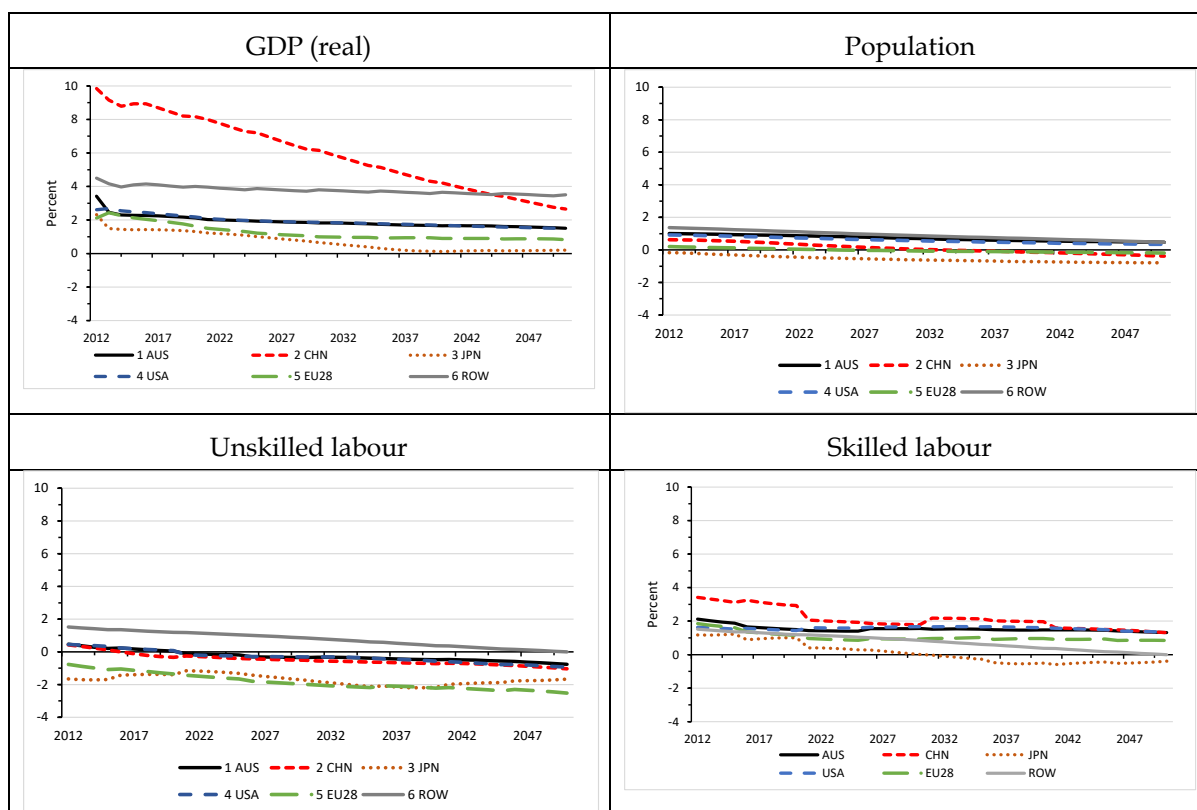


Figure 6: Baseline projections of GDP, population and labour input growth by region, projections to 2050, percentage change

Source: CEPII estimates provided with GDyn_V36, file: Projectionsforthe112_v3.zip downloaded from GTAP webpage 26 June 2016.

These projections are augmented by projections of changes in the rate of gross saving to GDP derived in the first instance from the CEPII projections of GDP and saving. For Australia, Japan, the USA, EU28 and the rest of the world, the projections closely follow the 2011 database rates and closely align WDI data for that year (figure 7, top left panel).¹⁶ For China, a modified approach is followed. In order to stabilize the balance of trade to the income ratio at 2011 database levels (equivalent to around 4 percent of GDP) and illustrate the operation of the revised consumption-saving theory against actual data, the baseline gross saving rate was estimated in a two-step process. In the first step, a simulation was conducted with the balance of trade to income ratio fixed (exogenous) to represent the evolution

¹⁶ The estimates in levels do not align directly partly because saving in GDyn includes unrequited transfers of regions (Hertel and Tsigas 1996, p. 53, Corong et al. 2017, p. 8. GDyn accounting separates income on financial holdings against real assets (termed 'equity' in Ianchovichina and MacDougall 2012, p. 46).

of that economy from export led growth, and the new *twistcs* term endogenous.¹⁷ The saving rate was thereby projected by the model. The model-consistent consumption-saving *twistcs* values so derived were then introduced into the final baseline as exogenous values (that is, with the swap reversed).

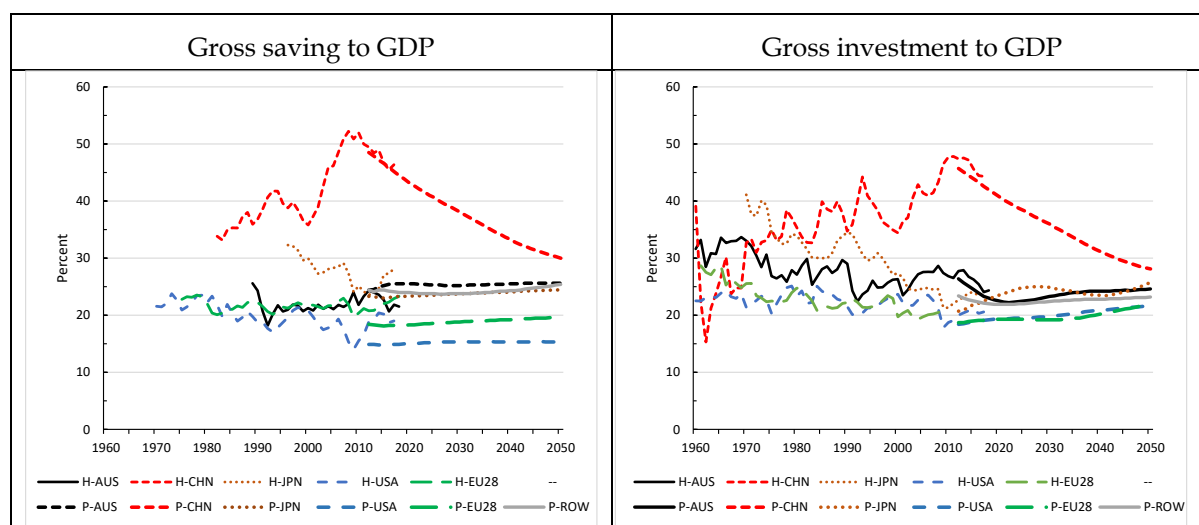


Figure 7: Progression of gross saving and gross investment to GDP, historical data and baseline projections to 2050, percent

Note: The prefix H in legends indicates historical estimate; P indicates a projection.

Source: World Development Indicators (2019), Author estimates based on GDyn-FS model.

Under this approach, the gross saving rate as a proportion of GDP is projected to decline from around a peak of 50 percent of GDP to around 27 percent of GDP – a level approaching the average for the other regions modeled (figure 7, left panel). With the downward projection of the saving rate for China, the gross investment is also projected to gradually decline, again towards the average for other regions (figure 7, right hand panel). While the illustrative projected saving rate for China closely follows actual data to the period 2018, an historical calibration over the period 2011 to 2018 was not undertaken for the other regions modelled.

The illustrative simulations recognize that differences in regional risk and institutions may not be eliminated over the projection period. In the absence of other information, it is assumed that difference in country institutions and risk are measured by the difference between the global average and the regional gross rates of return in the initial 2011 database.¹⁸ Deviations from this assumption or

¹⁷ Implemented by: **Swap** *twistcs*("CHN") = *DTBALR*("CHN"); ! *en* = *ex*

¹⁸ This assumption is implemented by setting the model target rate of return by region *RORTARG*(*r*) equal to the gross rate (*RORGROSS*(*r*)) in 2011.

the introduction of other assumptions about technological progress, how much each region should save, social and environmental factors, population and labour market dynamic, and trade policy and institutional factors could lead to alternative, more nuanced projections. Similarly, a detailed historical validation across the overlap years between actual data and projections from the database year 2011 (or earlier or later database years) could help inform forward projections. Such exercises are beyond the scope of this paper which in this section has focused on an illustrative application of the more flexible formulation of the top-level utility function of the representative regional households.

3.3.2 Projected effects on global saving and adjustment costs

The decline in the projected saving rate for China, expansion of China in global economic output, with relative stable saving rates assumed for other regions, feeds through to a decline in the rate of saving at the global level (figure 8, left hand panel). With the compression of the saving rate towards a level consistent with projected growth in output, population and labour inputs, the baseline adjustment-cost term is projected in the neighbourhood of 1 percent, around one quarter of the depreciation rate.

The projections also indicate that in a baseline characterized by variable growth in output between regions combined with capital (and technology) deepening, regions are likely to tend towards region-specific gross investment to capital ratios (figure 8, right hand panel). The substantial decline in the investment to capital ratio projected for China reflects the reduction in assumed output growth, the substantial reduction in the projected saving rate (figures 6 and 7) and a home country preference in financing. On the other hand, the higher investment to capital ratio for the rest of the world grouping, reflects relatively high assumed output growth across regions and in proportion to labour growth. The capital is funded from the surplus of local savings over net lending abroad.

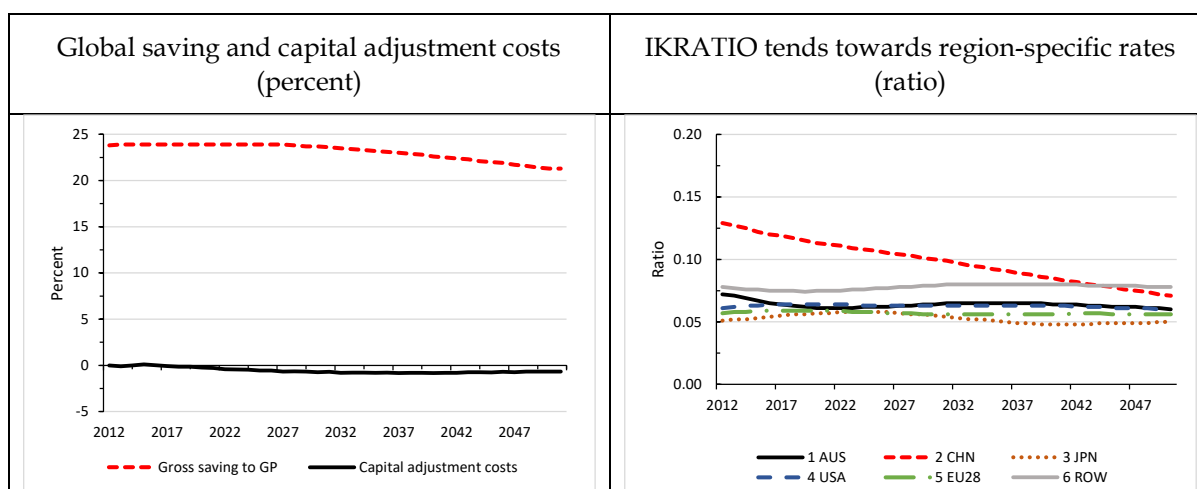


Figure 8: Capital adjustment costs and gross investment to capital, baseline projections to 2050, percent, ratio

Source: Author estimates based on GDyn-FS model.

3.3.3 Projected effects on the international investment position of regions

Figure 9 shows baseline projections of outward foreign investment in foreign real tangible assets by regional households, inward foreign investment in real tangible asset accumulation by regional firms and net foreign investment to regional GDP for the years 2012 to 2050. Foreign investment can be through direct, portfolio or other investment and be made using equity, debenture, loans or other instruments. The figure also shows projections of regional shares of global real asset wealth over the period 2012 to 2050 (bottom, right hand quadrant) to place the distributional effects of real tangible asset accumulation into a global context.

Foreign real tangible assets holdings are projected to increase for Japan, the USA and the EU28 mainly on account of foreign wealth increasing with global production (via equation 27) ahead of regional GDP (figure 9, top left hand panel). For Australia, holdings of foreign tangible assets are projected to increase at a similar rate to GDP by value, influenced by both real growth and positive terms of trade effects. For the relatively faster growing regions of China and the rest of the world, the share of holdings of foreign real assets in regional GDP is projected to decline. The projected decline for China is influenced by the decline in the saving share in GDP by value, which lowers wealth creation including in foreign assets, relative to GDP. The decline in the rest of the foreign investment holdings is influenced by demand for finance for domestic capital accumulation.

The projections of inward foreign investment in regional real assets relative to regional GDP broadly maintain database shares (figure 9, top right hand panel). This follows because the equity/debt position of firms to regional households and

offshore investors is projected to move in line with the value of firm capital (via equation 30) which moves closely with the value of regional output.

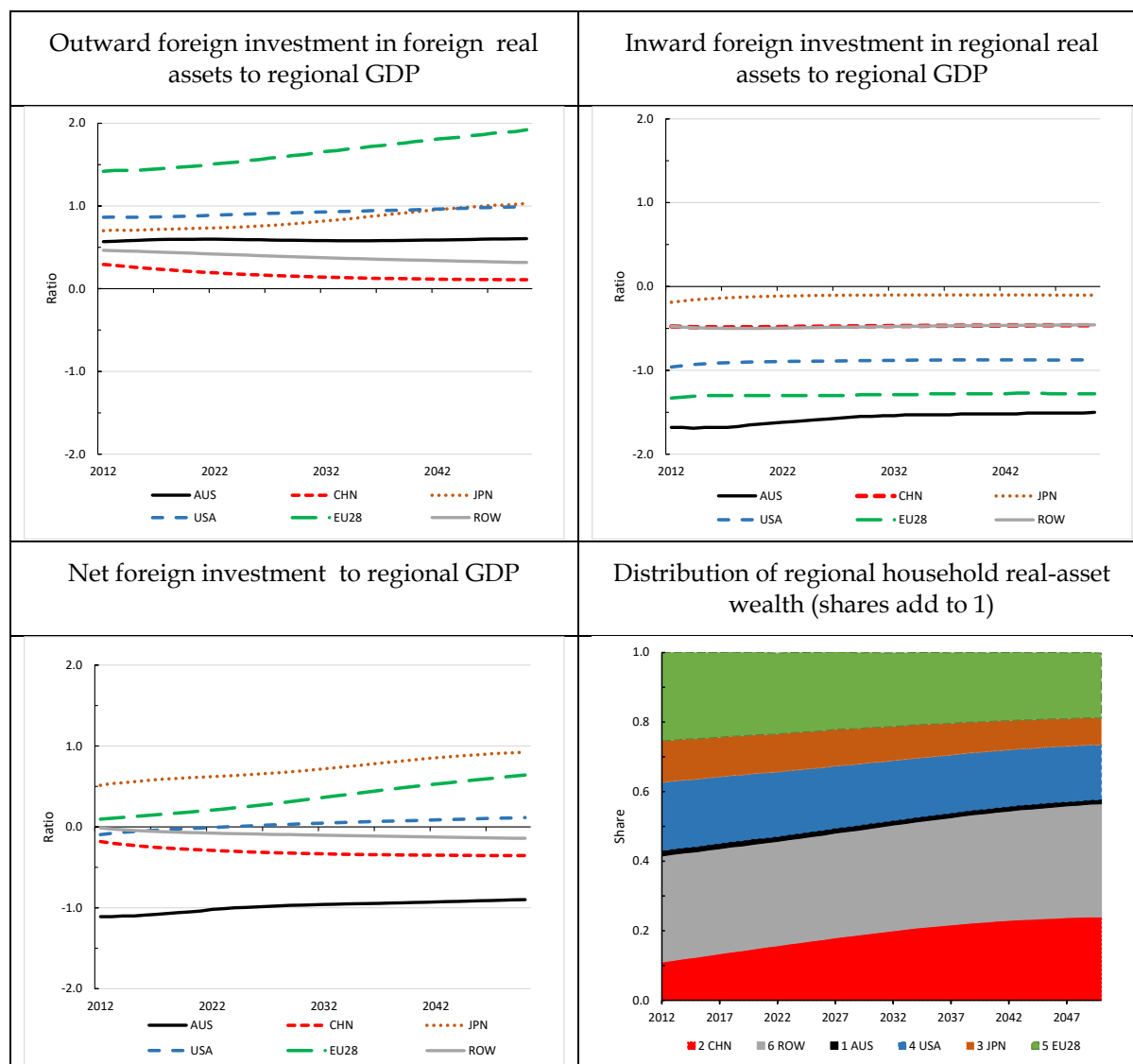


Figure 9: Outward and inward foreign investment in real assets as a share of regional GDP and regional distribution of household real-asset wealth, baseline projections to 2050, ratios, percent

Source: Author estimates based on GDyn-FS model.

With the ratio of inward foreign investment to GDP projected to remain relatively stable across regions, the main influence on the ratio of net assets to GDP is though changes in asset positions. This is particularly evident for Japan, the

United States, and EU28 (figure 9, bottom left hand panel). The net asset position is projected to decline for the expanding regions of China and the rest of the world while Australia is projected to remain a net borrower in proportionate terms.

Economic growth and changes in net foreign investment is projected to bring some shifts in regional wealth in real assets, relative to the present day. Under the projections of real growth, the shares for China and the rest of the world are projected to increase while the shares of other regions are projected to decline (figure 9, bottom right hand panel).

The model as presented provides a new basis for analyzing foreign investment real asset accumulation over the longer term. Matters that could be given attention include reconciliation of GDyn database capital flows with IMF data on the international investment position of regions, as well as institutional and economic factors that may influence the foreign investment activity of regions over time and how these influences may flow back to the real economy.

3.4 *Illustrative analysis of lower capital inflow to Australia*

The investment decisions of foreign firms affect the Australian economy in the first instance through access to finance for investment in Australia. For an individual activity, the concern is access to finance for its operations whether domestically or foreign sourced. For the nation as a whole, the concern is access to foreign sourced finance to make up any gap between domestic investment opportunities and funds available from local savings. Foreign investment can also establish new pathways for the development of markets, and the transfer of technologies and ways of working to enhance local productivity at the sectoral and economy-wide levels.

McDougall (1960) analyzed the economic costs of lower capital inflows to Australia, while the Australian Productivity Commission introduced bilateral investment behaviour into a longer-run comparative static version of GTAP to project the implications of preferential and non-preferential reductions in the risk premium on FDI into Australia and a large partner economy (the USA) (PC 2010, p. 55). Gali and Taplin (2012) applied a national general equilibrium dynamic modelling approach using the MMRF model, to project the impact of a 1 percent reduction in capital inflows on the Australian economy. Bumann, Hermes, and Lensink (2013) provide a systematic meta-analysis of the empirical literature on the relationship between financial liberalization and economic growth by conducting a meta-analysis of 60 empirical studies. The findings indicate a weak positive effect between financial liberalization and growth on average. The findings also suggest that the significance of the relationship can be context specific.

Commentaries have long referred to the need to distinguish between issues concerning economic behaviour of foreign subsidiaries and issues concerning the exercise of sovereignty by home governments over the foreign operations of

national firms (Johnson 1972, p.9). Crawford *et al.* (1978, p.45) noted that dangers to Australia's political security are sometimes seen in the growth of international economic interdependence, more so through domination by foreign investors and business control than through trade dependence. Hanratty (1996) drew attention to a range of factors that were then entering into the public debate in Australia in favour of restricting inward foreign direct investment or policy liberalisation. The OECD restrictiveness index on foreign direct investment rates Australia as having one of the more restrictive foreign direct investment regimes in the OECD area (OECD 2019). Nevertheless, Australia records substantial levels of capital inflows relative to other regions (figure 9, top right hand panel).

Against this background, this section presents projections of the potential adverse effects of an erosion of confidence in investing in Australia. It focuses on the issue of what may be at stake for a capital importing country such as Australia, if policies or the broader economic environment are perceived to make investment more risky or institutions less favourable to investment activity, than otherwise. The scenario does not necessarily represent the effects of a single policy, but rather a broad change in the policy environment and other factors that are perceived by investors (foreign and domestic) to make investing in Australia less attractive.

The scenario considered is an hypothetical policy-induced erosion of confidence across all investment – represented by an increase in the required longer-run rate of return on investment in Australia of 10 basis points which is equivalent to a 10 percent increase in the difference between the US and Australian real commercial bond rate averaged over the period 2000 to 2017 (based on data from World Development Indicators 2019). A 10 basis point increase would imply a 1.25 per cent increase in the economy-wide required gross rate of return for Australia as calibrated to the benchmark gross return for Australia in the GDyn model of 8.1 percent.

The policy-induced change is assumed to occur in one year while adjustment to such a change is modelled as being gradual. Key adjustment assumptions in the GDYN-FS model pertaining to these considerations are: (i) the changes are not anticipated by investors so the modelled actual and expected rates of return when the change occurs are formed by the business as usual case (the model baseline) (ii) installed capital depreciates on average at a rate of 4 percent per annum; (iii) installed capital is assumed to be mobile between industries, but subject to the capability of industries to substitute between labour and installed capital with the rate of substitution assumed to be 1.2 for most activities; and (iv) new investment, planned capital growth and output can adjust in any one year to close one fifth of the gap between the model expected, actual and reference (that is, target) gross rates of return on capital, all else being equal. Because the baseline embodies changes in the structure of the global economy, the projected impacts of a policy

change affecting one region (in this case Australia) will also be influenced by those global changes, that is, the policy projections will be 'path dependent'.¹⁹

A 10 basis point increase in required returns, that is the target rate of return, increases that rate relative to the expected rate, lowering the incentive to invest relative to the business as usual case by equation 10 (as shown in figure 10, centre panel). This flows through to a reduction in investment spending in the first period of around 5 percent (figure 10, top right panel). With the level of installed capital capacity now exceeding required levels, further reductions in investment spending are projected as firms gradually adjust capital stocks downward relative to baseline levels (figure 10, centre left panel).²⁰

The projected decline in investment spending flows through to reduced demand for domestically produced and imported capital goods contributing to lower aggregate imports (figure 10, bottom left panel). As capital stocks approach a new lower level, investors expected and firms actual returns are projected to gradually approach the target level (figure 10, centre panel). With a reduction in available capital, GDP is projected to decline by 0.93 percent after 10 years and converge to 0.55 percent in the long term (figure 10, top left panel).

Aggregate employment is maintained through lower real wages (figure 10, centre panel). In the early periods of adjustment, wages of unskilled workers, which include construction workers and process workers in trade exposed sectors, are projected to decline by more than workers in the skilled category. Lower real wages improves the competitiveness of the trade exposed sectors so that exports are projected to increase and imports decrease, particularly in the early years of adjustment. After a period of adjustment imports and exports converge close to baseline levels, albeit with a lower terms of trade.

Higher returns on the lower capital base do not make up for the reduction in real wages so that real incomes and real consumption decline over time (figure 10, right hand centre and bottom panels).

¹⁹ Sensitivity tests using a baseline in which only time is shocked indicate that the projected impacts of the policy scenario, as reported, are not particularly sensitive to baseline assumptions.

²⁰ The model market clearing and balance sheet conditions ensures that global investment (the sum of investment across regions) is equal to global saving and that total wealth holding by regional households is equal to the sum of real asset holdings of firms across regions.

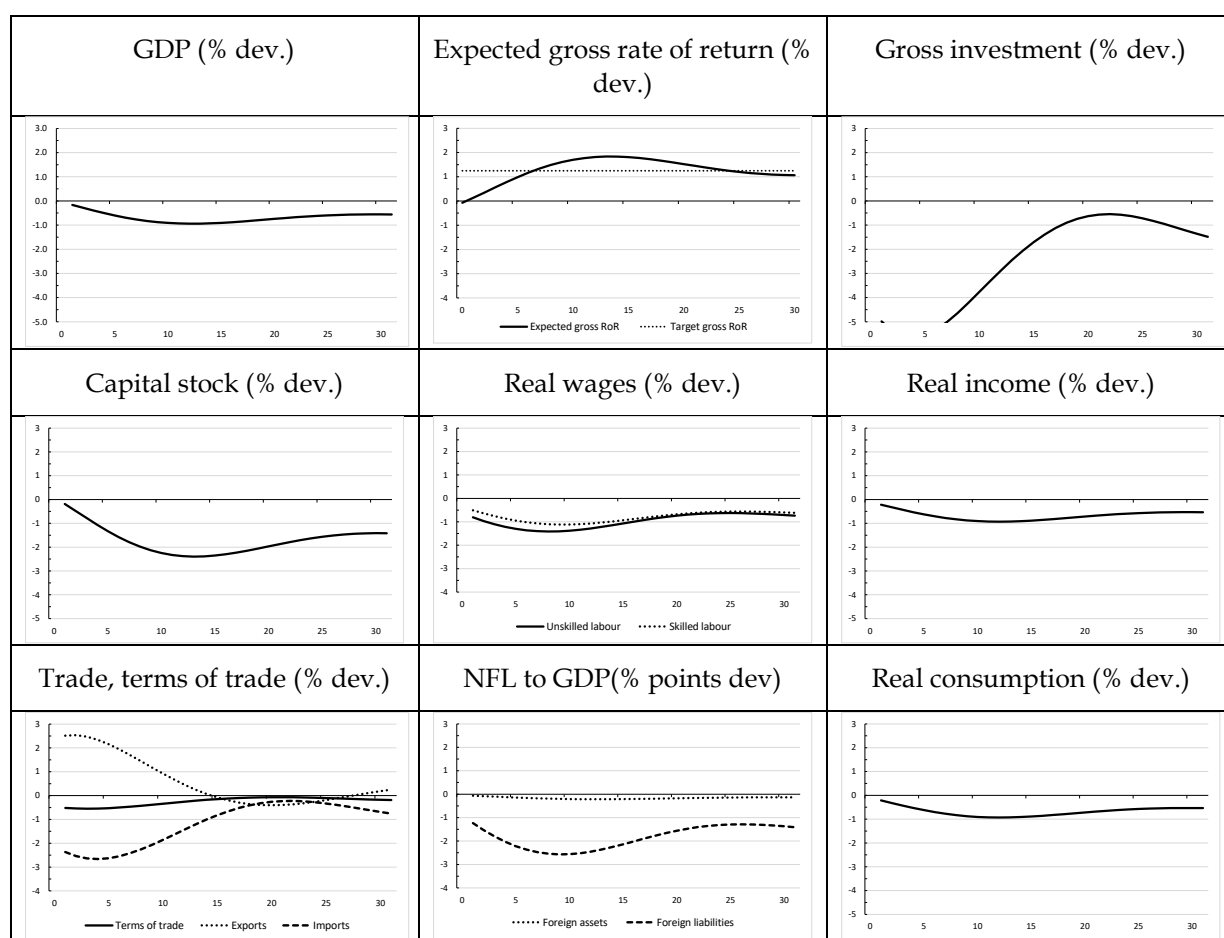


Figure 10: Illustrative projections of economy-wide adjustments to a 10 basis point increase in required returns to capital, Australia, percentage deviation from base line

Source: Author estimates based on GDyn-FS model.

Foreign liabilities of Australia firms are projected to decline in nominal US dollar terms (Figure 10, bottom centre panel). This reflects three effects: (i) a negative shift effect associated with the decline in domestic real capital stocks; (ii) a negative valuation effect associated with a (larger) projected decline in capital goods-prices; and (iii) a small positive substitution effect associated with the expected cost of local capital rising (with required rates of return) relative to finance from abroad. Because of the home-bias assumption adopted in parameter settings the substitution effect is small absolutely and relative to the other effects.

While in the simulation the valuation effect is temporary,²¹ the shift and substitution effects are permanent. In the longer run, therefore, the projected decline in the level of foreign investment in local firms relative to the baseline, closely aligns with, but on account of the substitution effect, is less than, the decline in the level of real assets of local firms.

The level of foreign assets held by Australian household is initially projected to decline with the value of the global trust. This decline is mainly associated with the decline in nominal asset values in Australia in which the trust invests. Over time, local households are projected to transform financial asset holdings away from investment via the global trust in favour of investment in local firms that are now yielding relatively higher returns, but against a lower base.

4. Conclusions

This paper adds to the capabilities of the GDyn model by: (i) relaxing the assumption of fixed shares in consumptions-saving decisions of regional households; and (ii) providing a mechanisms for systematically inducing changes in national consumption-saving choices over time that may accompany changed economic, institutional or social conditions. The paper also expands on the developments presented in Gretton (2018) to satisfy the long-run neo-classical equilibrium conditions set for the model and to introduce optimization behaviour of regional firms in financing capital investment and regional households in the allocation of household wealth between domestic firms and the model's global investment trust.

The paper applies this new approach to project the convergence from the historically high saving rates for China of around 50 percent of GDP in the database year towards historical levels and average levels prevailing across other regions. The projections suggest that without policy changes governing the inflow and outflow of funds, under such a scenario, the rate of accumulation of foreign assets as a share of GDP will slow or decline and that foreign investment in China (again as a share of national output) will remain relatively constant.

Against this illustrative baseline, projections are made of the implications of an erosion of willingness towards investing in a medium sized open economy, Australia, modelled by a 10 basis point increase in required returns on capital. These projections suggest that the cost in terms of output could be around 0.93 percent after ten years with the severity of the impact tapering as the economy adjusts adaptively to converge to a new steady state. There would be a commensurate decline in real wages, regional income and consumption.

The innovations introduced in this paper through the GDyn-FS model will facilitate the wider use of dynamic modelling in a global framework. They provide

²¹ This is ensured by setting the model price of global saving (*psavewld*) as the numeraire price and allowing mobility of saving and investment between regions.

a basis for further developments though historical validation and other research to inform baseline development, structural adjustment affecting consumption-saving and domestic-foreign investment mixes and long-term issues reliant on a stable baseline and modelling environment.

Acknowledgements

The author wishes to acknowledge useful feedback on the companion paper ‘Achieving a long-run equilibrium in the dynamic GTAP model’ (Gretton 2018) and helpful comments received at the National CGE Workshop, 17 August 2017, Victoria University, Melbourne, at a seminar at the Australian National University on 22 May 2018, a seminar at the Centre of Policy Studies, Victoria University on 27 March 2019 and the Global Economic Analysis Conferences in Cartagena and Warsaw. The author has also benefited from the advice of Angel Aguiar, Robert McDougall and Alla Golub on details of GDyn model, and Damien Eldridge on theoretical issues. All errors and omissions remain the responsibility of the author.

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Appendix A. Regional and sectoral mappings

Table A1: Country/region mapping

Regions in database	G20	Code	Country(s) in database region
1 Australia	G20	AUS	Australia
2 China	G20	CHN	China
3 Japan	G20	JPN	Japan
4 United States	G20	USA	The United States
5 European Union (28)	G20	FRA	France
	G20	DEU	Germany
	G20	ITA	Italy
	G20	GBR	United Kingdom
	G20	REU	Austria; Belgium; Bulgaria; Cyprus; Czech Republic; Denmark; Estonia; Finland; Greece; Hungary; Ireland; Latvia; Lithuania; Luxembourg; Malta; Netherlands; Poland; Portugal; Romania; Slovakia; Slovenia; Spain; Sweden
6 Rest-of-the-World		NZL	New Zealand
		HKG	Hong Kong
	G20	KOR	Korea
		TWN	Taiwan
	G20	IDN	Indonesia
		MYS	Malaysia
		PHL	Philippines
		SGP	Singapore
		THA	Thailand
		VNM	Vietnam
	G20	IND	India

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Regions in database	G20	Code	Country(s) in database region
		ROA	Cambodia; Iran; Kazakhstan; Kyrgyzstan; Laos; Myanmar; Pakistan; Sri Lanka; Bangladesh; Rest of East Asia; Rest of Oceania; Rest of South Asia; Rest of Southeast Asia; Rest of Western Asia
	G20	CAN	Canada
	G20	MEX	Mexico
	G20	BRA	Brazil
	G20	ARG	Argentina
		ROM	Bolivia; Caribbean; Chile; Colombia; Costa Rica; Ecuador; Guatemala; Nicaragua; Panama; Paraguay; Peru; Uruguay; Venezuela; Rest of Central America; Rest of North America; Rest of South America
27 Turkey	G20	TUR	Turkey
28 Russia	G20	RUS	Russian Federation
29 Rest of Europe		ROE	Albania; Armenia; Azerbaijan; Belarus; Croatia; Georgia; Norway; Switzerland; Ukraine; Rest of EFTA; Rest of Eastern Europe; Rest of Europe; Rest of Former Soviet Union
30 Saudi Arabia	G20	SAU	Saudi Arabia
31 South Africa	G20	ZAF	South Africa
32 Rest of World		ROW	Rest of Africa and the Middle East, and other countries not separately identified

Source: Author's GTAP version 9a database aggregation.

Table A2: GTAP industries and industry sectoring adopted

No.	GTAP code	Industries	No.	Industry sectors adopted
1	pdr	Paddy rice	1	Grains, Crops, Forestry
2	wht	Wheat	1	Grains, Crops, Forestry
3	gro	Cereal grains nec	1	Grains, Crops, Forestry
4	v_f	Vegetables, fruit, nuts	1	Grains, Crops, Forestry
5	osd	Oil seeds	1	Grains, Crops, Forestry
6	c_b	Sugar cane, sugar beet	1	Grains, Crops, Forestry
7	pfb	Plant-based fibres	1	Grains, Crops, Forestry
8	ocr	Crops nec	1	Grains, Crops, Forestry
9	ctl	Cattle, sheep, goats, horses	2	Livestock, fishing
10	oap	Animal products nec	2	Livestock, fishing
11	rmk	Raw milk	2	Livestock, fishing
12	wol	Wool, silk-worm cocoons	2	Livestock, fishing
13	frs	Forestry	1	Grains, Crops, Forestry
14	fsh	Fishing	2	Livestock, fishing
15	coa	Coal	3	Mining
16	oil	Oil	3	Mining
17	gas	Gas	3	Mining
18	omn	Minerals nec	3	Mining
19	cmt	Meat: cattle, sheep, goats, horse	4	Processed food
20	omt	Meat products nec	4	Processed food
21	vol	Vegetable oils and fats	4	Processed food
22	mil	Dairy products	4	Processed food

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No.	GTAP code	Industries	No.	Industry sectors adopted
23	pcr	Processed rice	4	Processed food
24	sgr	Sugar	4	Processed food
25	ofd	Food products nec	4	Processed food
26	b_t	Beverages and tobacco products	4	Processed food
27	tex	Textiles	5	Textiles and clothing
28	wap	Wearing apparel	5	Textiles and clothing
29	lea	Leather products	6	Light manufacturing
30	lum	Wood products	6	Light manufacturing
31	ppp	Paper products, publishing	6	Light manufacturing
32	p_c	Petroleum, coal products	7	Heavy manufacturing
33	crp	Chemical, rubber, plastic products	7	Heavy manufacturing
34	nmm	Mineral products nec	7	Heavy manufacturing
35	i_s	Ferrous metals	7	Heavy manufacturing
36	nfm	Metals nec	7	Heavy manufacturing
37	fmp	Metal products	7	Heavy manufacturing
38	mvh	Motor vehicles and parts	7	Heavy manufacturing
39	otn	Transport equipment nec	7	Heavy manufacturing
40	ele	Electronic equipment	7	Heavy manufacturing
41	ome	Machinery and equipment nec	7	Heavy manufacturing
42	omf	Manufactures nec	6	Light manufacturing
43	ely	Electricity	8	Utilities
44	gdt	Gas manufacture, distribution	8	Utilities
45	wtr	Water	8	Utilities

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No.	GTAP code	Industries	No.	Industry sectors adopted
46	cns	Construction	9	Construction
47	trd	Trade	10	Transport and communication
48	otp	Transport nec	10	Transport and communication
49	wtp	Sea transport	10	Transport and communication
50	atp	Air transport	10	Transport and communication
51	cmn	Communication	10	Transport and communication
52	ofi	Financial services nec	11	Financial services nec
53	isr	Insurance	11	Financial services nec
54	obs	Business services nec	11	Financial services nec
55	ros	Recreation and other services	12	Other services
56	osg	Public administration, defence, education, health	12	Other services
57	dwe	Dwellings	13	Dwellings

Source: Author's GTAP version 9a database aggregation.

Table A3: Primary factors

Description	GTAP code	GTAP database description
Unskilled labour	UnSkLab	Agricultural and Unskilled
	UnSkLab	Clerks
	UnSkLab	Service/Shop workers
Skilled labour	SkLab	Technicians/AssocProfessional
	SkLab	Officials and Managers
Land	Land	Land
Natural resources	NatlRes	Natural Resources
Capital	Capital	Capital

Source: Author's GTAP version 9a database aggregation.