1 An overview of the global trade and environment model (GTEM)

1.1 Motivation

Improving sectoral, spatial and temporal efficiency of resource allocation are some of the classic challenges faced by policy makers everywhere and at all times.

Sectoral efficiency of resource allocation assures that the available resources in any country are put to their best uses. Any impediments to this are addressed by policy changes. Spatial efficiency covers allocation of a given amount of resource across regions, within a given country or globally, so that societal benefits are maximised globally. Any impediments to this are addressed by interjurisdictional policy coordination. Attempts to free international trade are such examples. Temporal efficiency covers the issue of resource allocation over time so that the discounted sum of societal benefits over the relevant time horizon are maximised. Again, national and international policy adjustments and coordination would be required if there were inefficiencies. Climate change mitigation policies are examples of this nature.

The answers to the following questions have implications for intertemporal efficiency of resource allocation.

- What should be the consumption and production profile of nations over time?
- Should we, as a generation, invest now to enjoy a better life tomorrow while sacrificing some consumption today?
- Should we be concerned about the welfare of future generations and sacrifice some of ours now?
- Which policies support deep cuts in emissions and which one costs the least?
- Can a carbon tax alone stabilise atmospheric concentration of greenhouse gases?
- Which trajectory of carbon tax would stabilise atmospheric concentration of greenhouse gases?
- What are the economic costs and benefits of such a policy relative to promoting the development and adoption of zero emissions technologies?
- What if a carbon tax and clean technology development and diffusion have synergies?

The following questions are just some of the many that the policy makers in the government and in the private sectors (such as boardrooms of multinational companies) have to answer regularly.

- Should carbon free technologies be subsidised in Australia and/or in rapidly growing developing economies? If yes, for how long?
- What are the economic impacts for Australia of a given policy option, such as subsidising a zero-gen project (a project that aims to generate electricity from coal without releasing greenhouse gases to the atmosphere) in a particular region, say Queensland, or across the whole country?
- What happens to the world economy and trade if all agricultural subsidies in, say, Europe, the United States and Japan are removed? What would happen to Australia and to the countries removing the subsidies?
• What happens if the world adopts a completely free trade regime? Are there any losers? If yes, which countries benefit and which countries lose?

• Are there policies that can be adopted to compensate the losers while making the global trade freer?

• If all African economies start to grow at, say, 10 per cent a year from 2010 and sustain the growth rate for twenty years, what will be the impacts on Australian economy, on the world economy in general?

• What will be the evolving pattern of trade in commodities, including energy?

• What happens to the world economy and the environment if China’s and India’s economic growth rates continue unabated at their current rates for the next fifty years?

• How will the Australian economy respond to these shocks?

• Where will Australia’s comparative advantage lie in the days to come?

In short, society may always be seeking combinations of policies that guarantee sectoral, spatial and temporal efficiency of resource allocation. Society may also be interested to know ahead of the market the likely future outcomes in a dynamic world, so that strategic planning could be put in place to avoid or minimise the adjustment costs while the market is moving toward equilibrium.

Obviously, the need to answer these questions calls for analytical tools that are global in coverage, encompass all markets and take into account all resource constraints and their dynamics. Models of this calibre include dynamic general equilibrium models of the global economy and environment. GTEM – the global trade and environment model – developed at the Australian Bureau of Agricultural and Resource Economics (ABARE) is such a model.

A general equilibrium model captures the interlinkages between the markets of all commodities and factors, taking into account resource constraints, to find a simultaneous equilibrium in all markets. A global general equilibrium model extends this interdependence of the markets across world regions and finds simultaneous equilibrium globally. A dynamic model adds onto this the interconnection of equilibrium economies across time periods. For example, investments made today are going to determine the capital stocks of tomorrow and hence future equilibrium outcomes depend on today’s equilibrium outcome, and so on.

Thus a dynamic global general equilibrium model, such as GTEM, has the capability of addressing total, sectoral, spatial and temporal efficiency of resource allocation as it connects markets globally and over time. Of course, being a recursively dynamic model, its ability to address temporal issues is rather limited. In particular, GTEM cannot address issues requiring partial or perfect foresights. However, it does have the capability to project the economic impacts over time of given changes in policies, tastes and technologies in any region of the world economy on all sectors and agents of all regions of the world economy.

GTEM was developed out of the MEGABARE model (ABARE 1996), which contained significant advancements over the GTAP model of that time (Hertel 1997), and has been evolving ever since. As more data become available, more features are added. As understanding of the theoretical system improves or software becomes more intelligent or new and complex questions need to be addressed, the model is further improved. By doing so, the model becomes even richer.

Experience has demonstrated that no model can be so general that it can be used to answer all questions at all time. The model has to be adapted to suit the question being answered. In this sense, it is difficult to write a model documentation that covers all potential applications now or in the future. Nevertheless, in all applications there will be a core theoretical framework on which the actual problem specific modelling is done.
The purpose in this report is to document the core structure of GTEM to serve modellers as a sound framework suitable for a range of interesting and important policy applications. All models, by nature, are simplifications of reality. It is this simplification that makes a model manageable and usable. GTEM is no exception. As the insights provided by the model are also limited by the nature of the underlying assumptions, it is necessary to understand them before the model is actually presented. In this chapter, the fundamental assumptions that underlie GTEM are outlined, describing the model in a nutshell.

1.2 Simplifying assumptions of GTEM

The world
GTEM divides the world into \( r \) regions, and international waters. Each region could be a country or a group of countries aggregated. The size of \( r \) depends on the database aggregation and is normally limited to the number and aggregation of countries covered by the GTAP database at the time of model application. ‘International waters’ are a hypothetical region where global traders operate and use international shipping services to ship goods from one region to the other. It also houses an international finance ‘clearing house’ that pools global savings and allocates the fund to investors located in every region.

A region
A region consists of households, a government with a tax system, production sectors, investors, traders and finance brokers.

The economic core

Households, the government and the tax system
All households are considered to be homogeneous so that there can be a representative household in each region whose characteristics are that of an ‘average person’ residing in the region. Scaling up this representative household by total population yields the regional outcome in all respects from the individual one. As a consequence of this homogeneity assumption, distributional impacts within a region cannot be assessed by GTEM. It can, however, be used to assess the distributional impacts across global regions.

Households together are assumed to own all factors of production and to receive all payments made to the factors, all tax revenues and all net interregional income transfers. In other words, regional households together receive the gross national product (GNP) of the region. The representative household, by definition, therefore receives the per person GNP of the region.

It is assumed that the tax system (of the government) imposes taxes in almost all transactions and returns all proceeds to regional households. Government expenditure, which is taken to be for the provision of public good, is fully funded by regional households in proportion to their income.

Households allocate their income across private and public consumption and savings. The share of each component in GNP is assumed to remain fixed. There are two implications of this assumption. First, government expenditure in GTEM moves proportionately with the GNP of the region and all government deficits are fully financed by an implicit income tax. There is no role for other budgetary policy in GTEM. Second, regional savings are assumed to move in line with regional income. This assumption of a fixed savings rate puts GTEM into the class of Solow–Swan growth models but, as will be described below, with several extensions, including endogenous population and labour supply change.
Consumption expenditure on commodities is made by the private and government sectors on the basis of maximising their respective utility functions, taking prices as given. The utility maximising behaviour of a representative household has been employed to obtain the regional allocation of private consumption expenditure on commodities. Government consumption expenditure on commodities is allocated on the basis of a single consumer (society) maximising a simple utility function. This is done to represent government consumption expenditure as the consumption of public goods by society. Commodities for private and public consumption may come from domestic as well as foreign sources. In all respects, agents behave competitively and take prices as given.

Producers

Each region has \( n \) production sectors, each producing single products using all commodities and four factors of production — capital, labour, land and natural resources. The production functions have constant returns to scale — meaning that it is possible to replicate the current operation at any scale desired. Producers maximise profit (or minimise costs) and take all prices as given. Each production sector consists of numerous homogeneous ‘firms’ that employ identical technology and produce homogeneous products.

There are two exceptions to this assumption — the electricity sector and the iron and steel sector. It is assumed instead that, while firms in these two sectors produce homogeneous outputs, as in other sectors, they employ non-homogeneous technologies. According to the technology employed, they have been grouped into finite classes such that the technology is homogeneous within the group and non-homogeneous across groups. For example, electricity can be produced by a coal fired technology or by using hydroelectric technology and so on. To a user it is indistinguishable whether the power comes from a coal fired power plant or from a hydroelectric plant but their input use pattern and emissions profile are very different. To capture this difference, GTEM continues to use the technology bundle approach developed in MEGABARE. In some applications of GTEM the technology bundle approach has been extended to the land transport sector.

Irrespective of whether a sector has technology bundles or not, all microagents in GTEM are assumed to operate in perfectly competitive markets and have perfect information. Under these assumptions, prices will be set to cover costs and GTEM industries earn normal profits at all times, with all returns paid to primary factors of production. Thus, changes in output prices, in equilibrium, are determined by changes in input prices of materials and primary factors, given technological parameters and taxes.

Technological change

As a default, technological change is exogenous in GTEM. At the time of model application a model user will have to decide what sort of technological change is to be assumed and apply that accordingly.

There are two areas in the economic core of GTEM in which technological changes are endogenous. The first is infant electric power generation technologies, such as solar, are assumed to have a ‘learning by doing’ mechanism that lowers the primary factor input requirement per unit of output as cumulative experience with the technologies grows. The second area is in the natural resource extraction (mining) sector, where factor productivity declines with increases in the cumulative level of resource extraction. By further assuming that these effects depend on industry level experience, technological change occurs outside individual firms’ choice set.

Fixed participation rate and natural rate of unemployment

As a default in GTEM, assumed participation rates among working age populations are used together with the population module to determine labour supply to the market. It is further
assumed that there is a given unemployment rate among those who wish to participate in the labour market. This rate may loosely be called the natural rate of unemployment for the economy. As a result, there will be a fixed supply of labour available in any period in each region that will be fully employed. This fixed supply of labour will, however, change over periods because of changes in working age population. These default assumptions for the labour market can be changed by model users at the time of model application.

Factor supplies

Capital accumulates as a result of net investment. It is implicitly assumed in GTEM that it takes one year for capital to be installed. Hence supply of capital in the current period depends on the last period’s capital stock and investments made during the previous period. Labour supply in each period is determined by endogenous changes in population, given participation rates and a given unemployment rate. Supply of land is given for each region and the supply of natural resource is given for each sector in each region.

The model has the option for these assumptions to be changed at the time of model application if alternative factor supply behaviours are considered more relevant.

Factor mobility

It is assumed in GTEM that both capital and labour are fully mobile across sectors; they move in response to a higher reward. This implies that, in equilibrium, wage rates and rental rates on capital are equalised across all sectors of each region in GTEM. To a lesser extent, capital and labour can also be thought to move across regions through international flows of financial investment and migration of population. This sort of mobility is not in response to a higher rate of return per se and does not necessarily equalise wage rates and capital rentals across regions in GTEM.

Land is used only in the agriculture and forestry sectors and is assumed to move very slowly in response to a change in rental rates within the agriculture sector. Natural resources are sector specific. These assumptions imply that there is no reason for land and natural resource rentals to be equalised across sectors.

Trade

A key feature of GTEM is that it can potentially model bilateral trade flows of all commodities between all regions. In GTEM, like in many other general equilibrium models, an ‘Armington’ preference structure is adopted for each user to distinguish a good produced in different regions. This assumption implies that a good produced in one region is an imperfect substitute for the ‘same’ good produced by the same industry in other regions (Armington 1969a,b). In other words, this assumption implies that an otherwise identical commodity supplied by different sources can simultaneously be sold at different prices in a given location to a given buyer. This assumption, together with the cost minimising behaviour of all agents (rationality assumption), gives rise to bilateral trade in all traded commodities.

International transport services

Goods are transported between regions by an international transport industry. The cost of international transport is added to the cost of imports to each country. Transport services are supplied by all regions.

International mobility of financial capital

The capital account in GTEM is open. Domestic savers in each region purchase ‘bonds’ in the global financial market through local brokers, which are merely conceptual agents in GTEM. Investors in each region sell bonds to the global financial market to raise investible funds. A flexible global interest rate clears the global financial market.
It is assumed in GTEM that regions may differ in their risk characteristics and policy configurations. As a result, rates of return on money invested in physical capital may differ between regions and therefore may be different from the global cost of funds. Any difference between the local rates of return on capital and the global cost of borrowing is treated as the result of the existence of a risk premium and policy imperfections in the international capital market. It is maintained that the equilibrium allocation of investment requires the equalisation of changes in (as opposed to the absolute levels of) rates of return over the base year rates of return.

Any excess of investment over domestic savings in a given region causes an increase in the net debt of that region. It is assumed that debtors service the debt at the interest rate that clears the global financial market.

**Investor behaviour**

Investor behaviour in GTEM is consistent with the maximisation of shareholders value. Investment demands, in turn, are determined by the regional capital stock and regional expected rates of return relative to the expected global cost of borrowing. To keep the model recursive, the expectations are modelled as static, which means that investors think that the future rates of return will be equal to the current ones. Thus, changes in investment flows represent changes in demand for replacement (scale effects) and responses to changes in cost of borrowing relative to the rate of return (relative price effects).

**Balance of payments and exchange rates**

In equilibrium, exports of a good from one region to the rest of world are equal to the import demand for that good in the remaining regions. Together with the merchandise trade balance, the net payments on foreign debt add up to the current account balance. GTEM does not require that the current account be in balance every year. It allows the capital account to move in a compensatory direction to maintain the balance of payments. The exchange rate provides the flexibility to keep the balance of payments in balance.

**Population module**

Population and labour supply for each region are determined endogenously (within the model) over time. GTEM contains an elaborate description of population dynamics, which captures the idea that as countries move along the economic development path, with increasing per person incomes, changes in fertility and mortality rates follow a well defined path. The model uses estimates of the dependence of fertility and mortality rates on income and an exogenously imposed migratory pattern to predict age and gender specific population changes in each region.

Empirical evidence, however, limits the dependence of fertility rates on income growth to low and middle income countries. The dynamics of fertility rates in high income countries thus remains unexplained. It is therefore assumed that the birth rates in high income countries tend to converge to the birth rates of a reference region. The choice of a reference region for a target birth rate is left open to the model user. As a default, GTEM uses a region with the highest per person income as the reference region.

**Environment module**

The key assumptions that drive the environment module of GTEM are fairly straight forward. GTEM assumes that combustion emissions of greenhouse gases are proportional to the quantity of fossil fuel combusted. As a matter of convenience, combustion emissions also include emissions from the use of fertiliser in the agricultural sector. It is assumed that emissions are proportional to the quantity of fertiliser or chemical used. It is also
acknowledged in GTEM that, in some sectors such as cement, livestock and rice production, the production process necessarily emits greenhouse gases. It is assumed in GTEM that noncombustion emissions of these sectors are proportional to the quantity of output produced, except rice production, in which case the emissions are proportional to the area of land cultivated. In general, the emission intensity has been assumed to respond negatively to carbon tax rates and gas price. The exact form of response is represented by the respective emission response functions and their underlying parameters.

Currently, GTEM identifies and models all major sources of greenhouse gases with low global warming potential, except from land use change. Data on emissions from waste and emissions of gases with high global warming potential are not available by transactable sources and therefore cannot be modelled properly to bring them into the scope of carbon taxes. Ad hoc rules have been specified to describe the trajectories of these emissions, following current international modelling practice. These rules will have to change as more data become available and understanding of the sources and processes of these emissions improves.

1.3 The model in a nutshell

Based on the simplifying assumptions described above, the global trade and environment dynamic general equilibrium model (GTEM) consists of three modules — the economic module, the population module and the environment module. These modules can be interlinked or decoupled as desired by the model user. As a default they are connected.

There is two-way feedback between the population and economic module. Economic growth affects fertility and mortality patterns and thus brings changes in population structure and labour supply, which, in turn, affect economic growth. At this stage, the economic module and the environment module have only a one way relationship. (Two-way feedback mechanisms fall in the domain of integrated assessment models, such as GETEC — see Pant, Cao and Fisher 2005). Economic growth consumes more fossil fuels, which release more combustion emissions and need increased production of commodities that release more noncombustion emissions. There is no damage function in GTEM linking emissions growth to economic output through climate change or otherwise.

Even if there is no direct feedback from the environment module to the economic module, emission restriction policies will have impacts on the economic module and hence, in this sense, there is a strong link between the economic module and the environment module. It is not possible to reduce emissions without altering a combination of production and consumption patterns and technologies.

Given the assumption described above, world regions in GTEM are connected by trade and investment. Changes in economic activities and incentives in one region affect the economic fortune of other regions as their demand for imports and supply of exports and the terms of trade will change. Therefore, in GTEM, the impacts of policy changes initiated in a region may not be limited to the boundaries of that nation alone. It may have international ramifications. Take, for example, the potential impacts of the elimination of farm subsidies.

As mentioned earlier, the population module and the environment modules are additions to the economic module, which in itself consists of two parts — a static core and its dynamics, connecting the static cores over time. As GTEM is a recursive model, the threads connecting the static cores over time are provided by the accumulation relationships — capital accumulation, population changes and debt accumulation — the key part of the model where all the economic action takes place is therefore in the static core of the model.

The static core of GTEM is nothing but a Walrasian system of interconnected markets of all commodities and factors. For each commodity and factor there is a demand side, there is a
supply side and there is a market clearing condition. Each market is cleared by a flexible price. Any equation of the static core that does not fall into one of the above three classes is a summary equation and has been included there for convenience or as an instrument to facilitate the scenario analysis.

All players in each market behave competitively and are rational optimisers. Consumers maximise utility and minimise costs; producers maximise profits and minimise costs, as the situation demands. All microagents have behavioural functions that satisfy neoclassical regularity conditions, which together admit a unique and stable solution for the system. The agents do not have any money illusion. The model maintains, as a default, the real nominal dichotomy.

The main purpose of this document is to assist the reader to understand the basic structure of the model and navigate through the Tablo code of the model. Hence, in the following chapters of this report, extracts of the equations from the Tablo code of the model are presented in a logical order so that the reader can get a feel for the economic ideas working behind the model.

As listed in table 1.1 the equations of the model are presented in seventeen different categories. Of these the first thirteen categories form the static core of the model. The remaining four categories consist of a category for the population module, one for the dynamics, one for the environment module and one for the welfare analysis.

Regional incomes and prices are the starting point and determine the regional allocation of income between private and public consumption and savings ($CS$) and then allocate the consumption expenditures into commodities ($HC$). This is followed by the determination of investment demand for each region ($IC$). Input demands of all firms of all types ($FB$ and $TB$) are then determined. This gives domestic demands for all commodities and aggregate demand from all users for each imported commodity. Import demands are allocated to the sources of supply and the demand from international transport services in category $IT$ is determined. This completes the determination of global demand for each commodity produced in each region. It also covers the determination of demand for all factors.

The supply side of the factor market in category $FS$ and the supply side of commodities in the zero-profit conditions in category $ZP$ are then introduced. The market clearing conditions are included in category $MC$, which basically completes the description of the markets. Because of the presence of taxes, prices faced by users are usually different from the prices received by suppliers, which again is different from the market clearing price. The links between various prices via taxes are described in category $PL$ and price indices of various commodity aggregates are described in category $PI$.

Finally, the equations related to technical changes are presented in category $TC$ and all equations deriving the macroeconomic aggregates are presented in category $MA$, which includes the determination of regional income that was allocated by the regional household. This completes the circular flow of income and corresponding flows of goods and services in the static core of GTEM.
Table 1.1: Categories of equations in GTEM

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
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<tbody>
<tr>
<td>CS</td>
<td>Consumption–savings decision</td>
</tr>
<tr>
<td>HC</td>
<td>Household consumption (private and government) and savings</td>
</tr>
<tr>
<td>IC</td>
<td>International allocation of investment</td>
</tr>
<tr>
<td>TB</td>
<td>Technology bundle</td>
</tr>
<tr>
<td>FB</td>
<td>Firm’s behaviour</td>
</tr>
<tr>
<td>IT</td>
<td>International trade and transport</td>
</tr>
<tr>
<td>FS</td>
<td>Factor supply</td>
</tr>
<tr>
<td>ZP</td>
<td>Zero-profit conditions: supply of commodities</td>
</tr>
<tr>
<td>MC</td>
<td>Factor and goods market clearing conditions: market price determination</td>
</tr>
<tr>
<td>PL</td>
<td>Price links</td>
</tr>
<tr>
<td>PI</td>
<td>Price indices: prices of composite commodities</td>
</tr>
<tr>
<td>TC</td>
<td>Technical change</td>
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<tr>
<td>MA</td>
<td>Macroeconomic summary indices</td>
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<tr>
<td>PP</td>
<td>Population</td>
</tr>
<tr>
<td>DY</td>
<td>Dynamic equations</td>
</tr>
<tr>
<td>EM</td>
<td>Emissions accounting and trading</td>
</tr>
<tr>
<td>WD</td>
<td>Welfare decomposition</td>
</tr>
</tbody>
</table>

1.4 Policy analysis with GTEM

To repeat, GTEM is a recursively dynamic model. It includes relationships between variables at different points in time. Hence GTEM has the capacity to capture the impacts on all future equilibrium outcomes of a policy decisions taken today. Because of this capability, policy analysis using GTEM is slightly more involved than with a static model. Policy analysis with a static model is much simpler — it involves comparing outcomes between two equilibriums, one before a policy change and one following. This comparison, however, ignores the possible nonuniform impacts that the policy may have on the future values of the relevant variables (the so-called dynamic efficiency effects). This is what sets a dynamic model, such as GTEM, apart from a comparative static model.

To estimate the value of a policy to society, the underlying dynamics require simulating GTEM under two scenarios — business as usual, and policy.

• In the ‘business as usual’ scenario, all exogenous variables, which are given to the model, will change as assumed or projected by an external model but without the proposed policy change.

• In the policy scenario, the exogenous variables change as in the business as usual case but with the proposed policy change.

These two scenarios give two trajectories of the criterion variable, such as welfare level or net benefits, defined appropriately. The difference in the value of the criterion variable between the two trajectories can then be attributed to the proposed policy
change on a year on year basis, which can be used to estimate the value of the proposed policy change.

This point is illustrated with the help of figure 1.1. The figure contains two panels — the left panel illustrates the welfare effect of a given policy change in a static framework, while the right panel illustrates the possible effects of the policy change in a dynamic context. In the static framework, the welfare level rises instantaneously as a result of the policy shock and remains at that level unless another shock is applied exogenously.

Figure 1.1 Effects of a policy change in a static versus dynamic model

If it is assumed that the new long run equilibrium was attained within the period, then for all subsequent periods welfare remains unchanged. As the gap between the pre-shock and post-shock welfare levels remains constant for all future periods, the value of the policy change can be estimated by multiplying the the initial gap between the two paths by a factor that depends on the discount rates used. Hence the key problem of policy analysis with static models is to know the gap between the pre- and post-shock equilibrium welfare levels.

In a dynamic context, however, the pre-shock path is not necessarily a horizontal line; there are accumulation relationships (equations of motion) that describe how the stocks (state variables) will change over time and therefore the economy may be moving toward its steady state equilibrium. Such a time path is marked as ‘baseline’ in figure 1.1. Even if exactly the same one-shot policy change has been applied as in the static case, the impacts on annual welfare levels may not be the same in a dynamic environment. The policy change may have dynamic efficiency effects as it may alter

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1 Static models do not have a clearly defined concept of time periods. The long run versus short run equilibrium is distinguished by the choice of model closure — mainly by the assumptions imposed on factor mobility and price flexibility. In the long run, factor mobility is perfect and prices are fully flexible, some of which may not be true in the short run. It may be useful to note that the annual equilibrium in GTEM corresponds to the long run equilibrium in comparative static models.

2 If \( r \) is the discount rate used, then the factor is \( (1+1/r) \). This means that if a 5 per cent discount rate is used, the factor would be 21. In other words, the value of the policy would be 21 times the difference in the annual welfare level. Since this multiplicant remains the same, a policy would be chosen among its alternatives if it yielded the greatest gain relative to the initial equilibrium. Note that the factor would be \( 1/r \) if it was assumed that the welfare effect was realised only after one period, in which case it needs to be discounted to make it comparable with present values. Here, instantaneous adjustment is assumed and the factor is taken as \( (1+1/r) \).
the rates of factor accumulation, and productivity levels may change if there are endogenous technical changes modelled. In a dynamic model these changes are captured endogenously.\(^3\)

Depending on the dynamic efficiency effects of the policy change, the post-shock path may look like path 1 or like path 2 in figure 1.1 or something different. In path 1 the policy yields a positive impact on the steady state value of the welfare level, while in path 2 the steady state level of welfare is converging to the base line level and hence the policy has only transitory effects. Clearly, the value of a policy change cannot be obtained by knowing the initial gap between the two trajectories nor can it be obtained by computing the difference between the welfare levels at any particular point in time. It requires an estimate of the total welfare value (TWV) of the policy change, which is the discounted sum of all annual differences in welfare levels over the entire time horizon. Clearly, the TWVs are different between path 1 and path 2, which in turn may be different from the value obtained from the static model, which explains why it is important to take dynamic effects into account.

The equivalent annuity of the TWV is the static model equivalent (SME) annual welfare effect of the proposed policy change.\(^4\) GTEM can thus be used to rank alternative policy proposals dynamically either by comparing their respective TWVs or by comparing their SME annual welfare changes.

### 1.5 Outline of the report

There are nine more chapters in this report. Chapter 2 presents a snapshot of a region in equilibrium and a social accounting matrix of a region in the context of global general equilibrium. Chapter 3 describes the static core of the economic module of GTEM. Chapter 4 presents the population module, while chapter 5 describes the dynamics connecting the static economic and demographic systems over time. Chapter 6 describes the environment module of GTEM. It provides details of emissions accounting and mechanisms to impose emissions restriction and trade under various trading regimes. Chapter 7 describes the database required to specify the model numerically and chapter 8 the basic model closure and the properties to which the model is expected to adhere. Chapter 9 presents the welfare measure used in GTEM and decomposition of welfare changes into their sources. Finally, chapter 10 provides a summary, limitations and a wish list for further development of the model.

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\(^3\) It is possible to reproduce the results of a recursively dynamic model using a comparative static model by computing the net changes in stocks and productivity changes, if any, from history and shocking the model appropriately in each period. The only difference is in the automation of the process. The story is entirely different if the agents in the dynamic model are forward looking, in which case results of a dynamic model cannot be reproduced by a static model as future events determine current choices.

\(^4\) If \(W^*\) is the total welfare value of a policy change based on the discount rate \(r\), then the annuity \([r/(1+r)]W^*\) gives the static model equivalent (SME) annual effect of the policy change. By comparing the SME annual effect of a policy change with the actual annual impacts in the year that the policy change is completed it is possible to get an idea of the value added by dynamic models relative to static ones. This will then provide a basis to determine whether the gain in additional insight is worth the additional efforts (and resource cost).