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Measurement and decomposition of welfare changes in GTEM

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It is demonstrated in this paper that changes in real GNP yield the equivalent variation measure of welfare changes. This measure of welfare change is decomposed into changes in real GDP, real income attributable to movements in the terms of trade and international income transfers. It is also shown that changes in 'real' tax revenue do not always correctly measure the allocative effects of relative price changes. Therefore, given the state of the art, allocative effects of domestic relative price changes cannot be isolated if factor supply and/or technical changes are endogenous or shocked.

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1 Introduction

One of the great advantages of applied general equilibrium models is that they can be used to analyse the sectoral, economywide and, in some cases, global impacts of a policy change. Frequently, applied general equilibrium models are used to identify winners and losers at the sectoral, national or global level. They are also used to analyse and/or rank alternative policy proposals.

Various policy options are often ranked on the basis of the projected impacts on a predetermined aggregate variable taken to represent the change in economic welfare. The choice of this welfare measure , however, has been the subject of much debate. For example, in international climate change analysis, a range of macroeconomic variables has been used in recent literature to measure the overall impact of climate change policies on national economic welfare. These include gross domestic product (Manne and Richels 1998), gross national product (McKibbin and Pearce 1996; Brown et al. 1999; Kennedy, Polidano, Lim and Fisher 1998), gross national expenditure (Brown et al. 1997), direct net cost measures (Jacoby et al. 1998), real consumption and equivalent variation (Montgomery 1997; Hertel and Tsigas 1997). The choice of the appropriate welfare measure for a particular model is thus an unresolved issue.

Analysing and explaining the impacts of policy changes on economic welfare and ranking policy options is a key issue for model based economic analysis. This task is much simplified if the sources of welfare change are known and their contributions with respect to a given shock can be quantified. Harberger s seminal paper (Harberger 1971) laid the foundations for this work. He argued that the sources of welfare changes induced by a policy change are four: changes in deadweight losses (Harberger s triangles) *plus first order income effects* from new resources, new technology (gifts from science and nature) and improved trading terms should any of these change with the policy change. Huff and Hertel (1996) applied this approach to welfare decomposition in the context of GTAP, an applied general equilibrium model of the global economy. They decomposed the GTAP welfare measure, equivalent variation, into its sources — contribution of change in the terms of trade, changes in factor employment, productivity growth and changes in the deadweight loss.

The purpose of this paper is to tackle the decomposition of welfare change in the context of Global Trade and Environment Model (GTEM), which is a dynamic GE model of the global economy.[1] While doing so, this paper identifies an appropriate expression for equivalent variation, a commonly used measure of welfare change, in the context of GTEM and examines whether standard approach to welfare decomposition to its sources, as used by Huff and Hertel (1996), is valid in a dynamic model.

The remainder of paper is presented in three sections. In section 2, Huff and Hertel s decomposition of the welfare change is revisited and two examples are produced to show that

[1] GTEM contains the structure of GTAP model at its static core. GTEM includes capital, debt and population accumulation mechanisms that make it recursively dynamic. In addition to that GTEM contains emission accounting and allows trade in emission permits under various trading arrangements. All these and many other features of GTEM are ignored here, as they are not directly relevant to this paper. A short description of the main features of the model relevant to this paper can be found in the appendix. For interested readers, the TABLO code of GTEM can be found on ABARE website at http://www.abareconomics.com/pdf/gtem.doc.

changes in real tax revenue cannot always measure the allocative effects of an exogenous shock. In section 3 the GTEM measure of welfare change and its decomposition are described. The paper is concluded in section 4.

2 Decomposition of welfare changes in GTAP revisited

Huff and Hertel (1996) derived the decomposition of the EV measure of the welfare change in the GTAP model. Their decomposition confirms the sources and measure of welfare change with respect to an exogenous change in policy as proposed in Harberger (1971). They have decomposed the welfare change resulting from an exogenous shock into four components:

Terms of trade effects — the difference between the value of the initial vector of net exports at new and initial vector of world prices. Welfare in a particular country improves, other things remaining the same, if this difference is positive.

Allocative (efficiency) effects — the welfare effect due to reallocation of existing resources. This effect is measured by changes in the tax revenues at unchanged specific tax rates (*real* tax rates), where taxes are the only distortions.

Endowment effects — welfare gain from additional resources.

Technology effects — welfare gain from improved productivity of existing resources.

Given a policy shock, such as trade liberalisation, the third and the fourth of the above four sources of welfare change would disappear in a typical GTAP simulation, as endowment and technology variables would be treated as exogenous. Hence the prime sources of welfare change associated with a policy change in a static GE model would boil down to the first two sources: the terms of trade effects and the so-called allocative efficiency effects.

Huff and Hertel have calculated the allocative efficiency effect, as proposed in Harberger (1971), by summing all the changes in *real* tax revenues caused by the quantity changes as a result of the policy change. This approach leaves out any allocative effects (the so-called allocative efficiency gain) that may arise in an undistorted economy as a result of an exogenous shock (as there are no distorting taxes) when the terms of trade, technology or the resource supply change. Therefore whether the change in real tax revenue is a correct measure of allocative effects is a valid question. If not, how can the welfare change be decomposed and the contribution of each source be quantified? As changes in the *real* tax revenue have been used to measure the allocative efficiency effect of the shock, Huff and Hertel (1996, p. 7) note, if there are no taxes in the initial equilibrium, and the nature of the shock is other than a tax/subsidy intervention, then there will be no allocative efficiency effect from the simulation. Similar arguments can be found in Harberger (1971, p. 794). The following two examples, however, show that changes in the *real* tax revenue do not always correctly measure the allocative efficiency effect of a policy change.

Two examples

Example 1: A small economy with a prohibitive tariff on imports

Consider a small open 2x2 economy of the textbook type with a single representative consumer with a given taste, technology and endowment. Assume that the country has imposed a prohibitive tariff on imports and therefore is currently at the autarkic equilibrium.

Let P denote the relative price of the importable in terms of the exportable in the small country, Q denote the vector of output and X be the vector of demand. Let (P^0, Q^0, X^0) be the autarkic equilibrium, and let $P^0 = P^*(1+T^0)$ where P^* is the world price of the importable and T^0 is the ad valorem tariff rate. In this autarkic equilibrium $Q^0 = X^0$.

Let the country remove the tariff fully so that the post change domestic price ratio is equal to the international terms of trade, ie $P^1 = P^*$ holds. Let (P^1, Q^1, X^1) denote the new equilibrium. The following calculation yields the EV measure of welfare change in this case[2]:

$$\begin{aligned} EV^{01} &= P^0 X^1 - P^0 X^0 \\ &= P^0(E^1 + Q^1) - P^0 Q^0 \\ &= P^*(1+T^0)E^1 + P^0(Q^1 - Q^0) \end{aligned}$$

where E is the vector of excess demand, which is equal to $(X - Q)$.[3] Noting that the aggregate value of excess demand vanishes at the world price (under trade balance constraint), the above expression can be written as

(1) $$EV^{01} = P^* T^0 E^1 + P^0(Q^1 - Q^0) .$$

Equation (1) decomposes the welfare change resulting from the removal of the tariffs into two components that depend on changes in quantity of net imports, E^1, and changes in outputs, $(Q^1 - Q^0)$. Changes in imports arise because the relative prices have changed and changes in output arise because changes in commodity prices induce changes in relative factor prices, which alters production equilibrium. The first term is positive as long as imports rise when tariffs are removed and the second term is negative because $P^0Q^0 > P^0Q^1$ as Q^0 is optimal at price P^0. Thus the overall welfare effect of the tariff reduction depends on the relativities of the two effects.

The first term gives the tariff revenue that would have been collected from the current level of imports (the increased level of imports) at the unchanged tariff rates. This change in real tax revenue gives Harberger s measure of welfare change (Harberger 1971) or Huff and Hertel s

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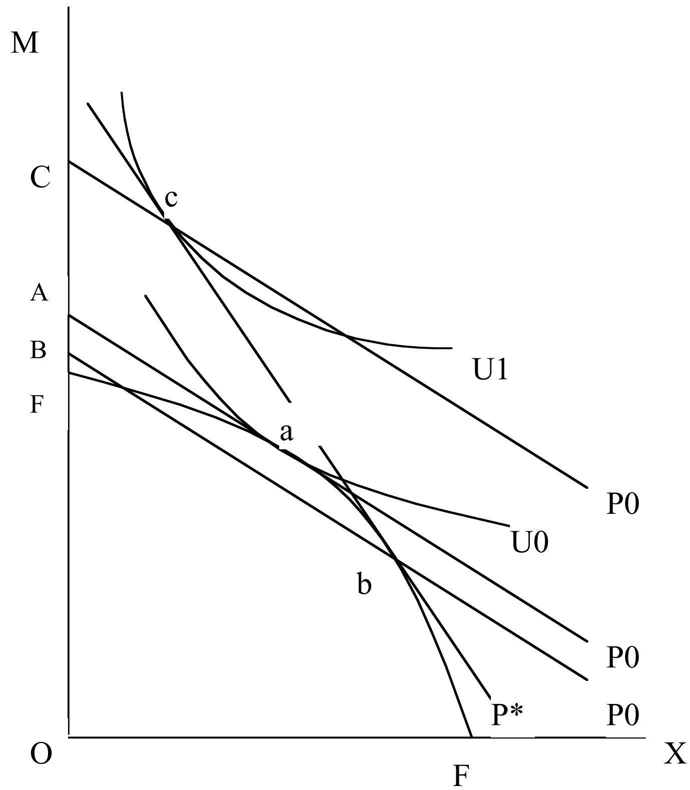
[2] Throughout this paper the calculation of EV is based on Slutsky measure of the income effects of price changes.

[3] More formally, $(1+T^0)$ can be taken as a diagonal matrix with power of tariffs (on imports) on the corresponding diagonal element and zeros elsewhere. Row and column vectors have not been distinguished here and should be interpreted accordingly.

measure of allocative efficiency gain in this case. Their measures therefore exclude the allocative effects that occur on the untaxed areas. The missing part in this example is the welfare impact that comes through changes in output mix of the economy.

This point is illustrated in figure 1. The autarkic equilibrium is depicted at point **a**, and the consumer attains the welfare level of U0 at domestic relative price P0, while the international relative price is given by P^*. As the tariff rate is removed, the production equilibrium moves to point **b** and consumption equilibrium moves to point **c**. Valued at the initial price, P0, the

Figure 1: **Welfare effects of trade liberalisation in a small economy**



welfare gain, as measured by EV, is given by the distance AC. Of this gain, BC gives the gain to consumers from changes in output price, which is equal to the change in the *real* tax revenue (ie, $P^*T^0E^1$) and AB equals the loss in the valuation of outputs at the old price (ie, $P^0(Q^1 - Q^0)$), all measured in units of M. Thus accounting only for taxed items into the measure of welfare change overstates the efficiency gain associated with the policy change in this case.

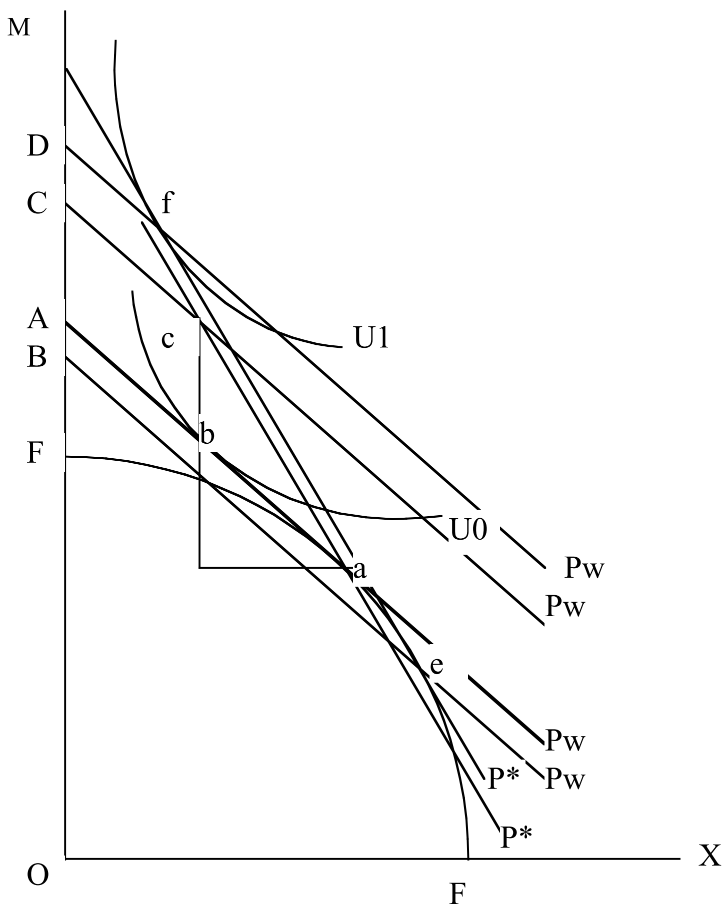
Thus the net welfare effect of trade liberalisation in this *small* economy is induced by changes in the domestic relative price or the *internal terms of trade*. This change in welfare was neither caused by changes in the *international terms of trade* nor by changes in endowments or technology. Neither is it that producers or consumers were inefficient before the liberalisation and become more efficient after the liberalisation. In this example, it is the existence of the tariff that made the domestic relative price inefficient because agents were not able to fully exploit the trading opportunities offered by the world market. Removal of this tariff removes this restriction and therefore is the source of the net gains.

Example 2: Terms of Trade change in a Small Freely Trading Open Economy

Now consider the same small economy, which trades freely with the rest of the world. There are no distortions in this economy to start with. The welfare impacts of an exogenous change in the terms of trade can be examined using figure 2.

Let *Pw* be the prevailing domestic as well as world price ratio in the two-good world and *FF* be the production possibility frontier of the home country. As shown in figure 2, point **a** is the production equilibrium and point **b** is the consumption equilibrium. Let the world price change to P^*.

Figure 2: **Welfare effects of terms of trade change in a small freely trading economy**



At unchanged domestic prices and, therefore, production, the first order income effect of this change in the terms of international trade comes from the ability to purchase an increased quantity of imports from a given quantity of exports. The economy can therefore consume at point **c**. The distance AC thus measures the terms of trade effect. As there are no taxes in this economy, the distance AC would be the Huff and Hertel measure of welfare effect of the given terms of trade change. However, as domestic prices adjust factors and commodities will be reallocated, which produces the so-called allocative efficiency effects. The production equilibrium moves to point **e** and the consumption equilibrium moves to point **f**. The distance (BA+CD) gives the income effect in consumption and the distance AB measures (a similar income effect) a loss in the value of the new output at old prices. Even if the output at point **e** worth less at old prices, it contains more units of exportable that can be exchanged with even more units of the importable. Hence, the distance CD measures the net income effects of the relative price change and AD = AC + CD gives the EV measure of welfare change caused by

the change in the international terms of trade. Thus, in this case, the *real* tax revenue based measure underestimates the allocative effects of the consequent domestic price change.[4]

In summary, if there is a change in resources, technology, external terms of trade or domestic distortion then the consequent change in the internal terms of trade (ie, domestic relative price) will have welfare consequences through allocative effects (or changes in the deadweight loss). This change cannot always be captured by changes in tax revenues at unchanged specific tax rates (or distortion levels). Therefore a true measure of allocative effects should take into account of the welfare impact of the relative price changes to all agents. The changes in the tax revenues commonly used in welfare decomposition literature may underestimate or overestimate the allocative effect associated with an exogenous shock.

3 Measurement and decomposition of welfare change in GTEM

3.1 A measure of welfare changes in GTEM

Following Hertel and Tsigas (1997) it is assumed in GTEM that regional households maximise utility from (private and government) consumption of commodities and additional ownership of bonds (ie, savings) subject to gross national product (GNP).[5]

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[4] In an open and freely trading economy, without any distortionary taxes, the decomposition of the welfare effects of an international terms of trade change into the above two effects can be simplified as follows. First, impose a tariff just enough to keep the domestic relative prices insulated from the terms of trade changes as the international terms of trade changes. Welfare change caused by a change in the international terms of trade before and after the hypothetical tariff is removed provides the conventional decomposition that matches the above analysis.

[5] GTAP takes the NNP whereas GTEM takes GNP as the budget constraint for two reasons. First, saving and investment decisions in the economy are considered to be separated and so depreciation cannot be cancelled from saving. It is because investment decisions are made by business sectors whereas households make decisions regarding savings. Second, at any point in time the choice of whether to replace the existing capital stock fully or not is a part of the intertemporal optimal program of the investors not that of the households. Any replacement investment that is being undertaken in the current period has to be matched by the current production of the capital goods that has to be included in the description of the production functions (or production sets). Studies that take NNP as a welfare indicator ignore this requirement (see, for example, Brekke 1994).

Given the prices and income of a region, the behavior of the regional household can be viewed as solving the following problem:

(2) Max $U(X)$

Subject to $P^0 X = Y^0$

where P^0 is a vector of prices and Y^0 is the total income of the regional household, which is GNP. Let a vector X^0, of commodities and real savings, solve the above problem. In equilibrium, it follows that

(3) $P^0 X^0 = e(P^0, U^0) = e(P^0, \vartheta(P^0, Y^0)) = Y^0$.

where ϑ is an indirect utility function and e is the minimum expenditure function. Note that X contains all commodities purchased by the regional household for private and government consumption and real savings (units of global bonds). The vector P contains the prices of all commodities as well as a deflator for the savings, which is the price of the global bond.

Suppose after a policy change the price and income faced by the regional household are P^1 and Y^1. Let X^1 solve the maximization problem (1) with appropriate modification in the constraint, so that

(4) $P^1 X^1 = e(P^1, U^1) = e(P^1, \vartheta(P^1, Y^1)) = Y^1$.

The change in the welfare (utility) from situation 0 to situation 1 can be measured by the difference in the cost of attaining these utility levels at the initial price vector. This money-metric measure of welfare change, commonly known as the equivalent variation (EV), is given by:

(5) $EV^{01} = e(P^0, U^1) - e(P^0, U^0)$.

Using (3) and (4), (5) can be written as

(6) $EV^{01} = P^0 X^1 - P^0 X^0$.

And (6) can be rewritten as

(7) $EV^{01} = \sum_i P_i^0 X_i^0 (X_i^1 - X_i^0) / X_i^0$, where i ranges over all commodities and real savings.

Noting that X contains all commodities consumed by the regional household, including units of real savings, it follows from (7) that *the EV measure of welfare change is the same as change in GNP at constant prices.*[6] This result can be seen clearly if we group the commodities and expenditures allocated to private consumption, government consumption and savings are grouped separately and note that the variable Y is in fact the *GNP* of the

[6] Note that the EV as defined in this paper uses the Slutsky measure of income effects not the Hicksian one. It is in this sense the change in real GNP approximately measures the welfare change resulting from exogenous shocks.

region. Equation (7) shows that EV is just the sum of changes in real private consumption, government consumption and real savings, which is just the change in real *GNP* (that is, GNP at constant prices).[7]

3.2 Decomposition of changes in real GNP – the measure of welfare change in GTEM

The next question is what are the sources of welfare changes and what are their measures? To answer this the changes in real GNP is decomposed into its primitive components. First, we note that

(8) GNP(r) = GDP(r) — FY(r) and

(9) GDP(r) = C(r) + G(r) + I(r) + X(r) — M(r)

where, notation follows standard conventions and FY(r) is the net interest payment to the global bank to service the net debt accumulated so far. Equation (8) states that gross national product (GNP) is gross domestic product (GDP) less net interest payments (and other transfers if there are any) to the rest of the world (FY).

Equation (9) is a national income identity that simply states that gross domestic product of a region is the sum of expenditures on private consumption expenditure (C), government consumption expenditure (G), gross investment expenditure (I), exports (X) less imports (M). GNP as defined in (8) gives the disposable income of the region. The regional household allocates this disposable income into private and government consumption of commodities and on acquiring additional units of bonds (savings). Hence

(10) GNP(r) = C(r) + G(r) + S(r).

From (8) to (10) it follows that

(11) I(r) — S(r) + X(r — M(r) — FY(r) = BOP(r) = 0.

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[7] At this point it is worthwhile to note that the equation used in the GTAP model to calculate the EV measure (not the decomposition) does not calculate the money metric welfare change but instead calculates welfare changes in units of utility. This measure in fact yields changes in net national product at constant price, which is a money metric if a monotonic transformation in the utility function is included via the normalisation of the expansion parameter, INCPAR. The EV measure yields changes in GNP at constant prices if gross real-savings (gross of depreciation) is used in the utility function instead of the net real savings as used in the GTAP model.

The normalisation required is that the budget share weighted sum over commodities i of the expansion parameter INCPAR(i,r) always remains equal to unity for each region r. The calibrated (or estimated) value of INCPAR(i,r) can be normalised as follows:

Define LAMBDA(r) = 1/SUM(i,COM,CONSHR (t,r)*INCPAR(t,r)) ;

and NEW_INCPAR(i,r) = LAMBDA(r)*INCPAR(i,r);

Then it can be seen that SUM(i,TRAD_COMM, CONSHR(i,r)*NEW_INCPAR(i,r)) =1

for all possible values of CONSHR.

Equation (11) states that the balance of payments of a region remains in balance as long as the regional households maintain the budget constraint that is implicit in (8) and (10). Equation (11) also states that given S(r) by the choice of households and FY(r) by history, the level of investment a region undertakes over a period determines the current account deficit, [M(r) — X(r)]. In any year, if the gross national expenditure (GNE = C + G + I) exceeds the gross national product (ie, investment exceeds the savings), debt accumulates and vice versa.

Linearising (8) and separating the terms for quantity and price changes gives[8]

(12) GNP(r)*qgnp(r) =
GDP(r)* qgdp(r) + [GDP(r)* pgdp(r) — GNP(r)* pgnp(r)] — 100* c_FY(r)

since

(13) GDP(r)* pgdp(r)
= C(r)* pc(r) + G(r)* pg(r) + I(r)* pi(r) + X(r)* px(r) — M(r)* pm(r) ; and

(14) GNP(r)* pgnp(r) = C(r)* pc(r) + G(r)* pg(r) + S(r)* ps(r) .

Using (13) and (14) to substitute out the aggregate price deflators in (12) yields

(15) GNP(r)*qgnp(r) = GDP(r)* qgdp(r)
+ [I(r)* pi(r) + X(r)* px(r) — M(r)* pm(r) — S(r)* ps(r)] — 100* c_FY(r).

It can be noted further that px(r) and pm(r) are fob and cif prices respectively which are expressed in local currencies; and ps(r) is the local currency price of savings. It follows that

(16) (a) ps(r) = ps_g + phi(r),
(b) px(r) = px^* (r) + phi(r)
(c) pm(r) = pm^* (r) +phi(r)

where px^* (r) and pm^* (r) are percentage changes in fob and cif prices of exports and imports respectively and ps_g is the price of the global bond, which is defined as the global average of regional price of capital goods. All international (or global) prices are expressed in global currency units — called SDR, and phi(r) is the percentage change in the nominal exchange rate of the currency of region r.

Equation (15) can be rewritten using (16b), (16c) and (11) as

(17) GNP(r)*qgnp(r) = GDP(r)* qgdp(r)
+ [I(r)*(pi(r) — phi(r)) — S(r)*(ps(r) — phi(r))]
+ [X(r)* px^* (r) — M(r)*pm^* (r)] + [FY(r)* phi(r) — 100* c_FY(r)]

which can be simplified further as

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[8] A notational convention has been followed. Level values are in upper case and lower case denote their percent change. When a value (V=PQ) is decomposed into quantity (Q) and price (P), the underlying price variable begins with p and written as (pv) and quantity variable begins with q and written as (qv). Similarly the differential of a variable X begins with the c_ and written as c_X.

(18) GNP(r)*qgnp(r) = GDP(r)* qgdp(r)
+ [I(r)*(pi(r) — phi(r)) — S(r)*(ps(r) — phi(r))]
+ [X(r)* px^* (r) — M(r)*pm^* (r)] — [100* L_phi(r)*c_FY_SDR(r)].

Dividing throughout by PGNP(r), the price deflator of GNP in region r, gives a decomposition of the changes in the units of GNP into its sources, which are also measured in units of the GNP.

(19) GNP(r) /PGNP(r) *qgnp(r) = GDP(r) /PGNP(r) * qgdp(r)
+ [I(r) /PGNP(r) *(pi(r) — phi(r)) — S(r) /PGNP(r) *(ps(r) — phi(r))]
+ [X(r) /PGNP(r) * px^* (r) — M(r) /PGNP(r) *pm^* (r)]
– [100* PHI(r) /PGNP(r) *c_FY_SDR(r)].

Equation (19) provides the first round decomposition of change in real GNP of a region into its sources. It shows that the total effect on the real GNP of any exogenous shock consists of changes in real GDP of the region, effects of external terms of trade (ETOT) changes on the capital and the current accounts, and the increase in net foreign *transfer income* in global currency units.

The contribution of change in the current account terms of trade to change in welfare is given by the term [X(r)/PGNP(r) * px^* (r) — M(r)/PGNP(r) *pm^* (r)]. Increase in the fob prices of exports relative to the cif prices of imports implies a terms of trade gain. It is so because a given quantity of exports can now buy more units of imports, which represents a (windfall) gain to the home country.

The excess of investment over savings is the surplus in the balance of capital account of any region. The term (pcgds(r) — phi(r)) measures the change in the price of local investment goods in global currency terms and the term (ps(r) — phi(r)) represents the change in the price of average unit of global capital goods or the saving in global currency units. The valuation of savings in global currency terms remains unchanged since this price has been held fixed while implementing Walras law. A rise in [pcgds(r) — phi(r)] implies that a unit of local investment is now worth more in units of global bonds or claims over the global capital stock. The term [I(r)* (pcgds(r) — phi(r))] therefore measures the gain due to changes in the international terms of trade in the capital account. This is because I(r) can conceptually be thought of as export that brings in global currency and S(r) as an import that causes an expenditure of global currency.

With respect to the decomposition of the real GNP, the following points are worth noting here:

- First, note that in equation (18) the changes are not expressed in physical units or at constant prices of the database year. They measure the changes at constant price at the beginning of each year. As the coefficient values, such as GDP, are updated every year by price and quantity changes, the changes involved in (18) do not, therefore, reflect the real changes over time. This is why the coefficients have been deflated by the respective price levels and then expressed in units of GNP, which yields (19).

- Second, as the EV measure of welfare change is expressed in units of GNP (or at constant prices of the initial database) these figures for each year are in commensurable units. Even if two different policy proposals are simulated against a given baseline the associated levels of EVs of the two policy proposals are comparable. Therefore the welfare impacts of the policies can be ranked on a year-on-year basis. If there is no clear dominance of one policy proposal over the other on a year-on-year basis, present value of the EVs over a given horizon may need to be calculated to determine whether one policy outperforms the other.

- Third, the contributions of the two terms of trade changes and the contribution from change in international transfer payments all collapse into one international terms of trade effect if a trade balance constraint is imposed on the model. In this case there will be no international flow of capital and no accumulation of foreign debt or assets.

- Fourth, changes in real GDP encapsulate the effects of changes in factor supplies, productivity growth and allocative efficiency gain induced by the shock. In the absence of changes in factor supplies, and productivity growth with the policy shock, changes in the real GDP (in GNP units) measure the allocative effects (on both production and consumption) of the internal price change. Under these conditions the above decomposition of real GNP provides the full decomposition of the welfare change in a static model. If, however, factor supplies and production technologies are allowed to change together with a policy change the decomposition of real GDP becomes quite involved. This is discussed in the following section.

3.3 Sources of change in real GDP

GDP from the income side is given by the sum of value added and indirect tax revenues (including trade taxes). For simplicity this relationship can be expressed as:

$$\begin{aligned} GDP = & \sum_{i \in FAC} P_i^o Q_i^o \\ & + \sum_{j \in IND} \sum_{i \in INPUT} T_{ij}^F P_{ij}^F Q_{ij}^F \\ & + \sum_{i \in COM} T_i^h P_i^h Q_i^h + \sum_{i \in COM} T_i^m P_i^m Q_i^m \end{aligned} \tag{20}$$

where, P represents price, and Q represents the quantity of commodity or factor transacted and T represents the ad valorem rate of tax on the commodity in question. The first term on the right hand side of (20) measures the value added in any given region, the second term gives the tax revenue collected from the purchases made by the firms, the third term represents the taxes collected from the household purchases and the fourth term represents the tariff revenue collected from imports.

Following the procedure adopted in Huff and Hertel (1996), equation (20) can be linearised in the context of general equilibrium to obtain:

(21)

$$
\begin{aligned}
GDP * qgdp = & \sum_{i \in FAC} P_i^o Q_i^o * q_i^0 \\
& + \sum_{j \in IND} \sum_{i \in INPUT} T_{ij}^F P_{ij}^F Q_{ij}^F * q_{ij}^F \\
& + \sum_{i \in COM} T_i^h P_i^h Q_i^h * q_i^h + \sum_{i \in COM} T_i^m P_i^m Q_i^m * q_i^m \\
& + \sum_{j \in IND} P_j^o Q_j^o * a_j
\end{aligned}
$$

where, a_j represents input neutral technical progress in industry j, and Q_j^o and P_j^o represent the output and supply price of industry j.[9] Dividing throughout by the GNP deflator, P_y , gives:

(22)

$$
\begin{aligned}
GDP / P_y * qgdp = & \sum_{i \in FAC} P_i^o Q_i^o / P_y * q_i^0 \\
& + \sum_{j \in IND} \sum_{i \in INPUT} T_{ij}^F P_{ij}^F Q_{ij}^F / P_y * q_{ij}^F \\
& + \sum_{i \in COM} T_i^h P_i^h Q_i^h / P_y * q_i^h + \sum_{i \in COM} T_i^m P_i^m Q_i^m / P_y * q_i^m \\
& + \sum_{j \in IND} P_j^o Q_j^o / P_y * a_j
\end{aligned}
$$

Equation (22) is a stylisation of the decomposition of changes in real GDP that is derived in GTEM.[10] It can be seen that there are three sources of changes in real GDP:

- *Changes in the supply of factors to a region* As a policy change alters regional real incomes, regional real savings will be altered. This will alter the global supply of real savings and therefore the level of global real investment. Over time, this amounts to changes in the stock of capital in all regions.[11] The effect of changes in the supply of factors on changes in real GDP is expected to be captured by the first term.

- *Change in the deadweight loss* The sum of the next three terms is to measure the changes in the deadweight loss as discussed above.

- *Technical change* The last term in (22) is normally expected to capture the impact of productivity growth in each production sectors.

While the decomposition presented in (22) *may* be applicable in the context of a static model, its use in a dynamic model can be questioned. This is because in dynamic models the marginal impact of a policy change on the contribution of various sources of welfare change

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[9] There could be other types of technical change included in the simulation. The input neutral technical change has been chosen to simplify the exposition.

[10] Taxes on government purchases, exports and on production are missing in the above account for simplicity.

[11] If the demographic module of the GTEM is turned on, even the supply of labor could be affected by the proposed change in a policy.

can only be obtained by taking the difference between the policy and baseline results term by term on a year-on-year basis. The changes in the value weights between the two situations can easily lead to results that are difficult to understand and interpret.

To make the above point clear, consider an example with trade liberalisation in an environment of trend productivity growth. Assume that a time path of a neutral technical progress is given and a neutral productivity improvement of a_j per cent a year is also given for each industry along the baseline together with other baseline shocks. A policy change, say a uniform tariff reduction of 10 percent a year, for the next five years is being proposed and the impact on real GDP of this policy shock is required. The sources of the real GDP change are also of interest. Running the baseline and policy simulation separately and taking the difference of the decomposed terms of (22) the contribution of each term of the annual change of welfare as shown in (23).[12]

(23)

$$
\begin{aligned}
&(GDP / P_y * qgdp)^{policy} - (GDP / P_y * qgdp)^{base} \\
&= (\sum_{i \in FAC} P_i^o Q_i^o / P_y * q_i^0)^{policy} - (\sum_{i \in FAC} P_i^o Q_i^o / P_y * q_i^0)^{base} \\
&+ \left[\begin{array}{l} \sum_{j \in IND} \sum_{i \in INPUT} T_{ij}^F P_{ij}^F Q_{ij}^F / P_y * q_{ij}^F \\ + \sum_{i \in COM} T_i^h P_i^h Q_i^h / P_y * q_i^h + \sum_{i \in COM} T_i^m P_i^m Q_i^m / P_y * q_i^m] \end{array} \right]^{policy} \\
&- \left[\begin{array}{l} \sum_{j \in IND} \sum_{i \in INPUT} T_{ij}^F P_{ij}^F Q_{ij}^F / P_y * q_{ij}^F \\ + \sum_{i \in COM} T_i^h P_i^h Q_i^h / P_y * q_i^h + \sum_{i \in COM} T_i^m P_i^m Q_i^m / P_y * q_i^m] \end{array} \right]^{base} \\
&+ \left[\sum_{j \in IND} P_j^o Q_j^o / P_y * a_j \right]^{policy} - \left[\sum_{j \in IND} P_j^o Q_j^o / P_y * a_j \right]^{base}
\end{aligned}
$$

As the productivity level is unchanged between the baseline and the policy scenario, the contribution of technical change to change in real GDP for any one year as:

(24) $$cont\_tech = \sum_{j \in IND} [(P_j^o Q_j^o / P_y)^{policy} - (P_j^o Q_j^o / P_y)^{base}] * a_j$$

It is clear from (24) that as long as the terms in the square bracket do not result in a zero, the above decomposition rule implies that there will be a non-zero contribution of technical change to the real GDP change as a consequence of trade liberalisation. In fact, the source of

[12] Readers familiar with dynamic simulation will note that the marginal contributions captured in (23) are annual changes. These changes need to be accumulated over the history of the policy shock to obtain the difference in the level values between the policy and baseline simulations.

this change is not the difference in the productivity levels between the two situations as tariff reduction does not make any sector or any input more productive. The sources of change are the different values of prices and quantities or the value weights that are applied in the calculation. The value weights will have different time paths in the two simulations. It is this difference in the time paths of the price and quantity variables that lead to a non-zero value for the so-called contribution of technical change to changes in real GDP. The output paths will be different because the policy change may affect the factor supply and there will be reallocation of factors between sectors as factor prices change as a result of change in product prices. This second effect forms the part of allocative efficiency effect of the policy change, which now is in the contribution of technical change. Prices necessarily change because the policy variable has changed. For these reasons there is no guarantee that the terms in the square bracket would be zero. Hence, the decomposition of real GDP remains questionable even in static models if the comparative static policy is run against a baseline projection that allows factors and technology to change.

In general, it cannot be determined

- how much of the real GDP change is due to change in factor employment and how much is due to factor price change induced by relative commodity price change when factor supplies are changing,

- how much of the real GDP change is due to technical progress and how much is due to change in the relative prices when technologies are changing.

Because of these reasons it is not possible to determine how much of the real GDP change is due to allocative effects of the relative price change when there factor supplies are changing with relative price changes induced by the policy change. The isolation of these effects does not seem straightforward given the current state of the art.

It is clear that the correct decomposition of real GDP changes and hence the complete decomposition of a welfare change to its sources is quite involved in a model in which resources and/or technology is changing. This is especially true in a dynamic model in which resources are always changing as a result of a policy change. Further research is necessary on all fronts (modeling as well as software) to untangle the cross effects and quantify the contributions of each source correctly.

4 Summary and conclusion

This paper examined the current approach to decomposing a welfare change into its sources and measuring their contributions. The discussion carried so far leads to the following conclusion. Changes in the real tax revenue cannot always measure allocative effects *correctly* when there is a shock of a change in policy, of a change in the terms of trade, of changes in the resource position and/or changes in technology. This is especially important in the case of a global model, in which a concerted policy change across regions leads to changes in every region s terms of trade. As a result the measure of the contribution of each of the four sources of welfare change based on the existing approach may give incorrect results. If applied in a dynamic context, in which there is a baseline trend in productivity growth, this approach may even show a spurious productivity growth being observed as a result of a policy change that does not involve a productivity enhancing effect at all.

In addition to that, it has also been shown that changes in real GNP provides a very good approximation of the EV measure of welfare changes. An attempt to decompose this measure in a dynamic context showed that at best the welfare changes can be decomposed into changes in real GDP, real income attributable to movements in the terms of trade and international income transfers. It is not possible, at this stage, to isolate the contributions due to allocative effects of domestic relative price change, due to change in the endowment of factors and due to improved production technologies. If changes in factor supplies and technological changes are controlled, changes in real GDP, however, reflect the welfare changes due to the allocative effects of the consequent relative price changes.

Appendix Some relevant features of GTEM

National income, savings and consumption

In GTEM, a representative household in each region owns all factors of production and receives all payments made to the factors, all tax revenues and all net interregional income transfers. The representative household allocates its total income into private and public consumption of commodities and savings. Savings are spent on buying new bonds from the global bank that represents, in a sense, a claim on the global capital stock.

The representative household gets satisfaction from the consumption of commodities and holding additional units of bonds. This utility function is separable in private consumption, government consumption and savings and is currently represented by a Cobb-Douglas function. The utility from the private consumption of commodities is represented by a CED function, while that from government consumption of commodities by a Cobb-Douglas function. The budget constraint for the lower level utility maximisation is thus set by the optimal solution at the top level, which implies a constant budget share across the three categories. The motivation for including savings (additional ownership of bonds) in the utility function is the same as in Tsigas and Hertel (1997), that it is consistent with the maximisation of an intertemporal utility function.

International capital mobility

Investment demands are determined by changes in regional GDP and regional expected rates of return relative to expected global rates of return. Thus, changes in investment flows represent changes in demand due to expansionary or contractionary effects (changes in real GDP) and expectation effects.

The expected global rate of return clears the transactions, global savings and investment, of the global bank. A shortage of global savings relative to investment raises the expected global rate of return.

All investors borrow from the global bank. The difference between investment and savings leads to foreign debt/asset accumulation of the region and is serviced at the global average rate of return on physical capital. Debt servicing constitutes the income transfer between the regions that is accounted for in the total income of the regional household.

Numeraire

The price of bonds (or the global price of real savings) is defined as the global average of the regional (producer) prices of capital goods. Both GTAP and GTEM, while implementing the Walras Law, have bonds as the numeraire commodity and therefore maintained the bond price as an exogenous variable.

In addition it is also useful to note how regional nemeraires are introduced in GTEM and the way prices of these numeraire commodities are determined. GTEM has implicit regional money markets, where it is assumed that (whatever the money demand) money supply in each region is always adjusted to target the regional consumer price index (CPI). While the supply of the global currency in the global market targets the price of global numeraire — global average prices of the capital goods. Instead of determining regional CPIs, as in GTAP, GTEM determines nominal exchange rates by holding the regional CPIs constant over the simulation period. The local currency value of a unit of global currency is defined as the nominal exchange rate.

Given this exchange rate, the relationship between the prices that prevail in the global market (prices at international waters such as fob and cif prices) that are expressed in global currency units and their corresponding local currency prices are well defined. As a result, it can be seen that the local price of a unit of savings or bonds in a region always moves with the exchange rate of the local currency relative to the global currency. The prices of other commodities faced by the regional household (and regional producers as well) are also linked to world prices through the exchange rate, and trade taxes.

Determination of exchange rates

Exchange rates in GTEM adjust to clear the underlying regional foreign exchange markets. In other words, exchange rates keep the balance of payments in equilibrium. For example, if agricultural trade liberalisation leads to a significant increase in agricultural export earnings from a particular region this will, all things being equal, result in an exchange rate appreciation for that region. The depreciation in the exchange rate will improve the competitiveness of exporters and import competing producers in that region. Exports will increase and imports decline, restoring balance of payments equilibrium. Here the responses of savings, investment and transfer payments as the exchange rate changes have been ignored. Movements in these terms will make further adjustments in the burden taken by the exchange rates.

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