Modelling the regional economic impacts of biofuels: A review of techniques and applications

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Abstract

The extent to which a regional economy is affected by hosting biofuels development is likely to depend upon a number of factors: the specific biofuels technology employed; the embeddedness of that technology into the regional economy; the extent to which new economic activity is created; and the structure and characteristics of the regional economy. These issues can be considered within appropriately disaggregated multi-sectoral regional models. Studies for biofuels have used (fixed price) Input-Output (IO) and Social Accounting Matrix (SAM) modelling frameworks widely. A nascent Computable General Equilibrium (CGE) literature – in which some of the assumptions of IO and SAM modelling can be relaxed – has begun to examine biofuels. We compare CGE and IO/SAM modelling approaches and discuss their appropriateness for modelling the regional economic impacts of biofuels production.

Keywords: Biofuels; regional modelling; Input-Output; Social Accounting Matrix; Computable General Equilibrium.

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1. Introduction

1.1 *Biofuels in global and regional context*

The recent decade has seen unprecedented growth in the output of the global biofuels industry. Worldwide ethanol production grew by 32.3% between 2007 and 2008, with production in the US and Brazil (which together account for 89.3% of worldwide ethanol production) growing by 38% and 29% respectively in a year (Renewable Fuels Association, 2010). Bioethanol production in the US alone expanded from 1,630 million gallons in 2000 to 10,600 million gallons in 2009 (Renewable Fuels Association, 2010). While the US and Brazil led the way, production of fuel ethanol in the European Union accounted for 4.2% of worldwide fuel ethanol in 2008, and rose 29% in the year to 2008 (Renewable Fuels Association, 2010).

Ethanol is produced in different parts of the world from feedstocks native to the specific region, and by alternative processes depending on the region and its level of development. US ethanol production is centred on the Midwest states – eight states[1] between them accounted for 78% of production in 2007 (Low and Isserman, 2009). Ethanol produced in the European Union typically comes from sugar beet and wheat. Spain was the largest ethanol producer in 2004. EU biofuels production however is largely biodiesel, produced primarily from rapeseed oil, but production is also viable from any vegetable oil or animal fat (Schnepf, 2006).

The amount of biodiesel produced in the EU rose 16.6% between 2008 and 2009, up to 9.046 million tonnes (European Biodiesel Board, 2010). EU biodiesel production is dominated by production in Germany and France which together produce half of EU biodiesel. Production across the EU has expanded rapidly since 2002, when just over 1.000 million tonnes was produced. UK biodiesel production in the same period has risen from 3,000 tonnes to 137,000 tonnes, and so represents just 1.5% of total EU biodiesel production in 2009 (European Biodiesel Board, 2010).

1.2 *Policy support mechanisms*

Biofuels development has not happened in a policy vacuum. In the US, the Energy Policy Act (2005) and then the Energy Independence and Security Act (2007) introduced and then raised a Renewable Fuels Standard. This obliges US transport fuel suppliers to use 15.2 billion gallons of renewable fuels in 2012, rising to 36 billion

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[1] These are Iowa, Nebraska, Illinois, Minnesota, South Dakota, Indiana, Michigan and Ohio.

gallons on 2022[2]. Further, until 2010 the Volumetric Ethanol Excise Tax Credit gave ethanol producers 51 cents for each pure gallon of ethanol blended, while states have also introduced their own incentives for ethanol production. These are complemented by a 54 cents per gallon tariff on ethanol imported to the US, plus a 2.5% ad valorem charge. The World Bank (quoted in Giampetro and Mayumi, 2010) report:

> "Governments provide substantial support to biofuels so that they can compete with gasoline and conventional diesel. Such support includes consumption incentives (fuel tax reductions); production incentives (tax incentives, loan guarantees, and direct subsidy payments); and mandatory consumption requirements. More than 200 support measures, which cost around $5.5 billion to $7.3 billion a year in the United States, amount to $0.38 to $0.49 per litre of petroleum equivalent for ethanol" (World Bank, 2008, p. 1)

In the UK, support for the biofuels industry is primarily delivered through the Road Transport Fuels Obligation (RTFO), administered by the Renewable Fuels Agency (RFA). This began in 2008/9 and requires suppliers of fuels for transport to provide a growing share of their fuels from biofuels, and providing Road Transport Fuel Certificates for that share of their total supply. The current target for the 2009/10 year is for 3.25% of transport fuels to come from biofuels, with certificates in place. The certificates also allow the RFA to monitor the sustainability of the biofuels used.

1.3 The intended and unintended impacts of biofuels

Giampetro and Mayumi (2010, p. 2) note that the development of the biofuels sector, and the mechanisms that support this, have been justified on three grounds:

- The large-scale production of biofuels can significantly improve energy independence and security, through the reduction of dependency on imported petroleum
- The large-scale production of biofuels can generate a significant reduction in greenhouse gas emissions
- The large-scale production of biofuels can help to improve rural development by supporting crop farm income.

The rapid development of biofuels production worldwide has not seen an unambiguous "triple-dividend" in terms of reduced emissions, improved energy security and raised farm income. Firstly, many commentators have posited a link

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[2] Before this was introduced, 4 billion gallons of ethanol were used in transport fuel in 2004.

between biofuels development and negative effects on food supply (e.g. Giampetro and Mayumi, 2010). Prices of basic food stuffs – wheat, corn, rice – have generally been volatile since the turn of the century and some have increased significantly, with the blame laid at the door of poorly designed agricultural (including biofuels) policies. A report by the World Bank (Mitchell, 2008) notes that between 70% and 75% of the increase in food production prices between 2002 and 2007, "was due to biofuels and the related consequences of low grain stocks, large land use shifts, speculative activity and export bans" (Mitchell, 2008, p. 17). This result is however controversial (e.g. Ajanovic, 2010). We might expect that any negative food supply and food price effects will be particularly felt by agricultural importers, and low-income countries, which rely on world markets for food.

Secondly, the contribution that biofuels can make to reducing CO2 emissions has been called into question. Fargione *et al* (2008) argue that changing land use from rain forest, grass land, peat land or savannah to plantations for biofuels feedstock can (depending on which land use is reduced, and the type of biofuel feedstock used) release between 17 and 420 times as much CO2 as the biofuels would displace by replacing fossil fuels. Searchinger *et al* (2008) examine the life-cycle emissions of alternative food and agricultural products and estimate that corn-based ethanol nearly doubles GHG emissions over 30 years and increases GHGs for 167 years. This conclusion is not without its critics (e.g. ADAS, 2008).

Finally, the implications for regional development – including rural income – of biofuels production are unclear. The extent to which a regional economy is affected by hosting biofuels development is likely to depend upon a number of factors: the specific biofuels technology employed; the embeddedness of that technology into the regional economy; the extent to which new regional economic activity is created; the structure and characteristics of the regional economy itself. These issues can be considered within appropriately disaggregated multi-sectoral regional models, such as Input-Output (IO), Social Accounting Matrix (SAM) and Computable General Equilibrium (CGE) models. Models are required as both an aid to analysis – "thinking through" the issues and tradeoffs in regional economic activity – and since, in their absence, policy might not be appropriately designed. We have seen above that some of the postulated benefits of biofuels could be offset by these "indirect", or unanticipated, effects. The most appropriate models should allow us to estimate the impact that marginal changes in biofuels production could have on various measures of economic activity and welfare.

1.4 Outline of paper

In this paper, we review the use of multi-sectoral regional models which estimate the economic impacts of biofuels production. This is crucial for future research into the impact on regional economies of producing biofuels from marine algae. As the science of biofuels from marine algae develops, it is vital that appropriate economic modelling frameworks can be used to demonstrate the potential economic impacts that such development could have on the regional economies in which biofuels production occurs.

In Section 2 we describe "fixed-price" modelling techniques – Input-Output (IO) and Social Accounting Matrix (SAM). We examine the academic literature on "demand-driven" IO and SAM modelling of the regional economic impacts of biofuels developments on in Section 3. In Section 4 we briefly summarise Computable General Equilibrium (CGE) modelling, before in Section 5 reporting some of the findings and lessons from CGE modelling of biofuels. In Section 6 we compare the IO/SAM and CGE modelling approaches, and in Section 7 we present our conclusions.

2. Input-Output (IO) and Social Accounting Matrix modelling

2.1 IO accounts and modelling

The expenditure and sales by a biofuels developments in the area in which it is located is potentially of vital importance for the development's economic impact. IO modelling requires that these monetary flows be quantified in an IO table. This shows – where column entries describe purchases, and row entries describe sales – the linkages between production sectors in an economy, and the links between these sectors and purchasers of output. A schematic of an IO table is shown in Figure 1. "Final demand" categories would typically include purchases of each sector's output by households, government, capital formation, stocks, and exports out of the region. The "intermediate quadrant" shows the size of the flows of spending between production sectors.

[Figure 1 here]

IO tables commonly serve two uses – attribution and modelling. Attribution typically refers to the use of the accounts to assign responsibility for the size and shape of production in the economy to categories of demand for the goods and services produced in the region (from a demand-side perspective). (Examples of this include McGregor *et al*, 2004[3]). Secondly, the interlinkages between industries can be used to

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[3] This uses a two-region IO for Scotland and the rest of the UK to assign responsibility for pollution in each region to final demand categories in each region.

model the economy-wide impact of demand- (or supply-[4]) side exogenous shocks. IO techniques can be used, for instance, to estimate the possible regional economic impact of changes to the demands for the output of specific sectors/industries already located in the region. Multipliers use the inter-industry linkages provided by an IO table to quantify the "knock-on" effect of changes in the level of economic activity for sectors in that region (Miller and Blair, 2009).

Appendix A shows the approach underlying multi-sectoral IO analysis and the calculation of IO multipliers in a "demand-driven" framework.

2.2 *New industry incorporation in IO*

While the impact of changes in the final demand for the output of existing production sectors is relatively straightforward to model – i.e. Equation A8 in Appendix 1– we are often concerned about the economic impact of a new facility or sector locating in a region. In this case there will not be a sector in the existing IO table that describes the expenditures and sales of this new sector.

Miller and Blair (2009, p. 421) report several studies which incorporate new energy technologies in an IO framework. These would be examples of industries which did not previously exist, and so the existing IO table could not be used could not use the existing sectors in the IO table. Just (1974), estimated the column of technical coefficients for the new technology. The economic impact was found comparing the economy without the new technology, to the economy where the new technology replaced a portion of existing electricity production. Similar approached were adopted by Gowdy and Miller (1991), Herendeen and Plant (1981), Blair (1979), and Casler and Hannon (1989). The IO framework therefore is extended by the addition of new rows and columns describing the pattern of sales and purchases by the new sector. Calculating new economic output for the augmented IO table, the difference between base year levels of output and new levels can be credited to the addition of the new technology.

$$X^* = (I - A^*)^{-1} F^* \qquad \text{Equation 1}$$

where A^*, F^* and X^* are the augmented A matrix, final demand matrix and gross output matrix respectively. The impact of the new sector on output is therefore ($X^* - X$). The economic impacts on other variables – i.e. employment, value added, and income – can be straightforward estimated. The extent to which the new sector/technology is

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[4] All of the IO and SAM applications use "demand-driven" modelling, so we focus on this application in this section, and Appendix A.

embedded into the regional economy through backward linkages is captured in the augmented A matrix, A^*.

2.3 *SAM accounts and modelling*

A SAM is an account of economic activity that takes in more information than an IO table, but also provides a snapshot of activity in the area under consideration. Thorbecke (1998, p. 281) describes a SAM as a "comprehensive, disaggregated, consistent and complete data system that captures the interdependence that exists within a socioeconomic system". It is comprehensive and disaggregated as transactions between sectors, institutions and agents are all captured. It is consistent, as its single-entry bookkeeping format requires that every income is also expenditure. Both of these are also true of (production within) IO, however, by "complete", Thorbecke (1998, p.283) draws attention to the fact that in a SAM, "both the receiver and sender of *every* transaction must be identified" (emphasis added). Miller and Blair (2009, p. 499-500) describe moving from IO to SAM: "the principle new feature added is to incorporate transactions and transfers related to distribution of income in the economy". A SAM can therefore be used to draw attention to the income and profit distribution between socioeconomic groups within an area (i.e. like the accounting use of IO tables) and thus also "as a conceptual framework to explore the impact of certain exogenous changes" (Thorbecke, 1998, p. 282).

[Figure 2 here]

As with IO modelling, we can use the schematic SAM framework of Figure 2 to show how exogenous demands (f_1, f_2 and f_3) are used to determine the incomes of the endogenous accounts (y_1, y_2 and y_3). As with IO, we begin by converting the endogenous part of the SAM accounts into a matrix of "average expenditure propensities or coefficients" (Thorbecke, 1998, p. 302).

The matrix of endogenous activity, A_n, is partitioned among the endogenous matrices given in Figure 2 as follows:

$$A_n = \begin{bmatrix} A_{11} & 0 & A_{13} \\ A_{21} & 0 & 0 \\ 0 & A_{32} & A_{33} \end{bmatrix} \qquad \text{Equation 2}$$

where A_{11} is the set of input-output coefficients, A_{21} is the value added coefficients (sectoral value added divided by sectoral output), A_{13} coefficients show the purchasing coefficients for the endogenous institutional sectors (which would include household categories), A_{33} shows the coefficients of expenditure for each (endogenous) institution of income received from other institutions[5] and A_{32} shows the "cents worth of each dollar earned by each type of resource (primary input) that is allocated to the household groups" (Thorbecke, 1998, p. 302).

We can calculate the endogenous total income by setting up three equations:

$$\begin{aligned} y_1 &= A_{11}y_1 + 0 + A_{13}y_3 + f_1 \\ y_2 &= A_{21}y_1 + 0 + 0 + f_2 \\ y_3 &= 0 + A_{32}y_2 + A_{33}y_3 + f_3 \end{aligned} \qquad \text{Equation 3}$$

Which, as with IO, we can then rearrange to solve for y_n in terms of the exogenous final demand (f) and endogenous production, factors and institutions.

$$y_n = (I - A_n)^{-1} f \qquad \text{Equation 4}$$

Once again, we can also use the marginal changes version of this model to show the impact of changes in final demand categories, which cause disturbance in the endogenous accounts. Some extensions are however worthy of note. Thorbecke (1998) discusses how "fixed price multiplier matrices" can be calculated to allow for different marginal expenditure propensities from those given by the initial (average) expenditures – this might be important where households are a particular focus of concern, and where unitary expenditure elasticities might not be appropriate.

2.4 Assumptions of "demand-driven" IO/SAM multipliers and modelling

The IO multipliers described above are examples of "demand-driven" multipliers, in that it is final demand which drives, through the Leontief inverse, economic output. As Loveridge (2004, p. 309) notes, SAM models "operate with the same basic set of assumptions and solution method as IO models", and "can be criticised on many of the same grounds as input-output". We note some of the specific ways in which SAM analysis might allow for some of these assumptions to be relaxed in Section 3.3. Fraser of Allander Institute (2007) summarise the most important assumptions underlying the use of "demand-driven" IO modelling:

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[5] These might include state pensions, for instance.

- Fixed technical coefficients and constant returns to scale
- Fixed coefficients in consumption (in the "closed" model – see Appendix A)
- Entirely passive supply side

The first of these assumptions implies that when the output of a particular sector changes due to a change in demand for that sector's output, the inputs used by that sector increase in proportion to the change in output. For example, if output increases by 10%, then that sectors demands for each of its inputs (from other intermediate sectors, and from primary inputs) will increase by the same proportion – i.e. the sector's inputs are characterised by fixed technical coefficients in production. Right-angled isoquants curves describe the lack of substitution possibilities between inputs in production. An alternative interpretation might be that input prices do not change as a result of the demand stimulus to the sector, such that the optimal production mix does not change from that given by the initial technical coefficients (McGregor *et al*, 1996).

Secondly, with households endogenised, changes in demand causes sectoral output and therefore household income to adjust, which leads to changes in household spending. The coefficients of household consumption (given in Equation A10 in Appendix A) describe the pattern of household spending in the region. Changes in household income will cause the purchases by households from each of the industrial sectors in the region to adjust by the same amount – a 5% increase in wage income will cause a $(1-m)$5% increase in demand for household consumption from each sector, where m is the share of household spending which is not retained in the local economy, but "leaks" out through savings, imports of goods and services or taxes.

The final assumption is perhaps key in "demand-driven" multipliers. Where demand for a sector's output increases, the demand for inputs to that sector's production increase, raising the demands for all sectors production to expand through their links to the directly stimulated sector, as recorded by the Leontief inverse. Not all sectors may be indirectly stimulated – for instance if sector j has each $\sum_{i=1}^{N} a_{ij} = 0$. Such features are, however, exceptionally uncommon for production sectors[6].

At no point in this "rippling" of production expansion are there assumed to be anything preventing the output of any sector expanding to satisfy the increased demand, e.g. there are no capacity constraints. There must therefore be no constraints on the ability of firms to source intermediate or primary inputs (e.g. labour, capital, or

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[6] Allan *et al* (2010) find this for the example of an onshore windfarm on Shetland.

other resources, which could include land). Supply reacts passively to demand, i.e. all increased demand can be accommodated through supply expanding. This may be consistent with a region which had extensive underutilisation of resources, significant underemployment of labour for instance, which could allow production to expand without constraints on its ability to source labour at the going wage. The same would be true of all factors of production. Thorbecke (1998, p. 301) writes that the effects of exogenous changes can be estimated using a SAM where there is "the existence of excess capacity and unemployed or underemployed labour resources". Similarly, in a region which was able to attract labour and capital resources through migration and investment respectively, such supply constraints could be non-binding (e.g. McGregor *et al*, 1996). The adjustment path, over which the change in the availability factors of production occurred, could be important for the response of the regional economy.

3. Fixed price multi-sectoral modelling of biofuels

Studies of the regional impact of biofuels developments (i.e. local to the vicinity of where the development takes place) appear to be more common in the USA, but examples exist in much of the developed world. Many of the US studies are prepared for ethanol plants and carried out by biofuel industry bodies (e.g. Urbanchuck, 2007; Urbanchuck, 2010). Swenson (2006, p2) notes that for the range of economic activity estimates attributed to the development of a biofuels industry, "very little appears to be based on rigorous research". National multipliers (produced in the US by the BEA), or through publicly available models such as IMPLAN have been used by many groups. Swenson (2006, p. X) describes users of these models ranging from "farm commodity groups, farm state politicians, many environmental organisations, automobile manufacturers as well as right and left wing political organizations". Jobs multipliers estimated (the ratio of total jobs supported across the nation or region by the development divided by the number of direct jobs created in the plant itself) in ethanol studies between 1994 and 2007 range from 3.4 to over 50 (Swenson, 2006).

Some of the studies use an IO table containing a biofuels sector and model the regional impacts of changes in demands for this sector. Others construct the new vectors corresponding to the sales and purchases of a new biofuels industry. Section 3.1 describes some of the linkages between a biofuels facility and the regional economy, while Section 3.2 outlines recent academic papers which have used IO and SAM techniques to model the regional economic impact of biofuels development, and Section 3.3 discusses some of the issues arising from the papers reviewed.

3.1 Linkages between biofuels facility and the regional economy

The direct effects of a biofuels facility on the regional economy in which it is located are those which are directly attributable to the facility itself. Such expenditures would include those purchases of goods and services which the facility would require to produce biofuels, as well as the direct payments to employees at the facility. We note from Swenson (2006) and Low and Isserman (2008) that the bioethanol feedstock is strictly location specific – i.e. it is grown in specific places, requires water, productive soil and other ingredients which may make production in other places more difficult. The stage of converting the feedstock into biofuels however could be done elsewhere. The development pattern of these feedstocks into biofuels, such as ethanol, indicates that, perhaps due to transportation costs of moving raw materials, ethanol production facilities are located close to where the feedstock (corn) is produced, and with access to transportation infrastructure (Low and Isserman, 2008).

3.2 IO and SAM biofuels applications

We summarise the IO and SAM academic applications modelling to biofuels production in Table 1. This categorises details about the specific applications of each paper under several headings, which we hope help to understand the modelling approach used in each case.

[Table 1 here]

3.3 Critique of fixed-price methods

We note from Table 1 that there are different strategies employed in IO and SAM modelling of biofuels to date. Each of the approaches could be appropriate Each of these can perhaps be summed up by the suggestion made by Low and Isserman (2009, p. 85) that "the world is not as simple as [a] demand-driven, fixed proportions input-output model". We can summarise three techniques which have been employed for adapting IO modelling of the specifics of biofuels technologies as:

- adjustments to the modelling results (e.g. Swenson, 2006)
- negative demand disturbances to offset impact of biofuels (e.g. Swenson, 2006; Kulišić *et al*, 2007)
- sectoral constraints imposed (e.g. Low and Isserman, 2009)

Swenson (2006) provides details of "ad-hoc" adjustments made to the results obtained from their IO modelling of three counties in Iowa. These typically adjust the assumed regional employment-output coefficients for individual sectors, after surveys with suppliers of those commodities purchased by ethanol plants. It is in the utilities sectors – gas supply, water, and electricity – that large employment boost are predicted. Swenson (2006)'s surveys and interviews found that the modelled response was likely to be an overstatement. Suppliers to the biofuels facility responded that perhaps between zero and thirty per cent of the estimated employment change would be observed in practice. The impact on employment given in Table 1 has therefore taken into account this finding. Swenson (2006) argues that these are "'reality check' adjustments".

Secondly, applications have modelled a negative demand-shock, alongside the positive boost to demand associated with the biofuels sector. Kulišić *et al* (2007) introduce a negative shock to the final demands for the petroleum sector, which produces indirect and induced negative effects on the economy as a whole. The sum of the positive effects of the biofuels shock and the negative petroleum shock give a net positive effect on Croatian GDP and employment in their example, but there is no reason why the impacts on the sectoral levels should all be positive. For instance, sectors where the biofuels sector has little linkage to, but the petroleum sector relied upon for inputs, could see net output and employment reducing.

One primarily modelling issue under this adjustment would be about the selection of the appropriate scaling of the offsetting demand shock. From the output multipliers reported for the biodiesel sector in Kulišić *et al* (2007) we can calculate that the positive stimulus is equal to a 492 million HRK change in the final demand for the biodiesel sector. The negative impact on output (assuming this due to a change in final demand for the petroleum sector) is due to a change in final demand for that sector of 73.9 million HRK. The difference in final demand changes here could suggest that subsidies for biofuels development are predicted to continue alongside the expansion in the sector. Alternatively, the smaller negative demand for petroleum products could be explained if a large amount of the expenditure on diesel in Croatia is on imported products. Switching to locally produced biodiesel, instead of imported diesel, would give this positive net economic impact to the Croatian economy.

Swenson (2006) input a negative shock to the grain sector in their model such that the output of the grain sector does not increase. While this is a shock to final demand, which will in fact produce (negative) indirect and induced effects, a more general use of the IO system to impose output constraints is the third category of adjustments we consider.

A third adjustment approach – similar in theory to what Swenson (2006) attempts – is to assume that the output of specific sectors is supply constrained, and so cannot adjust to increased demand. This would in practice be equivalent to assuming that the necessary demands can be met by increased imports, rather than from local (supply constrained) sectors. Rather than a negative demand calibrated to achieve no change in output for sectorally constrained sectors, Low and Isserman (2009) impose a technical coefficient of zero for the new biofuels sector's purchases from the corn sector which they assume to be supply constrained. This "prevents new local corn production as a result of the ethanol plant's demand" (Low and Isserman, 2009, p. 83).

A more general version of this procedure is described in Steinback (2004) where, rather than final demand for sectors being exogenous, and output endogenous, the final demand for supply constrained sectors can be made endogenous. Changes in the outputs of sectors can thus be modelled with those supply constrained sectors output remaining constant, but their final demand adjusting. In a bioethanol application, this would be in essence assuming that, rather than producing additional corn, regional corn output is fixed, so increased demand for local corn as inputs to biofuels production would divert corn from sales to final demands (with, for instance, lower exports).

Within SAM modelling, Thorbecke (1998, p. 306) discusses the use of "constrained multipliers" in estimating the impact of exogenous demand changes when output constraints exist (and are known). He writes,

> *"many analysts believe that the assumption of excess capacity an unused resources is unrealistic when applied to the agricultural sector of many regions of developing countries. In such instances, it is posited that demand increases alone are inadequate in bringing forth more than a marginal agricultural output response."*

The solution is to estimate the sectoral capacity (i.e. output) constraint for any constrained sector, and then apply the sectoral (SAM) multiplier for output increases up to the constraint, and then the "mixed multiplier" for demand changes above this constraint. The final sectoral multiplier would be the sum of the unconstrained multiplier and the mixed multiplier. While it can be argued that many sectors will have some constrained capacity, which is unlikely to be exactly the current level of output – Thorbecke (1998, p. 307) notes that "at the limit, all sectors are supply constrained and the multiplier values collapse to zero. Thus it can be argued that fixed price multipliers represent the upper bound estimates of the likely impact of an exogenous increase in demand".

4. Computable General Equilibrium modelling

4.1 CGE description and methods

CGEs are empirical economic models, where the economy of a particular region or nation is parameterised around a set of equations describing the pattern of production, consumption and trade. CGE models are widely applied for regional analysis, but they are not generally dominant in the area: IO analysis may be more applicable since there is not the data at the regional level which would allow a CGE model to be constructed. The nature of production, consumption and trade, in the economy described by a CGE model is largely down to the discretion of the modeller of that economy. Loveridge (2004, p. 310) notes that "production is modelling with standard economics non-linear production functions such as Cobb-Douglas or constant elasticity of substitution production functions". Such models have developed quickly since the early 1980s, largely as a result of the increased computing power allowing empirical solutions to be found where previously the computation of solutions would be a time-consuming task (Shoven and Whalley, 1992). Models can be configured for *n*-sectors, *m*-regions, and with *k*-transactor groups. Vargas *et al* (1999) summarise CGE modelling methods for the regional economy.

The base dataset describing the nature of production, consumption and trade is often a Social Accounting Matrix. Typically, CGE models are calibrated to the benchmark period dataset (Partridge and Rickman, 2008) which assumes that the initial dataset represents an equilibrium state for regional economic activity, and counterfactual simulations can be compared to this equilibrium state. Calibration has been criticised as being inferior to econometric estimation of each variable (McKitrick, 1998), however this would require a huge amount of time series data for every variable, which are often not available at the regional level. Partridge and Rickman (2008) note that any assumed elasticities or model closures used in the specification of the models which are not econometrically estimated can be subject to sensitivity analysis of model results to show the importance of key assumptions.

One key area of difference between the range of CGE models that exist and IO and SAM modelling is in the structure of production. Loveridge (2004) identifies the use of hierarchical production functions in which inputs to each sector are substitutable in response to changes in the relative prices of inputs. The structure of the potential substitutes are set out by the modeller in stated production functions, which are often, but not always, common across all production sectors. The AMOSENVI model for instance (Allan *et al*, 2007) uses a KLEM production function in which where capital (K), labour (L), energy (E) and materials (M) are combined by all production sectors – at various points of a hierarchical production function – to produce sectoral gross output.

The modelling of regional factors of production can be crucial for the results of a CGE model. This is arguably more important for a regional than national CGE model as, at the regional level, the labour market is more flexible – i.e. workers typically face lower costs to move between different regions of the same nation, than between nations.

4.2 *Approaches for modelling bioenergy in CGE models*

Kretschmer and Peterson (2010) identify three alternative approaches in the CGE modelling of biofuels. Firstly, some authors have adopted an "implicit approach" in which they avoid "an explicit modelling of bioenergy production technologies but instead prescribes the amount of biomass necessary for achieving a certain production level. Dixon *et al* (2007) model the US economy and examine what happens to economic activity when 25% of crude oil inputs are replaced by biomass. In practice, this makes the "underlying assumption needed to achieve identical per unit costs of the two technologies is a 33% reduction in the cost of producing biofuels between 2004 and 2020. Kretschmer and Peterson (2010, p. 678) note that this approach is "elegant" in that it circumvents many problems and doesn't require additional data work, however:

> "the underlying assumptions on the development of production costs of biofuels are rather strong and optimistic: they are not motivated by engineering studies but simply assume the cost reduction necessary to reach a 25% share of biofuels without government support".

The "implicit approach" thus shows the necessary cost developments to reach a target, and the economic implications of such a scenario. It cannot show the welfare implications of government support or the optimal role of biofuels for GHG mitigation (Kretschmer and Peterson, 2010). A more detailed version of the "implicit approach" is used by Banse *et al* (2008), but it also does not explicitly model the production sector.

The second approach uses a "latent technologies" approach to establish bioenergy technologies which are not active in the base year of the model but can become active in time, or in alternative scenarios. Kretschmer and Peterson (2010, p. 680) describe latent technologies as "production technologies that are existent but not active in the base year of the model since their production is not profitable". The modeller thus requires information on the input and cost structures of the technology, as well as the markup between production costs and the costs of substitutes to the latent technologies. Such an approach has been used by Boeters *et al* (2008) and Kretschmer *et al* (2008) to model the 10% EU biofuel target for 2020 using first-generation technologies. Reilly and Paltsev (2007), Gurgel *et al* (2007) and Melillo *et al* (2009) apply the "latent technologies" method to second generation – cellulosic – biofuels.

The final approach is to disaggregate the bioenergy production sectors directly from the SAM for the region/nation model. Kretschmer and Peterson (2010, p. 682) note that "this can be considered to be the most promising future approach… which should become increasingly feasible as more extensive and more reliable data on the growing biofuels sector become available". Disaggregation of the biofuels production sector has been attempted by Taheripour *et al* (2007), Taheripour *et al* (2008) and Taheripour *et al* (2009). Where there is limited production at the moment, the GTAP databases used by these approaches introduces "negligibly small production levels into the database" (Kretschmer and Peterson, 2010, p. 682), inputs to production by ethanol and biodiesel production facilities in each nation, while trade in ethanol is also estimated (biodiesel is assumed to be consumed domestically in these applications).

These disaggregated databases can therefore be used for modelling the impact of policy and non-policy changes and a wide number of applications of this have been made over the very recent past (for instance Birur *et al*, 2008; Hertel *et al*, 2008; Taheripour *et al*, 2008; Britz and Hertel, 2009). In comparing the three approaches employed to modelling bioenergy, Kretshcmer and Peterson (2010) summarise their strengths and weaknesses. These are given in Table 2.

[Table 2 here]

5. Discussion

Having seen the range of applications in the sections above, here we summarise the appropriateness of fixed price (IO/SAM) and more general CGE models to explore the economic impacts of biofuels on a regional economy. A number of commentators have drawn attention to the practicalities of the assumptions necessary for IO modelling and their relevance in biofuels modelling. The literature critiquing biofuels modelling (for instance, Swenson, 2006, Swenson, 2007, Swenson, 2008, and Low and Isserman, 2009) has neatly illustrated many of the practical weaknesses in using fixed price modelling for ethanol development in the US. Many of the issues identified in these papers may apply to some regions, but other issues might be of secondary importance for some. This literature has, however, not attempted to broaden these lessons to other regions. There is a small literature summarising the limitations of assumptions in regional IO and SAM modelling (for instance, Koh *et al*, 1992; West, 1995), and the appropriateness of CGE modelling for regional economic development (e.g. Partridge and Rickman, 1998 and Partridge and Rickman, 2008). In this section we attempt to apply these limitations of IO, SAM and CGE modelling to the specific case of regional modelling of biofuels.

West (1995) identifies some of the characteristics of the models and the assumptions employed in conventional IO (and SAM) demand-driven modelling, as well as the assumptions made in each case under CGE modelling approaches. This forms the basis for the comparison of model characteristics shown in Table 3.

[Table 3 here]

IO and SAM modelling will typically include linear functions, and assume fixed technical coefficients in production. As Swenson (2006) makes clear, this assumes that the average and marginal impacts of demand changes on inputs are the same. That paper argues that the specific nature of intermediate inputs to ethanol in the US – particularly utilities (e.g. gas, water, electricity) – makes this assumption over restrictive. The marginal response to a change in demand in these sectors is likely to be quite different to the estimated average. High capital intensity, and sunk investments in grid infrastructure will mean that for given changes in inputs there will be less than proportional increases in the production of these inputs.

CGE models on the other hand, in which all inputs to production are modelled together, would typically allow for the input mix to be sensitive to relative prices, and so adjust. The elasticities of substitution in production for each sector will be specified in advance – although econometric estimation of all values in the model is atypical. This would perhaps be an example of a case where assumed production functions would most appropriately not be identical for each sector.

In general, as we have seen, regions where biofuels production could compete with food supply, or other existing users of suitable land for biofuels, we would not expect that, other things being equal, introducing biofuels production would be met by increased use of land. Other factors of production in a regional economy (e.g. labour and capital) could be appropriately assumed to be variable over the long-run, as they might respond to price differences through the attraction of labour (migration) or capital (investment). At the regional level land supply will be a binding constraint. Modelling of biofuels should therefore take care to appropriately consider the availability of factors of production, something that CGE models forces the modeller to make explicit and model consistently.

This is not to say that there are not approaches using IO or SAM which can get around the non-availability of additional land. Low and Isserman (2009) show how constraining supply of grain at the regional level can be done, with the effect on regional economic activity likely to be reduced significantly (indeed, much of the additional employment estimated by Urbanchuck (2007) and criticised in Swenson (2007), comes from assuming that the agriculture sector which produces the feedstock used in biofuels production can expand without limits). Alternatively, some regions may not be constrained in the supply of available land, so new biofuels production is either using neglected land (e.g. as in Kulišić *et al*, 2007) or where there may be less constraints on land being sourced (e.g. Cunha and Scaramucci, 2007).

There is a secondary question as well. If supply constraints are a feature of the regional economy – for instance, through the lack of available land – where will this feed in to the maximum available output for each sector? Low and Isserman (2009) and Swenson (various years) consider that the output of the grain producing sector is fixed at its initial level. Such an assumption could be correct – in developed farming regions it is perhaps possible that major efficiencies in agricultural production have been largely exploited – but it is not necessarily true, and may not be so particularly for developing regions. SAM multipliers can be estimated where sectoral output constraints are known in advance (e.g. Thorbecke, 1998), but the constraints are necessarily imposed by the modeller.

Partridge and Rickman (2008) argue that nested production functions for industries would include intermediate goods (materials in the KLEM model described above), capital, labour (separately identified as high- and low-skilled) and land. Land, in the model they outline, substitutes at the first tier of the primary factors of production with a relatively low elasticity of substitution. The supply of land in their model is allowed to respond positively with its rate of return, allowing for land in use to expand (or contract) in response to changes in demand. They allow land to be useable across industries in the region, but the rate of elasticity between industries "should be small" (Partridge and Rickman, 2008, p. 10). Developed land therefore moves in use between different sectors in response to the return on land in each sector, and in equilibrium the price of land in each sector are equal. Their suggestions offer a useful guide to how land could appropriately be considered in regional CGE models.

Looking at the specific modelling of biofuels, Kretschmer and Peterson (2010) argue that CGE models are well suited due to their "encompassing scope": "such a modelling framework unveils direct and indirect feedback effects of certain policies or shocks across sectors and countries". Global, multi-regional CGE models particularly, "cover the whole world economy disaggregated into regions and countries as well as diverse sectors of economic activity" (Kretschmer and Peterson, 2010, p. 674).

Kretschmer and Peterson (2010, p. 675) identify four "general issues that are relevant for all approaches to model bioenergy and that greatly affect the results of… CGE models" the modelling of bioenergy. Two key ones[7] are:

- The modelling of land use
- Land use change

Given the requirement (of existing generations of biofuels) for land on which to grow the feedstocks, and competition from existing agricultural use of that land, it is vital that land as a factor of production is modelled in an explicit way. A number of alternative treatments for land exist. Firstly, land can be modelled as a homogenous factor of production available to the agriculture sector that is fixed in supply (for instance Dixon *et al*, 2007; Kretschmer *et al*, 2008). Secondly, land can be modelled using a constant elasticity of transformation (CET) formulation in which land used in different sectors can be changed to serve other sectors, with the ease of transforming land between sectors represented by the chosen elasticity of transformation. (Kretschmer and Peterson (2010) identify Hertel and Tsigas (1988) as the first use of a CET for land into a CGE model). The CET approach is adopted by Boeters *et al* (2008) and Keeney and Hertel (2009). Clearly, the chosen CET for land is crucial, and can be found from available econometric evidence or tested by using sensitivity analysis to show the importance of the estimate chosen (e.g. Boeters *et al*, 2008). A third option is to "nest" levels of land use within a CET framework. Banse *et al* (2008) adopt this approach, as well as incorporating a "land supply curve" which "models the relationship between land supply and land rental rate for each region and captures the idea than increased feedstock demand will have a larger impact on rents in land-scarce countries… which influences local biofuel production costs and hence their competitiveness" (Kretschmer and Peterson, 2010, p. 676). A final option – adopted by Gurgel *et al* (2007) and building on the work of Reilly and Paltsev (2007) is to model different five types of land and assume that when land is switched between uses it takes on the productivity of that land type.

Land use change, and its incorporation in CGE models, is also crucial for the results of these models of new bioenergy technologies. Kretschmer and Peterson (2010, p. 676) argue that "direct and indirect land use change is probably the most significant factor for the overall greenhouse gas balance and thus the environmental impact of biofuels". Land use changes such as converting high carbon storage land areas, such as forests, into cropland to grow energy crops, can actually increase the amount of carbon in the atmosphere rather than reduce it.

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[7] They also include Biofuel trade, and Biofuel by-products.

6. Conclusions

This paper has described Input-Output (IO), Social Accounting Matrix (SAM) and Computable General Equilibrium (CGE) modelling and review applications of these methods to the regional economic impact of biofuels developments. Further, we have detailed some of the strengths and weaknesses of each of these approaches for application to the biofuels industry.

The IO and SAM approaches examine the embeddedness of biofuels production into the regional economy, and employ "multipliers" to show either the impact of changes to existing biofuels sectors (if applicable), or the possible impact of new biofuels production locating in the region. It is vital for the modelled economic impact what is assumed about the response of production in other sectors across the region. These models are particularly appropriate where there are unemployed resources in the region. Sectors which are believed to be "supply constrained" can be modelled in such a way as to ensure that their output does not increase in line with biofuels production. SAM modelling employs similar assumptions, however is more complete in its coverage of every transaction in a region, rather than those linked solely to regional production activities. A useful extension of the SAM models has show how these can be used to accommodate the additional impact on a regional economy of any income (i.e. profits) retained locally through ownership. Such income would typically not be captured by IO models (see Allan *et al*, 2010) and this provides a useful addition to the regional modellers' toolkit.

While land is not always incorporated in many CGE models, recently modellers have increasingly turned their attention to biofuels development, which forces the explicit specification of land, and its substitutability, as a factor of regional production. Such models, with an active supply- as well as demand-side, can also avoid some of the potential drawbacks of "demand-driven" IO and SAM modelling. Biofuels development to date has been argued to have impacts on land prices, land use and food prices (e.g. Mitchell, 2008). CGE models, in which such prices and land use are able to respond to market signals may provide a "more plausible" modelling strategy than IO and SAM methods. Extensions to conventional IO and SAM multiplier modelling – such as "constrained multipliers" (Thorbecke, 1998) do offer some possibility for salvation of these techniques. In some circumstances, however, for example where there are limited supply constraints on factors of production, or where fixed technical coefficients may be representative of the response of production sectors, fixed price methods may be appropriate. We conclude by noting that models should be selected which are appropriate for the specific application.

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Figure 1: Schematic layout of IO table

Purchases ↓ Sales →	*Production sectors*	*Final demand categories*	*Gross output*
Production sectors	Intermediate quadrant	Final demand quadrant	Sectoral gross outputs
Primary inputs (including imports)	Primary input quadrant	Final demand purchases of primary inputs	Gross primary inputs
Gross inputs	Sectoral gross inputs	Gross final demand inputs	

Figure 2: Schematic layout of Social Accounting Matrix

				Expenditures				
				Endogenous accounts			*Exog.*	*Totals*
				Production activities	*Factors*	*Institutions, i.e. Households and companies*		
				1	2	3	4	5
Receipts	*Endogenous accounts*	*Production activities*	1	T_{11}	-	T_{13}	f_1	y_1
		Factors	2	T_{21}	-	-	f_2	y_2
		Institutions, i.e. Households and companies	3	-	T_{32}	T_{33}	f_3	y_3
	Exog.		4	ζ_1'	ζ_2'	ζ_3'	ζ	y_x
	Totals		5	y_1	y_2	y_3	y_x	

Source: Thorbecke (1998), Table 7-2, page 301

Table 1: Summary of IO and SAM applications to biofuels

Paper	*IO/SAM*	*Region(s)*	*Biofuel*	*Demand shock*	*Result (jobs, GDP)*	*Offset?*	*Constrained sector?*
Van Dyne *et al* (1996)	IO	Audrain county, Missouri	Biodiesel from oilseeds	Either: One plant in a single county; 10% of the farm level diesel usage in Missouri; or 25% of farm diesel usage.	"permanent job creation increases may be small, but temporary jobs will be created during the construction of biodiesel plants" (p. 5).	Potential negative effects on other industries – grain elevators, bulk fuel plants and local feed dealers all experience decline in demand.	None apparent
Swenson (2006)	IO	Three county region of Iowa	Ethanol from corn	$118.6 million final demand shock to new ethanol sector	Direct effect: 35 jobs, $18.4m Indirect effect: 75 jobs, $6m Induced effect: 23 jobs, $0.9m Total: 133 jobs, $25.4m	Reduction in final demand for grain sector output.	Grain sector output reduced through final demand shock to set modelled output in this sector to base year level.
Cunha and Scaramucci (2006)	IO	Brazil	Bioethanol from sugar cane produced using two technologies and two harvesting methods	R$95.22 billion additional final demand for ethanol (equivalent to produce 828% change in output of sector)	GDP up R$153 billion (11.0%), occupied people up 5.3 million (8.0%)	No offset	None apparent
Kulišić *et al* (2007)	IO	Croatia	Biodiesel from rapeseed oil	Doubling share of biodiesel in diesel consumption in Croatia from 5% to 10%.	Income up HRK 1,066.5 million and employment up 1,947	Negative demand shock to diesel sector	Assume rapeseed crops are grown on neglected agricultural land, so don't displace compete with food production.

Hodur and Leistritz (2008)	IO	Two facilities modelled in same region	Ethanol from corn and cellulosic ethanol	New ethanol production and construction of facilities.	Corn ethanol facility (50MGY) creates secondary employment of 497, and direct and secondary impact of $45.8 million. Cellulosic ethanol facility (50MGY) creates secondary employment of 2400, and direct and secondary impact of $185.2 million	None apparent.	None apparent
Low and Isserman (2009)	IO	Four counties in US Midwest and hypothetical facilities (2x 60MGY plants, 2x100MGY plants)	Ethanol from corn	New facilities sited locally, consuming inputs from local economy, and which pay (a small) premium for corn.	Employment effect varies between sites from 99 to 250 jobs, regional output up y between $137m and $248m	None specifically, although output of grain sector constrained to initial level.	Regional grain output remains unchanged by adjusting technical coefficient.
Swenson and Eathington (2006)	SAM	Three county region of Iowa	Ethanol from corn	$118.6 million final demand shock to new ethanol sector, but profits can either be retained locally through increased spending or investment	Each additional 25% of local retention of profits raises regional outputs by $1.2 million (if spending increases) or $2.7 million (if investment increases)	Reduction in final demand for grain sector output	Grain sector output reduced through final demand shock to set modelled output in this sector to base year level

Table 2: Three approaches of modelling bioenergy in CGE models

	Advantages	*Disadvantages*
Implicit approach	• Elegant approach avoiding a breaking up of the original model structure	• No explicit bioenergy production sector. • No commodity "biofuel". • Trade in biofuels cannot be modelled
Latent technologies	• More realistic representation of bioenergy production processes by including separate sectors • Allows for including trade in biofuels • Allows for including new developments (e.g. second-generation biofuels, new producing countries)	• Projections based on limited time series of biofuel production and trade data or even on pure assumptions • Complex procedure, increase in computational burden
Disaggregating the SAM	• *Ex-ante* inclusion of bioenergy technologies in underlying database • Coherence of modelling framework	• Full potential is so far restricted by data limitations • Limitations to model new developments

Source: Kretschman and Peterson (2010), Table 2.

Table 3: Model characteristics[9]

IO	*CGE*
Linear functions	Non-linear functions
Fixed coefficients (fixed technology)	Hierarchical production functions allowing for substitution between inputs in response to relative price changes
No price effects	All prices adjust in new equilibrium
Quantities adjust	Prices and quantities adjust
No supply constraints (demand driven)	Demand and supply interact and supply constraints can be imposed where appropriate

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[9] A third column of model is considered in West (1995) referring to Input-Output Econometric techniques. We omit this from Table 3 as there are no studies using this approach to study the regional economic impact of biofuels.

Appendix A: IO modelling and estimation of multipliers

The structure of a regional economy can be described in a set of equations, and corresponds to reading along the rows of the IO table. These show how output for each sector (x_i) is produced for consumption by other industries (z_{ij}) and by elements of final demand for each sectors output (f_i). The first subscript shows the producing (row) sector, while the second shows the consuming sector. We describe the specifics of IO matrices using a three sector example (i.e. i, j = 3).

$$\begin{aligned} x_1 &= z_{11} + z_{12} + z_{13} + f_1 \\ x_2 &= z_{21} + z_{22} + z_{23} + f_2 \\ x_3 &= z_{31} + z_{32} + z_{33} + f_3 \end{aligned} \qquad \text{Equation A1}$$

We can represent the pattern of purchases made by each sector (i.e. reading down the columns for sector j) by calculating technical coefficients (a_{ij}) where:

$$a_{ij} = z_{ij} / x_j \qquad \text{Equation A2}$$

We can restate Equation A1, replacing the z_{ij} elements with those from Equation A2. This gives us the following relationship between sectoral output and inter-industry purchases and sales to final demand.

$$\begin{aligned} x_1 &= a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + f_1 \\ x_2 &= a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + f_2 \\ x_3 &= a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + f_3 \end{aligned} \qquad \text{Equation A3}$$

If we express Equation A3 as the levels of inter-industry transactions and sectoral outputs in terms of the final demands for those sectors' output, we get:

$$\begin{aligned} x_1 - a_{11}x_1 - a_{12}x_2 - a_{13}x_3 &= f_1 \\ x_2 - a_{21}x_1 - a_{22}x_2 - a_{23}x_3 &= f_2 \\ x_3 - a_{31}x_1 - a_{32}x_2 - a_{33}x_3 &= f_3 \end{aligned} \qquad \text{Equation A4}$$

Or

$$\begin{aligned} (1-a_{11})x_1 - a_{12}x_2 - a_{13}x_3 &= f_1 \\ -a_{21}x_1 - (1-a_{22})x_2 - a_{23}x_3 &= f_2 \\ -a_{31}x_1 - a_{32}x_2 - (1-a_{33})x_3 &= f_3 \end{aligned} \qquad \text{Equation A5}$$

In matrix notation, we can express equation 5 as:

$$(I - A)X = F \qquad \text{Equation A6}$$

where capital letters denote we are considering matrices of each variable (F in this example is a 3 x 1 column vector, while (I-A) and X represent two 3 x 3 matrices. Rearranging Equation A6, we derive sectoral output in terms of the final demands for sectoral output and the inverse of the (I-A) matrix. This is the key equation in IO modelling, and the $(I\text{-}A)^{-1}$ element is termed the Leontief inverse, after the father of Input-Output analysis, Wassily Leontief[10].

$$X = (I - A)^{-1}F \qquad \text{Equation A7}$$

Equation A7 shows how (under the demand-side perspective) we can attribute output (X) to final demand (F) for the output of a regional economy. Identifying each of the individual elements of the F matrix – households, government, exports, etc. – we can estimate the importance of each category for regional output.

Alternatively, we can use Equation A8 to show the impact of changes in final demand on regional output.

$$\Delta X = (I - A)^{-1}\Delta F \qquad \text{Equation A8}$$

The IO modelling described here is termed "open", in that all regional sectors are endogenous, while all categories of final demand are exogenous. Miller and Blair (2009, p. 34) argue, "in the case of households… the exogenous categorization is something of a strain on basic economic theory". Household income would increase when production expands, and households typically spend their earnings in "well patterned" ways (Miller and Blair, 2009, p. 35). Household spending therefore would be related to the level of economic activity in the region, so changes in regional activity would be expected to change the level of household spending.

A common IO practice is to incorporate the spending and earnings by regional households into the Leontief inverse matrix, creating an endogenous "household sector". Incorporating the household sector in this way is termed "closing" the model

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[10] Wassily Leontief (1906-1999) won the Noble Prize in Economics in 1973 "for the development of the input-output method and for its application to important economic problems".

with respect to households. The column coefficients of the "household sector" are the purchases by the household final demand category (this is a column vector in the IO tables) divided by the sum of all payments to wage income (earned across all sectors purchases of labour (x_{n+1})).

$$a_{i,n+1} = z_{i,n+1} / x_{n+1}$$ Equation A10

The additional row for the household sector is calculated as follows. The "household sector" sells labour services to all sectors in the region, and so the row coefficients for the household sector are each sectors purchases of labour services divided by that sectors output.

$$a_{n+1,j} = z_{n+1,j} / x_j$$ Equation A11

Assuming the correctness of the Leontief inverse (Miller and Blair, 2009) the typical work of the IO modeller is therefore to use the matrix to show how regional activity will be disturbed by a change in final demand for sectoral output. For that purpose therefore, the analyst can calculate "multipliers" for each sector in the region, which provide a useful shorthand for the impact on measures of regional activity of disturbances to the demand for output of specific sectors. Multipliers calculated under the "open" model are termed Type 1 multipliers. Multipliers calculated under the "closed" model, with households' income and spending endogenised, are termed Type 2 multipliers.