Developing a demographic sub-model and an Input-Output Structure for the Green Economy Macro-Model and Accounts (GEMMA) Framework

Final Report
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Introduction

This report describes the research undertaken in fulfilment of the terms and conditions of the CIGI-Research Grant given to Professors Victor and Jackson under the joint CIGI-INET Program on New Economic Theory, Practice and Governance. The project began on February 1, 2012 and ended on April 30, 2013.[1]

The specific objectives of the project were to help develop two specific components of the Green Economy Macro-Model and Accounts (GEMMA) framework on which Professors Jackson and Victor have been working since October 2010. The GEMMA framework provides a way of modelling a stock-flow consistent representation of an ecologically-constrained macroeconomy at the national level. Its principal aim is to integrate the financial economy, the real economy and relevant ecological constraints within a single framework. It consists of numerous inter-connected sub-models and it is still a work in progress. Funds from CIGI-INET were requested to support the work on two specific components of GEMMA:

1. A demographic sub-model for examining inter-generational issues such as provision for the elderly in an aging population.

2. An input-output sub-model to ensure internal consistency among sectors and to link the activities of the real economy to the biosphere through their requirements for materials, energy, water, land and waste disposal.

The funds provided by CIGI-INET were used to hire research associates in Canada and the UK for work on these two components of GEMMA, and to cover travel costs for Professors Victor and Jackson. The purpose of this report is to describe the

[1] The original completion date was 31 January 2013. Upon request a 3 month extension was granted.

demographic and input-output models that were developed with this research grant. A separate financial report provides details of the disbursement of the funds.

The Demographic Sub-Model

There are many interesting questions about the future of national economies that are related to demography. There are clear links for instance between demography and housing, between demography and the structure of the labour force, between demography and the size of the economy. A growing population is related to a growing economy: more people demand more economic goods and services, and more people are able to supply labour and knowledge which are used to produce economic goods and services.

The age structure of the population is dependent on certain life stages that relate to the ability and (social expectations) of people to supply labour and knowledge inputs, and to demand the economic outputs from others. Consequently the size of the population and its structural characteristics interact to affect the economy in numerous ways that affect important inter-generational issues.

One of the issues which is currently attracting a lot of attention is the provision of funding for the pensions and health care of an aging population. This is a particularly pressing concern in the absence of strong economic growth and represents a significant challenge to those who propose restraints on economic growth for ecological or social reasons.

In order to address these and other issues in which demography plays a key role, the aim of this research was to develop a detailed demographic sub-model for inclusion within the GEMMA framework. The following subsections describe the model and illustrate some findings in relation to Canadian and UK data . A user-friendly demonstration model, based on this work, is supplied along-side this report.

Model Description

The sub-model that has been developed for inclusion in GEMMA has the following features:

- **Age groups**: The population is divided into 5-year age groups from 0 to 89 years and by gender. A final age group of 90+ counts people who can live as long as 110 years.

- **Births, deaths, immigration, and emigration:** The likelihood of these events are specific to each age group of each gender. Since 'abridged' life tables are used in the sub-model, these likelihoods are assumed the same for all members in each 5 year age group (e.g. all men aged 30-34 years are subject to the same mortality rate). The likelihoods can change over time, allowing scenarios of varying fertility, mortality (hence life expectancy), immigration and emigration.

    - **Births**: Births are a function of the number of women who are of child-bearing age and their age-specific fertility rates.

    - **Fertility**: Average lifetime fertility rates are reported as the sum of all age-specific fertility rates. This helps to communicate the average number of children that an average woman would be expected to bear over her lifetime and can help assess whether fertility alone can replace a generation, given prevailing mortality rates. Changes to lifetime fertility rates can be explored in the sub-model. A rise or fall of this lifetime rate is applied uniformly to each age-specific rate, since the former is derived from the latter. For example, a 10% rise in average lifetime fertility is applied as a 10% rise in each age-specific rate. This preserves whatever relative pattern exists across all ages, such as a peak in the mid-30s and a fall to zero fertility by age 50.

- **Deaths:** Deaths are a function of the age-specific mortality rate (by gender), and the number of people subject to that rate. A gender-specific infant mortality rate is applied to births before they add to the 0-4 age category.

- **Life expectancy:** Life expectancy at birth is reported separately for men and women. This statistic is the number of years that an average person can expect to live after birth, based upon prevailing age-specific mortality rates. This helps to communicate average longevity and any changes in longevity over time. The sub-model can be used to explore changes in longevity. Each scenario is described by its maximum possible change in life expectancy, reached by a specific target year, and the change in gender- and age-specific mortality rates that correspond to this change. Changes are linearly phased-in from the start of the simulation until that target year, and then held constant. This allows scenarios of high versus low increases in longevity to be modelled as differences in the speed by which changes in longevity are realized.

- **Immigration**. The number of immigrants is calculated by multiplying an overall immigration rate by the total population. The total number of immigrants is then allocated to specific age groups (by gender) in proportion to their distribution in the base year. Thus if 8% of immigrants are males aged 30-34 at the start of the simulation, this ratio would be preserved even if immigration rates double or fall by half.

- **Emigration**. Each age group loses a portion of its population to emigration. This loss is the product of an age-specific rate, which does not change over time, and an overall emigration rate, which is a scenario-dependent variable. A growing population will increase the number of emigrants, even if the emigration rate does not change. The age structure of emigrants will vary in response to changes in the age structure of the population.

Data Requirements for the Demographic Sub-Model

The sub-model is structured in a way that can accommodate demographic data inputs from any OECD country. Canadian data for the initial (2010) population, age-specific fertility rates, and the age and gender distribution of emigrants and immigrants were sourced from the Statistics Canada CANSIM database (Statistics Canada, 2012a, 2012b, 2012c, 2012e). Population and fertility data for the United Kingdom were sourced from the Office of National Statistics (ONS, 2011a, 2011b), while data on emigrants and immigrants were sourced from the Eurostat Database (European Commission, 2012). Data for abridged (5-year age group) mortality rates and childhood mortality were sourced from the World Health Organization Global Health Observatory Data Repository (WHO, 2012). Labour force participation data were sourced from the "OECD.Stat" statistical database (OECD, 2012). The sub-model's forecast of trends in life expectancy (resulting from expected changes in mortality rates) was based upon estimates from Canada (Statistics Canada, 2010b) and the UK (ONS, 2011a) as a function of their population growth scenarios.

The least readily available data for OECD countries is time-use data on a gender- and age-specific basis. Canadian data published by Statistics Canada (2010a) informed Canadian estimates on an age-basis, but does not distinguish between genders. UK estimates were sourced from the European Commission (Eurostat, 2012) for most age groups, and are specified by gender, but data gaps for older (>75) and younger (<20) people were filled in by proportionally adjusting Canadian data.

Canadian Demographic Scenarios

The sub-model characterizes demographic scenarios with specific information about average lifetime fertility (which relates to age-specific fertility rates), changes in life expectancy at birth (derived from changes in age- and gender-specific mortality rates) and labour force participation rates, and changes in the rates of immigration and emigration. Five pre-set scenarios have been created to replicate the same high versus low-population growth, and stabilization, ranges explored by the Canadian and UK scenarios developed by Statistics Canada (2010b) and the Office of National Statistics (2011a). Other scenarios can be generated by changing the values of specific variables. The five pre-set scenarios are:

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Testing Model Forecasts against Statistics Canada Forecasts

The sub-model was initialized with Canadian data from Statistics Canada. This allowed demographic forecasts from the sub-model to be compared with Statistics Canada forecasts (CANSIM Table 052-0005), using common scenario assumptions that all begin from the same initial values (i.e. Lifetime Fertility Rate of 1.7, Immigration Rate of 0.8%, and a Life Expectancy At Birth of 78.6 (Male) and 82.7 (Female)).

- Scenario 1 = Low Population Growth: Fertility Rate falls to 1.5 by 2014, then held constant. Immigration Rate falls to 0.6% by 2011, then held constant. Life Expectancy at Birth rises to 82.3(M) and 86.0(F) by 2036, continuing to rise until 2058.

- Scenario 2 = Medium Population Growth, based on historical trends from 1981-2008: Fertility Rate remains 1.7 forever. Immigration rate remains 0.8% forever. Life Expectancy at Birth rises to 84.0(M) and 87.3(F) by 2036, continuing to rise until 2043.

- Scenario 3 = High Population Growth: Fertility rises to 1.9 by 2014, then held constant. Immigration rate rises to 0.9% in 2011, then held constant. Life Expectancy at Birth rises to 85.4(M) and 88.4(F) by 2036, with no further rise.

- Scenario 4 = Population Stabilization: The Immigration rate matches the emigration rate (0.15%). Fertility and life expectancy at birth mirror Scenario 2's medium growth.

- Scenario 5 = Stabilisation with modified retirement: In addition to the conditions in Scenario 4, in Scenario 5 retirement is delayed by linearly phasing in a 5-year shift in the age-specific participation rates for people aged 60 and older.

Statistics Canada does not include participation rates in its scenarios. The sub-model uses abridged life tables, whereas Statistics Canada uses detailed (annual) life tables. Nevertheless, population forecasts were within 1% of each other, over 20 years. Figure 1 provides a summary of the features of the demographic sub-model.

Figure 1
Summary of the Main Features of the Demographic Sub-Model

<table>
<tr><th></th><th>Representation in the sub-model</th><th>Initial Values</th><th>Projected Value</th></tr>
<tr><td>Population (by gender and age groups: <1, 1-4, …5yrs…, 90+)</td><td>One conveyor for each age group (arrayed by gender)</td><td>2010 Data</td><td>Calculated endogenously from existing population, mortality, fertility, immigration, emigration</td></tr>
<tr><td rowspan="5">Mortality Rate
(age- & gender-specific)</td><td>One graphical function of the initial rates by age >=1 (arrayed by gender)</td><td>2009 Data (from WHO) approximately equal to mortality rates from statistical agency</td><td rowspan="5">Linear decline from the initial value up to the maximum decline that would be achieved in the target-year;
after the target-year there is no more decline</td></tr>
<tr><td>An initial infant mortality rate (arrayed by gender)</td><td>2008 Data</td></tr>
<tr><td>A projected decline in infant mortality rate (arrayed by gender) that would be reached by the target-year</td><td rowspan="2">Calculated in Excel from past trends (currently last 20 years) projected to match projection from statistical agency</td></tr>
<tr><td>One graphical function of the decline from the initial values, by age>=1 (arrayed by gender), that would be reached by the target-year</td></tr>
<tr><td rowspan="2">The target-year in which the change is fully realized (used for projections of mortality rate and life expectancy at birth)</td><td rowspan="2">(Scenario variable)</td></tr>
<tr><td rowspan="3">Life expectancy at birth
(by gender)</td><td rowspan="3">Linear gain from the initial value up to the maximum gain that would be achieved in the target-year; after the target-year there is no more gain</td></tr>
<tr><td>An initial life expectancy at birth, which is calculated by statistical agency from age-specific mortality rates</td><td>2009 Data (from WHO) approximately equal to mortality rates from statistical agency</td></tr>
<tr><td>A projected gain in life expectancy at birth, from projections of the statistical agency's forecast of age- and gender-specific mortality rates</td><td>(Scenario variable based on population projections from statistical agency)</td></tr>
<tr><td rowspan="3">Fertility Rate (age-specific)</td><td>One graphical function of the initial rates by age</td><td rowspan="2">2008 Data (Canada),
2009 Data (UK)</td><td rowspan="3">Initial age-specific values are all equally adjusted up or down depending upon whether the user-specified average lifetime fertility rate (in a given year) is higher or lower than the initial average lifetime fertility rate</td></tr>
<tr><td>The initial average lifetime fertility rate that is derived (in Excel) from the values from the graphical function of the age-specific rates</td></tr>
<tr><td>One graphical function of the average lifetime fertility rate, over each future year</td><td>(Scenario variable)</td></tr>
</table>

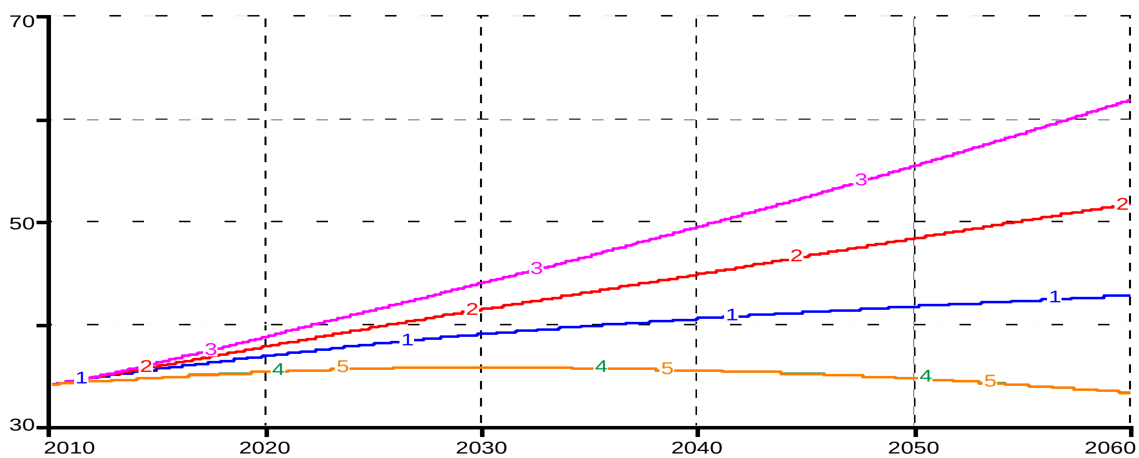
Figure 1 continued

	Representation in the sub-model	Initial Values	Projected Value
Immigration rate (age- and gender-specific)	One graphical function (arrayed by gender) of the proportion of initial immigrants in each age group	2010 Data	The amount of immigrants are determined by the user-specified rate, and then input to the appropriate age/gender conveyors based upon the initial age/gender distribution
	One graphical function of the yearly immigration rate, which is the ratio of the number of immigrants compared to the total population	(Scenario variable)	
Emigration rate (age- and gender-specific)	One graphical function (arrayed by gender) of the proportion of initial emigrants in each age group	2010 Data	Initial age-specific emigration rates (by age group) adjusted up or down if the yearly immigration rate is higher or lower than it was initially
	One graphical function of the yearly emigration rate, which is the ratio of the number of emigrants compared to the total population, for a given year	(Scenario variable)	
(Paid Labour) Participation rate (age- and gender-specific)	One graphical function (arrayed by gender) of the initial labour force participation rates by age	2010 Data	A linear change from the initial value up to the rates achieved by the target-year, staying constant after. This allows GEMMA, for example, to explore increased participation in old age, given increased longevity and agility of older workers
	One graphical function (arrayed by gender) of the change in age-specific rates achieved by a target-year	Calculated in Excel, presently based upon intuition that participation rates above 60 will shift by 1 year for each 1 year gain in life expectancy	
	A target-year when the change is fully realized	(Scenario variable)	
Available paid and unpaid worktime (age- and gender-specific)	One graphical function (arrayed by gender) of hours available for (paid and unpaid) work, by age	2010 Data Presently no data for under 15 year olds and not distinguished by gender	Does not change over time
	One graphical function (arrayed by gender) of the proportion of worktime devoted to paid work		

Canadian Demographic Scenarios

Figure 2 forecasts the size of Canada's population under different scenarios of population growth. The highest-growth scenario (3) generates close to a doubling of the population by 2060 while the no-growth (stabilization) scenarios (4&5) have the Canadian population peaking by 2030 followed by a decline to its 2010 level by 2060. The low (1) and medium (2) growth scenarios result in population between these two bounds, with the medium scenario reflecting present demographic patterns of fertility, migration, and changes in mortality rates (life expectancy).

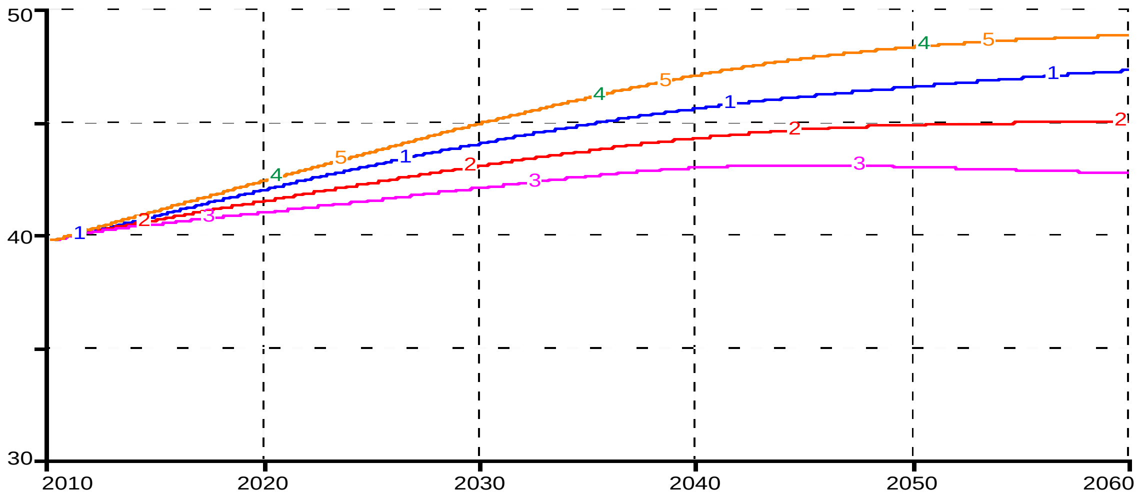
Figure 2: Forecast of Canada's total population (in millions) under different scenarios



Scenario 1=Low population growth, 2=Medium population growth, 3=High population growth, 4&5=Stabilization (balanced migration)

The results show that all growth and no-growth scenarios result in an aging Canadian population. Figure 3 shows how different scenarios affect the aging of Canada's future population. The high-growth scenario (3) results in the average age of Canadians being 3 years older by 2060 than in 2010, which is 6 years younger than the average age without population growth (scenarios 4&5).

Figure 3: Average age of Canadians under different scenarios



Scenario 1=Low population growth, 2=Medium population growth, 3=High population growth, 4&5=Stabilization (balanced migration)

Canadian Labour Force and Dependency Ratios

A number of economic variables are related to demographic characteristics. Of particular significance are the size of the labour force and questions of the dependency of the population on the working population. This section illustrates how the demographic sub-model can be used to explore these issues.

The size of the paid labour force is calculated in the model in the following way:

- The number of people in the paid labour force is calculated from gender- and age-specific participation rates, multiplied by the population within each group. These people are available to work; whether they are employed is a function of labour demand.
- The implications of changes in participation rates are modelled by specifying a maximum change, on an age- and gender-specific basis,

and a year when the change would be fully phased in. This is particularly useful for exploring scenarios of greater participation in old age.

Using the labour force calculations, it is also possible for the sub-model to identify the time available in the economy for paid and unpaid labour. The sub-model incorporates the number of hours on an age- and gender-specific basis that are available for paid and unpaid labour. Unpaid labour is the sum of time spent on household work plus civic and voluntary work outside of the household. Data from time-use surveys are used to populate the initial values.

The sub-model calculates the amount of time spent working for pay based upon participation rates, an overall employment rate, and a scenario-specific variable that allows changes in work time to be explored. The sub-model also calculates the amount of time available for unpaid work, which is the remainder of available work time that was not paid.

Perhaps the most interesting application of the demographic sub-model is its ability to analyse the degree of dependency of the non-working population on its work force. Two different kinds of dependency ratios are calculated in the sub-model:

- **Demographic dependency ratios:** These include a Total Dependency Ratio (TDR), a Youth Dependency Ratio (YDR), and a Senior Dependency Ratio (SDR). These ratios measure the dependency of an age group upon the population aged 20 to 64. This latter group is sometimes characterized as the working-age population. However these measures of demographic dependency are based upon age alone, not actual employment status. The sub-model reports these measures because they are commonly reported by statistical agencies and used by analysts to make international and temporal comparisons.

  TDR = [youth (under 20 years) + seniors (65 and above)] per [100 people of age 20-64]

YDR = [youth (under 20 years)] per [100 people of age 20-64]

SDR = [seniors (65 and above)] per [100 people of age 20-64]

- **Labour market dependency ratio:** This ratio measures the number of people outside of the labour force per 100 people who are part of it, regardless of age. This reflects the possibility that seniors and youth may be employed (or seeking employment), and that some working-age people may not be working or seeking paid work. This ratio is more reflective of economic dependency than demographic dependency.

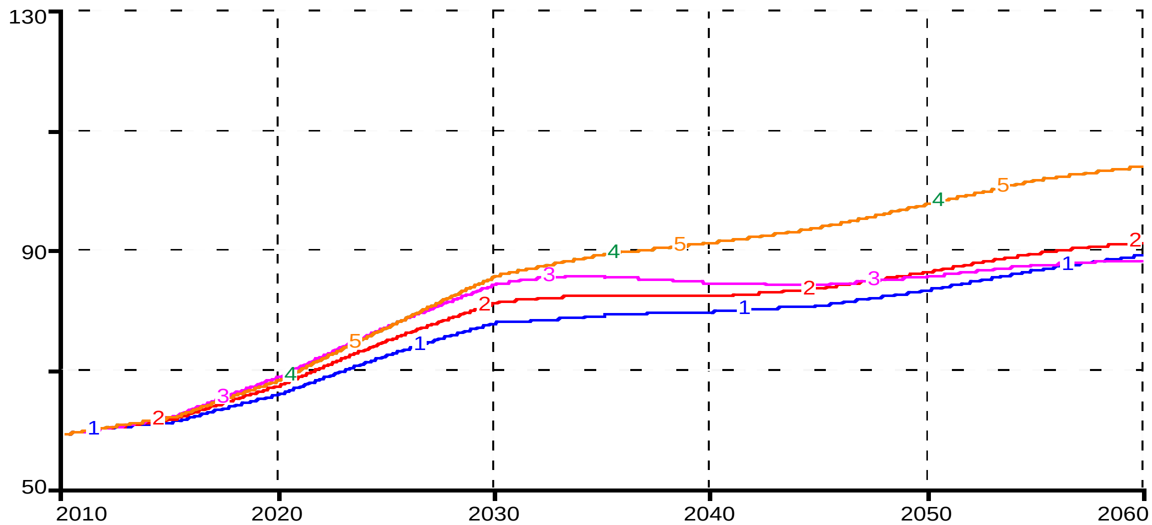
  LDR = [people not participating in the labour market] per [100 people participating]

Using different definitions of dependency, some of the socio-economic implications of different population scenarios can be explored. This analysis allows exploration of the consequences of demographic transition, and analysis of the impacts of different responses to demographic change, using different measures of dependency.

Firstly, using a demographic dependency ratio, figure 4 reveals that all scenarios result in greater demographic dependency, measured as the number of youth (under 20 years of age) plus seniors (above 64 years of age) relative to the number of working-age people (aged 20-64). A higher population-growth scenario generates more dependency than a low population-growth scenario. Stabilization results in the same growing level of dependency than the highest population-growth scenario up to 2030, after which stabilization results in ever-growing dependency reaching almost twice the level by 2060 as existed in 2010.

This increase in dependency is not unprecedented; by 2060, all growth scenarios would reach a dependency of 89 (per 100) – the same level that was reached in Canada in 1971 (Statistics Canada, CANSIM Table 051-0001, 2012). However the stabilization scenarios result in 15 more dependents per 100 people by 2060 than were experienced in 1971.

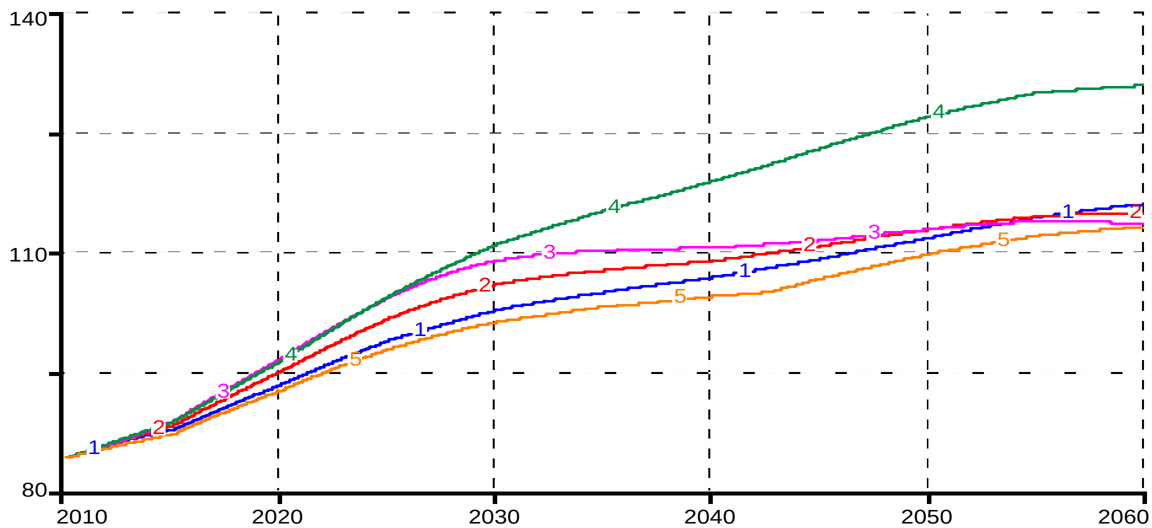
Figure 4: Demographic dependency, measured as the number of young plus old dependents forecast per 100 Canadians between the ages of 20 and 64.



Scenario 1=Low population growth, 2=Medium population growth, 3=High population growth, 4&5=Stabilization (balanced migration)

Although widely used, age is an imperfect measure to characterize whether someone is economically dependent or supports dependents – and therefore an imperfect measure to forecast future dependency. Young and old people can participate in the labour force, and "working-age" people may not participate. Consequently, a measure of labour force dependency was developed in this project by modelling the age- and sex-specific patterns of labour force participation to be able to forecast the consequences of different growth scenarios. Results confirm that projections of dependency are significantly different when they rely upon age versus labour force status. Future increases in dependency are less dramatic when measured by the labour force, than by age-related measures alone.

Figure 5: Labour-force dependency, measured as the number of non-working people per 100 Canadians who are participating in the labour force



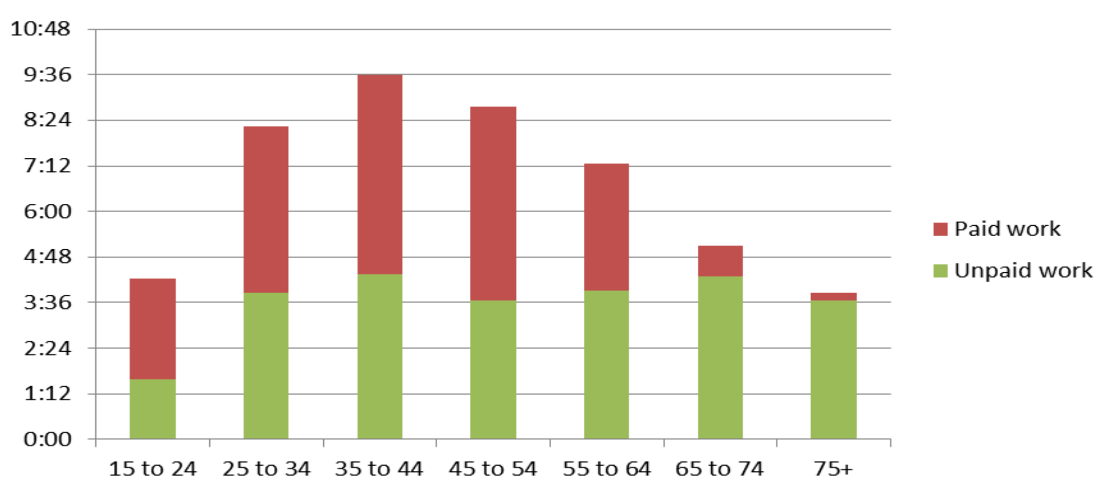
Scenario 1=Low population growth, 2=Medium population growth, 3=High population growth, 4=Stabilization; 5=Stabilization with delayed retirement

Figure 5 shows that this measure of labour-force dependency will increase under all scenarios, but by a comparatively less than the age-based measure profiled in Figure 4. By 2060, the stabilization scenario (4) results in 80% more dependents measured on the basis of age, compared to 60% more dependents measured on the basis of labour force participation. These proportions are 50% and 40%, respectively, when the growth scenarios (1, 2, & 3) are evaluated. Interestingly a high-growth future (scenario 3) worsens dependency when compared to a medium or low-growth future (scenarios 2 and 1). In Canada in 1971, there were 154 Canadians who were not in the labour force for every 100 labour force participants (OECD, 2012). This rate of labour-force dependency would not be experienced over any of the next 50 years if there were an absence of growth.

Figure 5 also illustrates the consequences of scenario 5's delay in retirement when compared to scenario 4, keeping all other variables unchanged. Retirement is delayed by linearly phasing in a 5-year shift in the age-specific participation rates for people aged 60 and older than they were in 2010 (OECD, 2012). By 2042, the shift is fully phased in, such that males aged 65-69 would have the same participation rates as males aged 60-64 had in 2010. Since the concept of "retirement" is somewhat arbitrary, we used this approach to phasing in the fall in participation rates at retirement in order to mirror the current tendency of men and women to *reduce* but not *eliminate* their labour force participation during their senior years. Results from this exploration confirm that a 5-year delay in retirement can fully offset the dependency consequences of an absence of population growth, resulting in a future in which dependency grows less than the high-growth scenario (3).

Labour force participation leaves out unpaid provisions of care from all people. Figure 6 illustrates that seniors provide about as much unpaid work as people of a working-age, and more than younger Canadians. (Statistics Canada, 2010a) Since a significant source of unpaid care for seniors comes from other seniors (Statistics Canada, 2002) it should, in future, be reflected in broader measures of dependency.

Figure 6: Average number of hours spent each day (7 days per week) by Canadians in 2010 in paid work and unpaid household work plus civic and voluntary work outside of the household.



Source: General Social Survey (Statistics Canada, 2010)

The impacts of the scenarios on differences in the amount of unpaid work that could be provided if patterns of time use remain constant was modelled. The high-growth scenario would result in lower per-capita provisions of unpaid work than all other scenarios, since relatively more of the population is in younger age categories that provide less unpaid work. However, the implications of these differences are unclear. Statistics about the supply of unpaid work would need to be compared to an estimate of the requirements for unpaid work, in order to derive a measure of unpaid time dependency. There are more complete statistics about the time that Canadians spent providing childcare than providing eldercare, and insufficient statistics about how much unpaid time is demanded for unpaid care as a function of age and sex.

It appears from these results that Canada's population will continue to age over the foreseeable future and that plausible levels of higher population growth will not prevent this aging. A higher level of population growth cannot, by itself, lessen the impacts of aging on the dependency on the working population. Over most of the next 50 years, higher rates of population growth would generate higher burdens of dependency than lower rates of population growth.

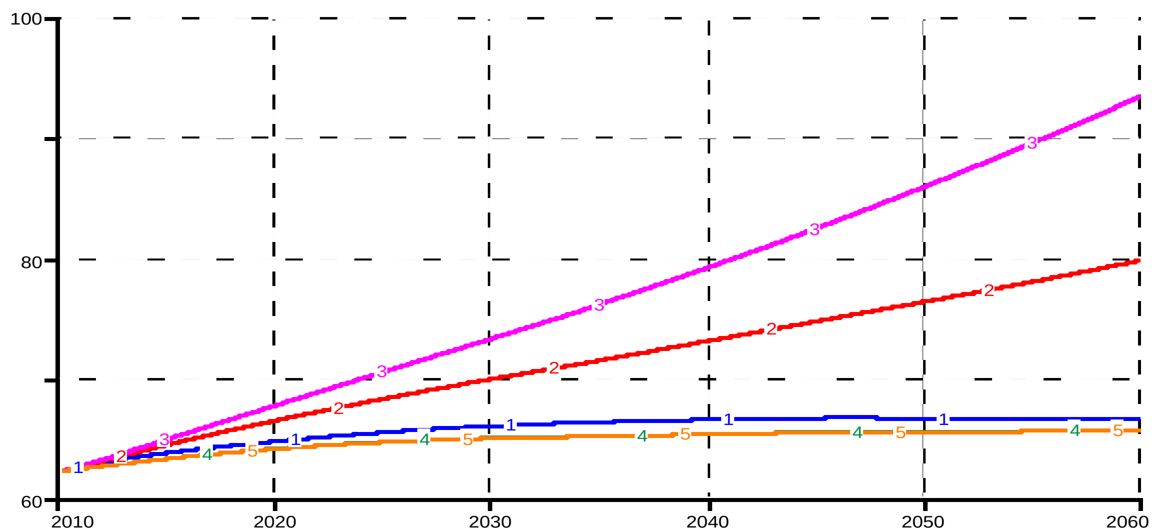
Age-based measures of dependency suggest more dramatic consequences of an aging population than measures that rely upon the labour force participation of Canadians. Patterns of provision and dependency should be understood on the basis of behaviour in the labour market rather than by age. People can also provide and receive "unpriced" care outside of the market economy, which is not captured by measures of labour force dependency. It would be useful to have measures which incorporate the paid and unpaid supply and demand for care in order to fully assess the economic implications of an aging population.

Slight differences in labour force participation rates have significant consequences when compared to the consequences of growth. A 5-year delay in retirement, phased in over a generation (30 years), will more than offset the dependency consequences of a total absence of population growth. Without any changes in participation, a stabilization of the Canadian population over the next 50 years will result in fewer labour-force dependents than were supported in the 1970s. To the extent that Canada was able to accommodate changes in the amount and age-structure of dependency in the past, the continued aging of Canada's population can also be managed.

UK Demographic Scenarios and Dependency Ratios

The preceding conclusions for Canada also apply to forecasts for the United Kingdom. Figure 7 shows the time path of population forecasts for the UK. Under a high-growth scenario, the UK population could increase by 50% over the next 50 years, whereas lower rates of growth could stabilize the population at levels only 8% higher than in 2010. A stabilization scenario that relies upon medium-growth assumptions but with balanced migration (no net immigration) generates a smaller, but still growing population.

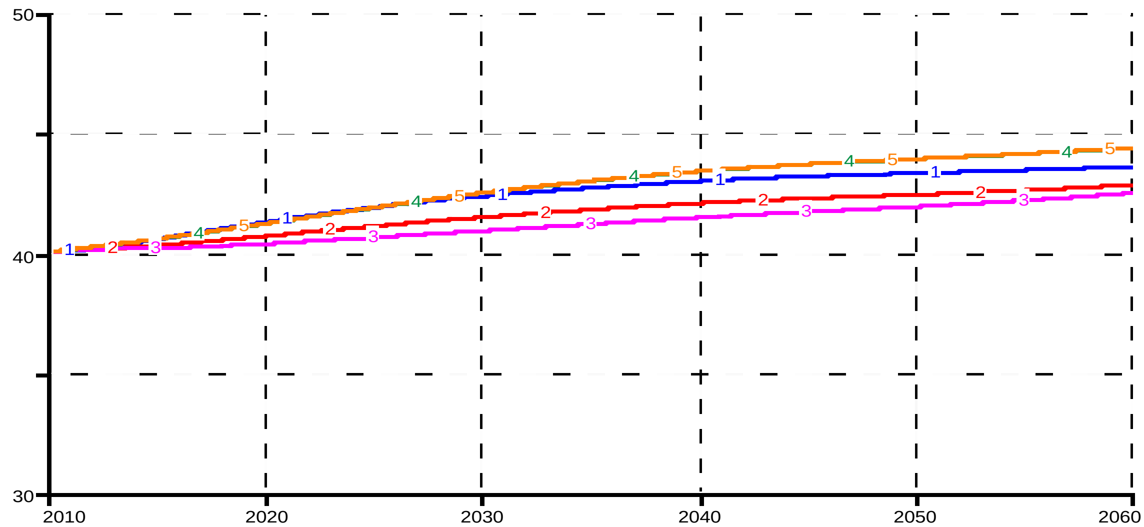
Figure 7: Forecast of the UK population (in millions) under different scenarios



Scenario 1=Low population growth, 2=Medium population growth, 3=High population growth, 4&5=Stabilization (balanced migration)

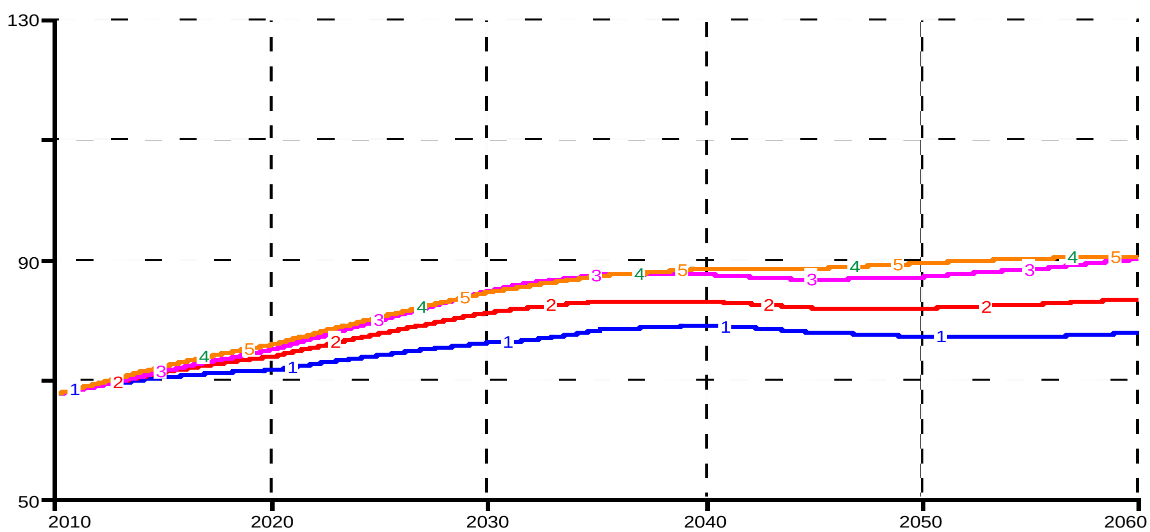
Figure 8 reveals that the average age of the UK population is expected to become older under all plausible scenarios. This is the same conclusion from the Canadian data, but the extent of this change for the UK is relatively smaller than for Canada.

Figure 8: Average age of UK residents under different scenarios



Scenario 1=Low population growth, 2=Medium population growth, 3=High population growth, 4&5=Stabilization (balanced migration)

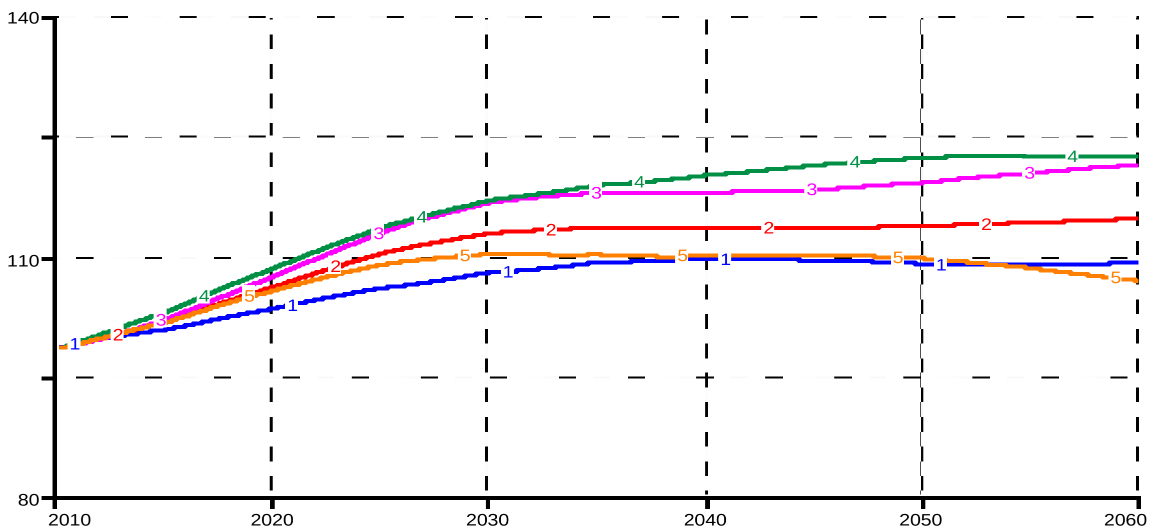
Figure 9: Demographic dependency, measured as the number of young plus old dependents forecast per 100 residents of the UK between the ages of 20 and 64.



Scenario 1=Low population growth, 2=Medium population growth, 3=High population growth, 4=Stabilization; 5=Stabilization with delayed retirement

Higher levels of population growth cannot, by themselves, lessen the impacts of aging on measures of dependency. Figures 9 and 10 show that age-based and labour-market based measures of dependency would be higher under scenarios of high growth than low growth over the next 50 years. Balanced migration under a stabilization scenario would generate changes in dependency that approximate the effects of higher population growth. Over most of the next 50 years, higher rates of growth would generate higher burdens of dependency than lower rates of population growth.

Figure 10: Labour-force dependency, measured as the number of non-working people per 100 residents of the UK who are participating in the labour force



Scenario 1=Low population growth, 2=Medium population growth, 3=High population growth, 4=Stabilization; 5=Stabilization with delayed retirement

Like in the Canadian case, delayed retirement has a significant effect upon labour force dependency. Figure 10 reveals how delayed retirement (scenario 5) lessens dependency such that a stabilized population scenario could generate about the same level of labour-force dependency as a scenario of low-growth.

The Input-Output Sub-Model

Input-output models of national economies were first proposed by Wassily Leontief in the 1930s. Input-output models start from a set of inter-industry accounts that record the transactions among each industry (or sector) as well as the transactions between each sector and final consumers (i.e. households, investment in fixed capital, government expenditures on goods and services, and net exports). By assuming that the input requirements per unit of output for each sector are constant, the table of inter-industry accounts can be used to generate a predictive model of the economy.

The main appeal of input-output models lies in the comparatively high level of empirical detail that they provide for entire economies and the internal consistency that they maintain by virtue of the fact that they are derived from balanced tables of accounts. Conventional input-output models are typically used for estimating the direct, indirect and total output requirements and associated employment of any actual or projected level of final demand.

In the late 1960s and early 1970s several economists, including Leontief, suggested ways in which input-output models could be used for analyzing various economic aspects of environmental pollution. Victor (1972) showed how input-output models could be extended systematically to include material flows to and from economies and the environment by applying the principle of materials balance. In this way, economies could be understood and modelled as sub-systems of the biosphere in which they are embedded. Victor developed the theoretical framework for this approach and produced the first estimates of the direct, indirect and total material flows (resource inputs and waste outputs) for a national economy. The approach has subsequently been adapted to explore a variety of environmental features of the economy, including: the ‘carbon trade-balance’ of a national economy (Proops et al 1993, Jackson et al 2007); the distribution of carbon emissions attributable to different socio-economic groups and expenditures (Druckman and Jackson 2009); and the extent of the rebound effect from efficiency savings (Druckman et al 2011).

Three main research issues had to be confronted in the development of an input-output sub-model suitable for incorporation into GEMMA. The first was to choose an appropriate level of aggregation for a standardized input-output structure within GEMMA. The CIGI-INET project proposal envisaged a distinction between ‘the expanding green and contracting brown sectors’ (Victor and Jackson, 2011, p.5) without specifying the number of sectors that this entails, though implying it would be few, perhaps as low as two. After experimenting with aggregations of 5, 10 and 12 sectors it was decided that a 12 sector input-output model would be a good compromise between the highly disaggregated input-output models available for individual countries and the technical feasibility of incorporating an input-output sub-model into GEMMA which is set within a systems dynamics framework that does not lend itself readily to the incorporation of an input-output sub model (see below). With 12 sectors it will be possible to examine possibilities for inter-sectoral shifts from sectors with high labour requirements per unit of high material flows per unit of output to sectors with much lower material flows per unit of output, and between sectors with different labour and energy intensities (Jackson and Victor, 2011).

A further innovation in this approach is to disaggregate the components of final demand according to their contribution to reducing environmental impacts, (e.g. between conventional investment and ‘green’ investments that reduce material flows and other sources of environmental impact) the input-output sub-model will be used to explore implications of shifts in final demand from brown to green expenditures.

The second research issue was to determine which specific existing input-output models should be aggregated and eventually incorporated in GEMMA. Most countries of the world maintain a national input-output model of their economies, based on the accounting conventions proposed by the UN (1999). However, there are substantial differences among these input-output models in terms of levels of aggregation, whether commodities and industries are specified separately[2], and other technical issues relating to the calculation and classification of different components of expenditure and income. Since one of the objectives for GEMMA is to apply it to many developed economies it made sense to look for a database in which the input-output models of

[2] Input-output models usually start from accounting data in which commodities and industries are shown separately. These are the ‘make’ and ‘use’ tables from which the input-output tables are constructed. In some countries such as Canada, the distinction between commodities and industries is maintained so that each industry or sector can produce multiple commodities and each commodity can be produced by multiple sectors. In other countries such as the USA each industry or sector is assumed to produce a single sectoral output as originally conceived by Leontief.

different countries have been transformed to a common format so that once a way of incorporating an input-output model into GEMMA had been found, it could be applied to any country of choice. Such a database was identified in the OECD Structural Analysis Database (OECD, 2013).

The third research issue relating to developing an input-output sub-model for incorporation into GEMMA was how to integrate the system of linear equations of an input-output model with the difference equations of a systems dynamics model. This proved to be a challenge as explained below.

Aggregating the OECD Input-Output Tables into 12 Sectors

The OECD publishes input-output tables for its member countries in a standardized format of 37 input-output sectors, 8 categories of final demand, 2 categories of value added and 2 categories of taxes and subsidies. (OECD, 2013) Input-output tables are available online for OECD member countries for the mid-1990s, the early 2000s and the mid 2000s.[3]

Figure 7 shows a simplified input-output table in which the private and public sector organizations in the economy have been combined into 8 sectors. The table records the annual transactions in the economy. Reading across the rows labelled 'Producers', the shaded cells show the sales of each sector to all sectors. This is known as intermediate demand or inter-industry transactions. Continuing along these rows, the cells show the sales by each sector to various categories of final demand. Only sales to final demand are included in gross domestic product. Intermediate sales are not included. The row totals shown in the last column are the total sales of each sector.

Reading down the columns of intermediate demand the shaded cells show the purchase of each sector from all sectors. Continuing down the columns, the cells show the indirect taxes less subsidies paid by each sector, compensation paid to employees,

[3] The actual year depends on the country. Not all countries publish annual input-output tables.

and profit plus capital consumption allowances. These comprise the value added by each sector, the total of which also equals gross domestic product. The column totals shown in the last row are the total sales of each sector and they are equal to the corresponding row totals.

Figure 7
Simplified Input-Output Table

		INTERMEDIATE DEMAND								FINAL DEMAND				
		Agric	Mining	Constr	Manuf	Trade	Transp	Services	Other	Personal Consumption Expenditure	Gross Domestic Investment	Govt Purchases of Goods & Services	Net Exports of Goods and Services	Total
PRODUCERS	Agriculture													
	Mining													
	Construction													
	Manufacturing													
	Trade													
	Transportation													
	Services													
	Other													
VALUE ADDED	Government	Indirect business taxes less subsidies								GROSS DOMESTIC PRODUCT				
	Employees	Employee compensation												
	Business owners and capital	Profit and capital consumption allowances												
	Total													

Source: adapted from Miller and Blair (2009) p. 3

Tables 1a and 1b show the 12 sector input-output table for Canada for 2005 derived from the more detailed OECD input-output table for that year.. The table has been divided into two sections to make it easier to read. Table 1a shows Canadian inter-industry transactions in $million in 2005. The first 12 row totals in the last column of table 1a show the sales by each sector to all sectors, including themselves, i.e. total intermediate demand. The ‘Total Consumption’ row in table 1a shows the sum total of purchases by each sector from all sectors, including themselves. The next four rows in table 1a show two categories of taxes less subsidies, compensation of employees and gross operating surplus. These comprise the value added of each sector. The total value of the output of each sector is shown in the final row. (See OECD 2008 for definitions of terms)

Table 1b is a horizontal continuation of table 1a. The entries in table 1b show the sales by each sector to the various categories of final demand. The OECD input-output tables do not break out housing investment as a separate category. Since green housing investment offers an important way of reducing energy use it is desirable to show housing investment as a separate investment category. Data from input-output tables prepared by Statistics Canada were used to make this disaggregation.

Table 1a

12 Sector Canadian Input-Output Table for 2005: aggregated from the OECD 37 sector input-output table

Inter-industry transactions and valued added in $million

	Agriculture	Mining and quarrying	Food	Goods & services n.e.c.	Machinery & equipment	Utilites	Construction	Wholeseale & retail	Transport & storage	Financial services	Personal & social services	Public sector	Totals
Agriculture	11,500	48	20,317	11,824	106	26	1,182	256	174	56	1,209	622	47,321
Mining and quarrying	489	12,666	825	63,696	634	4,714	9,655	1,597	585	2,107	2,060	844	99,872
Food	4,202	186	15,760	1,014	384	45	230	1,134	177	423	12,281	674	36,510
Goods & services n.e.c.	7,639	7,148	7,832	112,770	34,932	1,580	51,123	12,948	12,049	7,733	28,087	12,253	296,092
Machinery & equipment	1,979	3,969	780	5,782	77,071	819	10,189	1,846	2,689	1,609	9,684	3,742	120,159
Utilites	857	1,983	767	8,108	983	48	274	2,781	659	2,716	4,604	1,959	25,741
Construction	855	1,093	124	1,168	311	1,285	292	872	1,698	11,514	3,060	3,892	26,163
Wholeseale & retail	3,935	4,065	3,700	18,168	9,016	505	12,423	6,231	4,710	5,265	18,045	7,452	93,516
Transport & storage	1,835	1,644	2,327	11,283	3,334	575	3,611	8,634	17,678	5,069	8,327	3,579	67,896
Financial services	2,899	5,969	1,949	9,410	4,594	1,056	6,197	24,428	6,412	44,128	25,069	5,858	137,970
Personal and social services	2,205	5,347	3,580	15,196	11,595	1,382	15,466	28,137	5,901	28,684	51,012	45,008	213,513
Public sector	255	320	313	1,233	425	464	742	1,897	808	1,782	3,028	5,929	17,196
Total Consumption	38,651	44,438	58,274	259,651	143,385	12,498	111,385	90,761	53,541	111,086	166,466	91,813	1,181,951
Taxes less subsidies on Products	(4,182)	328	87	234	(135)	(734)	3,573	1,999	(348)	3,265	572	933	5,592
Taxes less subsidies on Production	1,678	1,287	510	2,888	924	1,718	3,596	5,596	2,343	33,276	5,683	2,345	61,844
Compensation of employees	8,534	16,779	11,980	72,976	33,102	7,952	50,124	98,762	34,621	61,932	221,347	76,984	695,093
Gross operating surplus	12,965	92,997	14,087	44,972	16,772	21,692	22,165	43,380	18,289	136,666	79,423	18,660	522,068
Total Output	57,648	155,829	84,938	380,720	194,048	43,127	190,844	240,499	108,445	346,225	473,491	190,734	2,466,548

Table 1b

12 Sector Canadian Input-Output Table for 2005: aggregated from the OECD 37 sector input-output table

Final demand in $million

	Households	Green Household Expenditure	Government Current Expenditure	Green Government Current Expenditure	Government Investment	Green Government Investment	Housing Investment	Green Housing Investment	Non-Government (nonhousing) Investment	Green Non-Government (nonhousing) Investment	Exports	Imports	Inventory change	Total domestic final demand	Total domestic demand
Agriculture	7,760	-	-	-	9	0	0	0	51	0	10,605	8,185	87	10,326	57,648
Mining and quarrying	5,018	-	-	-	79	-	0	-	1,200	-	80,076	32,975	2,559	55,957	155,829
Food	46,402	233	-	-	30	0	8	0	257	1	19,310	17,935	122	48,428	84,938
Goods & services n.e.c.	66,110	600	-	-	1,226	25	342	7	10,664	218	158,159	157,587	4,863	84,628	380,720
Machinery & equipment	44,859	407	-	-	5,620	234	1,569	65	48,877	2,037	150,804	182,766	2,182	73,889	194,048
Utilites	15,367	-	-	-	40	-	2	-	100	5	3,277	1,414	8	17,386	43,127
Construction	63	1	-	-	23,862	2,075	63,046	3,318	67,303	5,066	141	194	(2)	164,680	190,844
Wholeseale & retail	116,424	1,533	-	-	2,020	27	63	1	15,382	203	21,975	10,654	12	146,984	240,499
Transport & storage	20,056	264	-	-	163	2	56	1	1,185	16	29,271	10,465	0	40,549	108,445
Financial services	196,825	2,592	-	-	167	2	11,015	145	1,880	25	9,245	13,641	0	208,255	346,225
Personal and social services	152,499	2,009	95,367	1,946	1,386	18	67	1	6,563	86	34,072	34,043	8	259,978	473,491
Public sector	8,646	-	160,440	2,443	468	-	27	-	952	-	1,856	1,306	11	173,538	190,734
Total Consumption	680,027	7,641	255,806	4,390	35,071	2,384	76,195	3,538	154,414	7,656	518,790	471,166	9,851	1,284,597	2,466,548
Taxes less subsidies on Products	70,781	790	-	-	1,637	111	3,556	165	7,205	357	115	3,314	-	88,031	

In table 1b the categories of households, government current, government investment, housing, and non-government investment were divided into conventional expenditures and green expenditures based on data from a US survey in the absence of similar data for Canada. (US Department of Commerce, Economics and Statistics, 2010) This survey estimated that “green products and services comprised 1% to 2% of the total private business economy in 2007 in the United States” (ibid p.1). For the purpose of this research, a portion of each component of Canadian final demand in 2005 was designated ‘green’ such that 2% of total final demand for goods and services in the 12 sector input-output table is classified as green. Table 2 shows the allocation, which may be revised in future based on further research.

Table 2
Green Expenditures as a Percentage of Final Demand, Canada 2005

	Household Expenditure	Government Current Expenditure	Government Investment	Housing Investment	Non-Government (Non-Housing) Investment
Agriculture	0.5%	0%	0.5%	0.5%	0.5%
Mining and quarrying	0.0%	0%	0.0%	0.0%	0.0%
Food	0.5%	0%	0.5%	0.5%	0.5%
Goods & services n.e.c.	0.9%	0%	2.0%	2.0%	2.0%
Machinery & equipment	0.9%	0%	4.0%	4.0%	4.0%
Utilites	0.0%	0%	0.0%	0.0%	5.0%
Construction	2.0%	0%	8.0%	5.0%	7.0%
Wholeseale & retail	1.3%	0%	1.3%	1.3%	1.3%
Transport & storage	1.3%	0%	1.3%	1.3%	1.3%
Financial services	1.3%	0%	1.3%	1.3%	1.3%
Personal and social services	1.3%	2%	1.3%	1.3%	1.3%
Public sector	0.0%	2%	0.0%	0.0%	0.0%

The final step in the process of creating a 12 sector input-ouput table was to use input-output coefficients derived from the 2005 table and information on final demand for 2010 for Canada obtained from Cansim (Statistics Canada’s database) to create a complete input-output description of the Canadian economy for 2010. Row and column balances were obtained by adjusting the values of gross operating surplus.

Integrating the Input-Output Model into GEMMA

At the most fundamental level, input-output models are systems of linear equations that can be solved using standard procedures from linear algebra. Unlike the demographic model, which lends itself to representation in the difference equations of systems dynamics, input-output models cannot easily be integrated into a systems dynamics framework. One of the major tasks of this research project was to find a way of overcoming this problem.

The first approach investigated was to see if the import-export provisions in the STELLA[4] program which allow it to link automatically to Excel could be used. The idea was to import values from the input-output table in Excel, use them in GEMMA and export the results iteratively. This approach proved impractical because the links between STELLA and Excel are far too slow to be used for each iteration of GEMMA. Typically in GEMMA each year is divided into 10 time steps. A model run of 50 years would require a series of 500 data imports and 500 data exports between and, within each iteration the input-output model would have to be solved in Excel. The link routine in STELLA is simply not designed for this level of frequency of data exchange. Nor can it be made to work that way as was confirmed in conversation with technical staff at High Performance Systems, the makers of STELLA.

The second approach that was considered for integrating an input-output sub-model in GEMMA was the use of the array function in STELLA. This function is used in STELLA to simplify the representation of models in which the same structure is repeated. An input-output table and a table of input-output coefficients derived from such a table can be represented as a two dimensional

[4] STELLA is a commercially available program for creating systems dynamics models.

array in STELLA. However, there is no built-in matrix inversion function in STELLA so that the input-output model cannot solve the conventional Leontief equation within GEMMA, using the standard mathematical approach for solving sets of simultaneous linear equations. (Miller and Blair, 2009, Chapter 2)

Finally, an approach was developed which directly replicates the set of linear simultaneous equations that describes the input-output framework described in Figures 1 and 2 above.[5] By avoiding the need to invert matrices in GEMMA, it is possible to solve the simultaneous equations directly within STELLA in stages as follows:

- set initial values for the sector outputs (obtained from the base year input-output table)
- select values for the final demands for outputs from each sector (obtained from elsewhere in GEMMA)
- use the equations for sector outputs derived from the input-output coefficients (i.e. the equations showing direct input requirement per unit out, not the inverse showing direct and indirect requirements) to calculate the change in sector outputs for each sector.

This approach proved to be quite practical and has been incorporated into GEMMA.

An Excel version of the input-output model is provided separately. See Appendix A for a detailed row by row description of the spreadsheet.

[5] In formal terms, the set of equations defined by: $X = A.X + Y$ where X is output, A is the matrix of inter-industry coefficients and Y is the final demand matrix are replicated. This enabled the usual Leontief form $X = (1 – A)^{-1}$ to be bypassed and avoid the inversion of matrices in STELLA.

Results from the Input-Output Sub-Model

Employment

Input-output models can be used for many purposes. One in particular is to explore the employment implications of simultaneous expansion and contraction of various sectors in a non-growing economy to mitigate the impacts on employment of a non-growing economy. Table 3 shows the direct employment required in each sector per $1m of output in 2005.

Table 3
Canadian Employment Data for 2005

	Total employed, all classes of workers 2005	Employment/ $m of sector output 2005
Agriculture	443,800	7.7
Mining and quarrying	215,400	1.4
Food products	312,863	3.7
Goods and services nec	1,299,095	3.4
Machinery and equipment	597,543	3.1
Utilities	124,100	2.9
Construction	1,015,400	5.3
Wholesale and retail	2,564,900	10.7
Transport and storage	794,600	7.3
Financial services	986,100	2.8
Personal and social services	6,939,900	14.7
Public sector	831,000	4.4
Total	16,124,700	6.5

Source: Based on employment data from Statistics Canada Cansim Table 282-0008

Table 4 shows estimates of the direct and indirect employment generated in each sector by $1million of final demand for the output of each sector (and zero for all other sectors). The values on the diagonal are for employment in the sector supplying the output to final demand. In all cases these values are greater than the direct employment reported in table 3 reflecting the fact that each sector's output requires inputs from sectors including themselves, all of which generates employment. The last column of table 4 shows the total employment generated across all sectors, ranging from a high of 14.7/$m of final demand for the output of the personal and social services sector to a low of 4.2/$m of final demand for the output of the mining and quarrying sector.

For consistency with the OECD input-output tables, these employment estimates are based on data for 2005, the latest year for which OECD has produced input-output tables for its member countries. Further work will be required to examine the stability of the input-output relationships over time and to understand possible reasons causing them to change. This is necessary to assess the relevance of these results for examining the employment implications of possible future changes in the pattern of final demand. With this caveat in mind, some initial indications can be obtained from table 4 of how employment can be sustained by transferring demand among sectors in a non-growing economy.

A transfer of $1m of final demand from the goods and services sector to the personal and social service sector would result in an estimated net gain of 6.1 jobs and from the financial services sector to agriculture the net gain would be 10 jobs. These estimates are approximate since the 12 sectors in the input-output model are aggregations of many sectors and there could be considerable variation in employment requirements within each sector. While it is possible to undertake a similar analysis to that described here using more detailed input-output models, the 12-sector model developed in this project is of a scale that lends itself to practical inclusion in GEMMA which remains a priority. Similar analysis can be undertaken for any OECD country for which an input-output table and related employment statistics are available

Table 4
Estimates of the Employment (direct and indirect)
Required to Meet Final Demand of $1million for the Output of Each Sector

	Agriculture	Mining and quarrying	Food products	Goods and services nec	Machinery and equipment	Utilities	Construction	Wholesale and retail	Transport and storage	Financial services	Personal and social services	Public sector	Total
Agriculture	10.01	0.12	0.45	1.18	0.32	0.10	0.16	1.43	0.59	0.36	1.88	0.05	16.6
Mining and quarrying	0.05	1.54	0.02	0.38	0.17	0.05	0.06	0.48	0.18	0.19	1.00	0.02	4.2
Food products	3.02	0.11	4.68	1.05	0.20	0.08	0.09	1.25	0.59	0.28	1.95	0.05	13.3
Goods and services nec	0.50	0.39	0.06	5.15	0.20	0.12	0.08	1.08	0.52	0.25	1.72	0.04	10.1
Machinery and equipment	0.20	0.14	0.05	1.67	5.21	0.07	0.06	1.31	0.49	0.28	2.56	0.04	12.1
Utilities	0.05	0.20	0.02	0.36	0.15	2.90	0.18	0.34	0.20	0.14	0.99	0.06	5.6
Construction	0.24	0.20	0.05	1.60	0.37	0.05	5.38	1.21	0.41	0.26	2.32	0.04	12.1
Wholesale and retail	0.09	0.05	0.05	0.44	0.09	0.05	0.07	11.20	0.43	0.41	2.49	0.05	15.4
Transport and storage	0.12	0.08	0.04	0.85	0.21	0.05	0.14	0.87	8.91	0.32	1.77	0.06	13.4
Financial services	0.05	0.04	0.03	0.28	0.07	0.04	0.22	0.37	0.22	3.32	1.88	0.04	6.6
Personal and social services	0.17	0.05	0.15	0.49	0.16	0.05	0.07	0.68	0.28	0.26	16.98	0.04	19.4
Public sector	0.14	0.06	0.06	0.58	0.18	0.06	0.15	0.78	0.32	0.22	4.57	4.52	11.7

Greenhouse Gas Emissions

A second use of the input-output model is to analyze the implications for greenhouse gas (GHG) emissions of simultaneous expansion and contraction of various sectors in a non-growing economy. This can be done using the identical methodology as that used for examining employment implications as described above. Table 5 shows the direct greenhouse gas emissions in kilotonnes (kt) from each sector per $1m of output in 2005 from a high of 2,842 kt/$m in the utilities sector to a low of 17 kt/$m in the machinery and equipment sector.

Table 5
Canadian Greenhouse Gas Emissions Data for 2005

	GHG Emissions (kt)	GHG Emissions tonnes/$m of sector output
Agriculture	73,668	1,278
Mining and quarrying	123,236	791
Food products	4,555	54
Goods and services nec	108,095	284
Machinery and equipment	3,383	17
Utilities	122,581	2,842
Construction	11,167	59
Wholesale and retail	21,840	91
Transport and storage	71,325	658
Financial services	16,599	48
Personal and social services	27,441	58
Public sector	9,270	49
Total	593,160	240

Source: Based on emissions data from Statistics Canada Cansim Table 153-0034

Table 6 shows estimates of the direct and indirect greenhouse gases emitted by each sector per $1million of final demand for the output of each sector (and zero for all other sectors). As with table 4 for employment, the values on the diagonal

Table 6
Estimates of the GHG Emissions (direct and indirect)
Required to Meet Final Demand of $1million for the Output of Each Sector

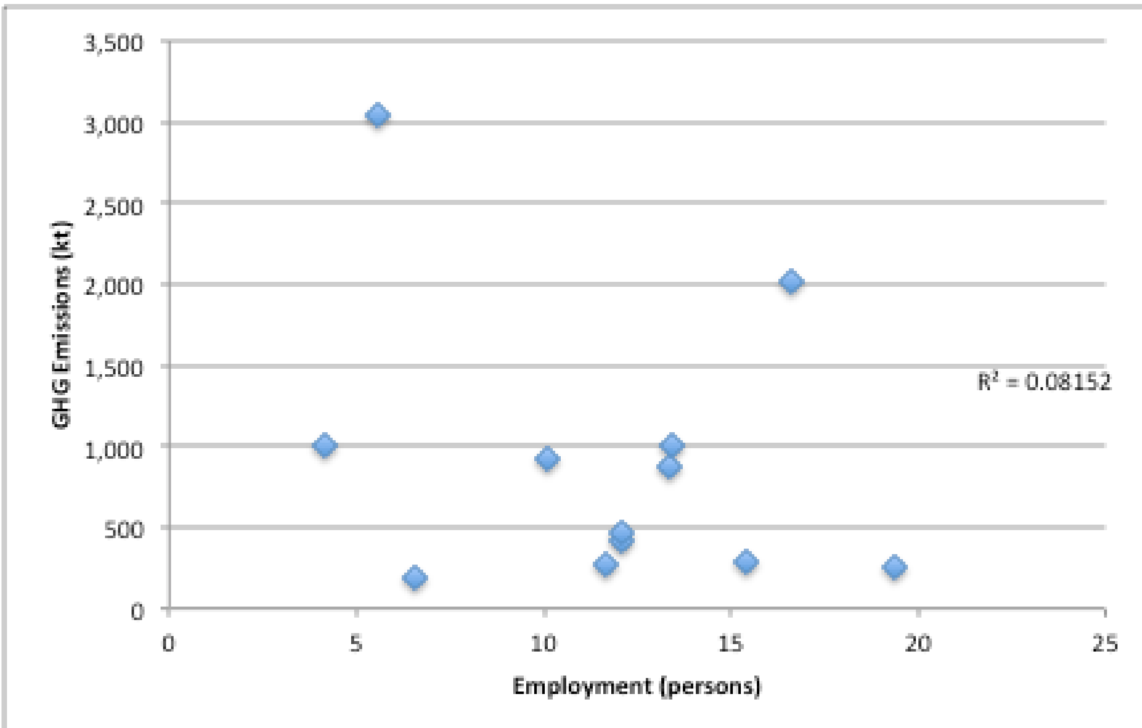
	Agriculture	Mining and quarrying	Food products	Goods and services nec	Machinery and equipment	Utilities	Construction	Wholesale and retail	Transport and storage	Financial services	Personal and social services	Public sector	Total
Agriculture	1662.0	67.2	6.6	97.9	1.8	96.3	1.7	12.2	53.3	6.0	7.4	0.6	2013
Mining and quarrying	8.7	880.2	0.3	31.3	1.0	53.7	0.7	4.1	16.3	3.2	4.0	0.2	1004
Food products	501.3	63.4	68.1	87.1	1.1	83.2	1.0	10.6	52.8	4.7	7.7	0.6	882
Goods and services nec	82.3	224.6	0.9	428.8	1.1	115.9	0.8	9.2	46.6	4.2	6.8	0.5	922
Machinery and equipment	32.8	80.8	0.8	139.2	29.5	71.7	0.7	11.1	43.6	4.6	10.1	0.5	425
Utilities	9.1	112.5	0.3	29.7	0.8	2863.2	2.0	2.9	18.2	2.4	3.9	0.6	3046
Construction	39.1	115.8	0.7	132.8	2.1	52.5	59.1	10.3	36.5	4.3	9.2	0.5	463
Wholesale and retail	14.5	29.0	0.7	36.7	0.5	54.3	0.7	95.3	38.5	7.0	9.9	0.6	288
Transport and storage	20.2	46.4	0.5	70.9	1.2	49.3	1.5	7.4	799.7	5.5	7.0	0.6	1010
Financial services	8.3	22.1	0.4	23.4	0.4	38.5	2.4	3.1	19.8	55.9	7.4	0.4	182
Personal and social services	27.6	28.9	2.2	40.7	0.9	49.9	0.8	5.8	25.1	4.4	67.1	0.5	254
Public sector	22.5	34.4	0.9	48.6	1.0	58.0	1.7	6.7	29.2	3.8	18.1	50.4	275

are for greenhouse gas emissions from the sector supplying the output to final demand. In all cases these values are greater than the direct greenhouse gas emissions reported in table 5. The last column of table 6 shows the total greenhouse gas emissions across all sectors, ranging from a high of 3,046 kt/$m of final demand for the output of the utilities sector to a low of 182 kt/$m of final demand for the output of the financial services sector.

These estimates can be used to examine the implications for greenhouse gas emissions of changes in the pattern of final demand, subject to the same caveats as with the employment estimates regarding the stability of the input-output relationships over time. Furthermore, the impact of green investment on the direct emissions of greenhouse gases from each sector would also have to be accounted when using these results to explore longer-term possibilities.

As an illustration of how these estimates might be used in conjunction with the employment estimates, consider the implications for greenhouse gas emissions that would complement a transfer of $1m of final demand from the goods and services sector to the personal and social service sector and from the financial services sector to agriculture. In both of these cases, significant increases in employment would be expected as noted above. However, in the first case there would be an estimated net reduction in greenhouse gas emissions of 668 kt but in the second there would be an estimated net increase of 1,831 kt. Clearly, the implications of adjustments in the pattern of final demand in the movement towards a steady-state economy become more complicated when employment and environmental consequences are considered together since, as figure 11 shows, there is no correlation between the estimated impacts on employment and greenhouse gas emissions of shifting expenditures among the components of final demand, at least at a 12 sector level of aggregation.

Figure 11
Employment and GHG Emissions per $m of Final Demand – Canada 2005



6

Next Steps

The demographic and input-output sub-models have been designed for integration into the larger GEMMA framework. This integration is proceeding but is not yet complete. The main input-output equations have been incorporated into GEMMA and a fairly comprehensive environmental database has been assembled for calculating coefficients for a wide range of ecological inputs and outputs from the economy. Investigation is also underway on ways in which

[6] As noted above, in this analysis no account has been taken of the direct emissions of greenhouse gases from final demand such as the from the combustion of fossil fuels used by households for home heating and transportation.

changes in the input-output coefficients (inter-industry and environmental) might be endogenised. Separation of investment into ‘green’ and ‘conventional’ categories provides a link to the environmental coefficients which will change depending on the pattern and level of green investment. Some modelling of this link has been undertaken, in particular for greenhouse gas emissions. Similar possibilities exist for conventional investment to affect the labour requirements of each sector.

Endogenisation of the inter-industry coefficients is also being explored. One possibility under investigation is to use calculations of value added derived from other parts of GEMMA as inputs into input-output price equations (Miller and Blair, 2009, 43-46). These price equations compute the relative prices of the sector outputs. Changes in these relative prices resulting from changes in value added can be combined with estimates of elasticities of the inter-industry coefficients to model changes in the coefficients over time.

The demographic sub-model has subsequently been used to develop a model of the housing market and is currently being used as an input in the estimation of a consumption function in which age appears as an independent variable.

Considerable work remains to fully integrate the demographic and input-output sub-models into GEMMA but through this research project, they have been developed to the stage where this is now possible.

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___. 2012b. *Table 051-0001 - Estimates of population, by age group and sex for July 1, Canada, provinces and territories, annual (persons unless otherwise noted),* CANSIM (database).

___. 2012c. Table 051-0011 International migrants, by age group and sex, Canada, provinces, and territories, annually (Persons), CANSIM (database).

___. 2012d. Table 052-0005 Projected population, by projection scenario, sex and age group as of July 1, Canada, provinces and territories, annually (Persons), CANSIM (database).

___. 2012e. Table 102-4505 Crude birth rate, age-specific and total fertility rates (live births), Canada, provinces and territories, annually (Rate), CANSIM (database).

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Appendix A – Detailed Description of the Input-Output Spreadsheet

The Excel spreadsheet which accompanies this report is configured as follows:

- Rows 2-54: The OECD input-output for Canada, 2005
- Rows 61–164: Columns and rows re-ordered to facilitate aggregation into a 12 sector input-output table
- Rows 167-188: 12 sector input-output table
- Rows 201-270: 12 sector input-output table modified in steps so that any input-output table can be imported from the OECD and automatically transformed into a 12 sector input-output table taking care of non-comparable imports, direct purchase abroad by residents, statistical discrepancies and valuables[7]
- Rows 273-295: final version of the 12 sector input-output table for Canada for 2005
- Rows 299-318: the A matrix (input requirements per unit of output)
- Rows 323-339: the I-A matrix (the A matrix subtracted from a matrix where all diagonal elements equal 1 and all off-diagonal elements equal 0)
- Rows 343-355; The Leontief Inverse (when this matrix is multiplied by the I-A matrix the result is a matrix in which all diagonal elements equal 1 and all off-diagonal elements equal 0 as shown in rows 343-355 columns Q-AB)
- Rows 358-364: equations for the basic Leontief input-output model
- Rows 366-373: equations for the employment model based on the assumption that number of employees per $million of sector output is constant
- Rows 375-390, vectors of values for final demand (set equal to 1 for the sector in question and zero for all other sectors)

[7] Most of these adjustments were not required to convert the OECD input-output table for Canada into a 12 sector input-output table.

- Rows 394-422, 12 x 13 matrices, one for each sector, showing the output of each sector required to meet $1m of final demand for each sector. The first column of each matrix is identical to the respective column of the Leontief inverse matrix when all final demand values are equal to 1.
- Rows 426-444: data on employment by sector in Canada derived from CanSim table 282-0008
- Rows 448-461: estimates of total (direct plus indirect) labour required to meet final demand of $1million for the output of each sector
- Rows 465 472: equations for the environment model based on the assumption that emissions per $million of sector output is constant
- Rows 476-494: data on ghg emissions by sector in Canada derived from CanSim table 153-0034
- Rows 500-512: estimates of total (direct plus indirect) ghg emissions from the 12 sectors (excluding direct emissions from final demand) required to meet final demand of $1million for the output of each sector
- Rows 517-530: data and scatter diagram showing no correlation between the estimates of employment and ghg emissions