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TIM JACKSON
PETER A. VICTOR

LowGrow SFC

A STOCK-FLOW CONSISTENT ECOLOGICAL MACROECONOMIC MODEL FOR CANADA

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Contact details

Tim Jackson, Centre for the Understanding of Sustainable Prosperity, University of Surrey, Guildford, UK. Email: t.jackson@surrey.ac.uk.

Peter Victor, Centre for the Understanding of Sustainable Prosperity, York University, Toronto, Canada. Email: peter@pvictor.com

Summary

This working paper presents a stock-flow consistent (SFC) simulation model of a national economy, calibrated on the basis of Canadian data. LowGrow SFC describes the evolution of the Canadian economy in terms of six financial sectors whose behaviour is based on 'stylised facts' in the Post-Keynesian tradition. A key feature of the model is its ability to provide a systematic account, not only of economic and financial variables, but also of key environmental and social dimensions of the economy. In particular, it tracks the evolution of carbon emissions and the distribution of incomes over time, under various policy assumptions.

The working paper describes in detail the structure of the model, its behavioural assumptions and the calibration of its variables and parameters. It develops two new performance indicators to track the progress of the economy: an environmental burden index (EBI) to describe the environmental performance of the model; and a composite sustainable prosperity index (SPI) based on a weighted average of seven economic, social and environmental performance indicators.

We use the model to generate three very different stories about the future of the Canadian economy, covering the half century from 2017 to 2067: a *Base Case* in which current trends and relationships are projected into the future, a *Carbon Reduction Scenario* in which measures are introduced specifically designed to reduce greenhouse gas emissions, and a *Sustainable Prosperity Scenario* which incorporates additional measures to improve environmental, social and financial conditions across society.

Only in this third scenario, with its much slower rate of economic growth, do we see an overall improvement in performance as indicated by the SPI. Contrary to the accepted wisdom, the results indicate the feasibility of improved environmental and social outcomes, even as the growth rate declines to zero.

1 | Introduction

This working paper describes a stock-flow consistent ecological macroeconomic simulation model for Canada (LowGrow SFC). The paper describes the structure of the model, explores some of the underlying detail and develops several scenarios for the Canadian economy under different assumptions about key macroeconomic, social and environmental variables.[1]

Our broad approach has been to bring together three primary spheres of modelling interest and explore the interactions between them. Specifically, we aim to provide an account of (1) the ecological and resource constraints on economic activity; (2) the processes of production, consumption, employment and public finances in the 'real economy'; and (3) the structure and stability of the financial economy, including the main interactions between financial agents.

Our principal aim is to determine whether important social and environmental objectives can be achieved in a modern economy without necessarily relying on continued economic expansion, defined conventionally as an increase in real GDP. In particular, we are interested in whether we can achieve full employment, reduced inequality, stable financial balance sheets and substantial reductions in greenhouse gas emissions (hereafter carbon emissions) and other environmental pressures, all in the context of much slower or even zero economic growth.

Our work therefore contributes to the emerging understanding that, for a variety of reasons, the advanced economies now face a significant post-growth challenge (Jackson 2019a). Managing – and achieving prosperity – without growth in the advanced economies may be essential if poorer nations are to achieve decent living standards without compromising the biophysical limits of the planet (Jackson 2009, 2017, Victor 2008, 2019).

2 | An overview of the model

The theoretical foundation for LowGrow SFC is the post-Keynesian macroeconomic approach of Godley and Lavoie (2012), which places a particular emphasis on a full and consistent account of the relationships between monetary stocks and flows within and between different financial sectors: so-called 'stock-flow consistent' (SFC) macroeconomic modelling.

The overall rationale of SFC macroeconomic modelling is to account consistently for all monetary flows across all sectors of the economy. This rationale can be captured in three broad axioms: first that each expenditure from a given sector is also the income to another sector; second, that each sector's financial asset corresponds to some financial liability for at least one other sector, with the sum of all assets and liabilities across all sectors equalling

1 A less detailed description of the model was included as a co-authored chapter (Jackson and Victor 2019a) in Victor 2019. The results here may differ slightly from those in the chapter, owing to subsequent refinements in model structure and assumptions. An interactive online version of the model is available at: https://www.cusp.ac.uk/themes/s2/lowgrow-sfc/ or at https://exchange.iseesystems.com/public/petervictor/lowgrow-sfc/index.html#page1.

zero; and finally, that changes in stocks of financial assets are consistently related to flows within and between economic sectors.

These simple understandings lead to a set of accounting principles with implications for actors across the economy which can be used to test the consistency of any scenario simulation. In the aftermath of the 2008 financial crisis, SFC modelling has gained a particular traction because of its ability to provide a comprehensive account of financial transactions in the economy and to map the impact of these on financial balance sheets – something that was conspicuously missing in the run-up to the crisis (Bezemer 2009).

LowGrow SFC is not simply a macroeconomic model in the post-Keynesian tradition, however. It is explicitly an ecological economics model in the sense of attempting to capture key environmental concerns and simulate policies that aim to achieve specific environmental targets. It takes some of its inspiration from an earlier ecological macroeconomic model of the Canadian economy developed by Victor (2008) and by Victor and Rosenbluth (2007). But the model described here has a substantively different underlying structure from that earlier work, in particular, in its adoption of an SFC accounting structure drawn primarily from a suite of SFC models developed more recently by Jackson and Victor (2015, 2016, 2017). Another key difference is that the rate of economic growth is endogenous in the model as are increases in labour productivity on which much of this growth depends. Environmental expenditures that divert funds away from conventional investment reduce increases in labour productivity resulting in slower economic growth.

An important element within LowGrow SFC is the inclusion of a number of key ecological and social aspects of the economy. Most importantly, perhaps, carbon emissions are modelled under various scenarios and an 'environmental burden index' (EBI) captures a broader sense of the environmental sustainability of different scenarios. The model incorporates key social indicators, such as a measure of the distribution of incomes and the overall system results are reported via a comprehensive 'Sustainable Prosperity Index' (SPI) which reports an aggregate number (based on a weighted average of seven sub-indicators) for each scenario year over a fifty year period from 2017 to 2067.[2]

LowGrow SFC is built using the STELLA Architect platform.[3] This kind of system dynamics software provides a useful platform for exploring economic systems for several reasons, not the least of which is the ease of undertaking collaborative, interactive work in a visual (iconographic) environment. A further advantage is the transparency with which it is possible to model fully dynamic relationships and mirror the stock-flow consistency that underlies our approach to macroeconomic modelling. STELLA Architect also allows for an

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2 The model itself runs from 2012 to 2067, with values from 2012 to 2017 calibrated on empirical data. Values are reported from the 'base year' 2017, which is also the date taken for the normalisation of indices.

3 See: https://www.iseesystems.com/store/products/stella-architect.aspx.

online user-interface through which the interested reader can follow the scenarios presented in this paper and explore their own.

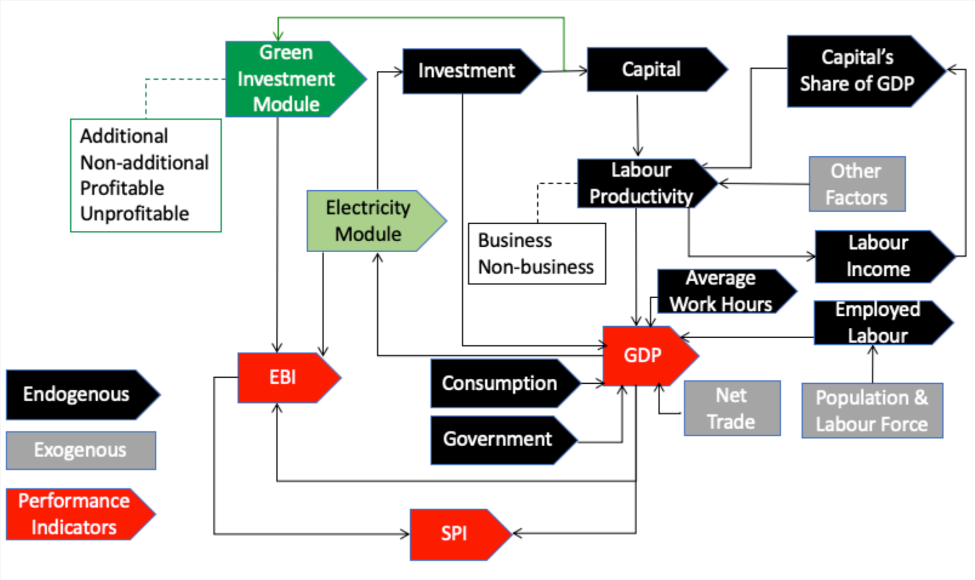

Figure 1: *An overview of LowGrow SFC's showing the structure of demand and supply relationship in the real economy.*

Figure 1 provides an overview of LowGrow SFC, focussing in particular on the components of the Gross Domestic Product (GDP) and the operation of the 'real economy', that is to say aspects of the economy that are associated with the production and consumption of goods, and their associated environmental impacts. In line with a post-Keynesian approach, LowGrow SFC is broadly a demand-driven model in which the GDP is calculated as the sum of household consumption expenditures (C), government expenditure (G), fixed capital investment (I), and net trade ($\bar{X}$):[4]

$$GDP_d = C + G + I + \bar{X}, \quad (1)$$

where $\bar{X}$ is the net trade with other countries defined as total exports minus total imports and the subscript d denotes that we are considering the expenditure or demand side formulation of the GDP. The model also calculates the GDP as the sum GDP_i of incomes in the economy:

$$GDP_i = W + F + \bar{T}^f + \bar{\tau}^f + \delta. \quad (2)$$

4 There are broadly three ways of measuring GDP in the System of National Accounts: the sum of all expenditures (as here); (2) the sum of all incomes; and (3) the sum of value added in production. In theory, all three measures should give identical results. In practice, there are 'statistical discrepancies' between different measures, but at the level of detail pursued in the current exercise, these discrepancies are irrelevant.

Where W is the total wages or labour compensation to households, F is the net profits from firms and banks distributed to households, $\overline{T}^f$ is the net taxes paid by firms to government, $\bar{\iota}^f$ is the net interest paid by firms and δ is the depreciation of the capital stock K. These two formulations of the GDP are, in the model as in the national accounts, equal to each other. That is, if the model is correctly balanced, we can define a single GDP such that:

$$GDP = GDP_d = GDP_i \tag{3}$$

At the same time, LowGrow SFC estimates the maximum supply potential of the economy, GDP_{max}, using an endogenous labour productivity and the average hours worked in the economy (see Section 4 for more detail).[5] The main use to which we put this maximum supply potential is to cap the demand GDP_d, so that it never exceeds the supply potential. To achieve this, we define a simple 'price level', p, in the model at any point in time as the ratio of the calculated GDP to the maximum supply potential GDP_{max} whenever the calculated GDP_d exceeds GDP_{max}, thus:

$$p = \begin{cases} GDP_d/GDP_{max} & \text{when } GDP_d > GDP_{max} \\ 1 & \text{when } GDP_d \leq GDP_{max} \end{cases} \tag{4}$$

This price level p is then used to deflate 'nominal'[6] variables to define real (price-adjusted) values of the same variable for each point in time, so that, for example, a real (supply adjusted) GDP_s value of the GDP is given by:[7]

$$GDP_s = GDP_d/p. \tag{5}$$

A core aim in our work was to embed a representation of the real economy into a financial architecture that reflects the structure of a modern economy, including the transactions and balance sheet positions of different financial actors (sectors). This architecture is necessarily simplified but it represents an important step towards addressing critical questions associated with the transition to a low-carbon, sustainable economy. It is particularly useful in terms of interrogating the potential to achieve stable, low-growth economies capable of maintaining high employment while meeting stringent environmental targets and reducing income inequality.[8]

5 Average hours are calculated separately for the business and the non-business sectors of the economy.

6 'Nominal' refers to the money-value of transactions, unadjusted for inflation. This is to be contrasted with the concept of 'real' value which has been adjusted for inflation.

7 It is clear from this simple price adjustment that it is possible for LowGrow SFC to take inflation into account, but the model is currently limited in not being able to explore potential deflationary dynamics. A fully price dynamic version of LowGrow SFC using mark-up pricing is an aim of ongoing research.

8 Hardt and O'Neill (2017) provide a useful overview of ecological macroeconomic models; several of these are drawn from the Post-Keynesian tradition, including some from our own previous work (Jackson and Victor 2014, 2015, 2016, 2017).

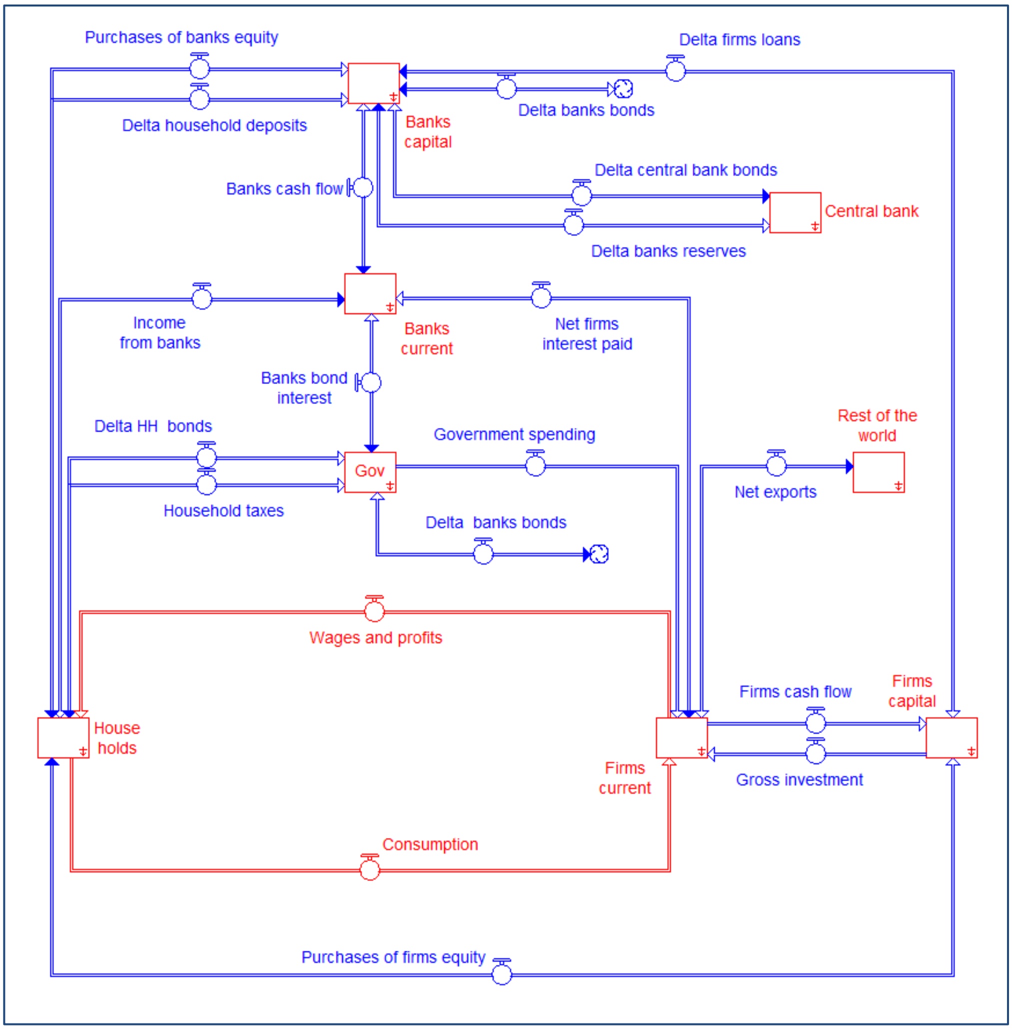

Figure 2 | *Overview of the financial sector structure of LowGrow SFC*

As Figure 2 shows, LowGrow SFC is constructed from six interrelated financial sectors: households (for which we use the subscript h), firms (f), banks (b), government (g), a central bank (cb) and a 'rest of the world' (row) or foreign sector. The accounts of firms and banks are further subdivided into current and capital accounts in line with national accounting practices. The so-called 'circular flow' between households and firms is clearly visible towards the bottom of the diagram in Figure 2. Firms employ labour and capital to produce goods which are purchased by households using the returns to their own labour (wages) and capital (profits) paid to them by firms.

The rather more complex structure that surrounds this circular flow represents the financial flows to and from the banking, government and foreign sectors. If the model is stock-flow consistent, the flows into and out of each financial sector should sum consistently to zero throughout the model run. So, for instance, the incomes of households (consisting of wages, dividends and interest receipts) must be exactly equal to the outgoings of households (including consumption, taxes, interest payments and the net acquisitions of new financial assets). Likewise, for each other sector in the model. These balances provide a ready test of consistency in the model.

The two descriptions of LowGrow SFC portrayed in Figures 1 and 2 each highlight different aspects of the underlying model structure, but of course they map onto each other to some extent. For instance, consumption is a function of household behaviour and government spending is a function of government policies. In other places, the two descriptions 'cut across' each other. For instance, investment is determined partly by firms' expectation of the capital stock required to meet expected demand. But other components of investment are determined by the demand for housing, by public sector decisions, and by assumptions made regarding what we call here 'green' investment, that is investment undertaken to achieve specific environmental objectives.

Green investment is a particularly important component of the analysis in LowGrow SFC. The particular characteristics of green investment have a profound effect on the performance indicators explored in the model. This includes success in meeting environmental objectives. But the structure of green investment also affects the performance of more conventional indicators such as the GDP. We therefore describe the structure of the investment architecture in the model in considerable detail in Section 4 below.

Our approach embodies a good deal of macroeconomic theory but LowGrow SFC is not a purely theoretical model. On the contrary, it has been calibrated empirically using national accounts data from Statistics Canada.[9] Some of the behavioural relationships in the model are based on econometric estimations using data from previous years. Others reflect plausible assumptions informed by the relevant literature. Simulation results are reported for a fifty-year period from 2017 to 2067. When using a model to describe alternative economic futures over half a century or more, statistical relationships estimated from data for the past two or three decades are not always a very reliable guide to future behaviour (Jackson 2019b). It is best therefore to think of the model as employing 'stylized facts' (Godley and Lavoie 2012) that are grounded in empirical data to paint a picture of future possibilities.

To make the task of model description tractable and the description itself readable, we have divided our detailed exploration of the model into the six financial sectors defined above and illustrated in Figure 2, namely: firms, households, government, commercial banks, the central bank, and the foreign sector. Our aim in this working paper is to provide sufficient detail to allow the reader to gain a broad grasp of the underlying structure of LowGrow SFC as a post-Keynesian, stock-flow consistent ecological macroeconomic model of the Canadian economy.

In pursuit of this aim, the next few sections present the basic accounting and behavioural structure of the model sector by sector with sufficient formal (mathematical) presentation to allow those interested in understanding the formal basis of the model to follow our decisions. We also accompany this with

9 Statistics Canada (2017) has one of the best and most accessible online national account data sets in the world.

a narrative description of the underlying relationships, which is hopefully accessible to a broader audience. A list of variable names, their associated symbols and their initial values in the model may be found at Appendix A.[10]

3 | Household Sector

In keeping with the nature of LowGrow SFC as a demand-driven model, we first describe the workings of the household sector. In the Canadian economy household consumption has accounted for some 55% of the GDP over recent years. This section describes the consumption and savings decisions that households make and outlines how these are captured in the model. Broadly speaking, household income includes wages, W, paid by firms and profits, F^{fd}, distributed by firms to shareholders. Households also receive profits, F^{bd}, distributed by banks and interest payments on deposits, D^h, they hold in banks. In addition, they pay interest on the unsecured loans, L^h and mortgages, M, they have taken out. Finally, they receive yields from the ownership of government bonds, B^h, which we model here as loans with a given interest rate, and income from private pension funds, P, schemes which we model as an additional form of deposit attracting the same interest as bank deposits.[11] Total household income, Y^h, is therefore given by:

$$Y^h = W + F^{fd} + F^{bd} + i_{B^h} + i_{D^h} + i_P - i_{L^h} - i_M \qquad (6)$$

where $i_{B^h} = r_B B^h_{-1}$ is the interest paid (at interest rate r_B) on the stock B^h_{-1} of bonds held by households in the previous period, $i_{D^h} = r_D D^h_{-1}$ is the interest paid on households deposits D^h_{-1} held in the previous period, $i_P = r_D P_{-1}$ is the income from private pension funds, $i_{L^h} = r_c L^h_{-1}$ is the interest paid by households to banks on the stock of unsecured loans L^h_{-1} held by households in the previous period and $i_M = r_M M_{-1}$ is the interest paid by households on mortgages M_{-1}.[12]

Household income is subject to tax, T^h, paid to governments who then redistribute some of these revenues back to households in the form of transfers

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10 A guided interface for LowGrow SFC is available online for the user to reproduce the scenarios here and explore their own http://www.cusp.ac.uk/lowgrowsfc. The STELLA equations are available on request.

11 Citizens also pay into state pensions funds and receive income from those funds when they reach retirement age. These payments and receipts will form part of household taxes (net of transfers) which are modelled in Section 5, below, and to avoid double counting are not treated separately here.

12 The superscript h in these terms refers to fact that they belong to households rather than some other sector; the suffix -1 shows that the value of the term is taken from the previous period. In LowGrow SFC, mortgages are only held by households, hence the superscript is dropped in this term. Generally speaking, and as common in SFC descriptions (Godley and Lavoie 2012), the variable for time is omitted from our nomenclature except where the value of the variable is not the current one.

or subsidies, Z^h. Household disposable income, Y^{hd}, is then calculated as income net of taxes and subsidies:

$$Y^{hd} = Y^h - T^h + Z^h. \tag{7}$$

The precise derivation of taxes and subsidies is described in the government sector description (Section 5) below. Real price-adjusted disposable income y^{hd} is defined (by analogy with equation (5) above) as:

$$y^{hd} = Y^{hd}/p \tag{8}$$

Disposable income is then available for households to spend on goods and services or else to save in the form of financial assets. Lowgrow SFC first models consumption, C, as a linear sum of two variables that have been identified in the literature as key determinants people's consumption decisions, namely 1) expected disposable income y^{hde} and 2) real net household worth in the previous period nw^h_{-1} (Pichette 2004; Godley and Lavoie 2012). Specifically, we have:

$$C = \alpha_1 y^{hde} + \alpha_2 nw^h_{-1} \tag{9}$$

where the values of the propensity α_1 to consume out of disposable income and the propensity α_2 to consume out of real net worth have been estimated on the basis of historical trends in Canada[13] and the expected disposable income y^{hde} is calculated in the model as a simple linear extrapolation from the previous two years' incomes:[14]

$$y^{hde} = y^{hd}_{-1}\left(1 + \frac{(y^{hd}_{-1} - y^{hd}_{-2})}{y^{hd}_{-1}}\right). \tag{10}$$

Nominal household net worth NW^h is calculated as the net financial worth NFW^h plus the market value, H, of residential fixed assets, in the form of housing:

$$NW^h = H + NFW^h \tag{11}$$

The net financial worth of households NFW^h is given in its turn by the sum of financial assets minus the sum of financial liabilities:

$$NFW^h = D^h + P + B^h + E^f_h + E^b - L^h - M \tag{12}$$

13 The value of α_1 is taken here as 0.79 and the value of α_2 is 0.01.

14 In some scenarios, an ad hoc reduction to real consumption is made to reflect the additional costs associated with carbon abatement in the electricity and non-electricity sectors.

where E_h^f is the stock of firms' equities owned by households and E^b is the stock of banks' equities.[15] Real net financial worth nw^h is defined using a compound price level, $\tilde{p}$, such that:

$$nw^h = NW^h/\tilde{p} \tag{13}$$

where the compound price level, $\tilde{p}$, is given by:

$$\tilde{p} = \textstyle\sum_0 (p - p_{-1}), \tag{14}$$

reflecting the fact that the stock of net wealth is built up over numerous periods each with a different simple price level p.

It is worth remarking here that the housing wealth (the value of housing) is determined by households' desire to hold such wealth, whereas the real value of residential assets is determined by the scale of fixed capital investment in residential housing, which (in accordance with national accounting conventions) is deemed to be carried out by firms and covered (see Section 4) in the firms' sector. These separate calculations of the 'real' value of the housing stock and the 'nominal' value of housing wealth allow us to calculate a housing price level, p_h, which is then fed back into the estimation of residential investment (see Section 4).

Nominal household savings, S^h, are then calculated as the difference between disposable income and consumption spending:

$$S^h = Y^{hd} - C.^{16} \tag{15}$$

In line with the national accounting framework, households do not themselves make fixed capital investments in LowGrow SFC, and residential investment is treated as a business-related investment (see Section 4 below), so the net lending NL^h of households is given simply by:

$$NL^h = S^h. \tag{16}$$

Net lending plays an important role in SFC macroeconomics. A key accounting identity holds that the sum of the net lending of all financial sectors must be equal to zero:

$$\textstyle\sum_x NL^x = 0 \qquad x \in \{h, f, g, b, cb, row\} \tag{17}$$

A systematic account of net lending by sector therefore serves both to ensure the consistency of the model and also to identify potential balance sheet instabilities in the evolution of the economy.

15 Since households are the sole owners of banks equities in LowGrow SFC, the subscript h is dropped for this variable.

16 In some scenarios, an additional subtraction is made on the right-hand side of equation (15) to reflect the passthrough of taxes from firms to households (see section 4 below)

The next step in the model is to determine the allocation of net lending between different assets and liabilities. Households allocate net lending in a variety of directions: to invest in private pension funds P; to buy shares in firms (E_f^h) and banks (E_b), to pay off loans (L^h) and mortgages (M), or else to save in the form of deposits (D^h) in commercial banks or government bonds (B^h). To make the asset allocation process tractable we have made a number of simplifying assumptions regarding this allocation.[17]

For instance, households are deemed to have a fixed 'liquidity preference' (drawn from historical data) which determines a desired level of bank deposits as a proportion of their household worth. This preference then allocates a flow of funds into or out of household deposits, depending on whether the ratio of deposits to household worth is greater than or less than the desired proportion. Likewise, households are also assumed to want to hold constant proportions of their overall wealth in the form of pensions. This allows us to determine how much of their savings people invest in private pension funds. We assume here that these private pension funds are provided by the financial sector (banks) and model the relationship as a fund with a given rate of interest, which then provides an additional stream of benefits from banks to households.[18]

Likewise, households are deemed to want to hold a certain proportion of their net worth in the form of fixed assets – ie as housing wealth. For the purposes of the scenarios developed in this paper, the target housing wealth proportion is assumed to be constant at a level consistent with historical data for the Canadian economy. As the actual housing wealth in the model differs from the target housing wealth, households are assumed to adjust their house-buying behaviour to maintain this target value. For instance, if the actual housing wealth falls below the target value, households will tend to engage in more house-buying in an attempt to increase their housing wealth.[19] As in real life, the demand for housing wealth is facilitated in part by mortgages, the level of which is determined according to a desired loan-to-value ratio in housing, drawn from empirical data.

For the remaining financial assets – namely equities and government bonds – it is assumed that the household sector is the 'balancing purchaser'. In other

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17 A more realistic description of these asset and liability allocation processes would involve adjusting fixed preferences on the basis of the rates of interest or return on the various assets and liabilities and allowing the price of the assets to vary (Brainard and Tobin 1968). But such complexity lies beyond the scope of this version of LowGrow SFC. For an example of a model that does endogenize asset and liability preferences see Jackson and Victor (2015). See also Jackson et al 2014, Godley and Lavoie 2012. The initial values for assets and liabilities for households (and other sectors) may be found at Appendix A.

18 A state pension is included separately under the assumption that pension contributions are included in the taxes to government, and pension payments are included in the transfers from government.

19 It is worth noting that, since households buy houses from each other, this behaviour leaves the level of savings available to purchase other financial assets in the household sector unchanged and the change in housing wealth does not therefore enter into equation (12).

words, households' demand for equities and bonds is taken to be equal to the remaining supply of equities and bonds, once the demand from other sectors has been satisfied. In the case of firms' equities, for example, this means that the household demand for equities is equal to firms supply of equities adjusted for the demand for equities from the foreign sector (Section 8). For bonds, household demand is equal to the supply of bonds by government (Section 5), adjusted for the demand for bond purchases (or sales) by banks (Section 6), the central bank (Section 7) and the foreign sector (Section 8). For banks equities, households are deemed to be the sole purchasing sector, and absorb any changes in the level of banks equities directly. Under some scenarios, this can mean that households are net sellers rather than net purchasers of equities or bonds.

The final item in the acquisition of assets and liabilities by households is the unsecured loans which households borrow from banks. This item is deemed to be the balancing item in the net lending accounts of households. Specifically, the change in loans ΔL^h is given by:

$$\Delta L^h = \Delta D^h + \Delta B^h + \Delta E_f^h + \Delta E_b + \Delta P - \Delta M - S^h. \qquad (18)$$

One of the advantages of SFC modelling is the ability to identify 'fragilities' in the balance sheet of specific sectors – such as those that arose in the run-up to the financial crisis in 2008. When liabilities exceed a certain proportion of net worth, there is a clear danger that some households will default on loans, may lose their homes, and could find themselves in conditions of severe economic hardship. Even before this happens there is a chance that they will curtail their consumption patterns, in the face of escalating loan repayments and declining savings. In LowGrow SFC we are able to simulate these kinds of conditions by defining an overall loan-to-value ratio LTV^h according to:

$$LTV^h = (L^h + M)/NW^h. \qquad (19)$$

The model allows for the possibility of using this loan to value ratio as a brake on consumer spending: when LTV^h rises above or sinks below a desired level $LTV^h_{desired}$, consumer spending can be constrained by multiplying the right hand side of equation (9) above with the ratio, $LTV^h_{desired}/LTV^h$, of the desired to actual loan-to-value ratio.

One further adjustment is made on consumer spending in scenarios where carbon emissions reduction takes place. As described in greater detail in Section 9.4 below, the non-investment related costs of non-electricity related carbon abatement are assumed to be paid directly by consumers and subtracted from the estimated consumption derived in equation (9) – adjusted where necessary for the constraint on loan-to-value.

4 | Firms Sector

Non-financial firms play a critical role in the structure of the economy. First of all, they employ labour and invest in fixed capital in order to produce goods and services for households and governments and also to provide the capital goods needed for production itself. In other words, they are critical to the supply-side structure of the Canadian economy. Firms must also undertake at least some of the investment that is needed to achieve environmental targets and to deliver a sustainable prosperity. Finally, firms pay taxes to government and provide incomes to households in the form of wages and dividends. In the following sections, we outline the key relationships and behavioural assumptions in each of these three main areas.

4.1 Supply-side structure of firms

In line with most SFC models and with the financial accounts structure within the System of National Accounts, the firms' sector in LowGrow SFC incorporates both private corporations (the business sector) and non-commercial firms (the non-business sector, comprising public and not for profit firms). We divide the output or sales from each of these sectors using a simple proportion φ of real demand GDP_s attributable to the business sector with the reciprocal proportion $1-\varphi$ attributable to the non-business sector.[20]

Given the obvious differences between private and public corporations, we treat the dynamics of capital investment and labour employment differently in each sector. Turning first to the business sector, the demand for labour is determined by real output, φGDP_s, from the business sector, labour productivity measured as output per hour, η^b, and the average hours worked per employee in the business sector, h^b, both endogenously determined. Specifically, we have (by definition):

$$N^b = \varphi GDP_s / \eta^b h^b. \qquad (20)$$

We model non-residential investment decisions in the business sector through a capital–stock adjustment process. In other words, firms are deemed to have a target capital to output ratio sufficient to meet an expected level of output. If at any time the actual capital–output ratio falls short of the target ratio then investment is undertaken to close the gap. The rate at which the gap is closed by new investment is determined by an adjustment factor. Specifically, the target non-residential business capital, K_T^{bnr}, is determined by:

$$K_T^{bnr} = \kappa_T Exp(\varphi gdp_d) \qquad (21)$$

where κ_T is the target capital to output ratio and the expected value of business output, $Exp(\varphi gdp_d)$, is calculated through a simple extrapolation over

20 Based on Canadian data the business sector represents a proportion φ of the GDP equivalent to about 0.75.

previous periods. Investment then follows a partial adjustment (or accelerator) model (Godley and Lavoie 2012, p226), in which the gross non-residential business investment, I^{bnr}, is given by:

$$I^{bnr} = \gamma\left(K_T^{bnr} - K_{-1}^{bnr}\right) + \delta_{nr}, \tag{22}$$

where γ is a partial adjustment coefficient and $\delta_{nr} = r_{\delta_{nr}} K_{-1}^{bnr}$ is depreciation of non-residential business capital at a rate given by $r_{\delta_{nr}}$, drawn from historical data.[21] The actual non-residential business capital stock, K^{bnr}, is then given by:

$$K^{bnr} = K_{-1}^{bnr} - \delta_{nr} + I^{bnr}. \tag{23}$$

The calculation of business sector labour productivity follows the analysis of Baldwin et al (2014) who model the change in labour productivity from period to period as a function of the capital-to-output ratio $K^{bnr}/\varphi GDP_s$ of the business sector, capital's share of the GDP, and an exogenous labour productivity increase associated with changes in labour skills. Accordingly, in LowGrow SFC labour productivity, η^b, in the business sector is derived as:

$$\eta^b = \eta_{-1}^b + \Delta\eta^b, \tag{24}$$

with:

$$\Delta\eta^b = \alpha\Delta\left(K^{bnr}/\varphi GDP_s\right) + \alpha_3, \tag{25}$$

where α is capital's share of the GDP, determined endogenously in the model, and α_3 is an exogenous skills-related increase in productivity estimated on the basis of Canadian data.[22]

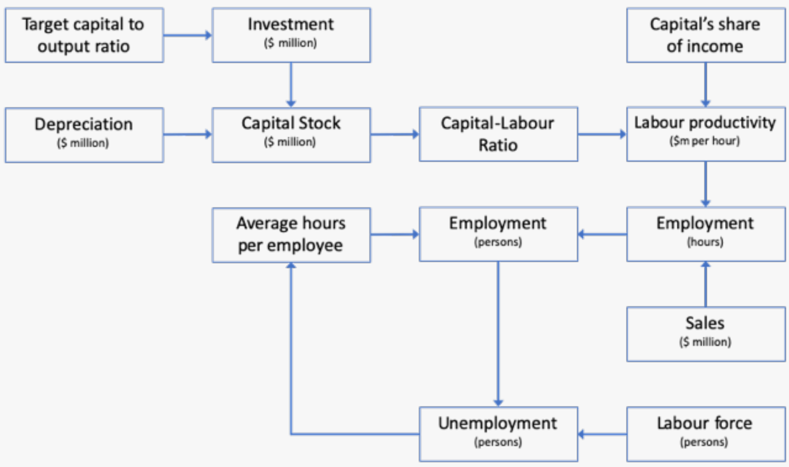

Figure 3: *Representation of the supply-side structure in LowGrow SFC*

21 These parameters are calibrated from Canadian data which suggest a value for γ of around 0.8 (Tutulmaz and Victor 2014) and a value for $r_{\delta_{nr}}$ of around 6%. LowGrow SFC also has the capability to vary the value of γ with the rate of profit or with the rate of economic growth. These variations could in principle be used to test greater or lesser responsiveness of investors to market signals (Minsky 1988 eg), although such variations are beyond the scope of this paper.
22 The value of α_3 in this paper is 0.75%.

The overall supply structure of the business sector in the LowGrow SFC economy is shown in Figure 3, with the labour relationships mainly shown on the right-hand side of the figure and the investment relationships on the left. These two sets of relationships are linked through the endogenous calculation of labour productivity which depends on the stock of non-residential business capital in two distinct ways, firstly through the capital-to-labour ratio and secondly through capital's share of income.

Also visible in Figure 3 (in the middle of the diagram) is the influence of the average hours worked by each employee in the business sector each year on employment. It is clear from equation (20) that the overall employment rate is an inverse function of the average hours worked in the economy. In line with discussions in the literature (eg Victor 2008, Jackson 2009, Coote and Franklin 2013), reducing the average hours worked in the economy is one of the ways in which employment can be maintained even as the growth rate declines. In fact, a secular decline in the hours worked is one of the factors that has contributed to high levels of employment over recent decades.

LowGrow SFC allows for both an adjustment to the average hours worked based on changes in the unemployment rate and for an additional secular decline in hours worked. Specifically, the change Δh in average hours worked per employee in each period is given by:

$$\Delta h^b = (\sigma - \alpha_4 \nu) h^b_{-1}, \tag{26}$$

where ν is the unemployment rate in the economy, α_4 is an exogenous constant estimated from the Canadian data and σ is a time-varying secular rate of decline.[23] The unemployment rate ν must of course be calculated across the economy as a whole, including both the labour employed, N^b, in the business sector and the labour employed, N^{nb}, in the non-business sector, as a percentage of the total labour force N^{LF} in the country as a whole. Thus:

$$\nu = 1 - (N^b + N^{nb})/N^{LF} \tag{27}$$

where, in direct analogy to equation (20), employment in the non-business sector is given by:

$$N^{nb} = (1 - \varphi) GDP_s / \eta^{nb} h^{nb}. \tag{28}$$

with η^{nb} as the labour productivity in the non-business sector and h^{nb} as the average hours worked by each non-business sector employee in the year.

Changes, Δh^{nb}, in average working hours in the non-business sector follow the same logic as for the business sector (equation 25). But there are all sorts of reasons why labour productivity in the non-business sector might not follow

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23 The value of α_4 is taken in this paper as 0.4; the secular rate of decline is taken as zero except in the sustainable prosperity scenario (Section 10) where it varies from 0 in 2017 to a little over 1% in 2067.

the progress of the Baldwin equation (24). For example, non-business labour productivity will follow public sector employment strategies that depend on government spending and policy rather than on the desire to substitute capital with labour or to improve revenue margins. A complete model of these relationships for the non-business sector lies beyond the current scope of the model. For simplicity, we adopt instead a strategy in which labour productivity growth in the non-business sector is estimated on the basis of the historical relationship in Canada between labour productivity growth in the business sector and labour productivity growth in the non-business sector. Explicitly then, by analogy with equation (24) we have:

$$\eta^{nb} = \eta^{nb}_{-1} + \Delta\eta^{nb}, \tag{29}$$

where, in this case, the change in labour over each period is defined by:

$$\Delta\eta^{nb} = \hat{\eta}^{nb}\eta^{nb}_{-1}, \tag{30}$$

and the labour productivity growth rate, $\hat{\eta}^{nb}$, in the non-business sector is estimated via:

$$\hat{\eta}^{nb} = \alpha_5\hat{\eta}^{b} \tag{31}$$

where α_5 is a regression constant derived from historical data.[24] Investment in the non-business sector is also estimated differently from investment in the business sector and is established via government consumption and investment targets which are discussed in more detail in Section 5 below.

There are some additional components of investment that we also need to include in our discussion of firms' behaviour at this stage. The first and most conventional of these is the investment, I^{br}, in residential fixed capital assets (ie housing). As remarked in Section 3, the System of National Accounts deems residential investment to be part of business investment, with the costs of servicing this investment (eg mortgage repayments) allocated to household consumption spending through a component known as the 'imputed rent' of the owner-occupied sector. For the sake of consistency with the data, we follow this same accounting convention in LowGrow SFC, whilst noting that important macroeconomic dynamics associated with the housing market may well be missed by assuming a model structure defined in this way.

Typically, then we would expect residential investment to increase both as the population increases and as the house price increases and to decrease when these factors fall. Specifically, we estimate gross housing investment, I^{br}, as a function of population and house prices, according to a linear equation given by:

24 The estimated value of α_5 in this version of LowGrow SFC is around 1.1, suggesting that labour productivity growth in the non-business sector is faster than in the business sector, albeit starting from a lower base. This is surprising, given that the non-business sector consists mainly of service-related activities which tend to have lower labour productivity growth (Jackson 2017, Ch 9), but reflects the data in the Canadian economy at the moment.

$$I^{br} = \alpha_6 + \alpha_7 Popn + \alpha_8 p_h, \tag{32}$$

where α_6 , α_7 and α_8 are positive regression coefficients estimated from Canadian data and $Popn$ is the Canadian population.[25] The variable, p_h, is a house price index defined by:

$$p_h = 100H/K^{br}, \tag{33}$$

where the housing wealth, H, is as defined in Section 3 and K^{br} is the real value of residential investment, net of depreciation, given by:[26]

$$K^{br} = K^{br}_{-1} - \delta_r + I^{br}, \tag{34}$$

in direct analogy to equation (23), except that $\delta_r = r_{\delta_r} K^{br}_{-1}$ now represents the depreciation and demolition of residential capital at rate, r_{δ_r}, derived from historical data. Firms' overall investment, I^b, is given (in the base case) by:

$$I^b = I^{bnr} + I^{br}. \tag{35}$$

In the following subsection, we adjust this equation to allow for the potential for green investment behaviours in selected scenarios.

4.2 Firms' green investment

There is one final component of firms' investment which is absolutely critical to our exploration of the transition to sustainable prosperity, namely: investment that is specifically undertaken in order to protect the environment, to reduce environmental impact, to achieve environmental targets or to reduce the resource intensity of the economy. For the purposes of this exercise we term this set of activities: 'green investment' and for the sake of clarity, we aim to distinguish this class of investment, which is undertaken with the specific goal of reducing the environmental impact of the economy, and *conventional investment*, characterised as investment that reproduces or expands the productive capital stock (as detailed in the previous subsection).

It is important to note that some portion of conventional investment will also have a tendency to reduce the environmental impact per unit of economic output. Even without a determined effort to increase green investment, we can expect economic progress to result in technological efficiency measures which reduce the rate of throughput of materials and pollutants. For example, investment in energy efficiency will have this effect. For this reason, we

25 For the purposes of the scenarios described here values for these parameters are taken as \$5157m, \$57 and \$1162m respectively. LowGrow SFC includes the possibility of adding speculative housing investment to the housing investment estimated with equation (32). This speculative investment is based on the average rate of change in the house price index. Working through changes in household net worth and depending on its magnitude, speculative investment in housing can generate cycles in the real economy.

26 The house price index is normalised to 100 in the base year (2017) by setting housing wealth H equal to K^{br} at that point.

incorporate a 'business-as-usual' improvement in the environmental performance of the economy in the model, which we assume to be a result of conventional investment, driven by stock adjustment type behaviours in pursuit of expected output as described in the previous section. The calibration of the environmental implications of both conventional investment and green investment is described in Section 9 below. In this section, we are mostly concerned with the macroeconomic aspects of green investment and in particular its impact on the productivity of the firms' sector.

In order to understand these implications, we make a fundamental distinction between *productive* and *non-productive* green investment. Recognising that some kinds of green investment will not only reduce environmental impact but also contribute to the productive capacity of the economy, just as conventional investment does, we call this component *productive green investment*. On the other hand, it is likely that some kinds of green investment can only be undertaken at a net cost or with a rate of return too low to be competitive with other investments. We refer to this latter type of investment as *non-productive green investment*.

Positive Financial Return (high to low)	Negative Financial Return (low to high)
Improved lighting	Reduced slash and burn agriculture
Residential appliance efficiencies	Reduce pasture land conversion
Motor systems efficiency	Grassland management
Constructed wetland	Organic soils restoration
Wastewater treatment systems	Storm-water management systems
Bio fuels	Degraded land restoration
Hybrid cars	Urban forests
Retrofit residential HVAC	Public Spaces
Cropland nutrient management	Pastureland afforestation
Tillage and residue management	Green Roofs/Walls
Building efficiency (new)	Low penetration wind
Landfill gas electricity generation	Solar PV
Efficiency improvements in other industry	High penetration wind
Waste recycling	Energy Storage
Small hydro	Reduced intensive agriculture conversion
Rice management	Protected areas
Urban agriculture	Conventional pollution control systems
Geothermal	Solar CSP
	Coal CCS retrofit
	Coal CCS new build
	Iron and steel CCS new build
	Gas plant retrofit

Table 1: *Illustrative examples of productive and non-productive green investment (after McKinsey 2010, Exhibit 6, p8)*

By way of illustrating this distinction, Table 1 presents a variety of different kinds of green investments which we have characterised as productive (left hand column) and non-productive (right hand column), respectively. This level of technological detail is not explicitly incorporated into the current version of LowGrow SFC, but we present these technologies as examples of the two different kinds of investments. Non-productive green investment relies on the ability of the economy to fund the investment flow, without at the same time benefiting from an increase in the productive capacity of the economy to deliver goods and services. This will turn out to have a significant impact on the ability of the model to generate long-term economic growth.

It is important to note that 'productive' is being used here in a conventional economic sense to relate to the capacity of the economy to produce economic goods and services as conventionally captured in the GDP. In a wider sense, needless to say, green investment is playing a quite fundamental role in protecting the ability of our economies to produce anything at all. So we could argue that green investment is also productive, in this fundamental sense, whatever its apparent short-term impact on the GDP. But the distinction between productive and non-productive investment (in the conventional sense) is an essential one for us in being able to understand the impact that green investment has on the macroeconomy. Productive green investment contributes to the capital stock of the economy used in the production of goods and services that make up the GDP. Specifically, it contributes to the ability of firms to meet their target capital-to-output ratios needed in the production of market goods and services. Non-productive green investment on the other hand is so termed here because it does not in itself contribute to the productive capital stock. It is an investment in a different kind of capital stock, so to speak, namely the environmental assets on which production ultimately depends.

There is a further distinction that is vital for assessing the macroeconomic impact of green investment. It concerns what we call *additionality.* We call green investment which is over and above the investment needed for stock adjustment as determined in equation (22), *additional* green investment. In this case, the total investment expenditure would exceed the investment determined by the stock-adjustment calculation alone. In other circumstances, it is possible that firms will have insufficient funds to meet the requirement for additional green investment. In this case, some or all of the green investment undertaken by firms may have to displace some of the investment that would be desirable from a stock-adjustment point of view. We call this *non-additional* green investment. The impact of non-additional green investment on the productive capital stock depends on whether or not this non-additional green investment is productive or non-productive, in the sense outlined above.

It is worth reiterating that there are broadly two kinds of macroeconomic effects that green investment might have in the economy, summarised in Table 2. One of these is an immediate impact on aggregate demand, during the period of investment, because investment spending contributes to aggregate demand (equation 1). Additional green investment will increase real aggregate demand but only in so far as the economy is not already operating at full capacity. Non-additional green investment simply displaces conventional investment by firms and there is no impact in terms of increased aggregate demand. If the economy is already operating at full capacity, then neither additional nor nonadditional green investment increases real aggregate demand.[27]

	Productive	Non-productive
Additional	Increases productive capital stock. Adds to aggregate demand.	No effect on productive capital stock. Adds to aggregate demand.
Non-additional	No effect on productive capital stock. No effect on aggregate demand.	Reduces productive capital stock. No effect on aggregate demand.

Table 2: *Productivity and additionality in green investment*

The second effect relates to the impact green investment has on the productive capacity of the economy. If all green investment is productive then it will tend to increase the productive capital stock beyond what would happen in the absence of green investment – but only to the extent that the green investment is additional to conventional investment. If all green investment is unproductive and is also non-additional, then it is likely to reduce the productive capacity of the economy because it displaces productive investment. If green investment is additional but non-productive or non-additional but productive it will have no effect on the productive capital stock.

Determining how much green investment is productive and how much is non-productive is, at this point in time, something of a judgement call. Clearly, the early 'low-hanging fruit' of efficiency improvements will tend to be rather productive, with longer-term efficiencies in the capital stock and strong positive rates of return. On the other hand, once these are exhausted, the same kinds of financial rewards may be more elusive and it seems likely that if the situation becomes more urgent as time passes, an increasing proportion of green investment will be non-productive, since it will consist of measures designed to lessen adverse impacts on the environment but not increase the economy's productive capacity. An example would be a seawall built to protect

27 In the simulations described later in this paper it is assumed that all green investment is regarded as non-additional, that is, it displaces other intended investments. This is to avoid attributing expansionary effects to green investment that arise simply because an economy is not at full capacity. In the event that the envisaged level of green investment is higher than the estimated level of conventional investment, then the excess is deemed as additional green investment

coastlines from rising sea levels, and stronger buildings to withstand more violent storms.[28]

Formalising green investment in the model requires us to amend the assumptions associated with firms' investment behaviours set out in equations (22) and (23) to incorporate the impacts of green investment. Suppose first that we divide firms' green investment, I_g^{bnr}, into the four components illustrated in Table 2. Specifically, we have:

$$\begin{aligned} I_g^{bnr} &= {}_aI_g^{bnr} + {}_{na}I_g^{bnr} \\ &= {}^pI_g^{bnr} + {}^{np}I_g^{bnr} \\ &= {}^p_aI_g^{bnr} + {}^p_{na}I_g^{bnr} + {}^{np}_aI_g^{bnr} + {}^{np}_{na}I_g^{bnr} \end{aligned} \tag{36}$$

where the superscripts p and np refer to productive and non-productive and the subscripts a and na to additional and non-additional (respectively). The first adjustment that must be made is to determine firms' actual spending on non-residential business investment including both the conventional stock adjustment calculation (equation 22) in a given period and taking into account green investment. In accordance with the analysis above, firms' *actual* business sector, non-residential, investment spend, $I^{\widetilde{bnr}}$, is given by:

$$I^{\widetilde{bnr}} = I^{bnr} + {}_aI_g^{bnr} \tag{37}$$

This actual spending is crucial in determining firms' cash flow requirements and financing needs. It also defines the non-residential business component of investment in the expenditure formulation of the GDP (equation (1)). But it does not straightforwardly define the productive capital stock in the same way that equation (23) does from equation (22). Instead, we must define firms' *effective* business sector non-residential investment $\bar{I}^{bnr}$, according to:

$$\begin{aligned} \bar{I}^{bnr} &= I^{\widetilde{bnr}} - {}^{np}I_g^{bnr} \\ &= (I^{bnr} - {}^{np}_{na}I_g^{bnr}) + ({}_aI_g^{bnr} - {}^{np}_aI_g^{bnr}) \\ &= I^{bnr} - {}^{np}_{na}I_g^{bnr} + {}^p_aI_g^{bnr}, \end{aligned} \tag{38}$$

from which we can calculate the productive capital stock $\bar{K}^{bnr}$, by direct analogy with equation (23), according to:

$$\bar{K}^{bnr} = (1-\delta)\bar{K}_{-1}^{bnr} + \bar{I}^{bnr}. \tag{39}$$

28 Our default assumption in the scenarios set out in this working paper is that 50 percent of total green investment will be productive. If it turns out to be more than this, then the implications of green investment for economic growth will be less than indicated in the scenarios. If it turns out to be greater, then the opposite will be true.

It is this effective capital stock which then enters the Baldwin calculation (equation 25) of labour productivity, thereby influencing the productivity of the economy as a whole. The lag of $\bar{K}^{bnr}$ also enters the partial adjustment equation in determining the desired stock-adjustment level of investment as the model proceeds (equation (22)).

Clearly, a similar adjustment needs to be made for residential investment which improves the energy efficiency of homes or incorporates environmental measures into the design or retrofitting of buildings. Once again, we assume a certain level of improvement in environmental performance associated with conventional residential investment and we distinguish again between additional green investment (that is over and above conventional residential investment) and non-additional green investment (that displaces conventional investment) in residential buildings. Since residential investment is not deemed to contribute to the productive capital stock, there is no need to incorporate a distinction between productive and non-productive residential investment. The formal presentation of additional and non-additional residential investment is directly analogous to equation (37) above, namely:

$$\widetilde{I^{br}} = I^{br} + {}_{a}I_{g}^{br} \tag{40}$$

And the actual residential capital stock is straightforwardly determined by amending equation (34) to:

$$K^{br} = (1 - r_{\delta_r})K_{-1}^{br} + \widetilde{I^{br}}. \tag{41}$$

There is one more category of green investment to be considered, namely that carried out by the non-business sector. We address this in Section 5 below on the government sector. The calibration of the level of green investment in relation to desired environmental targets is addressed in Section 9.

4.3 Firms' cash flow and financing

The final set of considerations in relation to the operation and behaviour of the firms' sector relates to the allocation of revenues between wages, dividends and retained earnings and the financing decisions that firms must make in relation to investment. In a model without intermediate sales, firms' aggregate nominal sales, X, are determined by the non-price-adjusted GDP_d given (by definition) as:

$$X = GDP_d = pGDP_s. \tag{42}$$

From these revenues, firms must first pay the nominal wage bill, W, which is given by the sum of the nominal wage bills W^b and W^{nb} for the business and non-business sector:

$$\begin{aligned} W &= W^b + W^{nb} \\ &= p(w^b + w^{nb}), \end{aligned} \tag{43}$$

where w^b and w^{nb} are the real wage bills in the respective sectors, given by:

$$w^b = \mu^b N^b$$

$$w^{nb} = \mu^{nb} N^{nb} \qquad (44)$$

with μ^b and μ^{nb} the real wage rate in the business and non-business sector respectively. The determination of real wage rates is potentially a somewhat complex issue in economic models, dependent in practice on the potential for wage bargaining, the relative power of labour and capital in the wage bargaining process, price levels in the economy and various other factors. Conventional economics supposes that wage rates should follow labour productivity growth in the economy. If more output is achieved per hour worked by the labour force, then workers should share in the rewards of this increased productivity. [29] In LowGrow SFC, we adopt a relatively straightforward approach to the determination of wage rates using historical data to estimate the relationship between labour productivity and wage rates in the respective sector: Specifically then we have:

$$\mu^b = \alpha_9 + \alpha_{10}\eta^b \qquad \text{and}$$

$$\mu^{nb} = \alpha_{11} + \alpha_{12}\eta^{nb} \qquad (45)$$

where α_9 to α_{12} are exogenous coefficients derived through estimation from Canadian data.[30]

Having established the derivation of firms' wage bill, W, it is possible to define firms' net operating surplus, NOS, according to:

$$NOS = X - W - i^f - \delta, \qquad (46)$$

where $\delta = \delta_{nr} + \delta_r$ is the combined depreciation on non-residential and residential capital stock and $i^f = r_L L^f_{-1} - r_D D^f_{-1}$, is the interest paid by firms to banks on outstanding loans, L^f, net of any interest received on deposits, D^f, as in equation (3). Interest rates r_L on loans and r_D on deposits are determined in Section 6 below. Firms pay taxes, T^f, on profits to government and receive transfers Z^f, from them, as detailed in section 5 below. In some scenarios, taxes, T^g, are also levied on carbon emissions from electricity generation. As outlined in Section 3, we assume that firms will pass on a proportion, π, of these taxes to households, so that firms' overall post-tax profits, F^f, are given by:[31]

$$F^f = NOS - \pi(T^f - T^g + Z^f). \qquad (47)$$

29 In practice, recent decades have seen some departure from this relationship, with wage growth falling below labour productivity growth in some advanced economies (Jackson 2019a).

30 Values taken in this paper are approximately: 3, 0.5, -7 and 0.7 respectively.

31 The value of π adopted in the scenarios in this paper is 50%. That is, we assume that firms pass through half of the cost of green taxes directly to households and absorb the other 50% themselves as additional costs.

Firms have a choice to make in relation to the net profits generated from their activities. Namely, they can retain them to pay for future investment or else distribute them to their shareholders. We simulate this decision in Low-Grow through a variable retained earnings ratio, ρ^f, which is given by:

$$\rho^f = \rho_0^f L^f / L_0^f, \tag{48}$$

where ρ_0^f is the initial value of the retained earnings ratio in the Canadian economy derived from historical data and L_0^f is the initial value of firms' outstanding loans.[32] Thus, if firm's indebtedness increases (in relation to the historical rate of indebtedness) we assume that firms prudently retain a higher proportion of their post-tax profits to prevent debt escalating in the future. If firms' indebtedness decreases on the other hand, they are tempted to retain less of the post-tax profit and distribute more to shareholders. Clearly, there are all sorts of conditions in which this relatively prudent behaviour might not be the case, and in principle LowGrow SFC could be used to model such conditions. But in the scenarios modelled here we keep this assumption of prudence. The retained profits ratio, ρ^f, is then employed to derive the portion, F^{fr}, of post-tax profits retained for future investment according to:

$$F^{fr} = \rho^f F^f, \tag{49}$$

and the portion, F^{fd}, distributed to shareholders (ie to households – see equation (6) in section 3) as:

$$F^{fd} = (1 - \rho^f) F^f. \tag{50}$$

Firms gross retained earnings, F_{gross}^{fr}, are assumed (as in the national accounts and in financial accounting frameworks generally) to include a capital consumption allowance equal to the depreciation of the capital stock, so that:

$$F_{gross}^{fr} = F^{fr} + \delta. \tag{51}$$

These retained earnings are available alongside new loans from banks and the issuance of new shares to fund gross investment in the residential and non-residential capital stock, as determined earlier in this section (equations (37) and (40)). Given those investment needs, the requirement for new loans and shares is determined by (the negative of) firms' net lending, NL^f, which is defined in its turn by:

$$NL^f = F_{gross}^{fr} - \widetilde{I^b}, \tag{52}$$

where $\widetilde{I^b} = \widetilde{I^{bnr}} + \widetilde{I^{br}}$ is the sum of the non-residential and residential gross investment defined in equations (37) and (40), respectively.

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32 The initial value of the retained earnings ratio used here is 0.22. The initial value of firms' loans is shown in the initial balance sheet (Appendix B).

Typically, net lending by firms is slightly negative. In other words, net lending is usually positive net borrowing by the firms' sector. In deciding between new loans and new equities as the source for this net borrowing, firms will again be driven by a wide variety of different factors including the rate of interest on loans, the strength of company equities on the stock market and so on. In LowGrow SFC, we assume that, at the sector level at least, this decision can be represented by a simple, target loan-to-equity ratio λ_T^f, and that the change in firms' loans, ΔL^f, is therefore given by:

$$\Delta L^f = -NL^f(\lambda_T^f/(1+\lambda_T^f), \qquad (53)$$

The issuance of equities, ΔE^f, is subsequently given by:[33]

$$\begin{aligned}\Delta E^f &= -NL^f + NL^f(\lambda_T^f/(1+\lambda_T^f) \qquad (54)\\ &= -NL^f(1/(1+\lambda_T^f)).\end{aligned}$$

In the case where, for whatever reason, firms' net lending turns out to be positive, then these funds are used first to pay down firms' existing loans and then to increase firms' deposits. In this case, needless to say, there is no need for the issuance of new equities.

5 | Government Sector

In LowGrow SFC the government sector represents the sum of all three levels of government in Canada: federal, provincial and municipal. Broadly speaking, this sector purchases goods and services from the firms' sector according to certain spending and investment targets and finances these purchases through taxation on households and firms. Some of this taxation is returned to households in the form of transfer payments (benefits to poorer households). Any shortfall between income and expenditure is financed through the issuance of government bonds. As in the firms' sector, some of government investment is directed towards green investment with the aim of reducing environmental impacts and governments also have the ability to levy green taxation on firms.

Government spending targets are set to follow the growth in real GDP in the economy with a countercyclical adjustment which boosts (or reduces) spending when unemployment rises above or falls below a certain point. Specifically, if we set the growth rate r_g in the model as the instantaneous growth rate in GDP_S, then real government consumption spending, G^c, is given by:

$$G^c = r_g G^c_{-1} + G^{cc}, \qquad (55)$$

with the countercyclical component, G^{cc}, defined in the following way:

33 In this paper we assume a target loan-to-equity ratio of 1:1.

$$G^{cc} = (\nu - \nu_{nairu})G_0^{cc} \tag{56}$$

where ν_{nairu} is the non-accelerating inflation rate of unemployment (NAIRU) and G_0^{cc} is a countercyclical spending injection per percentage point difference between the actual rate of unemployment and the NAIRU. Both variables are set exogenously in the model.[34]

Government investment, I^g, follows a similar logic to that for government consumption. Specifically, we assume:

$$I^g = r_g I_{-1}^g + I^{gcc} \quad , \tag{57}$$

with the countercyclical injection of investment, I^{gcc}, defined, by analogy with equation (57) as:

$$I^{gcc} = (\mu - \mu_{nairu})I_0^{gcc}, \tag{58}$$

where I_0^{gcc} is an exogenous countercyclical investment injection analogous to the countercyclical government consumption injection G_0^{cc}.[35] There is one further component of government investment, namely, public sector green investment, I^{gg}. The derivation of the level of green investment is dealt with in Section 9 below. In the meantime, it follows that government's overall level of investment spending, I_{tot}^g, is given by:

$$I_{tot}^g = I^g + I^{gg} = r_g I_{-1}^g + I^{gcc} + I^{gg}. \tag{59}$$

Government principle revenues consist in taxes, T^h, on households and taxes, T^f, on firms. In some scenarios, governments also levy a green tax, T^g, on firms. Governments return some revenues to households in the form of transfers (welfare benefits for example), Z^h. In the absence of green taxes, the model proceeds by defining household taxes net of transfers as a variable percentage, θ^h, of household income Y^h. That is to say that:

$$T^h - Z^h = \theta^h Y^h \tag{60}$$

where the net tax rate, θ^h, varies upwards or downwards according to the government's debt position. Specifically, when the government debt to GDP ratio, ψ, lies within a supposed 'normal' range $[\psi_L, \psi_U]$, the net tax rate takes an unchanging constant value, θ_0^h, calibrated on the initial tax rate net of transfers in the Canadian economy. When ψ is less than ψ_L the tax rate is

34 The value taken by ν_{nairu} in the model is 5.5%, while the value of the countercyclical injection per percentage point difference between actual unemployment and the NAIRU is $5000m. Counter cyclical injections can be lagged in the model so that they happen a discrete period of time after unemployment deviates from the NAIRU to reflect possible delays in policy interventions.

35 The value taken by this countercyclical investment injection is $2500m, half the value of the consumption injection, consistent with the normal balance between government consumption and investment expenditure.

progressively reduced, and when ψ is greater than ψ_U it is progressively increased, subject to the condition that the tax rate itself lies within a 'politically acceptable' interval $[\theta_L^h, \theta_U^h]$.[36] The incremental increase, $\Delta\theta^h$, in the net tax rate is defined by:

$$\Delta\theta^h = \min\{\overline{\Delta\theta^h}, \hat{\psi} + \alpha_{13}\}, \tag{61}$$

when ψ is greater than ψ_U and by:

$$\Delta\theta^h = \max\{-\overline{\Delta\theta^h}, \hat{\psi} - \alpha_{13}\}, \tag{62}$$

when ψ is less than ψ_L, where $\hat{\psi}$ is the rate of growth of the debt-to-GDP ratio, α_{13} is an exogenously defined constant increment and $\overline{\Delta\theta^h}$ is an exogenous maximum allowable tax increment.[37] Though it seems complicated, equations (60) to (62) are simply designed to increase or decrease the tax rate in such a fashion that any year on year increase is rather small and the tax rate ultimately stays within politically acceptable levels. This structure nonetheless represents a relatively realistic model of governments ability to increase or decrease taxes, according to its longer-term fiscal needs.

The treatment of taxes levied on firms proceeds in a similar fashion by defining firms' taxes as a percentage, θ^f, of firms' profits, by analogy with equation (60), according to:

$$T^f = \theta^f P^f. \tag{63}$$

Once again, the firms' tax rate takes a constant value, θ_0^f, defined by initial conditions and is varied subject to the condition that the value lies within an acceptable range $[\theta_L^f, \theta_U^f]$,[38] according to:

$$\Delta\theta^f = \min\{\overline{\Delta\theta^f}, \hat{\psi} + \alpha_{14}\}, \tag{64}$$

when ψ is greater than ψ_U and by:

$$\Delta\theta^f = \max\{-\overline{\Delta\theta^f}, \hat{\psi} - \alpha_{14}\}, \tag{65}$$

when ψ is less than ψ_L, where (as before) α_{14} is an exogenous tax increment, $\hat{\psi}$ is the rate of change of the debt to GDP ratio and $\overline{\Delta\theta^f}$ is a maximum allowable value for the overall tax increment.[39] In addition, as mentioned above, government may also levy green taxes, T^g, on the carbon emissions from the electricity sector. The derivation of the overall level of green taxation is detailed in Section 9 but we note here, that for accounting purposes, these taxes are also levied initially on the firms' sector. As we remarked earlier, the model allows

36 In the simulations presented in this paper, θ_0^h is 15%, ψ_L is 40%, ψ_U is 60%, θ_L^h is 5% and θ_U^h is 25%.

37 The simulations here assume the exogenous tax increment α_{13} is 0.5 percentage points and the maximum allowable tax increment $\overline{\Delta\theta^h}$ is 5 percentage points.

38 In this paper, we take θ_0^f as 30%, θ_L^f as 10% and θ_U^f as 50%.

39 Here we adopt the same values for α_{14} and for $\overline{\Delta\theta^f}$ as we did for α_{13} and for $\overline{\Delta\theta^h}$.

for firms to pass through a proportion, π, of its tax burden to households. Irrespective of this passthrough, the overall level of taxes, T_{tot}, received by government is given by:

$$T_{tot} = T^h + T^f + T^g. \quad (66)$$

The question of transfers from government to business is treated slightly differently from the transfers from government to households. Specifically, transfers, Z^f, to business are taken as a constant percentage α_{15} of the GDP in each year and these transfers are then subtracted from the level of taxation, T^f, levied on firms as shown in equation (47).[40]

Another feature of LowGrow SFC is the capacity for government to increase its redistributive transfers under certain scenarios, with the aim of improving distributional outcomes. Specifically, the model incorporates an initial distribution of incomes in the Canadian economy in terms of income deciles and calculates the Gini coefficient associated with this distribution. In the Sustainable Prosperity *Scenario* (Section 10), an additional stream of transfer payments, Z^{ha}, is then distributed to households in inverse ratio to their level of income, over a specified period of time.[41]

The total government receipts, T_{net}, net of transfers is then given by:

$$T_{net} = T_{tot} - Z^f - Z^h - Z^{ha}. \quad (67)$$

Against these receipts, the government incurs total outgoings of G_{tot}, given by the sum, G, of its consumption spending, G^c, and its investment spending I^g_{tot} plus its servicing of the interest on the outstanding stock of government bonds. Specifically, we have:

$$G_{tot} = G + r_B B_{-1}, \quad (68)$$

where r_B is the interest rate on outstanding bonds, B. We are now in a position to establish the net lending position, NL_g, of government, which is given by:

$$NL_g = T_{net} - G_{tot}. \quad (69)$$

When net lending is positive, government is said to be running a surplus. More usually, the net lending position of government is negative, as the government maintains a deficit. This deficit is generally funded by the issuance of government bonds which are purchased by other sectors of the economy for a variety of purposes. For example, households (see Section 3) buy government bonds as part of their financial savings portfolio. The issuance of new government bonds, ΔB, is given by:

$$\Delta B = -NL_g. \quad (70)$$

40 The value chosen for α_{15} in this paper, based on historical data, is 2%.
41 In the *Sustainable Prosperity Scenario* described below, an amount rising over 10 years to an additional $20 billion per year is distributed, starting in 2020.

When the government is running a surplus, ΔB is negative, meaning that the government is in a position to repay or buy back a portion of outstanding bonds.

It is worth remarking briefly on another feature of the LowGrow SFC model, which allows for the possibility that governments can issue sovereign currency without debt, as suggested for example by some proponents of Modern Money Theory (Wray 2012). It is an idea that has a long pedigree dating back to the so-called Chicago plan but has been revisited quite widely in recent years (see eg Benes and Kumhof 2011). This 'overt monetary finance' (Turner 2017) can, argue its proponents, be spent directly into the economy, reducing the need for government to issue bonds to cover a deficit. In the scenarios in this paper, we do not include sovereign money, but the model has the capability to include this option.

6 | Banks Sector

The simplified representation of banks in LowGrow SFC serves an important purpose in allowing for a stock-flow consistent account of the financial balance sheets of the entire economy. In formal terms, it reflects the sector represented by financial corporations in the Canadian financial accounts.[42] In practice, this sector covers a wide range of financial institutions including depository institutions (banks), insurance and pension funds and other financial intermediaries. For the sake of simplicity, we treat the sector as though it consisted entirely of banks.

In brief, banks receive deposits, ΔD^h, from households and extend unsecured loans, ΔL^h, and mortgages, ΔM, to them (as described in section 3). They also provide loans, ΔL^f, to firms and accept deposits, ΔD^f, from them (as described in section 4). LowGrow SFC also includes a provision for private pensions, P, which are also modelled as deposits held by banks. Additionally, banks are assumed to hold central bank reserves R, for liquidity purposes and to issue equities, E^b, in order to meet capital adequacy requirements (as described in more detail below).

Banks current account transactions flow from the interest received from (and paid on) these various assets (and liabilities). Their income consists in the interest, $r_L L^f_{-1}$, received on loans to firms, the interest, $r_L L^h_{-1}$, received on loans to households, the interest $r_M M_{-1}$ received on mortgages, the interest $r_B B^b_{-1}$, received on government bonds, held for capital adequacy purposes, and the interest $r_R R_{-1}$, on central bank reserves held for liquidity purposes. Its expenditure consists in the interest, $r_D D^f_{-1} + r_D D^h_{-1} + r_D P_{-1}$, paid out on

42 See: https://stats.oecd.org/Index.aspx?DataSetCode=SNA_TABLE710.

deposits (and private pensions) to firms and households.[43] Hence, banks' profits, F^b, are given by:

$$F^b = r_L L^f_{-1} + r_L L^h_{-1} + r_M M_{-1} + r_R R_{-1} + r_B B^b_{-1} - r_D D^h_{-1} - r_D D^f_{-1}. \qquad (71)$$

Our assumption in LowGrow SFC is that these profits are all distributed as dividends, F^{bd}, to households, which suggests that banks net lending, NL^b, is given by:

$$NL^b = F^b - F^{bd} = 0 \qquad (72)$$

meaning that banks net acquisitions of financial assets is also zero. Changes in the level of deposits (including pensions) and loans (including mortgages) are determined in the household and firms' sectors. Changes in reserves and banks equities are determined by the need for liquidity and the imposition of capital adequacy requirements respectively (cf Jackson and Victor 2015). Consequently, the balancing item in banks' capital accounts is their net acquisition of government bonds. We describe these various acquisitions and disposals in the following paragraphs.

First, we assume that commercial banks keep a certain level of reserves, R, with the central bank, depending on the level of deposits held on their balance sheet, to ensure that they are sufficiently liquid in response to withdrawals by households or firms. The additional reserve requirement ΔR in any year is determined according to:

$$\Delta R = \beta\left(D^h_{-1} + D^f_{-1} + P^p_{-1}\right) - R_{-1}, \qquad (73)$$

where β is a desired (or required) reserve ratio. Banks 'pay for' these reserves by exchanging an equivalent value in government bonds with the central bank, thus depleting their stock of bonds by an amount ΔB^{cb} equal to ΔR, and increasing the stock of government bonds held by the central bank by the same amount.

To comply with capital adequacy requirements under the long-term targets set out under the Basel III accord (BIS 2019), banks are required to hold capital (equity) equivalent to a given proportion of risk-weighted assets. In LowGrow SFC we take the sum of risk-weighted assets to be equal to the sum of loans, L^f, to firms and the loans and mortgages, $L^h + M$, issued to households. Banks' capital is defined here by the book value of the banks sector equity, E^b, according to:

$$E^b = L + R + B^b - D \qquad (74)$$

where B^b are government bonds held by the banks' sector, $D = D^f + D^h + P$, and $L = L^f + L^h + M$. The long-run Basel III requirement is then met by

43 We note here that the banks sector does not pay wages in LowGrow SFC. These are deemed to be paid via the firms' sector just as public sector wages are.

ensuring that the stock of banks equities is greater than a target capital adequacy ratio, ζ^T, multiplied by the risk-weighted assets, L, so that: [44]

$$E^b \geq \zeta^T L. \tag{75}$$

Assuming initial conditions in which this requirement is met, then the capital adequacy ratio is maintained in the model under the assumption that:

$$\Delta E^b = \zeta^T \Delta L. \tag{76}$$

In other words, banks' issue new equities (which are purchased in LowGrow SFC by the household sector) equal to the change in loans multiplied by the capital adequacy ratio.

The final balancing element on the banks' balance sheet is government bonds, which we assume that banks will hold in preference to reserves where they can – ie once the reserve requirement is met – because they bring income from interest. The target value of banks' bonds, B^{bT}, can be determined from equation (74) as:

$$B^{bT} = D - R - L + E^b \tag{77}$$

Or equivalently, using the reserve requirement to determine R and the capital adequacy ratio to determine E^b, we can write:

$$B^{bT} = D(1-\beta) - L(1-\zeta^T). \tag{78}$$

To achieve this target, banks purchase additional government bonds:

$$\Delta B^b = B^{bT} - B^b_{-1} + \Delta B^{cb} \tag{79}$$

where the last term on the right-hand side of equation (79) is included to offset the purchase of government bonds by the central bank to meet reserve requirements.

In summary, the simplified role of the financial sector in LowGrow SFC is threefold. First, banks create loans and receive deposits for households and firms. Next, the profit generated from an interest rate spread on these loans and deposits is returned directly to households as dividends. Finally, the banks sector holds relatively small quantities of central bank reserves and government bonds in proportions that provide to ensure financial stability. It is also worth mentioned that the model includes the capability for banks to impose lending restrictions on households, when necessary. Specifically, when the household loan-to-income ratio rises beyond a predetermined point, the level of unsecured loans is reduced in the model, essentially suppressing household consumption.

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44 The value chosen for ζ^T in the model is 10%, which is higher than the Basel III requirement of 8% but more consistent with Canadian data.

7 | Central Bank Sector

The role of the central bank is highly simplified in LowGrow SFC and consists in two basic functions. Firstly, the central bank provides liquidity in the form of central bank reserves in exchange for government bonds (as described in the previous section). In any one year, the central bank capital account is simply a balance between reserves, R, and its holdings of government bonds, B^{cb}, such that:

$$\Delta R = \Delta B^{cb}. \qquad (80)$$

This position results in the central bank paying interest, $r_R R_{-1}$, on reserves and receiving interest, $r_B B_{-1}^{cb}$, on government bonds. We assume any profits generated through the difference between these amounts is returned to the government.[45]

In addition, the central bank has the capability to adjust the interest rate, r_R, on reserves in response to the level of unemployment in the economy. Specifically, the bank increases the interest rate r_D on bank deposits by a given increment when unemployment falls below a certain threshold in order to reduce inflationary demand and decreases them when unemployment rises above a certain threshold in order to stimulate demand.[46] Interest rates r_B on bonds, r_L on firms loans, r_M on mortgages and r_C on unsecured consumer debt are determined by fixed spreads above the interest rate r_D on bank deposits.[47]

8 | Rest of the World or ‘Foreign’ Sector

The final sector necessary to describe the Canadian economy is the ‘foreign’ sector representing trade between Canada and the rest of the world. Net overseas trade – the difference between exports and imports – is one of the components of GDP (Equation 1). In addition to the payment, Imp, for imports and the receipt, Exp, for exports, the foreign sector also pays taxes on exports to the Canadian government and receives interest payments $r_b B_{-1}^{row}$ on government bonds. Compared with consumption and investment, the foreign sector measured as the difference between exports and imports, is typically very small, in the region of 2.5 percent or less of Canadian GDP from 2011 to

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45 In practice, in the simulations described here, the initial holdings of reserves are equal to the initial holdings of government bonds, changes in the holdings of reserves is exactly in step with acquisitions of bonds (as described in Section 6), and the rate of return on reserves is equal to the rate of return on bonds, meaning that no profits are generated by the central bank.

46 In the simulations explored here, employment rates are kept relatively constant, by construction. The upper threshold for interest rate changes is taken as 10% percent and the lower threshold as 5%.

47 For the purposes of the simulations here, the initial values of r_R, r_D, r_B, r_L, r_M and r_C were taken as 0%, 1%, 3%, 5%, 5% and 15% respectively. The spreads between these interest rates are kept constant during the simulations described in this paper.

2016 (Statistics Canada 2017). Nonetheless, a long-term trade deficit can potentially have important repercussions for the national balance sheet.

The net lending position, NL^{row}, of the foreign sector is then given by:

$$NL^{row} = -\bar{X} - T^{row} + r_b B_{-1}^{row} + F_{row}^{fd}, \qquad (81)$$

where $\bar{X}$ is net exports (ie $Exp - Imp$) and the last terms is the dividends associated with the foreign holding of Canadian firms' equity. This term is included in the model for the following reason.

If there is a positive net lending position for the foreign sector these funds must be held somewhere. They might of course be held purely as reserves of Canadian dollars. More likely they will be invested in Canadian assets. The default assumption in LowGrow SFC is that the foreign sector uses a positive trade balance to invest in Canadian government bonds. If sufficient bonds are not available for purchase however, then the foreign sector uses its trade surplus to invest in equities in non-financial firms.

On the capital account side of the foreign sector, we can also express the foreign sector's net lending as:

$$NL^{row} = \Delta B^{row} + \Delta E_{row}^{f} \qquad (82)$$

It is worth noting that a persistent positive net lending position for the foreign sector can have significant impacts both on the GDP directly and also on the net financial worth of Canada with respect to the rest of the world. If the foreign sector's current account position remains positive it must be a net purchaser of Canadian assets. When this happens, it reduces the availability of both bonds and equities to households, pushing people's investment portfolio towards more liquid assets.

In addition, of course, there is an impact on the real economy through the increasing interest payments associated with higher holdings of Canadian assets abroad. All of these things have the potential to undermine the Canadian currency in the long run.[48] The default assumption in our scenarios is that the gap between exports and imports beyond 2017 remains at zero which is consistent with long run sustainability and close to its actual value in 2016.

9 | Environmental and resource dimensions

Mapping the environmental and resource dimensions of the economy was one of our key aims in this work. We are particularly interested in the macroeconomic implications of the green investments needed to achieve

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48 In this version of the model, we don't adjust the exchange rate itself, but in choosing the evaluation of our scenarios in the next section, we have been wary of the potential pitfalls from unbalanced trade.

specific environmental goals and to remain within 'planetary boundaries' (Steffen et al 2015). In particular, of course, we want to explore the implications of the transition to a low- or net-zero-carbon economy.

These implications depend on the nature of the green investment needed to achieve the transition impacts on the economy. Section 4 described the way in which the model distinguishes between 'productive' and 'non-productive' and between 'additional' and 'non-additional' green investments. These categories allow us (Table 2) to distinguish between investments which increase the long-term productivity of the economy and those which don't; as well as between those that increase short-run aggregate demand and those which don't. These distinctions are often overlooked in conventional analyses of green investment, leading to erroneous conclusions about the feasibility of 'green' growth (Jackson and Victor 2019b, Victor and Sers 2019).

The level of green investment in the scenarios described below is determined by the need to achieve a given environmental target. Broadly speaking, LowGrow SFC simulates four kinds of changes in response to such targets:

1) the electrification of the economy;
2) the decarbonisation of the electricity sector;
3) the decarbonisation of the non-electricity sector; and
4) non-carbon related environmental improvement.

The first three changes are associated with the need to tackle climate change by reducing carbon emissions from economic activity. The last allows us to make some simplistic assumptions about additional investment needed to protect biodiversity (for instance) or to reduce other environmental impacts. The first two dimensions above are modelled in a more detailed way than the last two, but in combination these aspects of the model allow us to parametrise various environmental and resource implications of the economy and to explore the transition to a sustainable economy.

9.1 Electrification of the economy

It is generally assumed that the transition to low- or net-zero carbon will require a shift in the energy sector of the economy towards increasing electrification of road and rail networks. LowGrow SFC simulates such a transition as part of its description of environmental dimensions. The broad structure of the way we model the electricity system is illustrated in Figure 4. The underlying demand for electricity, $\tilde{Q}$, is determined from the GDP through a simple electricity intensity parameter, e, according to:

$$\tilde{Q} = eGDP. \tag{83}$$

The intensity, e, can be progressively reduced over the course of a run, depending on scenario assumptions, so that:

$$e = e_{-1} - \varepsilon_1, \tag{84}$$

where ε_1 represents a scenario-specific improvement in overall electricity efficiency. To this underlying demand is added a component of demand, $\tilde{Q}_+$, associated with an increase in the electrification of the road and rail sector:

$$\tilde{Q}_+ = \tilde{x}W \tag{85}$$

where W is the energy required for road and rail transport expressed in terms of electricity demand and $\tilde{x}$ is a conversion factor which increases from zero at a linear rate ε_2 over a specified time frame according to:

$$\tilde{x} = \tilde{x}_{-1} + \varepsilon_2. \tag{86}$$

The overall electricity demand, Q, is then given by:

$$Q = \tilde{Q} + \tilde{Q}_+ \tag{87}$$

The model also includes an adjustment to overall demand on the basis of a 'price effect' – for example a suppression of demand when the price of energy rises above the price in a 'base case' scenario.

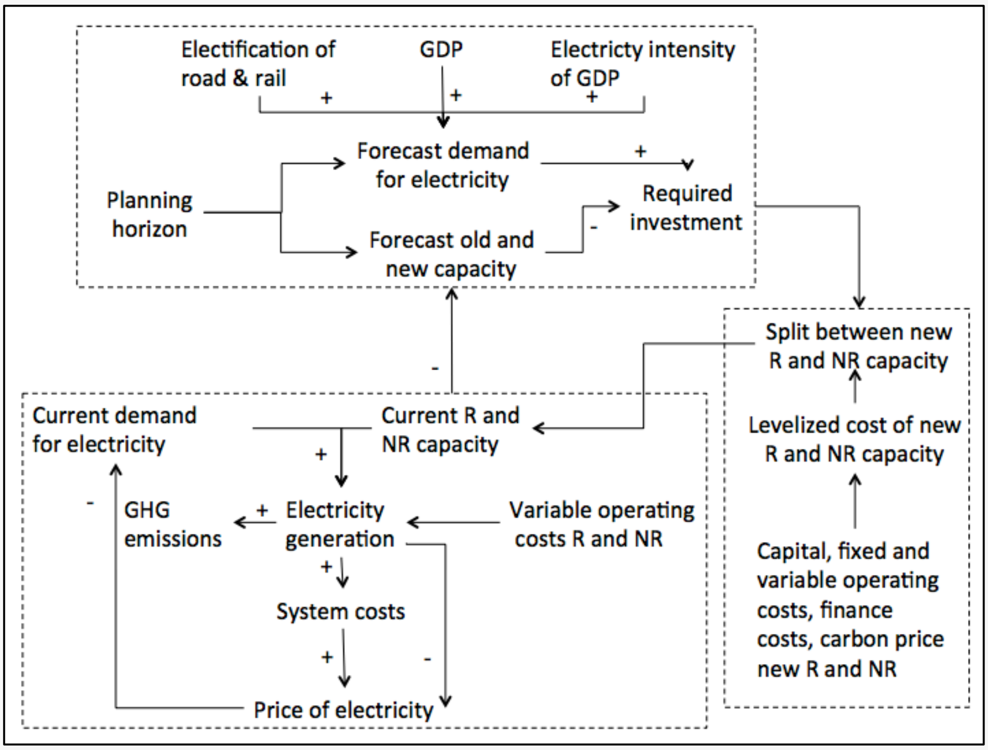

Figure 4 | *A schematic overview of the electricity sector*

9.2 Decarbonisation of the electricity sector

Once the overall demand for electricity is known, the model then simulates investment decisions in new generating capacity, taking into account the expected demand along the planning horizon, the rate at which existing plant is coming to the end of its life and (in some scenarios) the desire to shift away from non-renewable (NR) generating capacity and towards renewable (R) generating capacity.[49] In most scenarios, the allocation of investment to each type of generation (NR or R) is price-induced. Specifically, the market shares, ξ_{NR} and ξ_R, of non-renewable and renewable generation (respectively) is based on the relative 'levelized cost' of each technology:[50]

$$\xi_{NR} = (lc_{NR})^{\chi}/((lc_{NR})^{\chi} + (lc_R)^{\chi}) \text{ and}$$

$$\xi_R = (lc_R)^{\chi}/((lc_{NR})^{\chi} + (lc_R)^{\chi}), \qquad (88)$$

where lc_{NR} and lc_R are the levelized unit costs of non-renewable and renewable technologies respectively and χ is a user-defined market-share parameter which is adjustable in the model.[51] The levelized costs themselves are derived from current levelized costs for renewable and non-renewable technologies in the Canadian economy. We assume that these costs change according to a given profile as renewable technologies become cheaper and non-renewable technologies become more expensive over time. At any point in time, this investment portfolio gives rise to a fixed amount of capacity of non-renewable (NR) and renewable (R) electricity generation plant that can be used to meet the current demand for electricity.

The model then simulates the dispatch of electricity from the available installed capacity, allowing for own use of electricity by the electricity sector and transmission losses, on the basis of their respective variable costs.[52] Generation sources are prioritized in the model based on lowest variable operating cost in the following order: (1) existing renewable sources; (2) new renewable sources; (3) new non-renewable sources; (4) existing non-renewable sources.

The model also responds to a shortage or surplus of electricity generation at any given time by feeding the supply-demand balance into the investment decision-making process. If there is a surplus, which can happen if new capacity is added that is subject to a minimum capacity factor, no additional new

49 The renewable and non-renewable technologies are weighted composites of several technologies: onshore wind, solar photovoltaics and hydroelectric for renewables, and natural gas, coal and nuclear for non-renewables.
50 The levelized cost is a well-defined way of identifying an average cost per unit of electricity generation for a given technology over its lifetime. These levelized costs include capital costs, operating costs, financing costs and a carbon price. Storage costs are also included for renewable sources to overcome the problem that some renewable electricity supplies are intermittent.
51 In the scenarios in this working paper the value adopted for χ is 2.1.
52 These variable costs differ from the levelized costs in only including the fuel, operating and maintenance costs of the respective technologies – and omitting fixed costs associated with capital investment.

capacity is added until the surplus is eliminated. If there is a shortage, this is included in the demand for electricity in the assessment of the need for additional capacity.

The principal output measure from this side of the model is the calculation of carbon emissions from electricity generation. For the non-renewable technologies, these based on established emission factors for fossil fuel (and nuclear) electricity generation.[53] The carbon emission factor for renewable sources of electricity is set at zero. In scenarios, where electrification of road and rail transport is phased in, the resulting reduction in carbon emissions is also estimated and subtracted from the carbon emissions associated with non-electricity emissions. Under an option in the model to set a net zero carbon target, it is possible to choose the time at which no further investment is made in non-renewable sources of electricity.[54]

There are numerous interactions between the electricity sector and the rest of the economy. Most obviously, of course, GDP is one of the main drivers of the demand for electricity. At the same time, green investment for electricity generation and distribution arising from road and rail electrification or resulting from a shift from non-renewable to renewable technologies will have an impact on both short-run aggregate demand and long-run productivity. In the scenarios developed in this paper, decarbonisation investment is considered to be non-additional (Table 2) and therefore to reduce firms' net productive investment. On the other hand, if investment for electricity declines because a carbon price reduces electricity sales, this is assumed to free up additional productive investment in the firms' sector. The revenues associated with any carbon price imposed in a scenario go to the government (see section 5 above) with the option in the model of reducing income and profits taxes so that the carbon price is revenue neutral.

9.3 Decarbonisation of the non-electricity sector

Carbon emissions from the generation of electricity are incorporated into a wider account of the carbon (greenhouse gas) emissions arising from the economy as a whole. Broadly speaking, the model adds the emissions calculated in the previous subsection to those attributable to the rest of the Canadian economy, calibrated on the basis of historical data. Emissions from non-electricity sector sources are assumed to depend on the endogenous rate of economic growth, r_g, the rate of energy efficiency improvement, r_{eff}, and a

53 Various data sources were used to calibrate the electricity sector sub-model, the main ones being the US EIA 2017, the IEA 2014 and Environment Canada 2014. These sources provided information on the capital costs, fixed and variable operating costs and GHG emissions for each technology.

54 Net zero emissions can be achieved by eliminating all carbon emissions or by achieving a rate of carbon removal at least equal to the level of carbon emissions.

background rate of decarbonisation, r_{decarb}, so that in the base case, Carbon emissions, GHG, are given by:[55]

$$GHG = GHG_{-1}(1 + r_g - r_{eff} - r_{decarb}). \tag{89}$$

Further abatement of non-electricity sector carbon emissions can be triggered in the model over and above this background level of abatement. The precise reduction profile depends on the scenario chosen in the model. Under an option in the model to achieve a net zero carbon target, it is possible to choose the time over which non-electricity sector carbon emissions are reduced to zero.

Whereas the costs of abatement in the electricity sector flow from the levelized costs of electricity generation associated with investment in renewable energy, the overall costs of abatement in the non-electricity sector are estimated as a percentage of the GDP using a parametrisation established by Cline (2011) on the basis of an aggregate carbon abatement cost curve drawn from two separate studies.[56]

Specifically, Cline (2011) reports cost estimates for carbon dioxide emission reductions of 17% in 2020, 42% in 2030, 65% in 2040 and 89% in 2050. For the Net Zero Scenario, we extrapolated these reductions backwards to 2012, where they are assumed to be zero, and forward to 2100, where they are assumed to be 100%.

Following Ackerman and Bueno (2011), we assume that negative cost technologies are already included within the background abatement set out in the previous paragraph. The costs for incremental abatement over and above this background level are parametrised using the Cline cost curve. To avoid double counting, both the costs and the emissions abatement estimated using the Cline parametrisation are reduced by a proportion equal to the ratio of carbon emissions from electricity to overall carbon emissions in 2012.

The costs of these incremental non-electricity sector carbon abatements are deemed to fall partly on consumers and partly on businesses. A proportion, α_{16}, of the overall costs, C_{ca}, of carbon abatement is deemed to be associated with investment, which is carried out by firms, and must be financed as part of their non-additional green investment expenditures (see Section 4). The remaining costs $(1 - \alpha_{16})C_{ca}$ are assumed to be an additional cost on consumers and are subtracted from the household consumption calculated in equation (9) in Section 3 above.

55 In the scenarios in this paper, the background rate of energy efficiency improvement falls from 1.64% to 0.75% over the first 25 years of the run in line with assumptions in Cline (2011). The background rate of decarbonisation falls from 0.32% to 0.09% over the same period.
56 The abatement cost functions in Cline (2011) are for CO2. They have been adjusted based on CO2 as a proportion of global GHG emissions in 2012. (US EPA, http://www3.epa.gov/climatechange/ghgemissions/global.html.

9.4 Non-carbon related environmental improvement

Climate change is not the only environmental problem of concern. The planetary boundaries literature (Steffen et al 2015) identifies nine environmental problems of global concern, including climate change. Of particular concern, are the impacts arising from human activities on the habitats of other species triggering unprecedented loss in biodiversity (IPBES 2019). It is beyond the scope of this version of LowGrow SFC to model policies aimed at reducing non-carbon related environmental impacts in detail. However, it was felt important to signal the vital importance of these non-carbon impacts. Consequently, we have included a simple model of non-carbon-related green investment, which treats these other environmental impacts as a single variable. Specifically, we assume that there is a component of green investment (see section 4) which aims to build up a stock of new 'green capital', K^g. This green capital then provides a certain level of additional environmental services, $r^g K^g$, at a given 'rate of return', r^g.

Given the very heterogeneous nature of this capital, the kinds of services that it provides and the range of environmental pressures that it is designed to mitigate, there are no data on which a meaningful rate of return can easily be based. For example, stilts can be used to provide space between the ground and the first floor of buildings located by the coast to reduce flood damage from rising ocean levels. This extra investment may only yield benefits rarely, but when it does, the benefits can be very significant. Improved soil management might only change yields marginally at first, but by enabling a more sustainable capacity of the soil to support crop growth they provide a lasting supply of food well into the distant future. For the purposes of this paper we adopt a default rate of return of environmental services on new green capital of 5%. These environmental services are then accounted for as a benefit in our performance indicators – to the development of which we now turn.

10 | Measuring Performance

LowGrow SFC generates the values of many variables which can be used to assess the performance of the economy. In the scenarios described in the following section, several conventional indicators are reported. These include: the GDP, GDP per capita, the rate of unemployment, carbon emissions, the ratio of government debt to GDP, and the ratio of household loans to net worth.

It can be useful to combine several indicators into a single index to gain an overall assessment of system performance. GDP is all too often used in this way despite its inclusion of items that bear no relation to well-being, the exclusion of others that do, and the reliance on market prices to measure value.[57] These

57 For a discussion of the limitations of the GDP as a measure of progress see (eg) Jackson 2017, Victor 2019). For an analysis of different kinds of 'green indicators' see Corlet-Walker and Jackson 2019, eg).

inadequacies of GDP are well-known and yet its popularity remains strong. One of the reasons for this is that economists have developed an extensive understanding of GDP and what lies behind it. When GDP grows, and we have some understanding of the reasons for the growth, we can make forecasts of future growth and design policies to promote it.

The fact that GDP emerges from a model of the economy is both a blessing and a curse. It is a blessing because it means that GDP is not just a passive metric that can be measured and monitored. It is a curse because it only captures a part of what matters in society and, by promoting its growth with such enthusiastic single-mindedness, we can miss opportunities that have a more beneficial effect on human well-being. To offset this danger, we have developed two additional composite indicators that are used to describe the scenarios developed in this paper: the Environmental Burden Index (EBI) and the Sustainable Prosperity Index (SPI). The EBI is designed to capture the environmental impacts of economic activity notably absent from GDP. The SPI is based on a combination of economic, environmental and social variables that provides a more comprehensive measure of how well or badly the economy is doing.

Both of these indicators should be regarded as preliminary in that there are many ways in which they could be improved if more and better data were available. However, the EBI and SPI both share with GDP the redeeming feature that they emerge from a model of the system in whose performance we are interested and so can be used to measure the effect of measures designed to make the system work better.

10.1 The Environmental Burden Index (EBI)

Economic activity has a diverse range of impacts on the environment. Many of these impacts are exacerbated by economic growth. Aside from the question of carbon (greenhouse gas) emissions, we make no attempt to capture these pressures in any detail in this version of LowGrow SFC. Rather we employ an environmental burden index (EBI) which attempts to capture the four distinct kinds of changes described in Section 9, and also to reflect the potential 'co-benefits' associated with carbon reduction.

The structure of the EBI, which has an initial value of 100, is shown in Figure 5. It consists of three components. The first component of the index (shown in the top panel in Figure 5) accounts for the level of carbon emissions over time. Specifically, the carbon component of the index, EBI^{ghg}, is defined by:

$$EBI^{ghg} = \omega_{ghg}(GHG/GHG_{2017})100, \qquad (90)$$

where GHG represents carbon emissions and ω_{ghg} is the initial weight assigned to carbon within the index.[58]

58 For the scenarios in this paper we have adopted a value of 0.25 for this initial weighting. This is the weight given to 'climate and energy' in the Environmental Performance Index

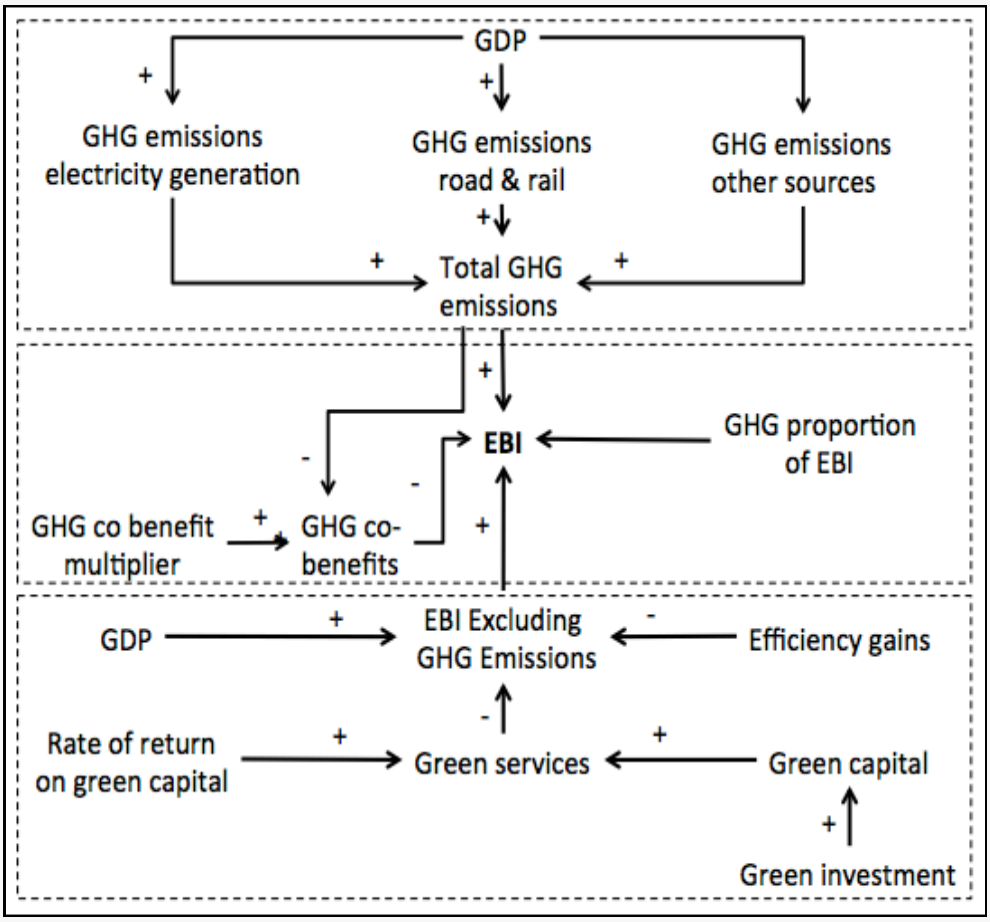

Figure 5: *The Structure of the Environmental Burden Index (EBI)*

Reductions in carbon emissions often lead to reductions in emissions of other pollutants, providing what are called 'co-benefits' from decarbonisation (shown in the middle panel in Figure 5). These co-benefits are health and environmental benefits that come from reductions in contaminants such as particulates which occur as a result of the reduction in carbon emissions. There is a considerable body of literature on these co-benefits, pointing out that their size relative to the climate change benefits from reduced carbon emissions depends very much on time, place and circumstances (Hamilton et al. 2017). This second component, EBI^{co}, of the index is calculated as:

$$EBI^{co} = (EBI^{ghg} - 100\omega_{ghg})\omega_{co}, \tag{91}$$

produced by Yale University (Hsu et al. 2016), for example. Yale's Environmental Performance Index is broad, detailed and well-documented, yet, as the authors acknowledge, it is not fully comprehensive because of a lack of globally comprehensive data. Areas where the data are incomplete include: freshwater quality, species loss, indoor air quality of residential and commercial buildings, toxic chemical exposures, municipal solid waste management, nuclear safety, wetlands loss, agricultural soil quality and degradation, recycling rates, and adaptation, vulnerability and resiliency to climate change (Hsu et al. 2016, p. 33). GHG_{2017} is the level of carbon emissions in the base year 2017.

where ω_{co} is the co-benefits multiplier, ie the additional environmental benefits per unit of reduction in carbon emissions.[59]

The final component of the index (shown in the bottom panel in Figure 5) is a generalised measure of environmental burden, EBI^{gen}, which attempts to capture a variety of different influences on the environmental burden imposed by the economy. For instance, it is assumed to increase as the GDP does, to decrease according to the environmental efficiency improvements associated with energy efficiency and decarbonisation and to decrease with increasing investment in green capital. The initial value of EBI^{gen} is defined by:

$$EBI_{2017}^{gen} = 100\left(1 - \omega_{ghg}\right). \tag{92}$$

Year on year changes are determined according to the following equation:

$$EBI^{gen} = EBI_{-1}^{gen}(1 + r_g - \tilde{r}_{eff} - r^g K^g / K^{gT}), \tag{93}$$

Where $\tilde{r}_{eff}$ is a background rate of (non-energy related) environmental efficiency improvement and K^{gT} is a 'target' level for additional green capital for the economy as a whole.[60] The overall environmental burden index is then constructed according to:

$$EBI = EBI^{ghg} + EBI^{co} + EBI^{gen}. \tag{94}$$

10.2 The Sustainable Prosperity Index (SPI)

Our broad understanding of sustainable prosperity (Jackson 2017) is that it consists in our ability to flourish as human beings on a finite planet. It remains an open question how progress towards this goal should be measured. Several indices have been developed in the literature to address shortcomings of GDP as a measure of social progress, by taking into account a wider range of factors that contribute to well-being.[61]

All these measures have something to offer in the effort to improve how we track the performance of the economic, social and environmental systems

59 In the simulations described in this paper, our default assumption is that co-benefits are equivalent to 20% of the benefits of reductions in carbon emissions.
60 Specifically, in the scenarios in this paper the background rate of environmental efficiency improvement declines from around 0.7% to 0.3% over the first 25 years of the run, somewhat less than half the value of the assumed background rate of energy efficiency improvements. The value chosen for the target value of green capital is $10 trillion. This value was chosen principally to facilitate comparison of carbon and non-carbon related changes to the EBI within the same index. It is interesting to note, however, that this value is also the value of Canada's natural wealth – as estimated by the UN Environment Programme's Inclusive Wealth report (UNEP 2012).
61 Examples include the Human Development Index (UNDP 2015b), the Genuine Progress Indicator (Kubiszewski et al. 2013), the Canadian Index of Wellbeing (CIW 2016) and the Inclusive Development Index (WEF 2018). See Corlet Walker and Jackson (2019) or Stiglitz et al. (2009) for a review of some of these alternative measures.

within which we live. Yet they lack an important dimension: they do not emerge from an articulated model of the system whose performance we are interested in. As noted earlier, this stands in marked contrast to GDP, which is constructed on the basis of a consistent macroeconomic model of the economy.

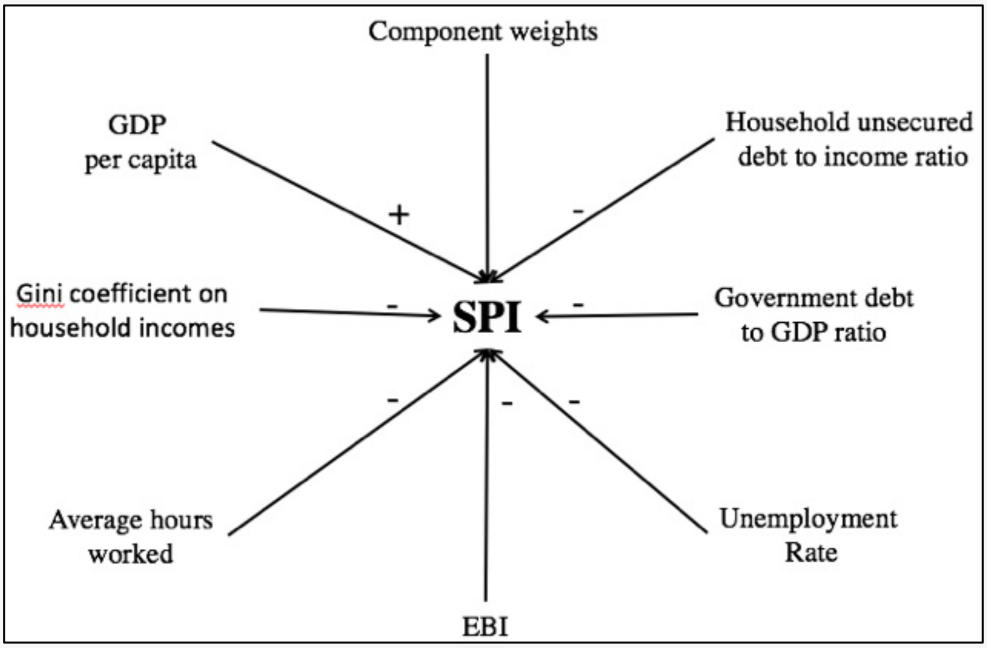

Figure 6: *Overview of the Sustainable Prosperity Index*

In order to compare and assess scenarios generated by the model described in this chapter, we have developed a new composite index – the Sustainable Prosperity Index (SPI) – drawn from variables of interest in the model (Figure 6). Specifically, the SPI consists in a weighted sum of measures of the GDP per capita, the Gini coefficient on household incomes, the average hours worked in the economy, the ratio of unsecured household debt to income, the government debt to GDP ratio, the unemployment rate and the EBI (as defined in the previous subsection). The signs shown in Figure 6 indicate whether SPI increases or decreases as the respective components increase. A '+' indicates that the SPI moves in the same direction as changes in the component measure, and a '−' indicates that the direction of change of the SPI is in the opposite direction to the component measure. For example, as the GDP per capita increases, so does the SPI (albeit in a non-linear way). On the other hand, as the ratio of unsecured debt to household income rises, so the SPI falls.

The default weights in the SPI that are used to combine the variables into a single index are constants except for those applied to the unemployment rate, the ratio of unsecured household loans to incomes, the ratio of government debt to GDP and the EBI. The weights applied to these variables increase as their size rises, to reflect the observation that concern is low or non-existent at low levels but rises in a non-linear manner as they increase. The contrary is the case for the ratio assigned to GDP per capita since, following Helliwell et al. (2017,

Table 2.1), the logarithm of GDP per capita is used in the SPI with a constant weight. This has the effect of reducing the weight given to GDP per capita as the economy grows.

The SPI is designed to provide an overall assessment of the performance of the economy as it emerges from the LowGrow SFC model. It also provides a means of assessing the results of any proposed policy intervention or system change that can be represented in the model. Since GDP is also generated by LowGrow SFC, it is possible to compare GDP with the SPI at aggregate and per capita level in any scenario generated by the model. Our broad aim in this paper is to use the SPI as a diagnostic tool to explore the evolution of several different scenarios emerging from LowGrow SFC, which we describe in the next section of the paper.

Nonetheless, it is important to recognise that the SPI, as defined here, inevitably has limitations. Its scope is restricted to the variables in LowGrow SFC and there is an inevitable arbitrariness to the weights used to add up these variables into a single number. Fortunately, these weights can be changed to test the sensitivity of a comparison of scenarios to the chosen weights.

Jones et al. (2016) recognize that 'quantified indicators for the implementation and measurement of social progress is a well-established policy tool', but that they can over-simplify and 'fail to do justice to objectives like sustainable prosperity'. They conclude that 'indicators can be a useful tool for constructing new understandings, holding powerful actors to account and enabling engagement with policy end goals' (Jones et al. 2016, p. 1). This is precisely in accordance with our view of the SPI.

11 | Three Futures for the Canadian Economy

In this section, we describe three potential scenarios for the Canadian economy. None of these scenarios is a prediction of the future. Rather they are intended to illustrate some of the possibilities facing Canada, to inform discussion and debate, and to suggest the kinds of choices available, not just to Canada but to similar economies, as we move further into the 21st century. The three scenarios presented here run over a period of 50 years from the beginning of 2017 until the beginning of 2067, the year in which Canada will mark the 200th anniversary of the establishment of the Canadian Federation.

Base Case Scenario

The *Base Case* scenario is a description of what would happen, broadly speaking, at the national level, if current trends continue through and beyond mid-century. It assumes that the Canadian economy will perform on average over the period 2017 to 2067 in much the same way as it did in the preceding 25 years or so. The *Base Case* is therefore a benchmark against which other scenarios can be compared. It is not in itself a prediction of what will happen in the absence of policy interventions. It says nothing about the marked regional differences that would accompany such trends. LowGrow SFC is simply too highly aggregated to reveal anything quantitative at the sub-national level.

However, we can be confident that, just as in the past, the economic fortunes of different parts of the country have moved in different, sometimes opposite, directions, so they will continue to do so in the future. Other than noting the importance of these regional differences, the focus in all that follows remains on national trends.

Some of the variables in the base case are based on predictions from other sources. For instance, we use the Statistics Canada population projections to define population growth in the model,[62] and as described above, we have calibrated starting values for the financial stocks and flows and the greenhouse gas emissions (for example) based on Canadian data.

Carbon Reduction Scenario

The *Carbon Reduction Scenario* adopts several policy measures specifically focused on reducing carbon emissions.[63] We simulate a comprehensive program of carbon emission reductions consisting of a substantial carbon price on GHG emissions from the electric power sector, GHG emissions reduction investments in the other economic sectors, and the electrification of road and rail transport. Emission reductions come from the increased use of renewable sources of electricity and the electrification of road and rail transport.

The conversion to renewables is induced by an increasing price on emissions from the electricity sector which affects the market share of renewables in the selection of new generating capacity as described Section 9. Preference is given to renewables in the dispatch of electricity since they have lower operating costs than non-renewable sources. A minimum requirement that 5% of dispatched electricity comes from new non-renewable sources is imposed to ensure they are kept in service ready to provide back up if renewable sources are inadequate.

A carbon price is a financial payment based on the quantity of greenhouse gas emissions.[64] The main means for imposing a carbon price is through a fee or tax, through emissions trading or a combination of the two. Several Canadian Provinces have introduced carbon pricing schemes. For example, British Columbia has a carbon tax and Quebec participates in a cap and trade emissions

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62 Statistics Canada (2017f) provides three projections to the year 2063, each of which can be selected in LowGrow SFC. Population values for years after 2063 are extrapolated based on the trend in the data. In the Base Case, we use the central population projection in which the Canadian population is expected to rise from 36.6 million in 2017 to 52 million in 2067.

63 This scenario is very similar to the one described as the GHG reduction scenario in Jackson and Victor 2019a. Despite the difference in nomenclature, both scenarios cover all main greenhouse gases.

64 Depending on the scope of the carbon pricing system, greenhouse gases in addition to carbon dioxide are converted to a CO2-equivalent and the price is imposed on the total quantity.

trading system. There is no single carbon price in Canada, but in 2017 the Federal Government announced its intention to impose a floor price of $10 per tonne of GHG emissions, rising by $10 per year to $50 per tonne in 2022. This carbon price will be imposed by the Federal Government on Provinces that do not have at least an equivalent carbon price in place (Government of Canada 2017). The federally established minimum is included in the base case.

In the *Carbon Reduction Scenario*, the $10 per year annual increase in the carbon price continues beyond 2022 for another 10 years, reaching a total of $300 per tonne on GHG emissions from the electric power sector. The effect of the carbon price is to increase the cost of generating electricity from fossil fuels and to increase the proportion of new generating capacity from renewable sources, leading to a reduction in GHG emissions (as described in Section 9). It also increases the price of electricity. Some of the additional costs of electricity to businesses are passed on to consumers, which tends to reduce households' demand for commodities in general. The additional costs to business are treated as a reduction in business investment. Increases in investment costs in the electricity sector stimulated by the carbon price (excluding the payment of the carbon price, which is a transfer between sectors) are treated as non-additional and non-productive investment (Table 2 in Section 4).

The use of fossil fuels in road and rail transport accounts for about a quarter of Canada's total carbon emissions (Government of Canada 2017). In the *Carbon Reduction Scenario*, the electrification of road and rail transport is assumed to proceed at 2% per year until 100 percent electrification is achieved. The transition will require more investment in the rail system (Fisher 2008) and in the installation of electric charging stations (Berman 2014). Electric vehicles are assumed to replace petrol and diesel-powered vehicles as they are taken out of service at no additional cost. All of the investment associated with road and rail electrification is deemed to be non-additional and non-productive.

Sustainable Prosperity Scenario

Finally, the *Sustainable Prosperity* scenario includes all of the innovations included in the *Carbon Reduction Scenario* and, in addition, it introduces further measures aimed at reducing a wider set of environmental impacts.[65]

Firstly, we impose a faster transition towards a net zero carbon economy, aiming to meet a net zero target by 2040. In order to avoid asset stranding, we stipulate that no non-renewable electricity generation capacity is built after 2025 and relax the 'minimum dispatch' setting of 5% from non-renewable sources. The rate of road and rail electrification is increased from 2% per year

65 Note that the Sustainable Prosperity Scenario described in this paper differs from the one described in Jackson and Victor 2019a in the online user-interface – in incorporating a net zero target of 2040. (Both versions of a Sustainable Prosperity Scenario are included in the online user-interface and both can be recreated by setting the control variables on the interface at the appropriate levels).

in the *Carbon Reduction Scenario* to 5% per year. This ensures that the electrification of road and rail transportation is fully achieved by 2040.

In the non-electricity sectors, we again adapt Cline's cost curve estimates as described in Section 9. However, the abatement cost curve was adapted to account for the increased cost of reaching net zero prior to 2100. Specifically, the costs given by the Cline estimate were increased by a constant factor π, defined by the number of years between the policy start year and the end of the century divided by the number of years from the policy start year to the net zero target year.[66]

Additional non-carbon environmental improvements are also specified in the Sustainable Prosperity Scenario. Specifically, starting in 2020 some of the depreciation of brown capital is invested in green capital. The percentage rises steadily over the next 20 years until a diversion rate of 20 percent is reached. Of this green investment, 50 percent is assumed to be productive, meaning that it continues to add to the capacity of the economy to produce goods and services that are included in GDP. The other 50 percent of this green investment is assumed to be non-productive, though of course it does generate significant (non-market) environmental benefits.

The *Sustainable Prosperity Scenario* also includes policies aimed at achieving beneficial social outcomes. This scenario introduces a substantial increase in annual transfer payments to reduce the inequality of incomes. Starting in 2020 these additional transfer payments increase until they amount to $20 billion per year (in 2007$). They are distributed to each income category based on the proportion of people with pre-tax incomes greater than the average income in that category, using data from Statistics Canada (2017). The greatest share of the increased transfers goes to people in the lowest income category of less than $5000 per year. Declining shares go to those in progressively higher income categories until those with incomes greater than $250 000 per year receive no additional transfers. The model calculates the change in the Gini coefficient of the distribution of pre-tax incomes over time from the additional transfer payments.[67]

Two further assumptions are changed in the *Sustainable Prosperity* scenario. First, we assume a slower rate of population growth (the low projection in Statistics Canada 2017 stabilizing after 2063). Second, we introduce a decline in the average hours worked.

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66 Since the start year is 2020 and the net zero target year is 2040, π is calculated as 80/15 = 5.3 in this scenario.

67 Distribution is made on the basis of pre-tax individual income since available data do not permit the calculation to be based on households. Since some households have more than one income earner, the Gini coefficient for the distribution of pre-tax household income is different from (likely lower than) the distribution of pre-tax individual incomes.

12 | Scenario Results

It is instructive to start our comparison of the results from the model by looking at the estimated GDP per capita over the period. Figure 7 shows this comparison for the three scenarios. Under the *Base Case*, per capita GDP about doubles from $52,000 in 2017 to just over $100,000 in 2067, with an average growth rate of 1.3 percent.[68] This is essentially a conventional, growth-based view of the future, in which the economy as a whole (taking into account population growth of around 44 percent) increases its magnitude 2.8 times by the year 2067.

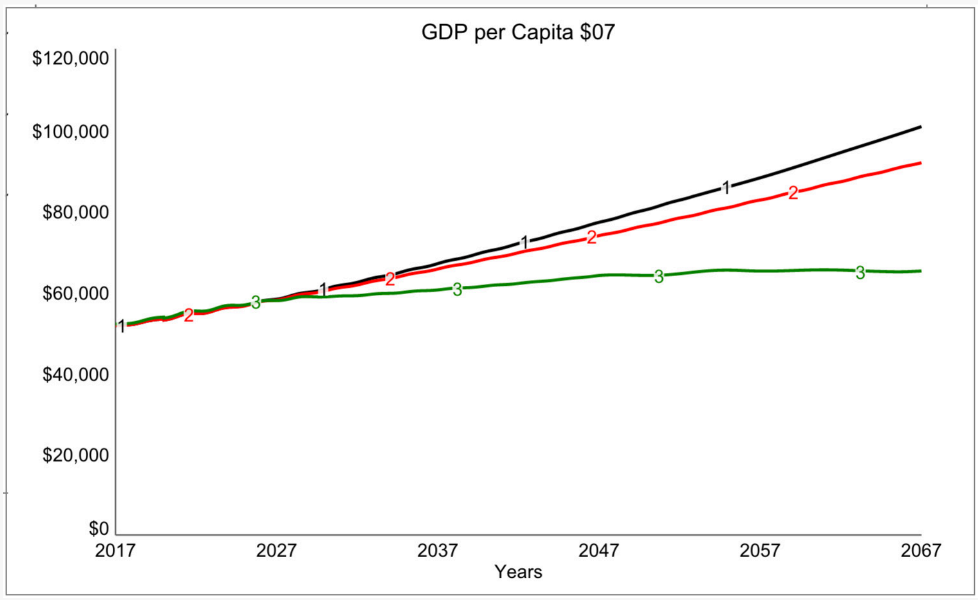

Figure 7: *Gross Domestic Product (GDP) per capita: 2017 – 2067*
1=Base Case; 2=Carbon Reduction; 3=Sustainable Prosperity

The *Carbon Reduction Scenario* has a somewhat lower average growth rate in GDP per capita of 1.1 percent, with incomes in 2067 reaching a level of nearly $92,000 per annum. It is worth remarking that the reduced rate of economic growth in this scenario is at the high end of the range of estimates of the impact on GDP from achieving significant reductions in greenhouse gas emissions, as cited in the literature (Ekins 2017). It also runs counter to the view that a green economy grows faster than a brown one (Bassi 2011; Victor and Jackson 2012). In LowGrow SFC, the reduction in economic growth comes about because of the diversion of investment away from the expansion of conventional 'brown' capital. Slower growth in brown capital means slower growth in labour productivity and hence a slower rate of growth in GDP. Other studies obtain an increase in the rate of economic growth from environmental expenditures because they assume that there is unused capacity in the economy. In this case,

68 Unless otherwise stated, values are in 2007 Canadian dollars.

green expenditures lead to increase aggregate demand which would not have happened otherwise.

The *Sustainable Prosperity Scenario* shows much more clearly marked differences from the base case, revealing a stabilization of per capita income at a level slightly above current income levels by the end of the run. Specifically, the GDP per capita in 2067 is $65,000 – an average annual increase of only 0.4 percent over the period. More significantly, both GDP and GDP per capita are essentially stable over the final twenty years of the scenario.

This scenario illustrates a transition from a growth-based economy to a quasi-stationary-state economy (Jackson and Victor 2015). The declining rate of economic growth and ultimately its cessation altogether result from the reduced investment in productive capital, the increased costs associated with deep carbon abatement and other green investments, and the reduction in average work hours.

Conventional wisdom would suggest that such a transition is impossible without causing irreparable damage to prosperity and well-being in society. But Figure 8 suggests that this undesirable outcome is avoided. In fact, the composite SPI described in the section 10 rises significantly in the *Sustainable Prosperity Scenario* despite falling in both the other two scenarios. Starting from a base of 100 in 2017, the SPI falls precipitously by more than 50% in the *Base Case*. Even in the *Carbon Reduction Scenario*, the SPI declines 11%. In the Sustainable Prosperity scenario, by contrast, the SPI increases 35 % between 2017 to 2067.

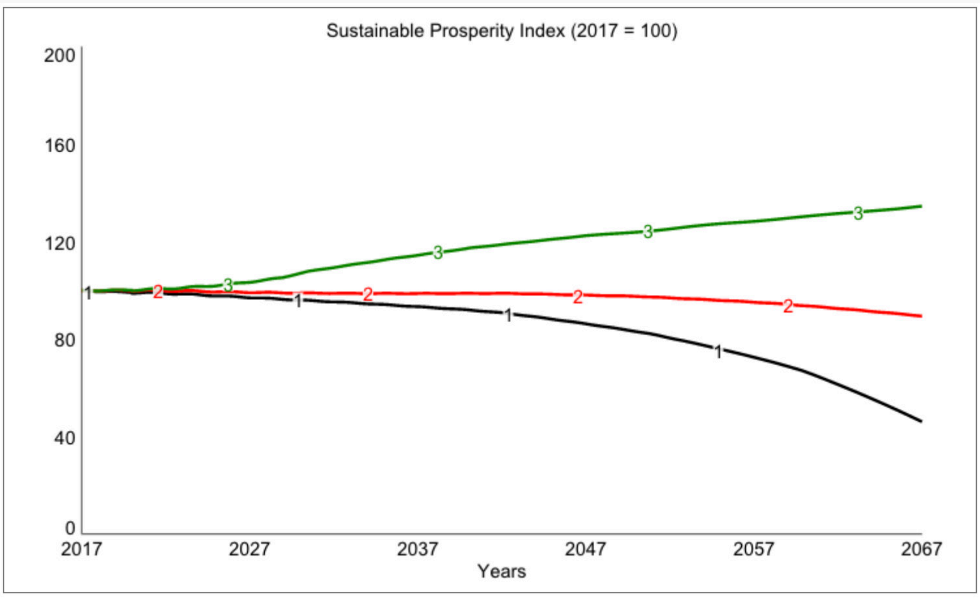

Figure 8: *Sustainable Prosperity Index (SPI): 2017 – 2067*
1=Base Case; 2=Carbon Reduction; 3=Sustainable Prosperity

To understand the reason for these differences, we must examine the component parts of the SPI (Figure 6) in more detail. One of those components is the GDP per capita itself, which tends to push the SPI upwards, the higher the level of GDP. This ought to be helping to maintain a high level of SPI. So clearly there are other factors which offset this apparent advantage for the *Base Case*. Alongside the GDP per capita, lie a variety of other indicators, some environmental, some social, some financial in nature, each of which has some effect on the overall measure of the SPI. These components are clearly sufficient to allow the *Sustainable Prosperity Scenario* to perform much better over the long run. It is worth looking at each of them in turn.

Environmental Influences on the SPI

Principal amongst the factors which favour the *Sustainable Prosperity Scenario* over the *Base Case* is the Environmental Burden Index (EBI), designed to include, amongst other things, the negative impact of carbon emissions. Figure 9 illustrates the changes in the indexed value of the EBI over time.

Clearly, here is a partial explanation for the reversal of fortunes witnessed as we move from an indicator based on GDP towards a broader measure of sustainable prosperity such as the SPI. The EBI for the *Base Case* more than triples over the period of the scenario, as greenhouse gases continue to rise and little is done to offset other environmental impacts from the economy. Since a rising EBI depresses the SPI, there is a partial explanation here for the poor performance of the *Base Case* in Figure 8.

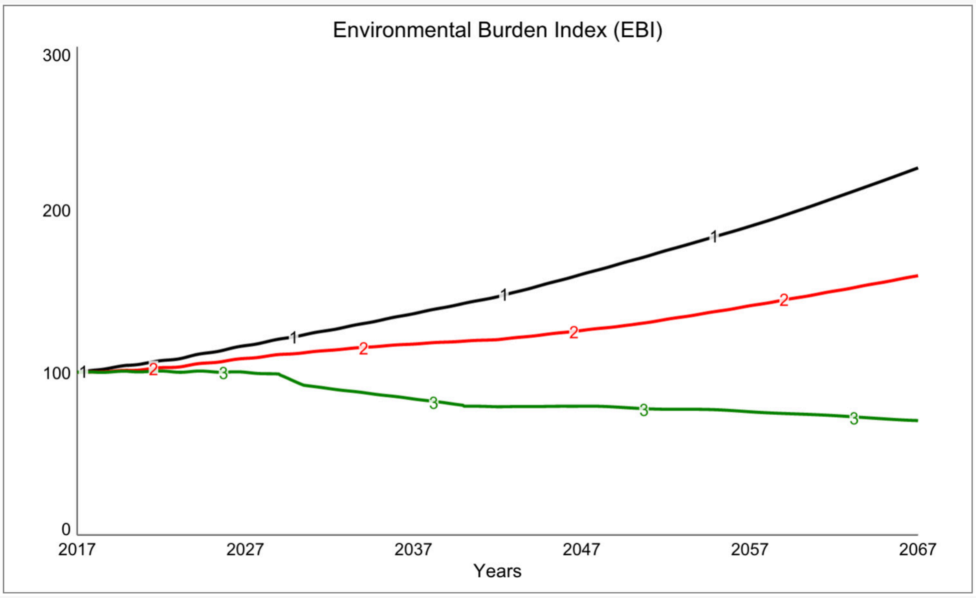

Figure 9: *Environmental Burden Index (EBI): 2017 – 2067*
1=Base Case; 2=Carbon Reduction; 3=Sustainable Prosperity

The EBI for the *Carbon Reduction Scenario* performs significantly better. The main reason for this is a significant decline in carbon emissions resulting from the combination of measures described in the previous section, alongside the somewhat lower rate of economic growth. Figure 7 showed that the GDP per capita still increases by almost 80% by 2067 for the *Carbon Reduction Scenario*. But greenhouse gas emissions decline to 27% of their level in 2017.[69] This is a version of 'green growth', though growth here is slower (not faster as some would claim) than the *Base Case*.

Disappointingly, the reduction in carbon emissions in the *Carbon Reduction Scenario*, while substantial, still falls short of the Canadian government's 80% reduction by 2050 (Munson 2016) with a projected decline of just over 60% from 2017 to 2050 as shown in Figure 10. Nonetheless, the reduction is sufficient to suppress the rise in the EBI and in doing so has a notably positive effect on the SPI shown in Figure 8. Certainly, the steep decline in SPI visible for the *Base Case* has been avoided. With a determined effort to reduce carbon emissions, the SPI declines much less than in the Base Case, most of the decline coming after 2050. Put another way, even though the GDP per capita is projected to grow at an average 1.1% per year in the *Carbon Reduction Scenario*, well-being as measured by the SPI declines slowly but steadily.

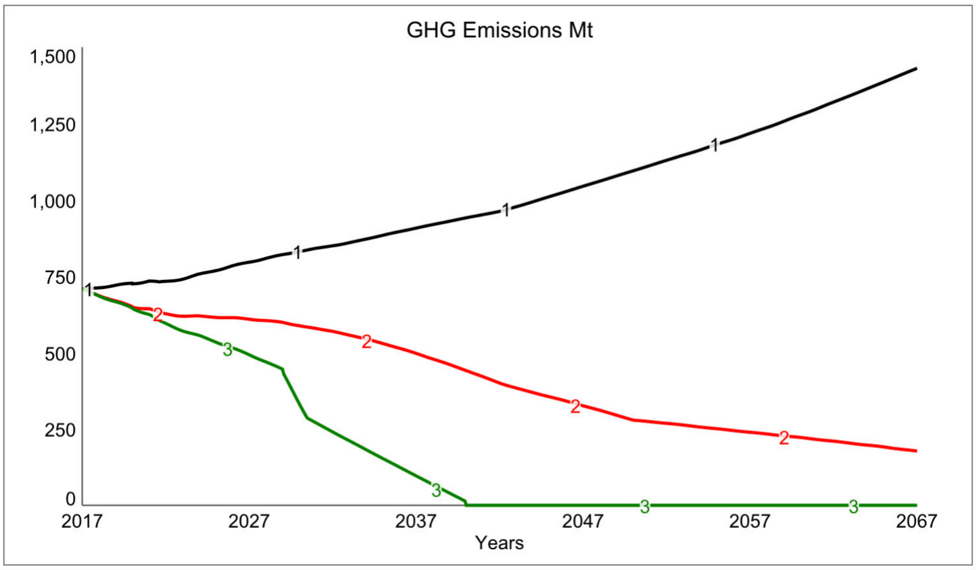

Figure 10: *Carbon Emissions (MtCO$_2$ equivalent): 2017 – 2067*
1=Base Case; 2=Carbon Reduction; 3=Sustainable Prosperity

By comparison, the *Sustainable Prosperity Scenario* achieves net zero emissions by 2040, by constructions (Figure 10). The high level of carbon reduction combined with considerable green investment to address other environmental

69 Canada's GHG emissions were 738 Mts in 2005 and 722 Mts in 2015 (Government of Canada 2017).

problems facilitates a decline in the EBI (Figure 9) for the *Sustainable Prosperity Scenario* of 30% by the end of the period, contributing significantly to the improved SPI score (Figure 8) for this scenario.

Social Influences on the SPI

Two specific social measures adopted in the *Sustainable Prosperity Scenario* also contribute to the improved performance of this scenario over the other two cases. The first of these is the redistributive fiscal policy described in the previous section, in which transfer payments are progressively increased from 2020 and distributed preferentially to the lower income categories.[70]

These enhanced transfers have the effect (Figure 11) of achieving a significant reduction in the Gini coefficient in the Canadian economy on pre-tax incomes, which declines from 0.47 in 2017 to 0.19 in 2067. A lower Gini coefficient improves the performance of the SPI (Figure 6) and this accounts for some of the advantage of the *Sustainable Prosperity Scenario* over both the *Base Case* and the *Carbon Reduction Scenario*.

Figure 11: *Gini Coefficient on per capita Income: 2017 – 2067*
1=Base Case; 2=Carbon Reduction; 3=Sustainable Prosperity

A further social policy adopted in the *Sustainable Prosperity Scenario* is the reduction in the annual average hours worked across the workforce. The average paid employee in Canada worked a little over 1750 hours in 2017. In the *Base Case* and the *Carbon Reduction Scenario*, this does not change

70 In practice, a proportion of these transfers might take the form of housing, food and other programs rather than cash. Or the transfers could be in the form of a universal basic income. The income transfers in the simulation can be considered a proxy for these.

significantly (Figure 12). Increases in labour productivity (the output per hour) are more or less offset by increases in output in these two cases and the small fluctuations in the rate of unemployment in these scenarios have a minimal impact on average work hours.

In the *Sustainable Prosperity Scenario*, however, the average hours worked in the economy falls to 1450 hours per year by 2067, an average annual rate of decline of less than 0.4 percent. The decline in hours worked is made possible by a combination of labour productivity growth and a stabilisation in the overall level of output. This innovation offers more opportunities for people to enjoy time with their families and friends, perhaps volunteering in the community or taking advantage of increased leisure, much as Keynes predicted in his famous (1930) essay on 'Economic possibilities for our grandchildren'. This reduction in the time spent in work is deemed to be a positive contribution to people's well-being and quality of life and contributes positively to the SPI, explaining some of its improved performance in the Sustainable Prosperity scenario.

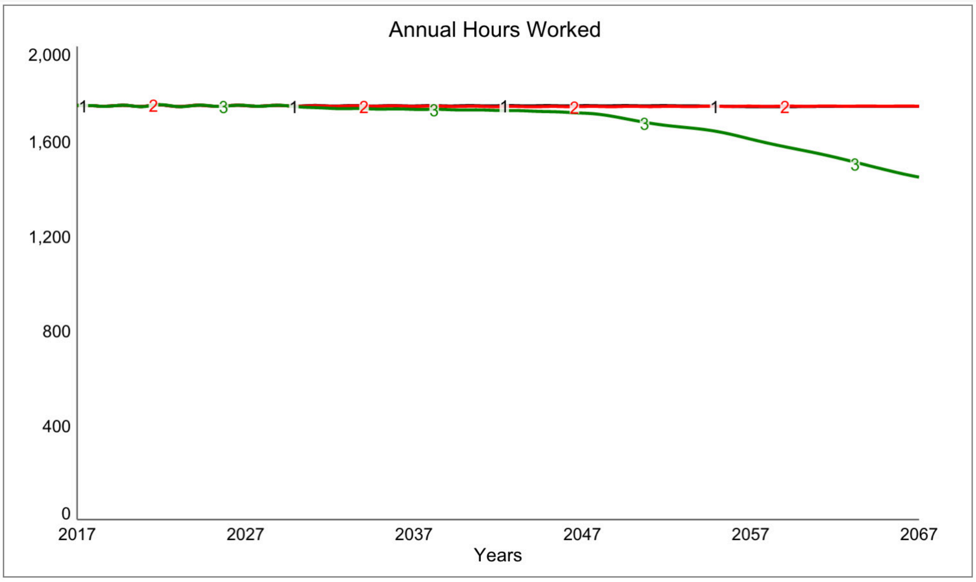

Figure 12: *Average Hours Worked per Year: 2017 – 2067*
1=Base Case; 2=Carbon Reduction; 3=Sustainable Prosperity

Reduced working hours also play a significant role in preventing unemployment rising as output stabilizes. As discussed previously, a stabilization of output in the context of increasing labour productivity would tend to exacerbate unemployment, leading to perverse social outcomes. Figure 13 reveals that despite some variability across the period, the average level of unemployment is very similar in all three scenarios with somewhat greater fluctuations in the *Sustainable Prosperity Scenario.*

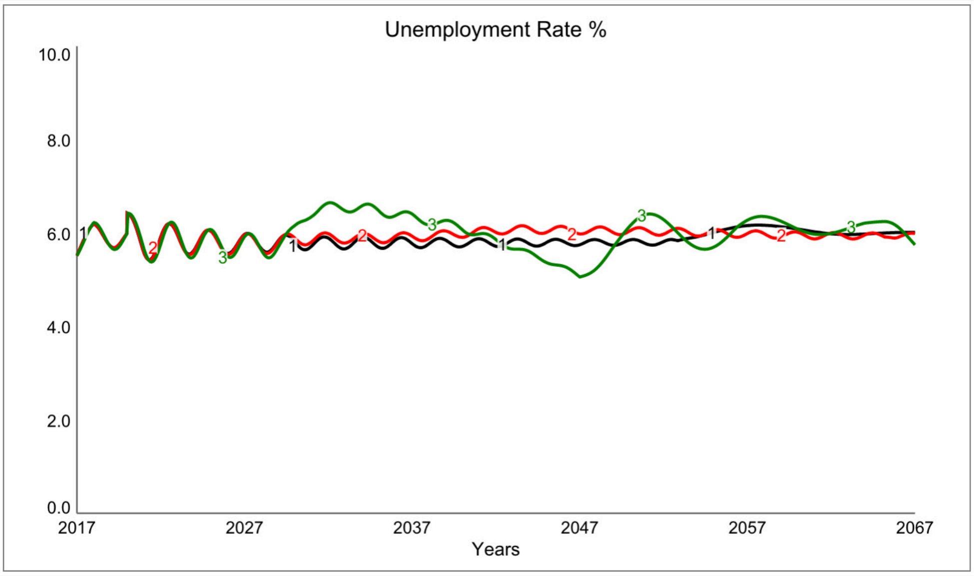

Figure 13: *Average Hours Worked per Year: 2017 – 2067*
1=Base Case; 2=Carbon Reduction; 3=Sustainable Prosperity

Financial Influences on the SPI

The advantage of a stock-flow consistent model such as LowGrow SFC is its ability to articulate the financial positions of different sectors in a meaningful and consistent way. So, for example, the net lending positions[71] of each sector can be determined under any scenario, as can the long-term impact of these positions on the financial worth of different sectors of the economy. The financial positions of the firms and banks sectors are obviously crucial to the long-term stability of the economy. In LowGrow SFC, stability in these sectors is achieved largely through financing and profit-sharing rules which aim to maintain relatively consistent net lending positions at or close to zero.[72] As we have mentioned, a consistently negative trade balance can also have a destabilizing effect on the long-term position of the Canadian economy, with respect to the rest of the world. In all three scenarios a zero trade-balance is assumed after 2017, a year in which it was showing a small positive balance.[73]

The financial position of the remaining sectors in the economy (households and government) are influenced by two things. First, the basic mechanism of stock-flow consistency ensures that the sum of all net lending across the economy (including the foreign sector) is equal to zero. For as long as banks, firms and the foreign sector maintain net lending positions close to zero, this means that any positive net lending position for government is offset by a corresponding

71 The net lending position of a sector refers to the amount of money the sector has over from its income once its consumption and investment spending is accounted for.
72 In the case of banks (see Section 5) this is by construction zero and in the case of firms (Section 4), net lending is maintained in a slight negative position, consistent both with the empirical data and the notion that net financial worth of firms, though typically negative, is more than offset by the value of physical assets (capital) in the economy.
73 The model includes the possibility of trade 'shocks' of different sizes and duration.

negative net lending position for households (and vice versa). As a consequence, the state always has the ability to balance the net lending position of households: by increasing its deficit when household saving drops too far or reducing it when household net worth rises excessively. In the long term, the health of the economy depends on having both public sector debt and household debt lie within reasonable bounds. The final two components of the SPI aim to reflect this requirement.

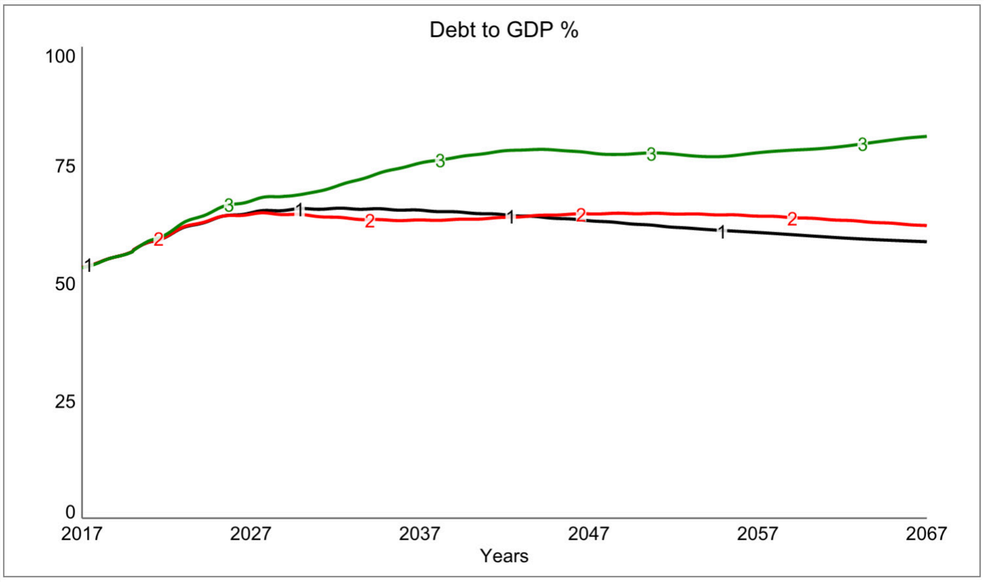

Figure 14: *Government Debt to GDP Ratio: 2017 – 2067*
1=Base Case; 2=Carbon Reduction; 3=Sustainable Prosperity

Figure 14 shows the ratio of combined government debt to GDP across the three LowGrow SFC scenarios. In 2017, the public debt in Canada was around 55% of GDP, somewhat lower than in other rich economies, partly because of the country's relative financial prudence in the run up to the 2008 crisis. In the *Base Case* and the *Carbon Reduction Scenario*, this value rises slightly to a peak of around 66%, before declining to near 60% by the end of the run, indicating a relatively stable position in relation to Canada's public debt.

In the Sustainable Prosperity Scenario, however, the debt to GDP ratio rises steadily, reaching more than 80 percent of the GDP by the end of the run. This is because the GDP itself has stabilized at that point in time while the Government continues to borrow and revenues from the carbon tax have fallen to zero because of the elimination of net carbon emissions. The rise in this indicator suppresses the SPI and raises a potential concern over the long-term sustainability of the Canadian economy. Nonetheless, it is worth pointing out that even at the end of the run, the debt-to-GDP ratio remains at a level that has been far surpassed by many countries without the collapse of their economies.

As an example, Japan's debt to GDP ratio has exceeded 200 percent since 2009, reaching 250 percent in 2016 (Trading Economics 2018).

It is also interesting to note here that modern money theorists such as Wray (2012) advise against the use of the debt-to-GDP measure as an indicator of long-run resilience, on the grounds that in countries with sovereign monetary systems such as Canada, the UK and the USA, the state does not have a budget constraint comparable to that of a household. The argument is that government can always pay debts denominated in their own currency (Wray and Nersisyan 2016). One approach to reducing the debt-to-GDP ratio in the Sustainable Prosperity scenario would, accordingly, be to allow the government to issue debt-free sovereign currency and spend this directly into circulation. In fact, the LowGrow SFC model allows for this possibility and when utilized it shows a dramatic reduction in the debt to GDP ratio and a consequent boost in the SPI. For the purposes of this working paper, however, we omit this possibility from our scenarios, leaving us with a rather conservative estimate of the SPI for the Sustainable Prosperity scenario.

With government running a deficit, it follows from the stock-flow consistency of the model (and the financial behaviours of the other sectors) that the overall net lending position of the private sector is positive in all three scenarios, leading to a healthy (if stabilizing) position in terms of household net worth. This expectation is confirmed in the findings from LowGrow SFC. Figure 15 shows the household net worth rising consistently in the model over the three scenarios.

Despite this relatively stable net worth, it remains possible that households' consumption decisions and portfolio preferences can lead them towards financial instability. For instance, it is still possible, even with positive net lending, for the ratio of households' loans to incomes to rise to a level where banks' confidence in their ability to repay those loans could fall. If the banks were then to impose a constraint on lending (as is possible in the model), it could have a destabilizing effect on household spending and potentially send the economy into a spiral of recession. This is why we have included households' loan-to-value ratio as a component of the SPI to measure the overall performance of the economy. As Figure 16 reveals, there are minor increases in the ratio of household loans to incomes in all three scenarios, with the smallest being in the *Sustainable Prosperity Scenario.*

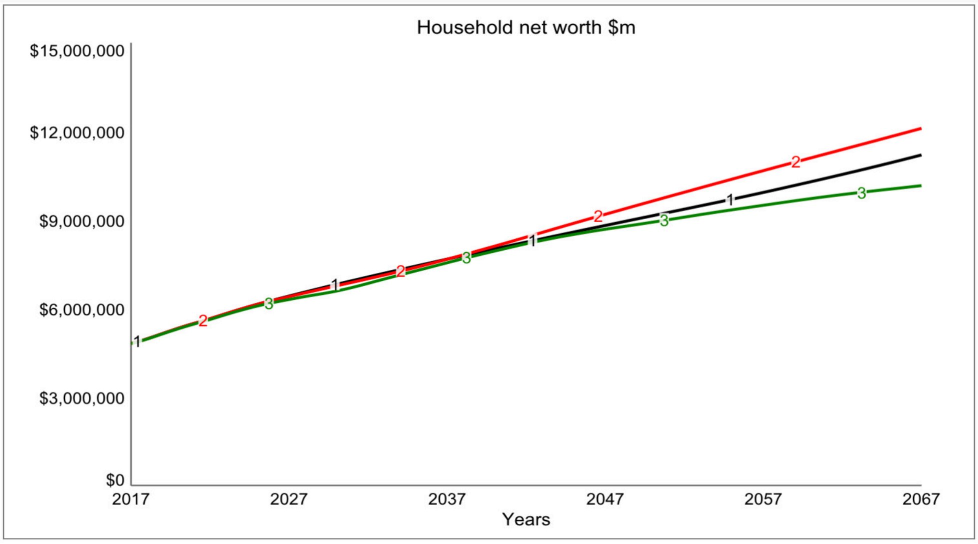

Figure 15: *Household Net Worth 2017 – 2067*
1=Base Case; 2=Carbon Reduction; 3=Sustainable Prosperity

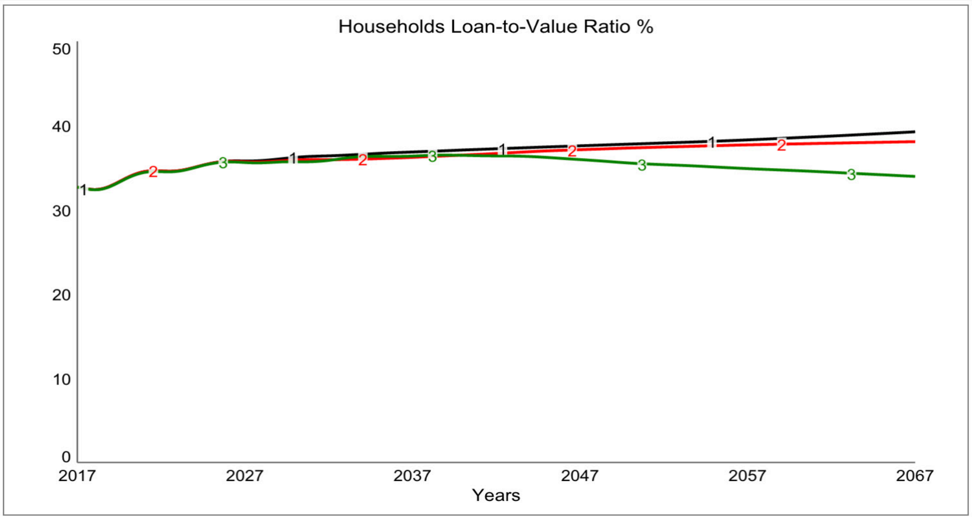

Figure 16: *Household Loan to Value Ratio: 2017 – 2067*
1=Base Case; 2=Carbon Reduction; 3=Sustainable Prosperity

13 | Concluding Remarks

This working paper has presented a simulation model of a national economy, broadly calibrated using Canadian data. We used the model to generate three very different stories about the future, covering the half century from 2017 to 2067: a *Base Case* in which current trends and relationships are projected into the future, a *Carbon Reduction Scenario* in which several measures are introduced specifically designed to reduce carbon emissions, and a *Sustainable*

Prosperity Scenario which incorporates additional measures to improve environmental, social and financial conditions across society.

On current trends (the *Base Case*) it may be possible to continue to pursue economic growth for the next half a century, but if this is typical of other advanced economies, it happens at the expense of a deepening environmental crisis leading to a high probability of runaway climate change. But we have also shown that substantial reductions in carbon emissions can be achieved with appropriate changes to the structure of the economy and the organisation of society.

The impact of these reductions on the macroeconomy depends on numerous factors, including: the speed of the transition and the productivity (and additionality) of green investments. For a relatively slow and shallow transition (the *Carbon Reduction Scenario*), the impact on the GDP is still larger than others have suggested and at odds with those who see a 'green' economy as growing faster than a 'brown' one. Furthermore, this 'green growth' scenario falls well short of the Government of Canada's greenhouse gas target reduction of 80% by 2050.

Deeper and faster transitions are also possible (the *Sustainable Prosperity Scenario*). These changes may well lead to a low or no-growth economy, but the simulations in this paper suggest that with appropriate policy interventions, they could also deliver a better quality of life with greater social equality and lower environmental impact. Only in this third scenario, in which the growth rate declines to zero over the scenario, do we see an overall improvement in performance as indicated by the SPI, an index comprised of seven variables whose values are calculated in the simulation model.

It is of particular interest to find that even the financial indicators of a low growth economy can, under the right conditions, remain relatively stable. Investment portfolios have changed, productivity growth has declined, consumption demand has stabilized, but the economy is nonetheless still financially resilient, its social outcomes are improved and its environmental burden on the planet is dramatically reduced.

An interesting question arises at this point. Does the *Sustainable Prosperity Scenario* still describe a viable form of capitalism? Or do the various policies and measures introduced to improve social and environmental outcomes and to maintain financial stability essentially mean that LowGrow SFC no longer describes a capitalist economy? It is beyond the scope of this working paper to address this question in detail. But it is perhaps worth remarking here that the rate of profit is expected to fall slightly in the Sustainable Development Scenario (Figure 17), suggesting some move away from a capitalistic economy with greater protections on wages and the distribution of income.[74]

74 For a fuller discussion of this point see Jackson and Victor 2019a.

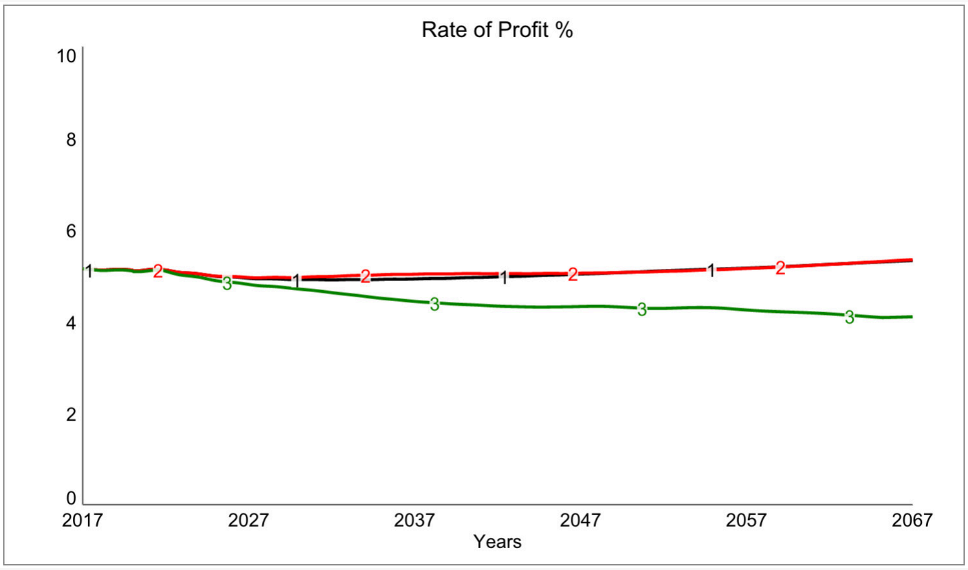

Figure 17: *Endogenous rate of profit in LowGrow SFC: 2017 – 2067*
1=Base Case; 2=Carbon Reduction; 3=Sustainable Prosperity

The former British Prime Minister, Margaret Thatcher, once insisted that 'there is no alternative' to the conventional economic model of economic growth. One of the key findings from this working paper is that there are in fact many alternatives. A single-minded focus on reducing carbon emissions will improve the outlook but a more holistic approach as represented by the *Sustainable Prosperity Scenario* offers the best alternative to the conventional wisdom of continual exponential growth, outperforming the *Base Case* in several important ways over the next half a century.

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Appendix A – Glossary of Terminology and Symbols

Symbols are presented in order of appearance in the paper. Initial values for stocks are from end 2011 and for flows from 2012. Between 2012 and 2016, the model is anchored to actual values of the main economic aggregates (GDP, consumption, investment eg). The base year for the model runs is 2017. Endogenous values (labour productivity, employment eg) are simulated from the start.

Symbol	*Meaning*	*Initial value*
GDP_d	Gross Domestic Product (expenditure basis)	\$1,636,182m
C	Household consumption	\$938,739m
G	Government spending	\$407,260m
I	Investment (gross fixed capital formation)	\$326,313m
$\bar{X}$	Net exports (exports minus imports)	-\$36,130m
GDP_i	Gross Domestic Production (income basis)	\$1,636,182m
W	Wages	\$946,140m
F	Profits net of taxes	\$157,466
$\bar{T}^f$	Net taxes paid by firms	\$171,624m
$\bar{\imath}^f$	Net interest paid by firms	\$55,960m
δ	Depreciation of capital	\$228,712m
GDP	Gross Domestic Product	\$1,636,182m
GDP_{max}	Maximum supply potential of the economy	\$1,680,611m
p	Price level	1
GDP_s	Price adjusted 'real' GDP	\$1,636,182m
Y^h	Household income	\$1,260,632m
F^{fd}	Firms profits distributed to households	\$122,823m
F^{bd}	Banks profits distributed to households	\$164,778m
i_{B^h}	Interest on government bonds held by households	\$3,066m
r_B	Interest rate on government bonds	3%
B^h	Stock of bonds held by households	\$102,204m
i_{D^h}	Interest on deposits held by households	\$9,950m
r_D	Interest rate on deposits	1%
D^h	Deposits held by households	\$995,009m
i_P	Interest paid on private pensions	\$13,875m
P	Pensions held by households	\$1,603,167m
P^p	Private pensions held by households	\$1,387,457m
P^s	State pensions held by households	\$215,710m
i_{L^h}	Interest paid on consumer loans	\$7,503m
r_c	Interest rate on consumer loans	15%
L^h	Consumer loans held in previous period	\$500,215m
i_M	Interest paid on mortgages	\$46,139m
r_M	Interest rate on mortgages	5%
M	Mortgages held in previous period	\$922,777m
T^h	Income tax on households	\$189,095m
Z^h	Transfers paid to households	\$152,559m

Glossary of Terminology and Symbols (Cont)

(in order of appearance in the paper)

Symbol	*Meaning*	*Initial value*
T^g	Green taxes	0
π	Proportion of green taxes passed to households	0.5
Y^{hd}	Household disposable income	$1,177,933m
y^{hd}	Real (price adjusted) disposable income	$1,177,933m
y^{hde}	Expected real disposable income	$1,177,933m
nw^h	Real net worth of households	$1,613,802m
α_1	Propensity to consume out of income	0.79
α_2	Propensity to consume out of wealth	0.01
NW^h	Nominal net worth of households	$4,330,287m
H	Market value of residential fixed assets (housing)	$1,613,802m
NFW^h	Nominal net financial worth of households	$2,716,485m
E_h^f	Firms equities held by households	$1,403,268m
E^b	Banks equities held by households	$44,305m
nw^h	Real (price adjusted) net worth	$4,330,287m
$\tilde{p}$	Compound price level	1
S^h	Households savings	$67,570m
NL^h	Household net lending	$67,570m
Δ	The change in an asset or liability in a given year	na
LTV^h	Household loan to value ratio	0.33
$LTV_{desired}^h$	Desired loan to value ratio	0.33
N^b	Number of employees in business sector	13.7m
φ	Proportion of GDP from business sector	0.796
η^b	Labour productivity in the business sector	$51/hr
h^b	Hours worked per employee in business sector	1,769
K_T^{bnr}	Target non-residential business capital stock	$3,412,198m
κ_T	Target capital to output ratio	2.8
I^{bnr}	Gross investment in non-residential business capital	$218,183m
γ	Partial adjustment coefficient on investment	0.8
K^{bnr}	Non-residential business capital stock	$2,782,381m
δ_{nr}	Depreciation of non-residential capital stock	$166,943m
$r_{\delta_{nr}}$	Rate of depreciation on non-res capital stock	6%
α	Capital's share of the GDP	0.42
α_3	Exogenous growth in skills related productivity	0.75%
σ	Secular rate of decline in average hours	0
ν	Unemployment rate	7.5%
α_4	Variation parameter on unemployment	0.4
N^{nb}	Number of employees in non-business sector	3.5m
N^{LF}	Number of people in the labour force	18,620k
η^{nb}	Labour productivity in the non-business sector	$69/hr
h^{nb}	Average hours worked in non-business sector	1,610
$\hat{\eta}^{nb}$	Labour productivity growth in non-business sector	0%
$\hat{\eta}^b$	Labour productivity growth in business sector	0%
α_5	Regression constant business:nonbusiness (LPG)	1.1

Glossary of Terminology and Symbols (Cont)

(in order of appearance in the paper)

Symbol	*Meaning*	*Initial value*
I^{br}	Investment in residential fixed capital	\$108,182m
α_6	Regression constant in res investment estimate	\$5,157
α_7	Regression coefficient on population	\$57
α_8	Regression coefficient on price of housing	\$1,162m
p_h	Price level of housing	100
$Popn$	Population of Canada	34.3m
K^{br}	Residential capital stock	\$1,613,802m
δ_r	Depreciation of residential capital stock	\$64,552m
r_{δ_r}	Rate of depreciation of residential capital	4%
I^b	The sum of residential and non-residential investment	\$326,313m
I_g^{bnr}	Business sector non-residential green investment	0
${}^{p}_{a}I_g^{bnr}$	Productive, additional non-res green investment	0
${}^{p}_{na}I_g^{bnr}$	Productive, non-additional non-res green investment	0
${}^{np}_{a}I_g^{bnr}$	Non-productive, additional non-res green investment	0
${}^{np}_{na}I_g^{bnr}$	Non-productive, non-additional, non-res green invest	0
$\widetilde{I^{bnr}}$	Actual business sector, non-residential investment	\$218,183m
${}_{a}I_g^{bnr}$	Additional, business, non-residential green investment	0
$\overline{I}^{bnr}$	Effective, business, non-residential investment	\$218,183m
$\overline{K}^{bnr}$	Effective, non-residential capital stock	\$2,782,381m
$\widetilde{I^{br}}$	Actual business sector, residential investment	\$108,182m
${}_{a}I_g^{br}$	Additional, residential green investment	0
X	Firms nominal sales	\$1,636,182m
W	Total nominal wage bill	\$946,140m
W^b	Business sector nominal wage bill	\$700,370m
W^{nb}	Non-business sector nominal wage bill	\$245,770m
w^b	Real (price adjusted) business sector wage bill	\$700,370m
w^{nb}	Real (price adjusted) non-business sector wage bill	\$245,770m
μ^b	Business sector wage rate	\$29.5
μ^{nb}	Non-business sector wage rate	\$40.4
α_9	Regression constant in wage rate equation (business)	3
α_{10}	Regression coefficient on business labour productivity	0.5
α_{11}	Regression constant in wage rate equation (non-bus)	-7
α_{12}	Regression coefficient on non-bus labour productivity	0.7
NOS	Firms net operating surplus	\$237,978m
δ	Sum of depreciation on residential and non-res capital	\$228,712m
L^f	Loans held by firms	\$1,183,626m
D^f	Deposits held by firms	\$322,094m
T^f	Taxes paid by firms	\$183,896m
Z^f	Subsidies paid to firms	\$12,272m
ρ^f	Firms retained profit ratio	0.22

Glossary of Terminology and Symbols (Cont)

(in order of appearance in the paper)

Symbol	*Meaning*	*Initial value*
ρ_0^f	Firms initial retained profit ratio	0.22
F^{fr}	Firms retained profits	\$27,021m
L_0^f	Firms initial loans	\$1,183,626m
F_{gross}^{fr}	Firms gross retained earnings	\$263,355m
NL^f	Firms net lending	-\$62,958m
$\widetilde{I^b}$	Sum of residential and non-residential total investment	\$326,313m
λ_T^f	Target loan to value ratio of firms	1
E^f	Firms equities	\$1,618,978m
r_g	Endogenous growth rate in GDP_s	2.5%
G^c	Government consumption spending	\$407,260m
G^{cc}	Government countercyclical spending	0
v_{nairu}	Non-accelerating inflation rate of unemployment (NAIRU)	5.5%
G_0^{cc}	Countercyclical spending per %age point difference between unemployment and NAIRU	\$5,000m
I^g	Government gross investment in fixed capital	\$72,011m
I^{gcc}	Government countercyclical gross investment	0
I_0^{gcc}	Countercyclical spending per % point difference between unemployment and NAIRU	\$2,500m
I^{gg}	Government green investment	0
I_{tot}^g	Government overall investment including green	\$72,011m
θ^h	Rate of net taxation on household income	15%
ψ	Government debt to GDP ratio	0.5
ψ_L	Lower bound on government debt to GDP ratio	40%
ψ_U	Upper bound on government debt to GDP ratio	60%
$\hat{\psi}$	Rate of growth of debt to GDP ratio	0
θ_0^h	"Normal" tax rate between lower and upper bound	15%
θ_L^h	Political lower bound on tax rate on households	5%
θ_U^h	Political upper bound on tax rate on households	25%
$\overline{\Delta\theta^h}$	Maximum acceptable change in tax rate on households	5 % pts
α_{13}	Constant % pt increase in tax rate on households	0.5 % pts
θ^f	Tax rate on firms profits	30%
θ_0^f	Initial tax rate on firms profits	30%
θ_L^f	Politically acceptable lowest rate of tax on firms	10%
θ_U^f	Politically acceptable upper rate of tax on firms	50%
$\overline{\Delta\theta^f}$	Maximum acceptable change in tax rate on firms	5% pts
α_{14}	Constant % pt increase in tax rate on firms	0.5% pts
T_{tot}	Total tax receipts of government	\$562,448m
Z^f	Government subsidies to firms	\$12,272m

Glossary of Terminology and Symbols (Cont)

(in order of appearance in the paper)

Symbol	*Meaning*	*Initial value*
α_{15}	Firms subsidies as percentage of GDP	2%
Z^{ha}	Additional transfer payments to households in Sustainable Prosperity Scenario	0
T_{net}	Government receipts net of transfers	\$385,347m
G_{tot}	Total government outgoings (except transfers)	\$429,989m
B	Government bonds outstanding	\$807,948m
NL_g	Government net lending = $T_{net} - G_{tot}$	\$44,642m
R	Central bank reserves	\$56,124m
r_R	Interest rate on central bank reserves	0%
F^b	Banks profits	\$164,778m
NL^b	Banks net lending = 0 by construction	0
β	Desired (or required) banks' reserve ratio	2%
B^{cb}	Government bonds held by the central bank	\$56,124m
B^b	Government bonds held by the banks' sector	\$340,000m
ζ^T	Banks target capital adequacy ratio	10%
B^{bT}	Target banks holding of government bonds	\$340,000m
Exp	Exports to the rest of the world	\$498,593m
Imp	Imports from the rest of the world	\$534,723m
T^{row}	Taxes paid by the rest of the world	\$5,563m
NL^{row}	Net lending of the foreign sector	
B^{row}	Government bonds held by the foreign sector	\$315,422m
E^f_{row}	Firms equities held by the foreign sector	
$\tilde{Q}$	Underlying electricity demand	518 TWh
e	Electricity intensity of the GDP	316.5 MW/\$m
ε_1	Scenario specific reduction in electricity intensity	0
$\tilde{Q}_+$	Increase in electricity demand from electrification of road and rail sector	0
W	Energy required for road and rail transport (expressed in terms of electricity demand)	141 TWh
$\tilde{x}$	Time varying conversion factor for electrification of road and rail	0
ε_2	Linear increase in conversion factor over specified time	0
Q	Overall electricity demand = $\tilde{Q} + \tilde{Q}_+$	518 TWh
ξ_{NR}	Market share of non-renewables in electricity	99%
ξ_R	Market share of renewables in electricity	1%
lc_{NR}	Levelized unit cost of non-renewable electricity	£59/MWh
lc_R	Levelized unit cost of renewable electricity	\$378/MWh
χ	Market share parameter	2.1
GHG	Greenhouse gas emissions	699 MtCO2e
r_{eff}	Background rate of energy efficiency improvement	1.64%

Glossary of Terminology and Symbols (Cont)

(in order of appearance in the paper)

Symbol	*Meaning*	*Initial value*
r_{decarb}	Background rate of decarbonisation of energy	0.32%
C_{ca}	Costs of carbon abatement carried out by firms	0
α_{16}	Proportion of carbon abatement costs as investment	0.5
K^{g}	Green capital stock	0
r^{g}	Rate or return on green capital stock	5%
EBI	Environmental burden index	100
EBI^{ghg}	The carbon (greenhouse gas) component of the EBI	25
GHG_{2012}	Carbon emissions in 2012	699 MtCO2e
ω_{ghg}	Initial weight assigned to carbon within the EBI	0.25
EBI^{co}	The co-benefit component of the EBI	5
ω_{co}	Co-benefit multiplier on carbon reductions	0.2
EBI^{gen}	Non-carbon component of the EBI	75
$\tilde{r}_{eff}$	Background rate of nonenergy efficiency improvement	0.7%
K^{gT}	Target level of green capital	$10 trillion
r_{decarb}	Background rate of decarbonisation of energy	0.32%
C_{ca}	Costs of carbon abatement carried out by firms	0
α_{16}	Proportion of carbon abatement costs as investment	0.5
K^{g}	Green capital stock	0
r^{g}	Rate or return on green capital stock	5%
EBI	Environmental burden index	100
EBI^{ghg}	The carbon (greenhouse gas) component of the EBI	25
GHG_{2012}	Carbon emissions in 2012	699 MtCO2e
ω_{ghg}	Initial weight assigned to carbon within the EBI	0.25
EBI^{co}	The co-benefit component of the EBI	5
ω_{co}	Co-benefit multiplier on carbon reductions	0.2
EBI^{gen}	Non-carbon component of the EBI	75
$\tilde{r}_{eff}$	Background rate of nonenergy efficiency improvement	0.7%
K^{gT}	Target level of green capital	$10 trillion

APPENDIX B – LOWGROW SFC INITIAL BALANCE SHEET

	HH	Firms	Banks	CB	Gov	RoW	Total calc
NFA	2704354	-2480511	268683	0	-807948	315422	
Assets	4123731	322094	2999127	56124	215710	315422	8032207
Can Gov Bonds	96402		340000	56124		315422	807948
Deposits - canadian	976588	322094					1298682
Central bank reserves			56124				56124
Firms equities	1403268				215710		1618978
Banks equities	44305						44305
Loans - Mortgages			919162				919162
Loans - Other			1683841				1683841
Life Insurance & Pensions	1603167						1603167
Liabilities	1419377	2802605	2730444	56124	1023658	0	8032207
Can Gov Bonds					807948		807948
Deposits - Canadian			1298682				1298682
Central bank reserves				56124			56124
Firms equities		1618978					1618978
Banks equities			44305				44305
Loans - Mortgages	919162						919162
Loans - Other	500215	1183626					1683841
Life Insurance & Pensions			1387457		215710		1603167