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ABSTRACT
We examine the steady-state impact of a 10 percent reduction in the price of oil using a CGE model of the Canadian economy. The model includes a high degree of disaggregation at both the sectoral and provincial level, international and interprovincial flows of goods and services, labour which is mobile between sectors, capital which is partly mobile both inter-provincially and inter-sectorally, and equilibrium exchange rate adjustments arising from the oil price shock. The key result of our simulations is that—on balance—a negative oil price shock leaves Canadians worse off. We also find that the welfare losses associated with a negative oil price shock are shared broadly across the provinces. The corollary, of course, is that a positive price shock leaves Canadians better off. Our results have implications for the presence (or significance) of Dutch Disease in Canada; we argue that the "disease" is just one of a number of effects generated by oil-price changes.

Keywords: resource curse, dutch disease, petroleum markets, Canada, computable general equilibrium

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1 Introduction

What a difference a year makes. In July of 2014, when the price of oil was a little over $100 (U.S.) per barrel, all the talk was about how Alberta was the engine of growth for the Canadian economy. But all was not wine and roses, as there was also concern about how high oil prices may be impinging on the rest of the economy. In particular there was talk of a potential "hollowing out" of the manufacturing sector, primarily in Ontario, because of a Canadian strain of Dutch Disease due to an oil boom associated appreciation of the dollar to near 92 cents U.S. A year later, in July of 2015, with oil prices hovering under $60 (U.S.), the talk was about how *low* oil prices were impinging on the Canadian economy, as Alberta's growth engine sputtered to a stop. And, of course, with the Canadian dollar at less than 80 cents U.S., there was talk of a renaissance in Canadian manufacturing, as the other side of the Dutch Disease coin showed its face.

Many channels have been proposed in the literature through which Dutch Disease effects might be realized (Van der Ploeg, 2011). In the context of Canada (and many other economies of interest), a precursor to evaluating any of these hypotheses is to develop a precise understanding of how oil price shocks — positive or negative — are transmitted through the economy. That is the purpose of this paper.

We employ a computable general equilibrium (CGE) model calibrated to the Canadian economy which is disaggregated across both sectors and provinces. The model allows us to analyze the impact of an oil price shock in an equilibrium context, taking account of the myriad of price changes associated with the complex set of demand and supply interactions between sectors and provinces as companies and individuals respond to the change in the price of oil. This allows us to consider the impact of a change in the price of oil on outcomes including output, labour and capital demand, incomes, imports and exports at both the sectoral and provincial level. More importantly, we are able to determine the net impact of an oil price shock on the welfare of Canadian consumers.

We simulate the impact of a 10 percent reduction in the price of oil. The model is calibrated to reproduce a benchmark equilibrium based on 2007 data — a regime in which the oil price was quite high. The benchmark represents a long-term steady state in which the price of oil remains constant at the benchmark level permanently. We then compare this to a counterfactual calculation in which the price of oil is permanently lowered by 10 percent and examine the new, long-term steady state produced by the model.

Key aspects of the model, elaborated on below, include a relatively high degree of disaggregation at both the sectoral and provincial level, international and interprovincial flows of goods and services, labour which is mobile between sectors, capital which is partly mobile both inter-provincially and inter-sectorally, and equilibrium exchange rate adjustments arising from the oil price shock.

The simplest model of Dutch Disease effects begins with a small open economy with three sectors – resources, manufacturing and services.[1] Resources and manufactures are traded on the international market, services are not. The story then proceeds as follows. A resource boom drives up the export of the natural resource, which leads to an exchange rate appreciation and increase in factor prices as the resource sector expands, crowding out the export oriented manufacturing sector, in this case manufacturing. The non-traded service sector could be either helped or hindered, depending on the factor price effects and nature of

[1] See, for example, Cordon and Neary (1982) and more recently Van der Ploeg (2011)

the interactions with the other two sectors. Naturally, the mechanism may work in reverse as well; if there is a negative oil price shock, there is an exchange rate depreciation, the manufacturing sector expands, and so on.

Our model includes these aspects of the simple model, but extends the analysis to many sectors and employs a rich economic environment calibrated to the Canadian economy that takes a multitude of linkages between these sectors and factor markets into account. It also allows us to analyze the impacts on a sub-national basis.[2] So, in this sense, our CGE model might be considered a much richer version of a basic Dutch Disease model.

Studies of Dutch Disease effects in a Canadian context have focussed on the exchange-rate channel. For example, Beine et al. (2012) examine the 2002-2008 exchange rate appreciation and the associated run up in oil prices. They conclude that 42 percent of this appreciation could be attributed to the increase in the value of resource exports from Canada. They further conclude that 31 percent of the manufacturing job losses over this period were attributable to Dutch Disease.

Our model incorporates the exchange-rate effects highlighted in the Dutch Disease literature, but also incorporates a spectrum of other general equilibrium effects. This approach highlights that the "disease" is just one aspect of many important effects and interactions generated by an oil price change. The key result of our simulations is that despite the exchange-rate effect of lower oil prices, which does indeed expand the manufacturing sector, on balance a negative oil price shock leaves Canadians worse off. The corollary, of course, is that a positive price shock leaves Canadians better off. Therefore, in our setting, the "dis-

[2] All sectors of the economy may engage in international trade in our model. However, the degree to which they do trade in the benchmark equilibrium or may trade in our counterfactual simulations is governed by the benchmark input-output data and trade elasticities to which we calibrate the model. Thus, while service goods may in theory be traded there is little scope for it in practice due to the calibration of our model.

ease" is overwhelmed by other, positive impacts of a rise in oil prices, including the increase in resource wealth and purchasing power experienced by Canadian consumers.

We also find that the welfare losses associated with a negative oil price shock are shared broadly across the provinces. While the oil-rich provinces of Alberta, Saskatchewan, and Newfoundland are affected most directly, with large welfare losses, we find that almost every province experiences negative welfare impacts (the exception being New Brunswick, due to its large oil refining sector). In part, this is because the exchange-rate depreciation associated with a negative oil price shock hurts the purchasing power of consumers across all provinces. It is also due to the fact that the weakening of the comparative advantage of resource-rich provinces in oil production shrinks the markets for other goods and services throughout the rest of Canada. Thus, for example, while the manufacturing sector in Ontario does indeed modestly expand, on balance Ontarians suffer from the higher international prices of consumer goods and from the lower demand for the goods they export to other parts of Canada, most particularly the oil-producing regions. Important in this regard is the fact that inter-provincial trade is not subject to the exchange rate effects that international trade flows are. This proves to be important in transmitting the impact of the negative oil price shock across the provinces.

When we decompose the effects of the oil-price change into the impact of the exchange-rate depreciation, the reduction in domestic energy prices and the income effects associated with the shifts in comparative advantage within Canada, we find that the last effect dominates our welfare results, leading to an overall reduction in welfare.

It is important to acknowledge that our model does not capture the implications of the presence of economies of scale, learning by doing or knowledge spillovers in different sectors of the economy that may be impacted by oil price changes. Many Dutch Disease arguments focus on the permanent loss of scale or spillovers in manufacturing industries on growth and well-being. For example, Coulombe (2013), following Krugman (1987), uses the somewhat softer term "Dutch Affair" to describe the potential for a positive oil price shock to lead to a decline in the manufacturing sector in the short and medium terms. The more severe Dutch Disease term is then reserved for the long-run case when the resource is depleted and the manufacturing sector has shrunk to the extent that it cannot be revitalized due to lost economies of scale and forgone improvements in productivity due, for example, to learning by doing. Our CGE model does not allow for these possibilities. Moreover, issues associated with the broader "resource curse" literature, which involve the lack of government accountability, corruption, rent seeking, etc., in a resource based economy are not reflected in our model.[3]

What our findings do suggest, however, is that adjustments in manufacturing sectors come in tandem with offsetting adjustments to service-related industries, resulting in a picture that is more complex than is often acknowledged in the policy debate. As a consequence, policy proposals that emphasize Dutch disease effects must argue that the scale or spillover losses in manufacturing resulting from an increase in the price of oil are more important, in welfare terms, than the gains in service industries if a benefit-cost test is to be a measure of policy fitness. We are aware of no basis for this belief a priori.

[3]For a discussion in a Canadian context see Gelb (2014).

2 Overview of the Model

We use a static multi-sector, multi-region computable general equilibrium (CGE) model of the Canadian economy. It has previously been used in several other applications for assessment of energy-related policies in Canada.[4] This section summarizes the key assumptions of the model in general, nontechnical terms. A more formal description is provided in an appendix.

The model's description of provincial production and consumption patterns is based upon detailed input-output tables and linkages between provinces via bilateral trade flows. Each province is explicitly represented as a region.[5] Canada is modeled as a small open economy, where the rest of the world is a destination and source of import and export flows to Canadian provinces which are assumed to be price takers on international markets. Due to the importance of energy markets in our application, the model's aggregation scheme places emphasis on representing detail in energy use.

A single representative agent in each province receives income from labour, capital, and fossil-fuel resources. There are three fossil resources specific to the coal, crude oil and natural gas sectors in each province. Labour is treated as perfectly mobile between sectors within a region, but not mobile between regions. Labour is supplied elastically in each province via a representative agent's labour-leisure trade-off. The capital stock is treated as partially mobile across sectors and provinces. The model incorporates details of direct and indirect taxes which are received by the provincial or federal governments in order to finance public services.

[4]See Böhringer et al. (2015), Böhringer et al. (2014) and Beck et al. (2015).

[5]The exceptions are Prince Edward Island and the Territories, which are combined into one region.

The sectors in the model have been chosen to maximize the degree of disaggregation in the most energy-intensive sectors supported by the data. The energy goods identified in the model include coal, gas, crude oil, refined oil products and electricity. This disaggregation is essential in order to distinguish energy goods and the degree of substitutability when petroleum prices change. In addition the model features major energy-intensive industries which are potentially those most affected by the price of petroleum.

We now describe the structure of the model with a focus on sectoral production and trade. We focus on these aspects since they are the key model structures that affect the output and trade responses to changes in oil markets.

Production of non-fossil-fuel commodities in each region and sector pair is captured by nested constant elasticity of substitution (CES) cost functions describing the price-dependent use of capital, labour, energy and materials. Production is assumed to occur by perfectly competitive constant-returns-to-scale firms. At the top level of the production function, a composite of non-energy intermediate material demands is combined with an aggregate of energy, capital, and labour subject to a constant elasticity of substitution.

The intermediate good composite is a fixed (Leontief) composite of individual intermediate inputs, each of which is an Armington composite of imports and domestic production. Other inputs include energy, capital, and labour. Capital and labour inputs are aggregated into a CES composite which is then combined with an energy composite. Values for the elasticities of substitution between capital and labour, as well as between value added and energy differ by sector and are drawn from the econometric work of Okagawa and Ban (2008).

The energy composite is a nested CES aggregate of electricity, gas, refined petroleum products (oil), and coal. Specifically, the aggregate energy input is defined as a CES function of electricity and the composite of coal, oil and gas; and the composite, coal, oil and gas is a CES function of coal and a CES aggregate of oil and gas. Elasticities of substitution for energy goods are set equal to 0.25 for electricity, 0.5 for coal, and 0.75 for oil.

The production of fossil fuels (coal, crude oil and natural gas), follows a production function similar to the ones describe for non-fuel production, except the capital-labour-energy-materials aggregate is combined with a fossil fuel specific resource at the top level. The elasticity of substitution between this sector-specific resource and the other inputs is calibrated to reflect empirical evidence on fossil fuel supply elasticities as described in Rutherford (2002).

In all of the simulations we consider, we take technology as exogenous. That is, firms can move along isoquants in response to changes in (relative) prices, but isoquants are fixed.

Bilateral trade between provinces as well as between each province and the rest of the world is specified following the Armington (1969) approach, which distinguishes domestic and foreign goods by origin. Output produced in each sector is supplied to each of the domestic regions and the rest of the world. Given the ratio of regional and external prices a constant elasticity of transformation (CET) function determines quantities supplied to the domestic and export markets. In a similar way, all intermediate and final demand goods correspond to a CES composite that combines the domestically produced good and the imported goods from other provinces and the rest of the world.

All Canadian provinces are assumed to be price takers in the world market. There is an imposed balance of payment constraint between Canada and the rest of world aggregate. To implement this constraint, we fix the current account surplus exogenously at the benchmark level.

3 Results

3.1 Output and Factor Markets

We begin with a discussion of the impact of a 10 percent negative oil price shock on output. The first column of Table 1 shows the percentage change in output by sector relative to the base case at the national level. The sectors positively affected by the decline in the crude oil price are: Agriculture, Cement, Chemicals, Coal, Electricity, Manufacturing, Oil Refining, Paper and Pulp Products, Primary Metals, Retail and Wholesale Sales Margins, and Transportation. The sectors negatively affected are: Crude Oil, Natural Gas, Government, Mining, and Services.[6]

As one would expect, the Crude Oil sector shrinks substantially, by about 9.5 percent. We also see a reduction in the Mining sector, which includes oil sands activities, of about 4.8 percent. There is a slight decrease in output in the Natural Gas sector (0.8 percent) as well, for two reasons: 1) the substitution away from natural gas and towards cheaper oil as a fuel source; and 2) the reduction in the demand for natural gas due to the fact that it is an important input in the oil sands extraction process. Perhaps surprisingly, the Service sector also suffers a slight reduction in output (0.3 percent). The reason for this is that the Service sector is not widely traded on international markets, so gets little benefit from the depreciation in the Canadian dollar due to the fall in crude oil prices (more on this below). Moreover, services are an input into the production of crude oil, and therefore the Service sectors suffers from a reduction in demand as the oil sector declines.

The big winners from the reduction in crude oil prices are Oil Refining, Coal, Paper

[6] See Table 7 in the appendix for a concordance between the aggregated sectors represented in the model and the Statistics Canada sectors of which they are comprised.

and Pulp Products, Primary Metals, Cement, Chemicals, Transportation, and Agriculture. These sectors use a significant amount of oil as an input to production — either via energy consumption (Cement, Agriculture, Transportation), or as a feedstock (Oil Refining, Chemicals, Paper and Pulp Products, Primary Metals). Interestingly, the Manufacturing sector benefits only slightly in our simulations, with output increasing by about 0.85 percent. This is primarily due to the combined impact of lower energy prices and the depreciation in the Canadian dollar, which lowers the price of Canadian exports. As we discuss in more detail below, this exchange rate effect is rather small. Working against these positive effects is the reduction in demand for manufactured goods from the shrinking sectors in the Canadian economy. Our simulations show that a negative oil price shock of 10 percent leads to an overall steady state decline in GDP of approximately 1 percent nationally.

The second and third columns of Table 1 show the percentage change in output by sector for Alberta and Ontario, the two provinces often portrayed as being most affected (in opposite directions) by an oil price shock, and the focus of much of the discussion around Dutch Disease in Canada. They tell a similar story to the national figures, though the magnitudes are different. In particular, it is noteworthy that the percentage increase in the output of many of the non-oil sectors in Alberta, including Manufacturing, is significantly higher than in Ontario. The reason for this is two-fold. First, these are percentage changes from the base case. The non-oil sectors in Alberta are significantly smaller than in Ontario. Thus, small changes in absolute output can generate high percentage changes. Overall our simulations show that GDP falls by approximately 3.7 percent in Alberta and 0.3 percent in Ontario.

Second, and more interesting, factors of production — labour and capital — flow out of shrinking sectors and into growing sectors. Table 2 shows the percentage change in factor demands by sector at the national level as well as for Alberta and Ontario. The substantial reduction in output from the oil sector in Alberta releases both labour and capital on to the market. While there is, as expected, a substantial reduction in the demand for labour in the Crude Oil sector in Alberta, virtually every other sector increases its use of labour. Labour in our model is mobile between sectors, but not between provinces. The release of labour from the Crude Oil sector lowers wages, which lowers the cost of production in the non-oil sectors in Alberta, increasing their output.[7]

As a result, the non-oil sectors in Alberta (and other oil producing provinces) benefit significantly from the release of labour from the oil patch. A similar story is true for capital, though to a lesser extent. As discussed, our model assumes that capital is partially mobile across sectors and provinces. Thus, some — but not all — of the capital released from the oil sector in Alberta flows to other provinces and sectors, lowering their costs and increasing their output.

Also of note, the Government sector shrinks relative to the base case, because of a reduction in tax revenue. While Alberta government revenue obviously takes the biggest hit, it is interesting to note that the negative oil price shock also reduces revenue at the federal level and, to a lesser extent, in Ontario.

[7] We have assumed away the possibility of inter-provincial migration of labour supply. One reason for this is that assuming frictionless migration is likely to overstate the influence of this channel on our counterfactual simulations. Developing a model with a more sophisticated description of migration based on empirical evidence is outside the scope of this model. Another reasons is that in Alberta, the largest recipient of migrants within the Canadian economy in recent history, in-migration still accounted for less than 1.5 percent of the labour force in 2012. However, to the extent that migration is possible, it will tend to attenuate the negative aggregate welfare impacts due to a decline in the price of oil.

3.2 Exports and Imports

Tables 3 and 4 show the percentage changes in exports and imports by sector for our three focus regions — Canada, Alberta and Ontario. The columns of the tables also distinguish changes in international and interprovincial trade flows.

Focusing first on exports at the international level, it is evident from column (1) of Table 3 that the value of international exports increases for Canada as a whole in most sectors. The largest percentage increase is in Refined Oil, because of the reduction in the price of its feedstock, but we also see increases in several other sectors, including Manufacturing. This is, in large part, due to the increased international competitivess of Canadian exports arising from the depreciation in the exchange rate and the reduction in production costs due to lower prices for energy and other factors of production (labour and capital). Of course the obvious exception to this is the significant decline in the value of international exports in Crude Oil and Minerals.

Turning to Alberta and Ontario, we again see reductions in international Crude Oil and Minerals exports from Alberta and increases in most other sectors, again including Manufacturing. As discussed above, the percentage increase in international Manufacturing exports from Alberta is higher than Ontario because of the reduced cost of labour and capital in Alberta (and the fact that the sector is smaller). Table 4 shows that changes in international imports mirror what is happening on the export side, with reductions in all sectors at the national level except for Crude Oil.

The interprovincial trade numbers are informative. Table 3 shows that with the obvious exception of Crude Oil and Minerals we see interprovincial exports from Alberta increase in all other sectors. This is again due to the reduced cost of labour and capital in Alberta, which makes non-oil products cheaper and more competitive. Ontario, on the other hand, sees a reduction in interprovincial exports in most sectors, due to the reduction in overall demand discussed above, most particularly from the oil sectors. An important factor here is that interprovincial trade, unlike international trade, does not benefit from the depreciation in the Canadian dollar. This is a key factor in the transmission of the negative oil price shock through the Canadian economy. Again, the changes in interprovincial imports (Table 4) mirror these movements.

3.3 Welfare

Much of the popular discussion of the implications of changes in oil prices tends to focus on metrics such as output and GDP. We have seen in previous sections that there are some aspects of Dutch Disease highlighted by our model. In the case of a negative oil price shock, we do see a contraction of the resource sector and an expansion of other sectors in the economy, including Manufacturing. Indeed, in terms of output the Manufacturing sector in Alberta benefits significantly from the oil price drop. Importantly, however, we also saw that matters are more complicated than suggested in simple Dutch Disease models. There are many moving parts and importantly, on aggregate, in terms of total output a negative oil price shock is a net negative for the Canadian economy.

We also think that a more important and relevant issue concerns the impact on the economic welfare, or well-being, of Canadians. As goods and factor flows in the economy adjust to the decline in the price of oil, wages and output prices adjust accordingly. All of this affects the income and consumption of individual consumers, which is what ultimately determines their well-being.

We measure the net impact of the negative oil price shock on welfare using the concept of the Equivalent Variation (EV). EV measures the change in income, measured at benchmark (pre-oil price shock) market prices, that is equivalent to the oil price reduction in terms of its impact on the well-being of individuals. The results are shown in column (1) of Table 5, which presents our calculations of EV as a percentage of benchmark consumption across provinces. What is immediately clear is that overall, and for every province except for New Brunswick, our welfare measure is negative. This means that on net Canadian consumers are worse off because of the negative oil price shock. For the entire country, EV as a percentage of benchmark consumption is about negative 0.9 percent. This means that a long lasting negative oil price shock of 10 percent reduces the well-being of Canadians by an amount that is equivalent to a 0.9 percent reduction in their income. However, as shown in column (1) of Table 5, there is significant variation across provinces, with large equivalent reductions of income of 5.2 percent, 4.7 percent and 3.5 percent in the oil producing provinces of Newfoundland, Alberta and Saskatchewan, while for the rest of Canada the welfare reductions are much smaller. Only in New Brunswick are consumers better off (by 0.7 percent), because of a disproportionately high consumption of cheaper oil, due to the presence of the large Irving Oil refinery relative to the size of the province.

Many factors contribute to the net reduction in the welfare of Canadians that we observe in our experiments, but it is useful to think in terms of three broad effects. As discussed above, the substantial reduction in output from the oil sector in the oil producing provinces releases labour on to the market. In order to absorb this labour into other sectors, the wages of individuals in those provinces declines, making workers worse off. While labour is not mobile across provinces in our model, this is transmitted nonetheless to other provinces through interprovincial trade and increased competition from cheaper goods from the oil producing provinces. Similarly, the return to capital also declines as capital is released from the oil sector. In this case, because of the partial mobility of capital in our model, this is also transmitted to capital owners in other provinces more directly, but also through interprovincial trade. Thus, on balance the incomes of Canadians, in the form of both wages and the return to capital, declines, making consumers worse off. We call this the "income effect." However, offsetting this is the fact that an important input into production, oil, is cheaper. This lowers the cost of production, and therefore domestic prices, making consumers better off. This is the "energy price effect." Finally, the drop in the value of oil exports leads to a depreciation of the Canadian dollar. This raises the price of imports, which makes Canadians worse off, but also increases the competitiveness of export-oriented sectors, such as Manufacturing, making their stakeholders better off. We call this the "exchange rate effect." The sum of these three potentially offsetting effects — the income effect, the energy price effect, and the exchange rate effect — generate the net effect on consumer well-being, which, as indicated above, is -0.9 percent on average. Thus, on balance, our analysis shows that taking account of all of the opposing effects and interactions, Canadian consumers are worse off in response to a negative oil price shock. Of course the corollary to this is that they would be better off under a positive oil price shock.

To get a sense of the relative magnitude of the contributions of these different channels to the net welfare impacts in our experiments, we have conducted two diagnostic simulations. In the first, we simulate the effect of the same change in the exchange rate as we observe in our baseline oil price-shock experiment, but assume that the shock to the exchange rate is not derived from changes in crude oil markets. This isolates the exchange rate effect. In the second, we simulate the effect of a 10 percent reduction in the cost of crude oil inputs to Canadian consumers, but assume the shock does not also directly affect the output price of crude oil that Canadian oil producers are paid or results in the exchange rate changes we observe in our baseline experiment. This isolates the energy price effect.

Columns (2) and (3) of Table 5 report the welfare impacts of these diagnostic runs and column (4) calculates the percentage-point welfare impact of the oil-price shock after netting out the impacts of the exchange rate and energy price effects. The energy price effect effect in column (2) is generally small and positive across the provinces. That is, a 10 percent reduction in the price of crude oil to Canadian consumers results in a small welfare gain as these inputs become cheaper. New Brunswick and Newfoundland are the exception; these oil-intensive provinces register much larger positive impacts due to the energy price effect. This is due to the disproportionate impact of large refineries in these relatively small provinces.

As discussed above, the exchange rate depreciates as Canadian crude exports become less competitive, making foreign goods more expensive for Canadian consumers. This in and of itself would be expected to reduce welfare, which is confirmed in column (3). Notable here is that our simulations suggest that the exchange rate effect is quite small and relatively uniform across all provinces.

Column (4), reports the residual, which is the welfare effect that is left after accounting for the energy price and exchange rate effects in columns (2) and (3). As a residual, it incorporates a myriad of price effects captured in our detailed CGE model, but largely reflects the income effects arising from the reduction in wages and the return to capital discussed above. This can be seen by noting the very large negative welfare effects in column (4) in the energy-intensive provinces of Alberta, Newfoundland and Saskatchewan where income reductions are the largest. While the income effects are negative in the other provinces, they are significantly smaller.

For Ontario, a key non-resource-intensive province, we see that most of the welfare loss stems from the depreciation in the exchange rate. Thus, it appears that the gains to the manufacturing industries from increased competitiveness abroad are not sufficient to offset the loss in purchasing power from residents of this province. The exchange-rate effect also more than offsets the increase in welfare due to reduction in the price of oil intensive goods. Ontarians also experience a small, negative income effect as demand for Ontario's products domestically falls. This is likely due to the fact that interprovincial exports of Manufacturing and Services, two of Ontario's largest sectors, decline under our experiment (see Table 3).

4 Redistribution of Resource Revenues

Several policy options to insulate the Canadian economy from the presumed effects of Dutch Disease have been proposed. For example, Boadway et al. (2013) suggest various changes to the tax and transfer regime, changes to tax and royalty systems, and even the establishment of a federal Sovereign Wealth Fund. One aspect of the Canadian system that is claimed to exacerbate the perceived problems associated with Dutch Disease is the nature of resource ownership, which resides with the provinces. As a result of this the bulk of the tax and royalty revenues from the resource sector is collected by provinces. In the case of an oil boom the benefits, it is argued, accrue largely to the coffers of the governments of the oil rich provinces, while the costs are born by the other provinces. Of course in the case of a bust the opposite is true. Our model shows that in fact all provinces gain from an oil price boom and suffer from an oil price bust, though the magnitudes vary significantly between the oil producing and oil consuming provinces. In this section we explore the implications of an alternative fiscal arrangement which shares the costs and benefits more evenly.

In particular, we consider an alternative fiscal federalism system which spreads changes in government revenues associated with an oil price shock more evenly across the provinces. We do not explicitly model the precise details of this arrangement, which could, for example, reflect changes made to fiscal transfers such as the CHT, CST and equalization. Rather, we simulate the effects of such a policy by simply assuming that any revenue changes due to the oil-price shock are credited or debited to provinces in proportion to the federal tax revenues they receive in our benchmark data. This should result in a more even distribution of the fiscal gains or losses associated with our counterfactual experiments than in the baseline.

Table 6 reports on the results of this experiment. The first column of the table reproduces the regional welfare impacts from our baseline experiment and the second column reports the same measures under the experiment with the alternative tax-revenue distribution.

As expected, in the case of a negative oil price shock the move to a fiscal arrangement which shares the losses in government revenues more evenly makes the resource-intensive provinces of Alberta, Newfoundland and Saskatchewan better off (actually less worse off) relative to the base case, while the other provinces are worse off. Under our alternative fiscal arrangement the welfare losses due to the negative price shock decline by from 0.69% to 1.19% in the resource-intensive provinces, while they increase by from 0.13 percent to 0.25 percent in the other provinces. Of course under a positive price shock it would go in the other direction, with the resource-intensive provinces benefitting less from the price increase and the other provinces benefitting more.

5 Conclusions

The purpose of this paper is to examine the implications of a negative oil price shock within the context of a detailed computable general equilibrium model of the Canadian economy. We simulate the implications of a steady-state 10 percent decline in the price of oil on the Canadian economy. The key result of our simulations is that on balance a negative oil price shock leaves Canadians worse off. The corollary, of course, is that a positive price shock leaves consumers better off. In particular, we show that a 10 percent negative oil price shock leads to a long run reduction in GDP of approximately 1 percent nationally. We also find that consumer welfare, measured by the equivalent reduction in income (Equivalent Variation), declines by just under 1 percent.

Importantly, our simulations show that the negative welfare effects of the oil price shock are shared across the provinces. While the oil-rich provinces of Alberta, Saskatchewan, and Newfoundland are affected most directly, with large welfare losses, we find that almost every province (with the exception of New Brunswick) experiences a negative welfare impact. Thus, for example, while the Manufacturing sector benefits from the reduction in energy prices and increased international exports due to a depreciation of the Canadian dollar, on balance Ontarians suffer from the higher international prices of consumer goods and from the lower demand for the goods that they export to other parts of Canada, most particularly the oil producing regions.

Our analysis makes an important contribution to the Dutch Disease debate as it relates to Canada. A key aspect of the “disease” that is the focus of much discussion is the implications of an exchange rate appreciation associated with a resource boom. It is claimed that the resulting hollowing out of the export oriented manufacturing sector can have negative effects on the economy. Our results suggest that matters are more complicated than this and that the "disease" is overwhelmed by other, positive impacts associated with a positive oil price shock. Of course in the current context the corollary is that the negative aspects of a decline in the price of oil dominate any positive effects.

An important qualification to our results is that we do not model the implications of economies of scale, learning by doing, or knowledge spillovers in the manufacturing sector. To the extent that these features are important, our results overestimate the negative impact of a decrease in the price of oil on the Canadian economy. However, our finding that adjustments to the manufacturing sector come in tandem with offsetting adjustments to other sectors, most particularly the service sector, suggests that the picture is more complex than is often portrayed. What we don't know is if, for a positive oil price shock, any potential scale and spillover losses in manufacturing are more important in welfare terms than gains in other parts of the economy.

Finally, we show how the burden of oil price shocks can be shared more equally by changes to the system of fiscal federalism in Canada. In particular, any mechanisms which lead to a sharing of the impact of oil price shocks on government revenues, for example by way of transfers and/or changes in the equalization system, will lead to a more even distribution of the welfare impacts.

References

Armington, P. S. (1969). A theory of demand for products distinguished by place of production (une théorie de la demande de produits différenciés d'après leur origine)(una teoría de la demanda de productos distinguiéndolos según el lugar de producción). *Staff Papers-International Monetary Fund*, 159–178.

Beck, M., N. Rivers, R. Wigle, and H. Yonezawa (2015). Carbon tax and revenue recycling: Impacts on households in british columbia. *Resource and Energy Economics*, 40–69.

Beine, M., C. Bos, and S. Coulombe (2012). Does the canadian economy suffer from dutch disease? *Resource and Energy Economics 34*(4), 468–92.

Boadway, R., S. Coulombe, and J.-F. Tremblay (2013). Canadian policy descriptions for dutch disease. *IRPP Insight October*(3).

Böhringer, C., N. Rivers, T. F. Rutherford, and R. Wigle (2015). Sharing the burden for climate change mitigation in the Canadian federation. *Canadian Journal of Economics*.

Böhringer, C., N. Rivers, and H. Yonezawa (2014). Vertical fiscal externalities and the environment.

Cordon, W. and J. Neary (1982). Booming sector and de-industrialization in a small open economy. *Economic Journal 92*, 825–48.

Coulombe, S. (2013). The canadian dollar and the dutch and the canadian diseases. *SPP Reasearch Paper 6*(30).

Gelb, A. (2014). Should canada worry about a resource curse? *SPP Reasearch Paper 7*(2).

Krugman, P. (1987). The narrow moving band, the dutch disease, and the competitive consequences of mrs. thatcher: Notes on trade in the presence of dynamic scale economies. *Journal of Development Economics 27*(1–2), 41 – 55.

Okagawa, A. and K. Ban (2008). Estimation of substitution elasticities for cge models. *Discussion Papers in Economics and Business 16*.

Rutherford, T. (2002). Lecture notes on constant elasticity functions. *University of Colorado*.

Van der Ploeg, F. (2011). Natural resources: Curse or blessing? *Journal of Economic Literature*, 366–420.

Tables

	Canada	Alberta	Ontario
Agriculture	1.33	3.32	0.45
Cement	2.18	6.86	-0.64
Chemicals	1.99	6.49	0.52
Coal	3.43	7.58	
Construction	-0.05	-0.12	0.00
Crude Oil	-9.51	-7.83	
Electricity	0.09	-2.16	0.34
Natural Gas	-0.82	-0.80	
Government	-0.03	-0.08	-0.01
Manufacturing	0.84	3.94	0.45
Minerals	-4.76	-7.58	-4.80
Refined Oil	9.35	8.39	0.29
Paper & Pulp	2.85	9.70	1.50
Primary Metals	2.32	9.17	2.29
Services	-0.32	-0.56	-0.25
Sales Margins	0.02	0.10	0.03
Transportation	1.25	3.68	0.35
Total	1.00	-3.70	-0.30

Table 1: Percentage Change in Output by Sector and Region

	Canada		Alberta		Ontario	
	Capital	Labour	Capital	Labour	Capital	Labour
Agriculture	0.61	1.45	1.48	6.18	0.23	0.56
Cement	1.14	2.52	2.34	8.87	-0.31	-1.05
Chemicals	0.66	2.25	2.26	8.61	0.24	0.60
Coal		9.85		17.35		
Construction	-0.11	-0.04	-0.53	0.02	0.03	-0.03
Crude Oil		-23.61		-22.63		
Electricity	-0.10	0.08	-1.67	-3.42	0.17	0.40
Natural Gas		-2.77		-2.83		
Government	-0.05	-0.03	-0.53	0.00	0.03	-0.02
Manufacturing	0.32	0.98	1.29	5.59	0.22	0.54
Minerals	-2.42	-7.52	-3.70	-9.39	-2.01	-6.07
Refined Oil	3.12	9.91	2.94	10.77	0.05	0.04
Paper & Pulp	0.84	2.57	3.39	12.20	0.62	1.75
Primary Metals	0.92	2.75	3.49	12.51	0.93	2.68
Services	-0.20	-0.46	-0.69	-0.46	-0.09	-0.40
Sales Margins	-0.03	0.03	-0.43	0.32	0.04	0.01
Transportation	0.46	1.38	1.14	5.11	0.13	0.27

Table 2: Percentage Change in Factor Demands by Sector and Region

	Canada	Alberta		Ontario	
	International	International	Interprovincial	International	Interprovincial
Agriculture	1.58	3.32	3.96	0.45	0.81
Cement	6.56	6.86	11.27	-0.64	-2.51
Chemicals	1.63	6.49	3.63	0.52	-2.94
Coal	3.17	7.58	13.50	0.00	0.00
Construction	0.00	0.00	6.93	0.00	-1.71
Crude Oil	-9.70	-7.83	-2.60	0.00	0.00
Electricity	0.45	-2.16	19.76	0.34	1.13
Natural Gas	-0.75	-0.80	2.63	0.00	0.00
Government	-0.03	-0.08	9.45	-0.01	-1.07
Manufacturing	0.73	3.94	5.97	0.45	-0.20
Minerals	-2.76	-7.58	-9.39	-4.80	-9.38
Refined Oil	12.18	8.39	12.23	0.29	-3.71
Paper & Pulp	2.82	9.70	11.34	1.50	0.08
Primary Metals	2.22	9.17	9.59	2.29	1.73
Services	-0.31	-0.56	9.47	-0.25	-2.33
Sales Margins	0.03	0.10	10.20	0.03	-1.63
Transportation	1.41	3.68	5.84	0.35	-0.03

Table 3: Percentage Change in Exports by Sector, Region and Destination

	Canada	Alberta		Ontario	
	International	International	Interprovincial	International	Interprovincial
Agriculture	-0.10	1.39	2.86	-0.27	1.51
Cement	-4.85	-9.06	-4.75	-3.34	2.42
Chemicals	-6.84	-7.93	-2.17	-7.34	1.18
Coal	-0.13	-9.71	-4.15	-0.51	12.35
Construction	-1.36	-5.00	-3.89	-0.69	1.76
Crude Oil	24.05	33.99	5.15	27.66	0.40
Electricity	-1.46	-15.04	-9.32	0.28	-0.56
Natural Gas	-14.25	-22.00	-6.77	-18.17	2.05
Government	-1.32	-6.16	-4.85	-0.61	1.27
Manufacturing	-0.78	-1.91	-0.39	-0.28	1.84
Minerals	-8.44	-20.63	-8.60	0.11	15.30
Refined Oil	-8.74	-10.92	2.90	-6.37	13.22
Paper & Pulp	-2.36	-3.88	0.11	-1.45	2.84
Primary Metals	-1.61	-1.54	2.14	-1.57	1.58
Services	-2.46	-8.01	-6.25	-1.50	2.43
Sales Margins	-1.65	-6.41	-5.28	-0.71	2.90
Transportation	-1.97	-2.44	0.22	-1.82	2.28

Table 4: Percentage Change in Imports by Sector, Region and Destination

	Total Effect	Welfare Decomposition		
		Energy Cost	Exchange	(1)-(2)-(3)
	(1)	(2)	(3)	(4)
Resource-Intensive Provinces				
Alberta	-4.69	0.28	-0.26	-4.71
Newfoundland-Labrador	-5.24	0.77	-0.26	-5.74
Saskatchewan	-3.52	0.06	-0.26	-3.32
Other Provinces				
British Columbia	-0.26	0.11	-0.27	-0.10
Manitoba	-0.17	0.11	-0.28	0.00
New Brunswick	0.65	1.12	-0.28	-0.19
Nova Scotia	-0.26	0.27	-0.28	-0.25
Ontario	-0.16	0.15	-0.29	-0.02
Quebec	-0.19	0.18	-0.29	-0.07
Rest of Canada	-0.91	0.06	-0.23	-0.74
All of Canada	-0.89	0.19	-0.28	-0.80

Table 5: Percentage Change in EV Welfare Measure by Region and Impact Channel

	Baseline	Redistribution	(1)-(2)
	(1)	(2)	(3)
Resource-Intensive Provinces			
Alberta	-4.69	-3.96	-0.73
Newfoundland-Labrador	-5.24	-4.05	-1.19
Saskatchewan	-3.52	-2.83	-0.69
Other Provinces			
British Columbia	-0.26	-0.40	0.14
Manitoba	-0.17	-0.31	0.14
New Brunswick	0.65	0.40	0.25
Nova Scotia	-0.26	-0.40	0.14
Ontario	-0.16	-0.32	0.15
Quebec	-0.19	-0.32	0.13
Rest of Canada	-0.91	-1.16	0.25
All of Canada	-0.89	-0.89	—

Table 6: Percentage Change in EV Welfare Measure — Baseline versus Revenue-Redistribution Scenario

Appendix

A Industry-Sector Concordance

Sector	Industry
AGR	Grains and other crop products
AGR	Live animals
AGR	Other farm products
CEM	Non-metallic mineral products
CHM	Chemical products
CON	Engineering construction
CON	Non-residential buildings
CON	Repair construction services
CON	Residential construction
CRU	Mineral and oil and gas exploration
CRU	Mineral fuels
ELE	Utilities
GOV	Education services provided by government sector
GOV	Health and social assistance services
GOV	Health services provided by government sector
GOV	Other aboriginal government services
GOV	Other federal government services
GOV	Other municipal government services
GOV	Other provincial and territorial government services
GOV	Sales of other government services
MFR	Alcoholic beverages and tobacco products
MFR	Computer and electronic products
MFR	Electrical equipment, appliances and components
MFR	Fabricated metallic products
MFR	Fish and seafood, live, fresh, chilled or frozen
MFR	Food and non-alcoholic beverages
MFR	Forestry products and services
MFR	Furniture and related products
MFR	Industrial machinery
MFR	Motor vehicle parts
MFR	Other manufactured products and custom work
MFR	Plastic and rubber products
MFR	Textile products, clothing, and products of leather and similar materials
MFR	Transportation equipment
MFR	Wood products
MIN	Metal ores and concentrates
MIN	Mineral support services
MIN	Non-metallic minerals
OIL	Refined petroleum products (except petrochemicals)
PPP	Wood pulp, paper and paper products and paper stock
PRM	Primary metallic products
SER	Accommodation and food services
SER	Administrative and support, head office, waste management and remediation services
SER	Arts, entertainment and recreation services
SER	Depository credit intermediation
SER	Education services
SER	Imputed rental of owner-occupied dwellings
SER	Information and cultural services
SER	Other finance and insurance
SER	Other services
SER	Printed products and services
SER	Professional services (except software and research and development)
SER	Published and recorded media products
SER	Real estate, rental and leasing and rights to non-financial intangible assets
SER	Research and development
SER	Sales of other services by Non-Profit Institutions Serving Households
SER	Services provided by Non-Profit Institutions Serving Households
SER	Software
SER	Support services related to farming and forestry
SER	Telecommunications
TRD	Retail margins, sales of used goods and commissions
TRD	Wholesale margins and commissions
TRN	Transportation and related services
TRN	Transportation margins

Table 7: Sectoral aggregation correspondence with categories in Statistics Canada input-output data

B Formal Model Description

The model is formulated as a system of nonlinear inequalities. The inequalities correspond to the three classes of conditions associated with a general equilibrium: (i) exhaustion of product (zero profit) conditions for constant-returns-to-scale producers, (ii) market clearance for all goods and factors and (iii) income-expenditure balances. The first class determines activity levels, the second class determines prices and the third class determines incomes. In equilibrium, each of these variables is linked to one inequality condition: an activity level to an exhaustion of product constraint, a commodity price to a market clearance condition and an income to an income-expenditure balance.[8] Constraints on decision variables such as prices or activity levels allow for the representation of market failures and regulation measures. These constraints go along with specific complementary variables. In the case of price constraints, a rationing variable applies as soon as the price constraint becomes binding; in the case of quantity constraints, an endogenous tax or subsidy is introduced.[9]

In our algebraic exposition of equilibrium conditions below, we state the associated equilibrium variables in brackets. Furthermore, we use the notation Π_{gr}^{Z} to denote the unit profit function (calculated as the difference between unit revenue and unit cost) for constant-returns-to-scale production of item g in region r where Z is the name assigned to the associated production activity. Differentiating the unit profit function with respect to input and output prices provides compensated demand and supply coefficients (Hotelling's Lemma), which appear subsequently in the market clearance conditions.

[8] Due to non-satiation expenditure will exhaust income. Thus, the formal inequality of the income-expenditure balance will hold as an equality in equilibrium.

[9] An example for an explicit price constraint is a lower bound on the real wage to reflect a minimum wage rate; an example for an explicit quantity constraint is the specification of a (minimum)target level for the provision of public goods.

We use g as an index comprising all sectors/commodities including the final consumption composite, the public good composite and an aggregate investment good. The index r (aliased with s) denotes regions. The index EG represents the subset of all energy goods except for crude oil (here: coal, refined oil, gas, electricity) and the label X denotes the subset of fossil fuels (here: coal, crude oil, gas), whose production is subject to decreasing returns to scale given the fixed supply of fuel-specific factors. Tables 8 to 14 explain the notations for variables and parameters employed within our algebraic exposition. Numerically, the model is implemented under GAMS (Brooke et al. 1996)[10] and solved using PATH (Dirkse and Ferris 1995)[11].

Zero profit conditions

1. Production of goods except for fossil fuels ($Y_{gr}|_{g\notin X}$):

$$\Pi_{gr}^{Y} = \left(\theta_{gr}^{EX}\left(\frac{P_{gr}^{Y}(1-tp_{gr}^{Y}-tf_{gr}^{Y})}{\bar{P}_{gr}^{Y}}\right)^{1+\eta} + \left(1-\theta_{gr}^{EX}\right)\left(\frac{\mu(1-tp_{gr}^{Y}-tf_{gr}^{Y})}{\bar{\mu}_{gr}}\right)^{1+\eta}\right)^{\frac{1}{1+\eta}}$$
$$-\left(\theta_{gr}^{M}{P_{gr}^{M}}^{1-\sigma^{M}} + (1-\theta_{gr}^{M})\left(\left(\left(\theta_{gr}^{E}{P_{gr}^{E}}^{1-\sigma^{E}} + (1-\theta_{gr}^{E})\left(\theta_{gr}^{L}{P_{r}^{L}}^{1-\sigma^{L}} + (1-\theta_{gr}^{L}){P_{gr}^{K}}^{1-\sigma^{L}}\right)^{\frac{1}{1-\sigma^{L}}}\right)^{1-\sigma^{E}}\right)^{\frac{1}{1-\sigma^{E}}}\right)^{1-\sigma^{M}}\right)^{\frac{1}{1-\sigma^{M}}}$$
$$\leq 0$$

2. Production of fossil fuels ($Y_{gr}|_{g\in X}$):

$$\Pi_{gr}^{Y} = \left(\theta_{gr}^{X}\left(\frac{P_{gr}^{Y}(1-tp_{gr}^{Y}-tf_{gr}^{Y})}{\bar{P}_{gr}^{Y}}\right)^{1+\eta} + \left(1-\theta_{gr}^{X}\right)\left(\frac{\mu(1-tp_{gr}^{Y}-tf_{gr}^{Y})}{\bar{\mu}_{gr}}\right)^{1+\eta}\right)^{\frac{1}{1+\eta}}$$
$$-\left(\theta_{gr}^{R}\left(\frac{P_{gr}^{R}(1+tp_{gr}^{R}+tf_{gr}^{R})}{\bar{P}_{gr}^{R}}\right)^{1-\sigma_{gr}^{R}} + \left(1-\theta_{gr}^{R}\right)\left(\theta_{gr}^{L}P_{r}^{L} + \sum_{i}\theta_{igr}^{R}\frac{(P_{ir}^{A}(1+tp_{igr}^{D}+tf_{igr}^{D}))}{\bar{P}_{igr}^{A}}\right)^{1-\sigma_{gr}^{R}}\right)^{\frac{1}{1-\sigma_{gr}^{R}}}$$
$$\leq 0$$

[10] Brooke, A., D. Kendrick and A. Meeraus (1996), *GAMS: A User's Guide*, Washington DC: GAMS

[11] Dirkse, S. and M. Ferris (1995), "The PATH Solver: A Non-monotone Stabilization Scheme for Mixed Complementarity Problems", *Optimization Methods & Software 5*, 123-156.

3. Sector-specific material aggregate (M_{gr}):

$$\Pi_{gr}^{M} = P_{gr}^{M} - \left(\sum_{i \notin EG} \theta_{igr}^{M} \left(\frac{P_{ir}^{A}(1 + tp_{igr}^{D} + tf_{igr}^{D})}{\bar{P}_{igr}^{A}} \right)^{1-\sigma^{D}} \right)^{\frac{1}{1-\sigma^{D}}} \leq 0$$

4. Sector-specific energy aggregate (E_{gr}):

$$\begin{aligned}\Pi_{gr}^{E} = & P_{gr}^{E} - \left(\left(\theta_{ELEgr} \left(\frac{P_{ELEr}^{A}(1 + tp_{ELEgr}^{D} + tf_{ELEgr}^{D})}{\bar{P}_{ELEgr}} \right)^{1-\sigma^{ELE}} \right.\right. \\ & + (1 - \theta_{ELEgr}) \left(\left(\theta_{COAgr} \left(\frac{P_{COAr}^{A}(1 + tp_{COAgr}^{D} + tf_{COAgr}^{D})}{\bar{P}_{COAgr}} \right)^{1-\sigma^{COA}} \right.\right. \\ & + (1 - \theta_{COAgr}) \left(\theta_{OILgr} \left(\frac{P_{OILr}^{A}(1 + tp_{OILgr}^{D} + tf_{OILgr}^{D})}{\bar{P}_{OILgr}} \right)^{1-\sigma^{OIL}} \right. \\ & \left.\left.\left.\left.\left. + \quad (1 - \theta_{OILgr}) \left(\frac{P_{GASr}^{A}(1 + tp_{GASgr}^{D} + tf_{GASgr}^{D})}{\bar{P}_{GASgr}} \right)^{1-\sigma^{OIL}} \right)^{\frac{1}{1-\sigma^{OIL}}} \right)^{1-\sigma^{COA}} \right)^{\frac{1}{1-\sigma^{COA}}} \right)^{1-\sigma^{ELE}} \right)^{\frac{1}{1-\sigma^{ELE}}} \\ & \leq 0\end{aligned}$$

5. Armington aggregate (A_{ir}):

$$\Pi_{ir}^{A} = P_{ir}^{A} - \left(\left(\Theta_{ir}^{DM} \mu^{1-\sigma^{DM}} + \left(1 - \Theta_{ir}^{DM}\right) \left(\sum_{s} \Theta_{isr}^{MM} {P_{is}^{Y}}^{1-\sigma_{i}^{MM}} \right)^{\frac{1}{1-\sigma^{MM}}} \right)^{1-\sigma^{DM}} \right)^{\frac{1}{1-\sigma^{DM}}} \leq 0$$

6. Labour supply (L_r):

$$\Pi_{r}^{L} = \frac{P_{r}^{L} \left(1 - tp_{r}^{L} - tf_{r}^{L}\right)}{\overline{P_{r}^{L}}} - P_{r}^{LS} \leq 0$$

7. Mobile capital supply (K):

$$\Pi^{K} = \left(\sum_{r} \Theta_{r}^{K} \left(\frac{P^{K} \left(1 - tp_{r}^{K} - tf_{r}^{K}\right)}{\overline{P_{r}^{K}}} \right)^{1+\epsilon} \right)^{\frac{1}{1+\epsilon}} - P^{KM} \leq 0$$

8. Welfare (W_r):

$$\Pi_{r}^{W} = P_{r}^{W} - \left(\Theta_{r}^{LS} {P_{r}^{LS}}^{1-\sigma_{r}^{LS}} + \left(1 - \Theta_{r}^{LS}\right) {P_{Cr}^{Y}}^{1-\sigma_{r}^{LS}} \right)^{\frac{1}{1-\sigma_{r}^{LS}}} \leq 0$$

Market clearance conditions

9. Labour (P_r^L):

$$L_r \geq \sum_g Y_{gr} \frac{\partial \Pi_{gr}^Y}{\partial P_r^L}$$

10. Leisure (P_r^{LS}):

$$\overline{L}_r - L_r \geq W_r \frac{\partial \Pi_r^W}{\partial P^{LS}}$$

11. Mobile capital (P^{KM}):

$$\sum_r \overline{KM}_r \geq K$$

12. Sector-specific capital (P_{gr}^K):

$$\overline{K}_{gr} + K \frac{\partial \Pi^K}{\partial P_{gr}^K} \geq \sum_g Y_{gr} \frac{\partial \Pi_{gr}^Y}{\partial P_{gr}^K}$$

13. Fossil fuel resources ($P_{gr}^R|_{g \in X}$):

$$\overline{R}_{gr} \geq Y_{gr} \frac{\partial \Pi_{gr}^Y}{\partial (P_{gr}^R(1 + tp_{gr}^R + tf_{gr}^R))}$$

14. Energy composite (P_{gr}^E):

$$E_{gr} \geq Y_{gr} \frac{\partial \Pi_{gr}^Y}{\partial P_{gr}^E}$$

15. Material composite (P_{gr}^M):

$$M_{gr} \geq Y_{gr} \frac{\partial \Pi_{gr}^Y}{\partial P_{gr}^M}$$

16. Armington good (P_{ir}^A):

$$A_{ir} \geq \sum_g E_{gr} \frac{\partial \Pi_{gr}^E}{\partial (P_{ir}^A(1 + tp_{igr}^D + tf_{igr}^D))} + \sum_g M_{gr} \frac{\partial \Pi_{gr}^M}{\partial (P_{ir}^A(1 + tp_{igr}^D + tf_{igr}^D))}$$

17. Commodities (P_{ir}^Y):

$$Y_{ir} \frac{\partial \Pi_{ir}^Y}{\partial (p_{ir}^Y(1 - tp_{ir}^Y - tf_{ir}^Y))} \geq A_{ir} \frac{\partial \Pi_{ir}^A}{\partial P_{ir}^Y}$$

18. Private good consumption (P^Y_{Cr}):

$$Y_{Cr} \geq W_r \frac{\partial \Pi^W_r}{\partial P^Y_{Cr}}$$

19. Investment (P^Y_{Ir}):

$$Y_{Ir} \geq \bar{I}_r$$

20. Public Consumption (P^Y_{Gr}):

$$Y_{Gr} \geq \frac{INC^p_r}{P^Y_{Gr}} + \theta^G_r \frac{INC^f}{P^Y_{Gr}}$$

21. Welfare (P^W_r):

$$W_r \geq \frac{INC^{RA}}{P^W_r}$$

Income-expenditure balances

23. Income of representative consumer (INC^{RA}_r):

$$\begin{aligned} INC^{RA}_r = & P^{LS}_r \overline{L}_r \\ & + \sum_{x \in g} P^R_{gr} \bar{R}_{gr} \\ & + P^{KM} \overline{KM}_r \\ & + \sum_{g} P^K_{gr} \overline{K}_{gr} \\ & - P^Y_{Ir} \bar{I}_r \\ & + \mu \overline{BOP}^{RA}_r \end{aligned}$$

24. Income of provincial government (INC_r^p):

$$
\begin{aligned}
INC_r^p = & \; L_r \, P_r^L \, tp_r^L \\
& + \sum_{g \in x} \bar{R}_{gr} \, P_{gr}^R \, tp_{gr}^R \\
& + \sum_g Y_{gr} \, \frac{\partial \Pi_{gr}^Y}{\partial P_{gr}^K} \, P_{gr}^K \, tp_r^K \\
& + \sum_i \sum_g \left(E_{gr} \, \frac{\partial \Pi_{gr}^E}{\partial (P_{ir}^A (1 + tp_{igr}^D + tf_{igr}^D))} \, P_{ir}^A \, tp_{igr}^D \right. \\
& \qquad \left. + \; M_{gr} \, \frac{\partial \Pi_{gr}^M}{\partial (P_{ir}^A (1 + tp_{igr}^D + tf_{igr}^D))} \, P_{ir}^A \, tp_{igr}^D \right) \\
& + \sum_g Y_{gr} \, \frac{\partial \Pi_{gr}^Y}{\partial (p_{gr}^Y (1 - tp_{gr}^Y - tf_{gr}^Y))} \, P_{gr}^Y tp_{gr}^Y \\
& + \sum_g Y_{gr} \, \frac{\partial \Pi_{gr}^Y}{\partial (\mu (1 - tp_{gr}^Y - tf_{gr}^Y))} \, \mu tp_{gr}^Y \\
& + \mu \overline{BOP}_r^p
\end{aligned}
$$

25. Income of federal government (INC^f):

$$
\begin{aligned}
INC^f = & \sum_r \Big(L_r \, P_r^L \, tf_r^L \\
& + \sum_{g \in x} \bar{R}_{gr} \, P_{gr}^R \, tf_{gr}^R \\
& + \sum_g Y_{gr} \, \frac{\partial \Pi_{gr}^Y}{\partial P_{gr}^K} \, P_{gr}^K \, tf_r^K \\
& + \sum_i \sum_g \left(E_{gr} \, \frac{\partial \Pi_{gr}^E}{\partial (P_{ir}^A (1 + tp_{igr}^D + tf_{igr}^D)} \, P_{ir}^A \, tf_{igr}^D \right. \\
& \qquad \left. + \; M_{gr} \, \frac{\partial \Pi_{gr}^M}{\partial (P_{ir}^A (1 + tp_{igr}^D + tf_{igr}^D))} \, P_{ir}^A \, tf_{igr}^D \right) \\
& + \sum_g Y_{gr} \, \frac{\partial \Pi_{gr}^Y}{\partial (p_{gr}^Y (1 - tp_{gr}^Y - tf_{gr}^Y))} \, P_{gr}^Y tf_{gr}^Y \\
& + \sum_g Y_{gr} \, \frac{\partial \Pi_{gr}^Y}{\partial (\mu (1 - tp_{gr}^Y - tf_{gr}^Y))} \, \mu tf_{gr}^Y \\
& + \mu \overline{BOP}^f
\end{aligned}
$$

B.1 Notation

Symbol	Description
i	Goods excluding final demand goods
g	Goods including intermediate goods ($g = i$) and final demand goods, i.e. private consumption ($g = C$), investment ($g = I$) and public consumption ($g = G$)
r (alias s)	Regions
EG	Energy goods: coal, refined oil, gas and electricity
X	Fossil fuels: coal, crude oil and gas

Table 8: Sets

Symbol	Description
Y_{gr}	Production of good g in region r
E_{gr}	Production of energy composite for good g in region r
M_{gr}	Production of material aggregate for good g in region r
A_{ir}	Production of Armington good i in region r
L_r	Labour supply in region r
K	Capital supply
W_r	Production of composite welfare good

Table 9: Activity variables

Symbol	Description
p^Y_{gr}	Price of good g in region r
p^E_{gr}	Price of energy composite for good g in region r
p^M_{gr}	Price of material composite for good g in region r
p^A_{ir}	Price of Armington good i in region r
p^L_r	Price of labour (wage rate) in region r
p^{LS}_r	Price of leisure in region r
P^K_{gr}	Price of capital services (rental rate) in sector g and region r
p^R_{gr}	Rent to fossil fuel resources in fuel production in sector g ($g \in X$)and region r
p^{KM}	Price of interregionally mobile capital
p^K_{gr}	Price of sector-sector specific capital
p^W_r	Price of composite welfare (utility) good
μ	Exchange rate

Table 10: Price variables

Symbol	Description
INC_r^{RA}	Income of representative agent in region r
INC_r^{p}	Income of provincial government in region r
INC^{f}	Income of federal government

Table 11: Income variables

Symbol	Description
tp_{gr}^{Y}	Provincial taxes on output in sector g and region r
tf_{gr}^{Y}	Federal taxes on output in sector g and region r
tp_{gr}^{R}	Provincial taxes on resource extraction in sector g and region r
tf_{gr}^{R}	Federal taxes on resource extraction in sector g and region r
tp_{igr}^{D}	Provincial taxes on intermediate good i in sector g and region$r$
tf_{igr}^{D}	Federal taxes on intermediate good i in sector g and region$r$
tp_{r}^{L}	Provincial taxes on labour in region r
tf_{r}^{L}	Federal taxes on labour in region r
tp_{r}^{K}	Provincial taxes on capital in region r
tf_{r}^{K}	Federal taxes on capital in region r
$\bar{P}_{gr}^{Y}$	Reference price of good g in region r
$\bar{\mu}_{gr}$	Reference value of exchange rate
$\bar{P}_{gr}^{R}$	Reference price of fossil fuel resource g in region r
$\bar{P}_{ir}^{A}$	Reference price of Armington good i in region r
$\bar{P}_{r}^{L}$	Reference price of labour (wage rate) in region r
$\bar{P}_{r}^{K}$	Reference price of capital in region r

Table 12: Tax rates and reference prices

Symbol	Description
θ_{gr}^{EX}	Value share of international market exports in domestic production of good g in region r
θ_{gr}^{E}	Value share of energy in the production of good g in region r
θ_{gr}^{M}	Value share of the material aggregate within the composite of value-added and material in the production of good g in region r
θ_{gr}^{L}	Value share of labour in the value-added composite of good g production in region r
θ_{gr}^{R}	Value share of fossil fuel resource in fossil fuel production ($g \in X$) in region r
θ_{gr}^{ELE}	Value share of electricity in the energy composite of good g production in region r
θ_{gr}^{COA}	Value share of coal in the coal-oil-gas composite of good g production in region r
θ_{gr}^{OIL}	Value share of oil in the oil-gas composite of good g production in region r
θ_{ir}^{DM}	Value share of domestically produced inputs to Armington production of good g in region r
θ_{isr}^{MM}	Value share of imports from region s in the import composite of good i to region r
θ_{r}^{K}	Value share of capital supply to region r in overall (mobile) capital supply
θ_{r}^{LS}	Value share of leisure demand in region r
θ_{r}^{G}	Share of region r in overall public good consumption

Table 13: Cost shares

Symbol	Description
$\overline{L}_r$	Aggregate time (labour and leisure) endowment of region r
$\overline{K}_{gr}$	Sector-specific capital endowment of region r
$\overline{R}_{gr}$	Endowment of fossil fuel resource g by region r ($g \in X$)
$\overline{BOP}_r^{RA}$	Representative agent's balance of payment deficit or surplus in region r
$\overline{BOP}_r^{p}$	Provincial government's balance of payment deficit or surplus in region r
$\overline{BOP}^{f}$	Federal government's initial balance of payment deficit or surplus
$\overline{I}$	Exogenous investment demand
G_r^p	Exogenous provincial government demand
G_r^f	Exogenous federal government demand

Table 14: Endowments and emissions coefficients