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Essays on International and Environmental Economics

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A thesis submitted in partial fulfillment of the requirements for the degree in Doctor of Philosophy

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Jacob Wibe

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Abstract

This thesis consists of three chapters employing quantitative open economy models to study international trade transmission, the economic impacts of climate change, and remittance transfers.

The first chapter examines the role of production sharing and trade in the transmission of the 2008-2009 recession. In the model, production sharing is represented by a tradable sector that produces a composite good exclusively for the foreign market. The results suggest that trade transmission can account for 72% of the fall in output in Canada, 19% of the fall in output in Mexico, and about two-thirds of the fall in trade for both countries. The counterfactual experiments find that production sharing can account for about 40% of the fall in international trade, and 12% of the fall in output.

The second chapter quantifies the net economic impact of climate change and climate change policy on the Canadian economy. We combine a small open economy model of Canada with the ANEMI model, an integrated assessment model developed at Western University. We find that while a carbon tax that holds the stock of global emissions below the 550 ppm level would yield positive net benefits for the world economy, the impact of such a tax on the Canadian economy would be negative. (Joint with Jim MacGee and Jim Davies).

The third chapter examines the impact of remittance transfers on the allocation of productive factors across sectors in Latin American and Caribbean countries. It extends a two-sector open economy model to include an endogenous migration decision. Key findings are that net recipients of remittance payments experience a reallocation of productive factors from the tradable sector to the non-tradable sector, and that the benefit from remittance inflows is lower for countries which have a relatively less productive non-tradable sector.

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Levanger, Norway Jacob Wibe
October 1, 2012

To my parents

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Co-Authorship

The following thesis contains material co-authored by James C. MacGee and James B. Davies. All authors are equally responsible for the work which appears in Chapter 3 of this thesis.

Chapter 1

Introduction

This thesis consists of three essays employing quantitative open economy models to study international trade transmission, the economic impacts of climate change, and remittance transfers.

The first essay (Chapter 2) examines the role of production sharing and trade in the transmission of the 2008-2009 recession within NAFTA. Production sharing, or vertical specialization, refers to the production of goods in multiple, sequential stages where value added is provided by two or more countries. In North America, the production sharing intensity of intra-region manufacturing trade is about 50 percent, and production sharing is particularly prevalent in the auto industry and the Mexican Maquiladoras trade (Burstein, Kurz, and Tesar (2008)).[1]

[1]The Maquiladoras Trade in Mexico consists of mostly US owned assembly plants that import intermediate goods and raw materials to produce goods that are re-exported to the US.

Production sharing may have played a significant role in the transmission of the U.S. economic slowdown. During the recession, real trade fell roughly three times more than real GDP in the U.S. and Mexico, and by a factor of five in Canada. The fall in output and trade was largely accounted for by manufacturing, and the decline was particularly large in sectors with high levels of production sharing. The sudden and synchronized nature of the fall in output and trade suggest that international linkages played an important role in the transmission of the recession across countries.

International supply chains in manufacturing are generally very specialized, and there is little scope to substitute inputs at each production stage. This makes the supply chains vulnerable to demand shocks and interruptions caused by external events, because a fall in demand at any stage can cause a fall in demand across the whole chain.[2] Then, due to the high level of specialization at each production stage, such interruptions often lead to idling of productive factors, as full production shifts can be laid off and the capital may go underutilized. International supply chains therefore increase the interdependence of manufacturing sectors across countries.

Motivated by these observations, I develop a quantitative small open economy model to study the role of trade and production sharing in the transmission of the recession in North America. In the model, production sharing is represented by a tradable sector that produces a composite good exclusively for

[2]E.g. the recent earthquake in Japan and flooding in Thailand.

the foreign market. The results suggest that trade transmission can account for 72% of the fall in output in Canada, 19% of the fall in output in Mexico, and about two-thirds of the fall in trade for both countries. The counterfactual experiments find that production sharing can account for about 40% of the fall in international trade, and 12% of the fall in output.

The second essay (Chapter 3) quantifies the net economic impact of climate change and climate change policy on the Canadian economy. In particular, we seek to quantify the economic costs and benefits from different emission reduction targets on the Canadian economy, and how this compares with the average economic impact in the rest of the world economy.[3]

To tackle these questions, we combine a small open economy model of Canada with the ANEMI model. The ANEMI model is an integrated assessment model developed at Western University that incorporates an energy sector as well as fossil fuel production into a neoclassical growth model. We use the ANEMI framework to both develop our baseline analysis of the impact of carbon taxes on the world economy, and to generate a path of carbon emissions, climate, and (relative) price of fossil fuels which we feed into our small open economy model of Canada.[4]

The ANEMI model incorporates several key innovations that are absent

[3]This essay is joint work with Jim MacGee and Jim Davies.

[4]As a small economy, the direct impact of changes in Canadian greenhouse gas emissions on the level of global greenhouse stocks is relatively small, since Canada accounts for less than 3 percent of global GHG emissions This leads us to take the path of global greenhouse gas stocks as independent of Canadian emissions.

from the influential DICE framework of Nordhaus (2008). First, the ANEMI model includes an explicit energy sector which produces a composite energy good used in the production of final output. This energy intermediate good is in turn produced using a composite of two broad energy sub-composites: heat energy (i.e. fuel energy burned for transportation or industrial purposes) and electrical energy. Each of these energy types is produced using different technologies for each of the major energy sources. This structure provides a useful mid-point between aggregate models (such as DICE) which abstract from detailed modeling of energy and more detailed bottom up models which typically abstract from key features of dynamics and optimal choice. The second innovation on the climate side is the inclusion of a simple production structure for fossil fuels. As a result, the path of fossil fuels evolves endogenously in the model, so that climate policy (such as carbon taxes which seek to lower demand for fossil fuels) and the negative impact of climate change on aggregate productivity (which tends to lower energy demand) both impact the temporal path of fossil fuel prices. In turn, the equilibrium prices of fossil fuels impact investment in capital stocks to produce energy using different types of fossil fuels.

To highlight how Canada differs from the global average, we compare the results from our Canadian economy to those of the ANEMI model for a carbon tax designed to maintain the level of CO2e below 550 ppm. We find that the economic benefits to Canada of this carbon tax are much smaller (in fact, negative) than they are for the rest of the world. This finding is mainly due to large differences in the calibrated damage function in the Canadian and world model ANEMI economies. These differences reflect significant differences in estimated impact of small temperature increases on the Canadian and global economies. In addition, our benchmark simulation results highlight the large impacts that carbon taxes can have on long run shifts in fossil fuel prices by shifting the temporal path of consumption.

The third essay (Chapter 4) examines the impact of remittance transfers on the allocation of productive factors across sectors in Latin American and Caribbean countries. Remittance payments to many developing economies are large. Net remittances to Latin America and the Caribbean reached USD 53 billion in 2009, about 1.5% of the region's gross national income.[5] Indeed, for many countries, remittance flows exceed international aid and foreign direct investment.

Recent empirical studies have found that these remittance flows are large enough to impact (i.e. appreciate) the real exchange rate in remittance receiving countries, suggesting the presence of a *Dutch Disease effect*.[6] (For example Lartey, Mandelman, and Acosta (2012), Acosta, Lartey, and Mandelman (2009), and Amuedo-Dorantes and Pozo (2004)).

[5]World Bank, "Migration and Remittances Factbook" (2011).

[6]The term 'Dutch disease' was originally used to describe the difficulties faced by the manufacturing sector in the Netherlands following the development of natural gas on a large scale which triggered a major appreciation of the real exchange rate.

The Dutch Disease effect may substantially reduce the benefit of remittance inflows if the productivity in the non-tradable sector is low relative to the productivity in the tradable sector. By shifting productive factors into the non-tradable sector (services), a country may experience a significant deterioration of its aggregate productivity, if the remittance inflows are large and the productivity in the service sector relatively low. Duarte and Restuccia (2010) suggest that differences in labour productivity levels between rich and poor countries are larger in services than in manufacturing, and low relative productivity in services explains all the experiences of slowdown, stagnation, and decline in relative aggregate productivity across countries. In this paper I analyze how the aggregate productivity in the Latin American and Caribbean economies are affected by remittance inflows.

To quantify the impact of remittance transfers on aggregate productivity and welfare I develop a two-sector, small open economy model where remittances are a function of migration. Linking remittance inflows to the migration decision is important because remittances are not a random process, but transfers to family members from workers who migrated in order to obtain better economic opportunities abroad.

In the quantitative experiments I compare the benchmark calibration to a counterfactual where there is no incentive to migrate. That is, for each country I compare the benchmark steady state equilibrium to a recalibrated steady state with zero migration and zero remittance inflows. The results suggest that

Latin American and the Caribbean economies have experienced an increase in consumption per capita by 9.1% on average as a result of remittance transfers.

My results further suggest that the benefits from remittance transfers could be 33% higher in terms of increased GDP per capita, and 27% in terms of increased consumption per capita, if the non-tradable sector productivity increased to the tradable sector level. The benefit is reduced by the shift of productive resources into the less productive non-tradable sector. The remittance transfers generate a Dutch Disease effect where the non-tradable sector share increases by 6% on average, and by 15-20% for the high remittance countries.[7]

[7] In the sample, 10 out of the 33 countries are what I consider high remittance economies. In 2000, they received remittance transfers in excess of 5% of GDP.

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Chapter 2

The Role of Production Sharing and Trade in the Transmission of the Great Recession

2.1 Introduction

During the 2008-2009 recession, real trade fell roughly three times more than real GDP in the U.S. and Mexico, and by a factor of five in Canada. The fall in output and trade was largely accounted for by manufacturing, and the decline was particularly large in sectors with high levels of production sharing. The sudden and synchronized nature of the fall in output and trade suggest that international linkages played an important role in the transmission of the recession across countries.

Motivated by these observations, I develop a quantitative small open economy model to study the role of trade in the transmission of the recession in North America. A key feature of my model is production sharing. Production sharing, or vertical specialization, refers to the production of goods in multiple, sequential stages where value added is provided by two or more countries. In NAFTA, the production sharing intensity of intra-region manufacturing trade is about 50 percent, and production sharing is particularly prevalent in the auto industry and the Mexican Maquiladoras trade (Burstein, Kurz, and Tesar (2008)).[1]

Production sharing may have played a significant role in the transmission of the US economic slowdown. International supply chains in manufacturing are generally very specialized, and there is little scope to substitute inputs at each production stage. This makes the supply chains vulnerable to demand shocks and interruptions caused by external events, because a fall in demand at any stage can cause a fall in demand across the whole chain.[2] Then, due to the high level of specialization at each production stage, such interruptions often lead to idling of productive factors, as full production shifts can be laid off and the capital may go underutilized. International supply chains therefore increase the interdependence of manufacturing sectors across countries.

The large fall in trade relative to output during the recession may also be related to production sharing. At each step in a supply chain, some value added is produced before the intermediate good is shipped to the next location for further processing or sale at its final destination. Because trade flows

[1]The Maquiladoras Trade in Mexico consists of mostly US owned assembly plants that import intermediate goods and raw materials to produce goods that are re-exported to the US.

[2]E.g. the recent earthquake in Japan and flooding in Thailand.

are measured on a gross value basis, imported intermediate goods are double counted when they are re-exported as part of later stage intermediate goods or final goods. This double counting generates a larger fall in trade relative to output for production sharing goods than for standard traded goods, and the effect would be exacerbated for international supply chains crossing multiple national borders.

To quantify the contribution of trade and production sharing in the transmission of the recession I develop a small open economy model that nests the production structure of Backus, Kehoe, and Kydland (1994). The economy produces two tradable and one non-tradable intermediate good. The first tradable intermediate is combined with imported intermediate goods to produce a generic tradable composite good. The second tradable intermediate is combined with imported intermediates to produce the production sharing composite. The production sharing composite good is only demanded abroad, representing goods produced by Canada and Mexico for the US market. The generic tradable composite is combined with the non-tradable intermediate to produce the final good which is used for consumption and investment. Lastly, I add convex adjustment costs to capital.

The quantitative experiments focus on the role of trade in transmitting the US slowdown to Canada and Mexico. This is modeled as shocks to foreign import demand. I calibrate the demand shocks such that the model matches the observed terms-of-trade movements exactly for Canada and Mexico. I calibrate production sharing using OECD Input-Output tables and bilateral trade data.[3] By assuming that the share of imported intermediates used in producing export goods is proportional to industry output, the I-O tables provide weights to convert gross trade into value added measures. The benchmark calibration takes the stance that Canadian exports of auto parts and finished light vehicles, and Mexican exports from the Maquiladoras industry are *production sharing exports*.

The results indicate that trade was an important factor in transmitting the recession to Canada and Mexico. In the benchmark calibration the model can account for 72% of the fall in output in Canada, 19% of the fall in output in Mexico, and about two-thirds of the fall in trade for both countries. The tradable sector accounts for about three quarters of the fall in output. Intuitively, since the shock hits the economy's exports, the fall in output is larger in the tradable sectors than in the non-tradable sector. Output falls more in the production sharing sector because the shock can only be absorbed by reallocating productive factors. In the generic tradable sector the shock can be absorbed by either reallocating productive inputs or changing the household's consumption allocation, and output therefore falls less relative to the production sharing sector. Following shocks to foreign import demand, the capital adjustment costs act as a friction to the reallocation of productive factors across sectors. The interaction between the capital adjustment costs and the share of production sharing

[3]Several different measures are available to calibrate the degree of production sharing in trade. See for example Hummels, Ishii, and Yi (2001), Yi (2003), or Chen, Kondratowicz, and Yi (2005)

in the tradable sector generate the transmission dynamics in the model.

In the counterfactual experiments I quantitatively assess the contribution of production sharing to transmission. By comparing the model with zero production sharing to the benchmark (holding the share of value added exports to GDP constant) I find that production sharing can account for 40% of the fall in trade and 12% of the fall in output. Production sharing has a bigger impact on trade than output because of the relatively larger share of production sharing goods in the composition of trade. This suggests that production sharing was a contributing factor to the large fall in trade relative to output.

My work contributes to three main bodies of literature. First, it contributes to the relatively recent literature investigating the impact of international production sharing on comovement. Di Giovanni and Levchenko (2010) use industry level data and find that international production linkages explain 32% of the impact of bilateral trade on aggregate comovement. Burstein, Kurz, and Tesar (2008) use data on US multinationals and find that manufacturing sectors with higher levels of production sharing experience greater comovement in trade flows and output. Their results also suggest that the production sharing intensity is at least as important as trade volume in accounting for bilateral manufacturing output correlations. In Arkolakis and Ramanarayanan (2009) the authors study a model based on Eaton and Kortum (2002) where the degree of production sharing varies with trade barriers. With imperfect competition their model generates a positive link between trade intensity and output comovement. In my model I highlight how production sharing in North America is characterized by Canada and Mexico importing intermediate goods and producing for the US market. I model production sharing as a separate tradable sector producing a composite good that is exclusively exported. I argue that it is important to consider the location of production plants and the direction of trade flows when studying the impact of production sharing on comovement.

This chapter is also closely related to recent work on the post-Lehman fall in world trade and how it contributed to the transmission of the 2008-2009 recession. The empirical work in the literature generally agrees with the conclusion in this chapter; for example, Eaton, Kortum, Neiman, and Romalis (2011), Levchenko, Lewis, and Tesar (2010), and Bems, Johnson, and Yi (2010) all argue that trade linkages were important in the propagation of the global recession. Eaton, Kortum, Neiman, and Romalis (2011) use a multi-sector model based on Eaton and Kortum (2002) and Alvares and Lucas (2007), and argue that the fall in global trade and output was largely accounted for by a fall in demand for manufacturing goods. Bems, Johnson, and Yi (2010) use a global Input-Output framework and study how changes in final demand in the US and Europe was transmitted to other countries. Their estimates suggest that 27% of the fall in US demand was borne by foreign countries. Levchenko, Lewis, and Tesar (2010) find that the fall in US trade relative to GDP was larger than in previous recessions and argue that sectors producing intermediate inputs experienced larger falls in imports and exports. In addition, James (2009) analyze data from the US International Trade Commission and finds that US trade with preferential trade partners contracted faster than trade with the rest of the world. He suggests that the transmission of the recession in North America was principally through international trade. Chor and Manova (2011) argue that credit conditions were important for transmission of the trade shock. They find that countries with relatively tighter credit markets exported less to the US during the recession. In this chapter I restrict my attention to North America, and I focus on the impact of production sharing on trade transmission. I abstract from credit market and trade barrier frictions.

Lastly, this chapter contributes to the literature on international transmission of domestic shocks. A key challenge in this literature has been to account for comovement in international business cycle models. Schmitt-Grohe (1998) studies open economy models and finds that interest rate and terms-of-trade variations cannot explain US/Canadian output comovement. Baxter and Crucini (1995) develop a two-country model and study the importance of financial market linkages for the behaviour of business cycles. They find that the degree of financial integration is only important if shocks are highly persistent or are not transmitted internationally. Stockman and Tesar (1995) allow for non-traded goods in a two-country model. They find that technology shocks alone are insufficient to match the data, and include taste shocks to get predictions more consistent with measurements of comovement. Kose and Yi (2006) use a three-country framework with transportation costs to study the impact of trade linkages on comovement. The authors find a positive correlation between trade and comovement, but the model still falls short of matching empirical findings.

In this literature, my work is most closely related to Burstein, Kurz, and Tesar (2008). The foremost difference between our work is that I examine the 2008-2009 recession, whereas the aim of Burstein et al. is to evaluate the importance of production sharing as a mechanism to generate comovement. Structurally, our frameworks are similar as we both extend Backus, Kehoe, and Kydland (1994) and model production sharing as producing a composite good only consumed by one country. The main difference between our frameworks is that I develop a small open economy model where the production sharing good is traded, while in their two-country model only intermediate goods are traded. A second difference is that their model only has one intermediate good for each country, compared to my model which has two tradable goods and one non-tradable intermediate good. The number of sectors and which goods are traded are important distinctions because I include capital adjustment costs which impact the transmission dynamics in response to shocks. In the counterfactual experiments I carefully analyze the effects of the capital adjustment costs.

This chapter is organized as follows: Section 2.2 gives a brief review of evidence on output, trade and production sharing during the recession. Section 2.3 describes the model. In section 2.4 I describe the model parameters and calibration strategy. The benchmark results and quantitative exercises are described in section 2.5. Section 2.6 concludes.

2.2 Key Facts from the Recession

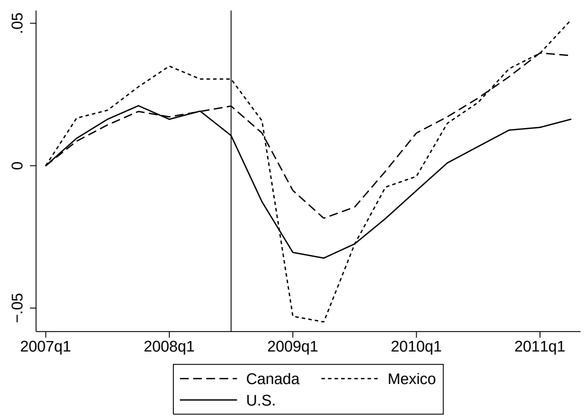
In this section I present three key facts on trade and the great recession in NAFTA: (i) the timing of the decline in output and trade, (ii) the magnitude of the fall in trade relative to output, and finally, (iii) production sharing and the composition of the fall in output and trade.

2.2.1 Timing

Several authors, including Baldwin and Evenett (2009) and Bems, Johnson, and Yi (2010), have pointed out the synchronised nature of the fall in output and trade during the global recession.

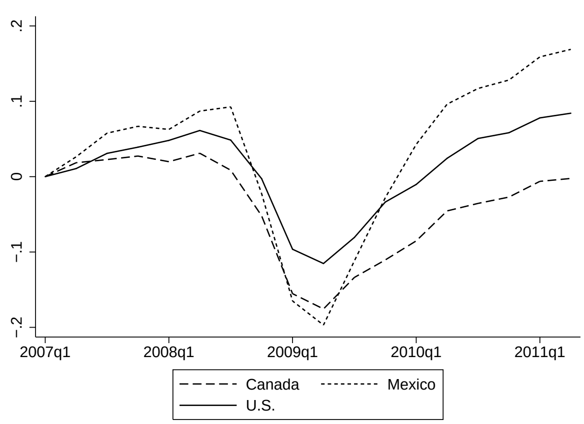
Figures 2.1 and 2.2 show the logarithm of real GDP and real trade for Canada, Mexico, and the US from Q1 2007 to Q2 2011. In Figure 2.1, the fall in US output leads Canada and Mexico by a quarter, indicating that the recession started earlier in the US. Figure 2.2 shows how the fall in real trade is more synchronized than the fall in output. Note that the fall in output in Canada and Mexico coincides with the fall in trade across all three countries. This suggests that trade played a role in the transmission of the recession.

Figure 2.1: Natural Logarithm of Real GDP, Seasonally Adjusted



Notes: Vertical line approximately marks the fall of the Lehman Brothers which filed for Chapter 11 bankruptcy protection on September 15, 2008.
Source: OECD Statistics - Quarterly National Accounts.

Figure 2.2: Natural Logarithm of Real Trade, Seasonally Adjusted



Source: OECD Statistics - Quarterly National Accounts.

Table 2.1: Real GDP and Real Trade - US, Canada, and Mexico

	U.S.	Canada	Mexico
Real GDP	-5.0%	-3.7%	-9.9%
Real Trade	-15.7%	-18.7%	-26.9%

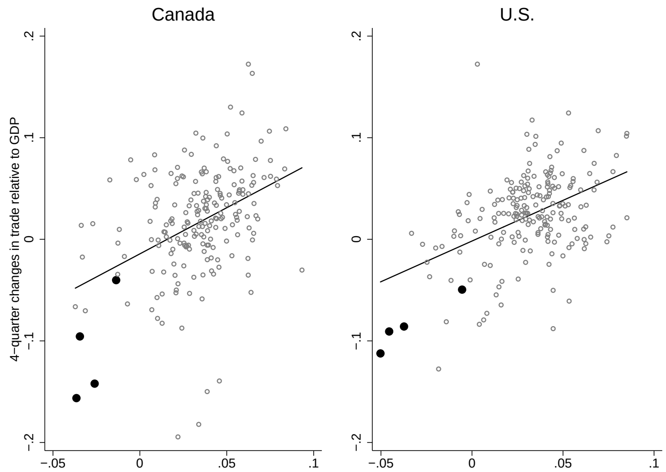
The quantitative exercises in this chapter focus on Q2 2008 to Q2 2009. This period roughly coincides with the peak to trough of US real GDP per capita. As shown in Figure 2.1, there is a small dip in US GDP (solid line) from Q4 2007 to Q1 2008 before it reaches a local peak at Q2 2008, and then declines until Q2 2009.

2.2.2 Fall in Trade Relative to Output

Table 2.1 displays the change in real GDP and real trade over Q2 2008 to Q2 2009. Real GDP fell 5% in the US, 3.7% in Canada, and 9.9% in Mexico. The declines in trade are more striking, as trade falls roughly three times more than real GDP in the U.S. and Mexico, and by a factor of five in Canada.

For Canada and the US the fall in trade relative to output during the recession was large compared to previous episodes. Figure 2.3 plots four-quarter changes in trade relative to GDP against the change in real GDP from Q1 1960 to Q4 2010 for Canada (left panel) and the US (right panel). The smaller gray

Figure 2.3: Trade Relative to GDP, 4 Quarter Changes



Notes: Four-quarter changes in trade relative to GDP against the change in real GDP, 1960-2010. A similar plot appears in Eaton, Kortum, Neiman, and Romalis (2011). Source: IMF International Financial Statistics (IFS).

dots and the regression line is based on the observations prior to the 2008-2009 recession, and the four solid black dots represents the observations for the recession period. For Canada, the solid black dots appear to the far left, indicating the severity of the recession, and three of the four dots are well below the regression line representing a deviation from earlier episodes. The US shows a similar but less pronounced pattern.

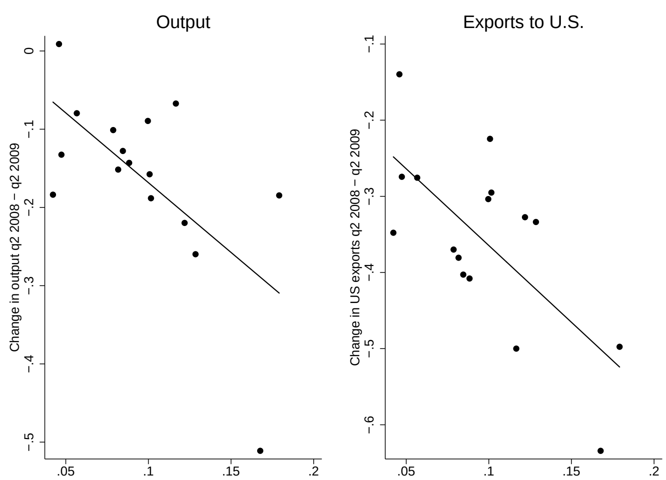
2.2.3 Production Sharing, Output and Trade

Table 2.2 presents a decomposition of GDP, and shows the contribution of each sector to the fall in GDP from Q2 2008 to Q2 2009.

Table 2.2: Decomposition of GDP - US, Canada, and Mexico

	Share of GDP Average 2006 - 2010			% Δ Q2 2008 - Q2 2009			Contribution to fall in GDP		
	U.S.	**Can**	**Mex**	**U.S.**	**Can**	**Mex**	**U.S.**	**Can**	**Mex**
Mining, oil, gas	1%	5%	5%	-39%	-7%	-2%	13%	9%	1%
Manufacturing	13%	14%	18%	-15%	-14%	-14%	47%	58%	30%
Other tradable	9%	19%	27%	-12%	-6%	-14%	25%	31%	45%
Non-tradable	77%	62%	50%	-1%	0%	-4%	15%	3%	24%

Figure 2.4: Production Sharing and the Fall in Output and Trade



Notes: Fall in output (left) and exports to U.S. (right) for manufacturing sectors in Canada against the ratio of imported intermediates to industry output for corresponding manufacturing sectors in U.S., Q2/2008-Q2/2009
Source: Statistics Canada, US International Trade Commission, OECD Input-Output Tables

The sectoral impact of the recession in Canada and the US is similar. The tradable sector (mainly manufacturing) largely accounts for the fall in output. The picture is less clear for Mexico, where manufacturing accounts for a third and the non-tradable sector a quarter of the fall in output, but transportation, retail and wholesale trade also experienced significant declines.

During the recession, Canadian manufacturing sectors with production linkages to the US experienced greater declines in output and exports. Figure 2.4 shows scatter plots of the fall in output (left panel) and exports to the US (right panel) for Canadian manufacturing sectors plotted against imported intermediates relative to industry output in the US. The regression lines show a negative relationship, suggesting that production sharing was important in transmitting the recession to Canada.

As an example, consider the impact on the Canadian automotive industry following the closure of several North American assembly plants during 2009. Most of the closures were temporary, although GM's Oshawa Truck plant and six US plants shut down for good. The effect of the assembly plant closures was severely felt by the Canadian auto parts industry. According to Industry Canada (2006), Canadian auto parts and component manufacturing consists of about 900 establishments which on average export 61% of their production value. The recession led to large scale layoffs at several major parts manufacturers, including about 400 workers at Magna International and 700 workers at Linmar Corp.

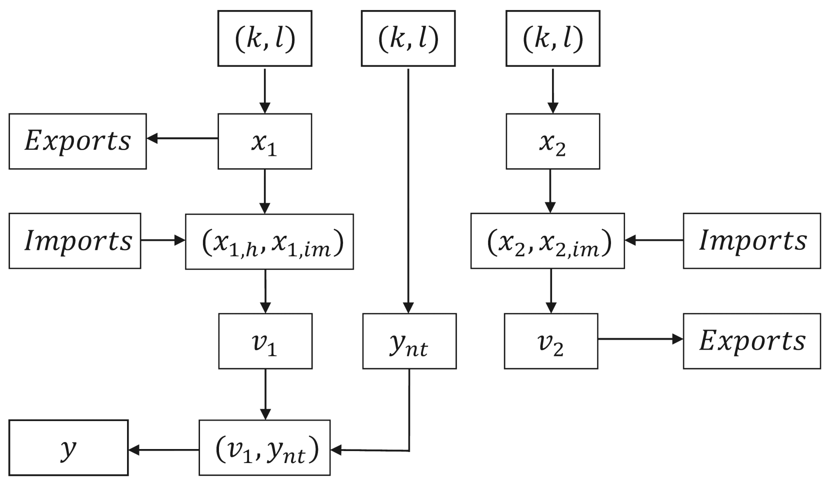
2.3 Model

To quantify the contribution of trade and production sharing in the transmission of the recession, I use a real business cycle framework that incorporates production sharing. The model is a small open economy that nests the production structure of Backus, Kehoe, and Kydland (1994).[4] The economy produces two tradable intermediate goods and one non-tradable intermediate good. The first tradable intermediate good is both exported and combined domestically with an imported intermediate good to produce a tradable composite good. The second tradable intermediate good is combined with an imported intermediate good to produce the production-sharing composite good. This good is only demanded abroad, and all of its production is exported. The production sharing composite represents goods produced by Canada and Mexico for the US market. Lastly, the first composite good is combined with the non-tradable intermediate to produce the (non-traded) final good which is used for consumption and investment. A flowchart describing the model is included in Figure 2.5.

To avoid excess volatility of investment in response to foreign demand shocks I include capital adjustment costs. The adjustment costs limit the investment response to shocks and change the transmission dynamics in the model. The financial market is represented by a one-period, non-contingent bond. Unless otherwise stated, all variables are denoted in per capita quantities.

[4] By setting the production sharing sector and the non-tradable sector to zero, my model collapses to an open economy version of the Backus, Kehoe, and Kydland (1994) framework.

Figure 2.5: Model Flowchart



Notes: x_1 is an intermediate good that is exported and used in producing the generic tradable composite good, v_1. x_2 is the production sharing intermediate good, aggregated with the imported intermediate $x_{2,im}$ to produce the production sharing composite good, v_2, which is exclusively exported. The final good y is produced by aggregating the non-traded good y_{nt} and the tradable composite good, v_1. The (non-traded) final good is used for consumption and investment.

2.3.1 The Representative Household

The economy is populated by a representative household that chooses consumption, leisure, investment, and foreign debt to maximize:

$$E_0\left(\sum_{t=0}^{\infty}\frac{\beta^t\left(c_t^{\mu}(1-n_t)^{1-\mu}\right)^{1-\sigma}}{1-\sigma}\right),\quad 0<\mu<1, 0<\beta<1, 0<\sigma \tag{2.1}$$

where c_t is consumption and n_t is the amount of labour supplied in period t. β is the discount factor, μ is the intratemporal share parameter for consumption and leisure, and σ pins down the intertemporal elasticity of substitution. The household's time endowment is normalized to 1.

The household supplies labour services and rents capital to the firms. The law of motion for gross investment in sector j (two tradable and one non-tradable) is:

$$i_{j,t}=k_{j,t+1}-(1-\delta)k_{j,t}+\Phi_k(k_{j,t+1},k_{j,t}),\quad j=1,2,nt \tag{2.2}$$

Φ_k is the capital adjustment cost function which follows Cogley and Nason (1995). The functional form implies that the marginal cost of adjusting the capital stock is a linear function of the rate of net investment:[5]

$$\Phi_k(k_{j,t+1},k_{j,t})=\frac{\psi_k}{2}\left(\frac{k_{j,t+1}-k_{j,t}}{k_{j,t}}\right)^2,\quad 0<\psi_k,\ =1,2,nt \tag{2.3}$$

[5] Mendoza (1991) uses a related specification where the marginal cost is a linear function of net investment.

Here, ψ_k is a constant parameter defining the capital adjustment cost function.

The household can borrow or lend in the international financial market by a risk-free bond. As Canada and Mexico are net debtors, I refer to the asset d_t as the household's debt. The household's debt evolves according to:

$$d_{t+1} = d_t(1 + r_{d,t}) - tb_t \tag{2.4}$$

where $tb_t = exports_t - imports_t$ is the trade balance.

To avoid a unit root in the log-linearized system, I introduce portfolio adjustment costs following Schmitt-Grohe and Uribe (2003). The representative household faces quadratic costs of holding debt quantities that deviate from the steady state level:

$$\Phi_d(d_{t+1}) = \frac{\psi_d}{2}(d_{t+1} - \overline{d})^2 \ , \quad 0 < \psi_d \tag{2.5}$$

where d_t is the current debt level, $\overline{d}$ is the steady state debt level, and ψ_d is a constant parameter defining the portfolio adjustment cost function.[6]

The household's budget constraint is:

[6]The portfolio adjustment cost function is a technical detail to make the model stationary for simulation purposes. Any impact on the quantitative results is negligible. See Schmitt-Grohe and Uribe (2003).

$$c_t + \sum_j i_{j,t} + (1 + r_t^d)d_t + \Phi_d(d_{t+1}) \leq \sum_j \left(r_{j,t}^k k_{j,t} + w_{j,t} n_{j,t} \right) + d_{t+1} \tag{2.6}$$

where $i_{j,t}$, $k_{j,t}$, $n_{j,t}$ is investment, capital, and labour supplied to sector j in period t respectively, d_t is the current period's debt, $r_{d,t}$ is the risk-free interest rate, and Φ_k and Φ_d are the adjustment cost functions for capital and external debt.

2.3.2 Technology

In the model, representative firms produce two tradable intermediate goods, the non-tradable intermediate good, two tradable composite goods, and the (non-traded) final good.

Intermediate Good Production

The two tradable intermediate goods are produced by competitive firms. Each firm has a Cobb-Douglas production technology and takes capital and labour as inputs.

$$x_j = k_j^{\alpha} n_j^{(1-\alpha)} \ , \quad 0 < \alpha < 1 \ , \quad j = 1, 2 \tag{2.7}$$

where k_j is the amount of capital rented, n_j is the amount of labour hired, and x_j is the amount of intermediate goods produced in sector j. α is capital's share in output. Each period, firms maximize profits:

$$\max_{k_j,n_j} q_j^x x_j - r_j k_j - w_j n_j \quad \text{s.t.} \quad k_j, n_j > 0 \tag{2.8}$$

where w_j is the wage rate, r_j the rental rate for capital, and q_j^x is the relative price of intermediate good j in terms of the final good.

The non-tradable intermediate good is produced from capital and labour by a Cobb-Douglas production technology:

$$y_{nt} = k_{nt}^{\alpha} n_{nt}^{(1-\alpha)} \; , \quad 0 < \alpha < 1 \tag{2.9}$$

where α is capital's share in output for the non-tradable sector. Each period the representative firm producing the non-tradable intermediate maximizes profits:

$$\max_{k_{nt},n_{nt}} q_{nt} y_{nt} - r_{nt} k_{nt} - w_{nt} n_{nt} \tag{2.10}$$

Here, q_{nt} is the price of the non-tradable good in terms of the final good.

Composite Good Aggregation

In each tradable sector j, a composite good is produced by a representative firm combining domestic and imported intermediates in an Armington aggregator:

$$v_j = \left(\omega_j x_{j,h}^{\eta_j} + (1-\omega_j) x_{j,im}^{\eta_j}\right)^{1/\eta_j} \; , \quad 0 \leq \omega_j \leq 1, \eta_j \leq 1, \quad j = 1, 2 \tag{2.11}$$

where $x_{j,h}$ is the domestic intermediate and $x_{j,im}$ the imported intermediate used in producing the composite good v_j. Note that, for $j = 2$, in the production sharing sector, $x_{2,h} = x_2$. ω_j is the CES share parameter representing the home-bias, and $1/(1-\eta_j)$ is the elasticity of substitution for the domestic and imported inputs. The perfectly competitive composite goods producers maximize profits each period:

$$\max_{x_{j,h},x_{j,im}} q_j^v v_j - q_j^x x_{j,h} - q_j^{x^*} x_{j,im} \tag{2.12}$$

where q_j^v is the price of composite good j and $q_j^{x^*}$ is the price of the imported intermediate good, both in terms of the final good.

Final Good Aggregation and Market Clearing

The final good is produced by a representative firm taking the tradable composite from sector 1 and the non-tradable intermediate good as inputs in an Armington aggregator:

$$y = \left(\gamma v_1^\theta + (1-\gamma) y_{nt}^\theta\right)^{1/\theta} \quad , \quad 0 \leq \gamma \leq 1, \theta \leq 1, \tag{2.13}$$

where γ is the CES share parameter and $1/(1-\theta)$ is the elasticity of substitution for the tradable composite and the non-tradable good. Each period the perfectly competitive firm producing the final good maximizes profits:

$$\max_{v_1, y_{nt}} y - q_1^v v_1 - q_{nt} y_{nt} \tag{2.14}$$

The price of the final good has been normalized to 1. The resource constraint for the final good is:[7]

$$c_t + \sum_j i_{j,t} + \Phi_d(d_{t+1}) \leq y_t \tag{2.15}$$

In the labour and capital markets, the quantities supplied by the household must equal the quantities demanded by the firms each period:

$$n^s = n_1^d + n_2^d + n_{nt}^d \quad \text{and} \quad k^s = k_1^d + k_2^d + k_{nt}^d \tag{2.16}$$

Market clearing for intermediate goods in sector 1 implies:

$$x_1 = x_{1,h} + x_{1,ex} \tag{2.17}$$

where x_1 is the quantity of intermediate good 1 produced, $x_{1,h}$ the quantity consumed at home, and $x_{1,ex}$ the quantity exported. The intermediate good produced in sector 2 is only used to produce the composite good in sector 2, and is not exported.

[7]By substituting for the value of the final good you can show that the resource constraint is equivalent to the household's budget constraint. See appendix for details.

2.3.3 Foreign Import Demand

The intermediate goods from sector 1 not consumed domestically, and all of the composite goods produced in sector 2 (the production sharing sector) are exported. The foreign demand for goods 1 and 2 is modeled as CES import demand equations:

$$\frac{q_1^{x^*}}{q_1^x} = \left(\frac{\omega_1^*}{1-\omega_1^*}\right)\left(\frac{x_{1,im}^*}{e^z x_1^* - x_{1,ex}^*}\right)^{1-\eta_1^*} \quad , \quad 0 \leq \omega_1^* \leq 1, \, \eta_1^* \leq 1 \tag{2.18}$$

$$\frac{q_2^{v^*}}{q_2^v} = \left(\frac{\pi^*}{1-\pi^*}\right)\left(\frac{v_{2,im}^*}{e^z v_2^*}\right)^{1-\phi^*} \quad , \quad 0 \leq \pi^* \leq 1, \, \phi^* \leq 1 \tag{2.19}$$

Here, from the perspective of the foreign economy, ω_1^* and π^* are the CES share parameters, while $1/(1-\eta_1^*)$ and $1/(1-\phi^*)$ are the elasticities of substitution between domestic and imported goods respectively. The prices $q_1^{x^*}$ and $q_2^{v^*}$, and the size of the sectors x_1^*, v_2^* are given exogenously. z represents the foreign demand shock, and follows an AR(1) process:

$$z_{t+1} = \rho z_t + \epsilon_t \; , \quad 0 < \rho < 1 \tag{2.20}$$

where ρ is the persistence parameter and ϵ_t is a normally distributed random variable with mean 0 and variance σ_ϵ^2.

2.3.4 Equilibrium and Solving the Model

An equilibrium in this model is a sequence of prices and quantities such that the first order conditions to the firms' and the household's maximization problems, and the market clearing conditions are satisfied in every period. The household maximizes (2.1) with respect to (2.6), (2.4), and (2.2).

To solve the model I use the linearization method now common in the international business cycle literature (e.g. see Uhlig (1995)). To linearize and simulate the model I use *Dynare*.[8]

2.4 Parameterization and Calibration Strategy

This section describes the model parameter values and the calibration strategy. First, I describe the choice of typical international business cycle parameters and the parameters specific to my model; second, I explain the calibration exercise used to match a set of observable moments.

I calibrate the model to Canada and Mexico. Each period corresponds to a quarter.

[8]Dynare is a software package developed at Cepremap. See Adjemian, Bastani, Juillard, Mihoubi, Perendia, Ratto, and Villemot (2011).

Table 2.3: International Business Cycle Parameters

Parameter	Value	Description
α	0.32	Capital share in output
β	0.99	Discount factor
δ	0.025	Depreciation rate
μ	0.36	Share parameter for consumption and leisure
σ	2.0	Risk aversion parameter
ψ_d	0.00074	Portfolio adjustment cost
ρ	0.95	AR(1) persistence parameter
$1/(1-\eta_1)$	3.0	E_s domestic and imported intermediate 1
$1/(1-\eta_2)$	3.0	E_s domestic and imported intermediate 2
$1/(1-\eta_1^*)$	1.5	E_s foreign import demand intermediate 1
$1/(1-\phi^*)$	1.5	E_s foreign import demand composite 2
$1/(1-\theta)$	2.0	E_s tradable and non-tradable goods

2.4.1 International Business Cycle Parameters

For parameters typically found in international business cycle models I take common parameter values from the literature. Table 2.3 lists the benchmark values for the parameters. Each parameter falls within the range of values used in the literature.

The portfolio adjustment cost parameter, ψ_d, from Schmitt-Grohe and Uribe (2003), is calibrated in their small open economy model to match observed volatility in the Canadian current-account-to-GDP ratio. α, capital's share of output is set to 0.32,[9] μ, the share parameter for consumption and leisure is set to 0.36, and σ, the coefficient of relative risk aversion is set to 2.0. $\beta = 0.99$ implies an annual risk-free interest rate of 4%. Similarly $\delta = 0.025$ implies an

[9] Gollin (2002) suggests that after accounting for labour income of the self-employed, income shares to labour/capital are similar across countries.

Table 2.4: Model Specific Parameters

Parameter	Canada	Mexico	Target Moment
$\overline{d}$	0.64	0.19	Net external debt share of GDP ($\overline{d}/\overline{y}$)
x_1^*	0.25	0.23	Relative sector size of tradable sector (x_1/x_1^*)
v_2^*	0.12	0.10	Relative sector size of manufacturing (v_2/v_2^*)
ψ_k	1.46	1.82	Relative volatility of investment and GDP (cv_i/cv_y)

annual depreciation rate of 10%. ρ, the AR(1) persistence parameter, is set to 0.95 because business cycle models generally need shocks to be very persistent in order to match observed quantity movements.[10] The Armington elasticity parameters are set to target the relative volatility of exports to output in the domestic sectors. The model matches the data better when the elasticities in the domestic sectors are higher relative to the foreign import demand equations. In the benchmark model, $1/(1-\eta_1)$ and $1/(1-\eta_2)$ are set to 3.0, and $1/(1-\eta_1^*)$ and $1/(1-\phi^*)$ are set to 1.5.

Table 2.4 lists the parameters I choose to target specific moments for Canada and Mexico. The steady state debt-level, $\overline{d}$, targets the net external debt as a share of GDP. x_1^* and v_2^*, the parameters representing the size of the foreign sectors for intermediate good 1 and composite good 2, are set to match the size of the Canadian and Mexican manufacturing and tradable sectors relative to the US. ψ_k, the capital adjustment cost parameter, is set to match the volatility of investment relative to GDP.

[10] See for example King, Plosser, and Rebelo (1988).

2.4.2 Calibration of Production Sharing

To calibrate production sharing in the model I use the CES share parameters from the domestic Armington aggregators and foreign import demand equations. I target the four moments listed in Table 2.5.

I use data on services, construction, and utilities to calculate the non-tradable share of GDP. The value added share of exports is calculated by subtracting the weighted average of imported intermediates used in production from gross exports. I assume that the content of imported intermediates used in the production of exports is proportional to the average for each sector. The share of the type 2 composite good in exports is the production sharing content of exports. For the benchmark calibration I assume that auto parts and light vehicles represents Canadian production sharing exports, and that the Maquiladoras sector represents production sharing exports for Mexico. To calculate the value added in the production sharing sector I subtract the weighted average of imported intermediates used in production in the respective sectors.

To implement the calibration I add four additional restrictions to the system of equations characterizing the steady state in the model. I solve for the CES share parameters from the domestic composite good aggregation and the foreign import demand equations simultaneously with the steady state. The calibrated CES share parameters are listed in Table 2.6.

Table 2.5: Calibration Moments

Benchmark Model Moments	Canada	Mexico
Non-tradable share of GDP	61%	50%
Value added export share of GDP	30%	23%
Type 2 composite share in exports	26%	52%
Value added in type 2 composite	56%	61%

Table 2.6: Calibrated CES Share Parameters

Parameter	Canada	Mexico	Description
ω_1	0.54	0.51	Home-bias, intermediate 1
ω_2	0.38	0.35	Home-bias, intermediate 2
ω_1^*	0.61	0.89	Foreign home-bias, intermediate 1
π_1^*	0.76	0.80	Foreign home-bias, composite 2

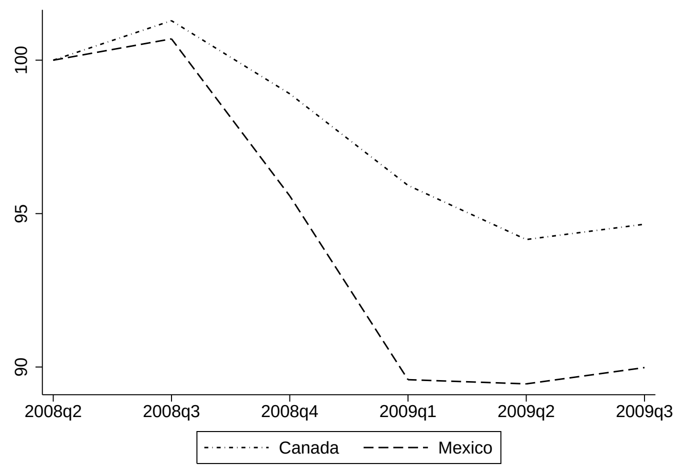
2.5 Results

This section uses the model to quantitatively assess the role of trade and production sharing in transmitting the 2008-2009 recession from the US to Canada and Mexico. I restrict my attention to North America because of the region's strong production and trade linkages.

I first present the benchmark results to quantify the total impact of trade on the transmission process. I then present counterfactual experiments to measure the contribution of production sharing to transmission, and the model's sensitivity to the capital adjustment costs. In the first experiment I vary the share of the production sharing export good in total exports, holding the capital adjustment costs constant. In the second experiment I vary the capital adjustment costs while holding the share of production sharing exports constant.

In the quantitative exercises I introduce a shock to the foreign import demand equations. For the benchmark, the shock is calibrated to match the observed terms of trade movements for Canada and Mexico. In the counterfactual experiments I restrict the analysis to Canada. The respective terms of trade shocks are displayed in Figure 2.6. For the simulations, I focus on the period from Q2 2008 to Q2 2009, and measure the impact of the shock on GDP, trade, investment, and hours.

Figure 2.6: Terms of trade - Canada and Mexico



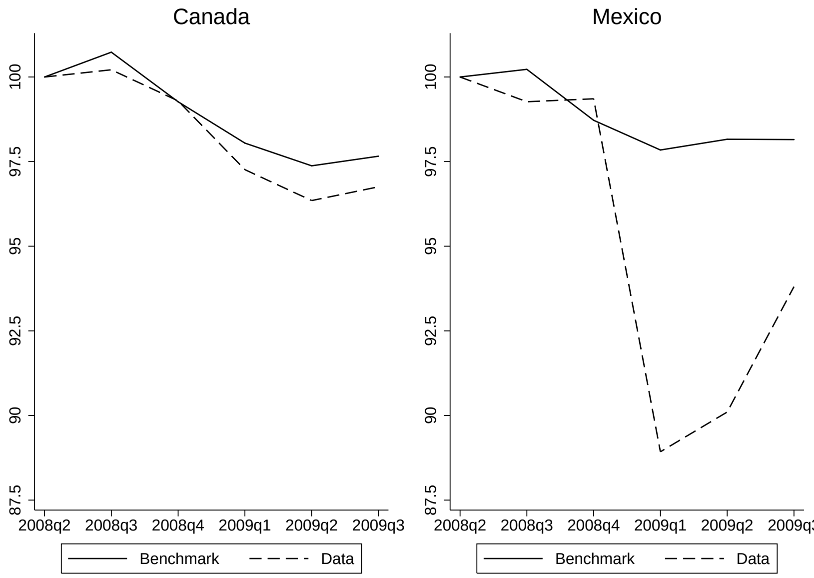
Notes: Bilateral terms of trade with US, manufactured goods.
Source: U.S. Bureau of Labor Statistics.

2.5.1 Benchmark Model Results: Canada

The benchmark results are displayed in Figures 2.7 - 2.11. For Canada, the model predictions account for 72% of the fall in GDP, 65% of the fall in trade, 54% of the fall in investment, and 20% of the fall in hours worked.

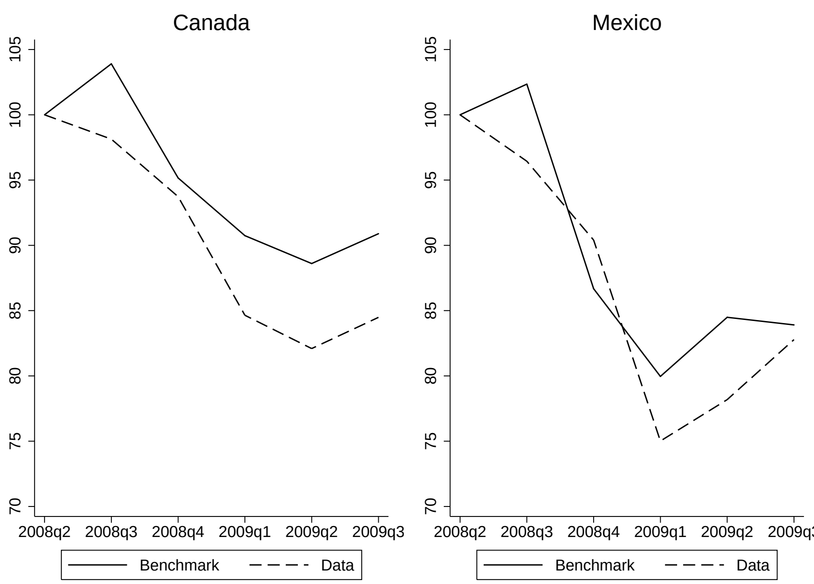
The left panel of Figure 2.7 displays real GDP for Canada and the model's prediction. The only shock in the model is the import demand shock, which is calibrated to match the observed terms-of-trade movement, and the simulated variables in the model inherit this shape. Therefore, the predicted path for GDP has an initial peak at Q3 2008, and then declines until the trough in Q2 2009. 74% of the decline in GDP is from the tradable sector, and the production sharing sector accounts for almost 30% of that decline. In the data, the

Figure 2.7: REAL GDP - Benchmark model results and data



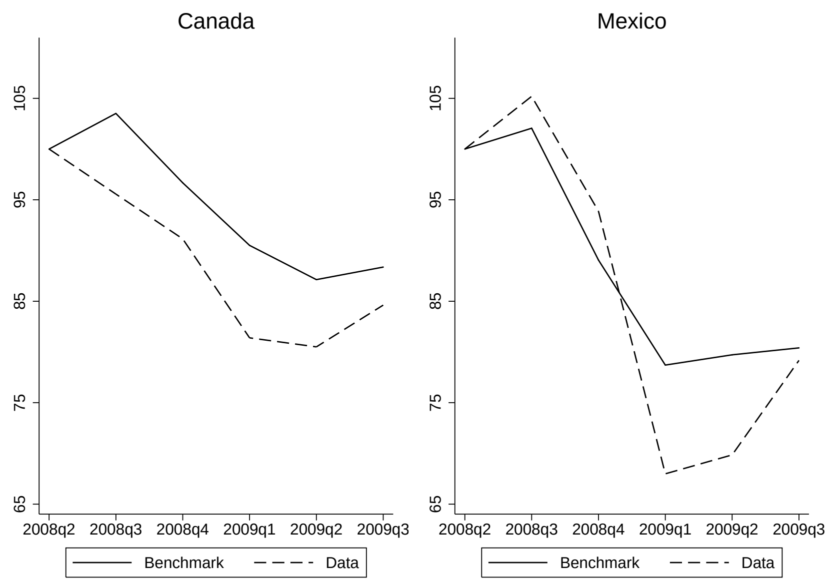
Source: IMF IFS.

Figure 2.8: REAL Exports - Benchmark model results and data



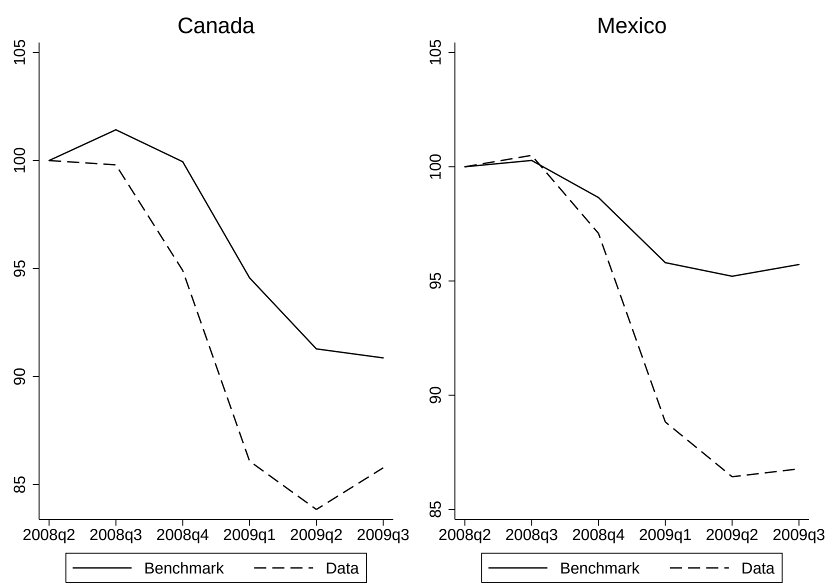
Source: IMF IFS.

Figure 2.9: REAL Imports - Benchmark model results and data



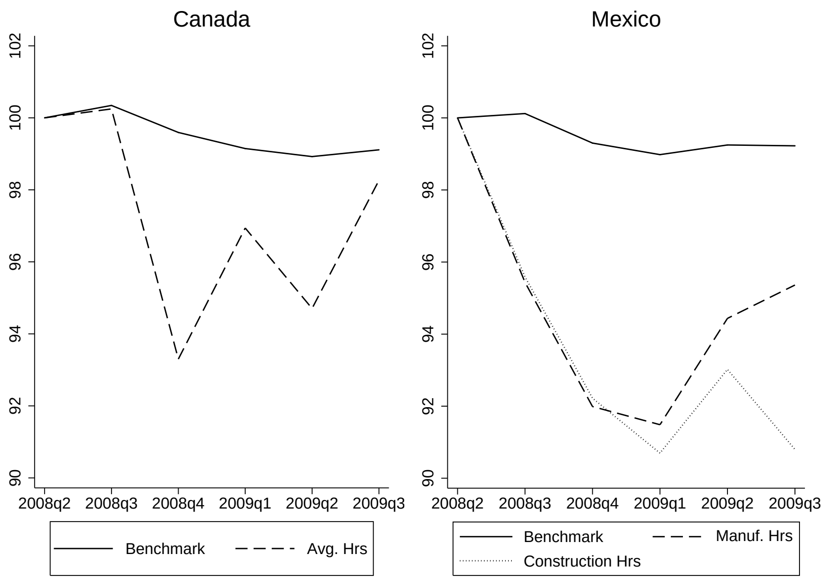
Source: IMF IFS.

Figure 2.10: Investment - Benchmark model results and data



Source: OECD StatExtracts.

Figure 2.11: Hours worked - Benchmark model results and data



Source: Statistics Canada and INEGI-BIE.

tradable sector accounts for 97% of the fall in output (counting wholesale and retail trade as tradable sectors), and transportation equipment manufacturing accounts for about 20% of the decline. The fall in output in the non-tradable sector is negligible as moderate declines in output for construction and utilities are offset by a small increase in output for services.

The results for Canadian exports are presented with the data in Figure 2.8. The shape is from the terms-of-trade, but the initial increase and subsequent fall are more exaggerated than GDP. 38% of the fall in exports is accounted for by the production sharing composite good, and the remainder is accounted for by the generic tradable sector. Exports are more responsive to the demand shock because its composition includes a larger share of the production sharing sector relative to GDP. The shock has a greater impact in the production sharing sector because the domestic economy can only respond to the shock by reallocating productive factors. For the traded intermediate in sector 1, the domestic economy can reallocate productive factors *and* adjust its consumption allocation between the tradable and the non-tradable composites. The magnitude of this effect depends on the severity of the capital adjustment costs.

Figure 2.9 shows real imports in the data and model. Imports experience a relatively large decline because the demand for imported intermediates falls following the foreign demand shock. The impact on imports is also affected by the relative size of the production sharing sector as intermediates used in the production sharing sector are more responsive to the demand shock compared to intermediates used in the sector 1 composite.

The model can account for roughly half of the fall in investment for Canada. Figure 2.10 shows the path for investment and the model prediction. The capital adjustment cost parameter was set such that the model matches the observed volatility of investment relative to output (as measured by the ratio of the coefficients of variation). The benchmark results explain about half of the fall in investment during the recession.

Figure 2.11 shows hours worked for the model and data. The model falls short in explaining the fall in hours worked, as there is no labour friction in the model. Following a shock to the tradable sectors, there is a moderate fall in aggregate hours worked, and some labour is reallocated into the non-tradable sector. Hours worked in the production sharing sector fall by 11%, in the other tradable sector they fall by 2%, while hours increase by 0.5% in the non-tradable sector. Aggregate hours worked fall by about 1%.

2.5.2 Benchmark Model Results: Mexico

For Mexico, the model predictions account for 19% of the fall in GDP, 69% of the fall in trade, 35% of the fall in investment, and 13% of the fall in hours worked.

The calibration for Mexico has a larger production sharing component in exports, but a smaller value added share of exports in GDP. Because of the larger production sharing share in exports, Mexican exports are more responsive to the demand shock than Canadian exports (Figure 2.8). However, because of the lower value added share of exports in GDP, Mexican GDP is less responsive to a demand shock than Canadian GDP (Figure 2.7).

71% of the decline in GDP is from the tradable sector, where the production sharing sector accounts for about 68% the decline. The production sharing sector also accounts for 83% of the decline in Mexican exports. These findings suggest that production sharing was more important in transmitting the trade shock to Mexico than to Canada.

In my model, these results are due to the larger share of production sharing exports in the benchmark calibration for Mexico. The results are consistent with the empirical findings of Di Giovanni and Levchenko (2010). According to their results, the bilateral trade intensity is more important for the impact of trade on comovement for North-North country pairs, while production sharing is more important for North-South pairs.[11] They estimate that vertical linkages can account for 73% of the overall impact of trade on comovement for North-South pairs, but only 17% for North-North pairs.

Overall, the model falls short in explaining the fall in output for Mexico. However, this is actually a positive sign since the Mexican economy experienced additional shocks that are not accounted for by my model. Remittance transfers from migrant workers and tourism receipts fell about 16% over the same period, and the H1N1 flu pandemic which broke out in March 2009 likely exacerbated the recession in Mexico. The impact of these additional factors likely contributed to the much larger fall in GDP experienced by Mexico relative to Canada and the United States.

2.5.3 The Role of Production Sharing in Transmission

Production sharing may have been a contributing factor to the large fall in trade and the transmission of the US economic slowdown. Di Giovanni and

[11]Here North refers to OECD countries and South refers to non-OECD countries. Their sample spans the period 1970-1999. Mexico became an OECD member in 1994 and is therefore counted as a non-OECD country in their estimations.

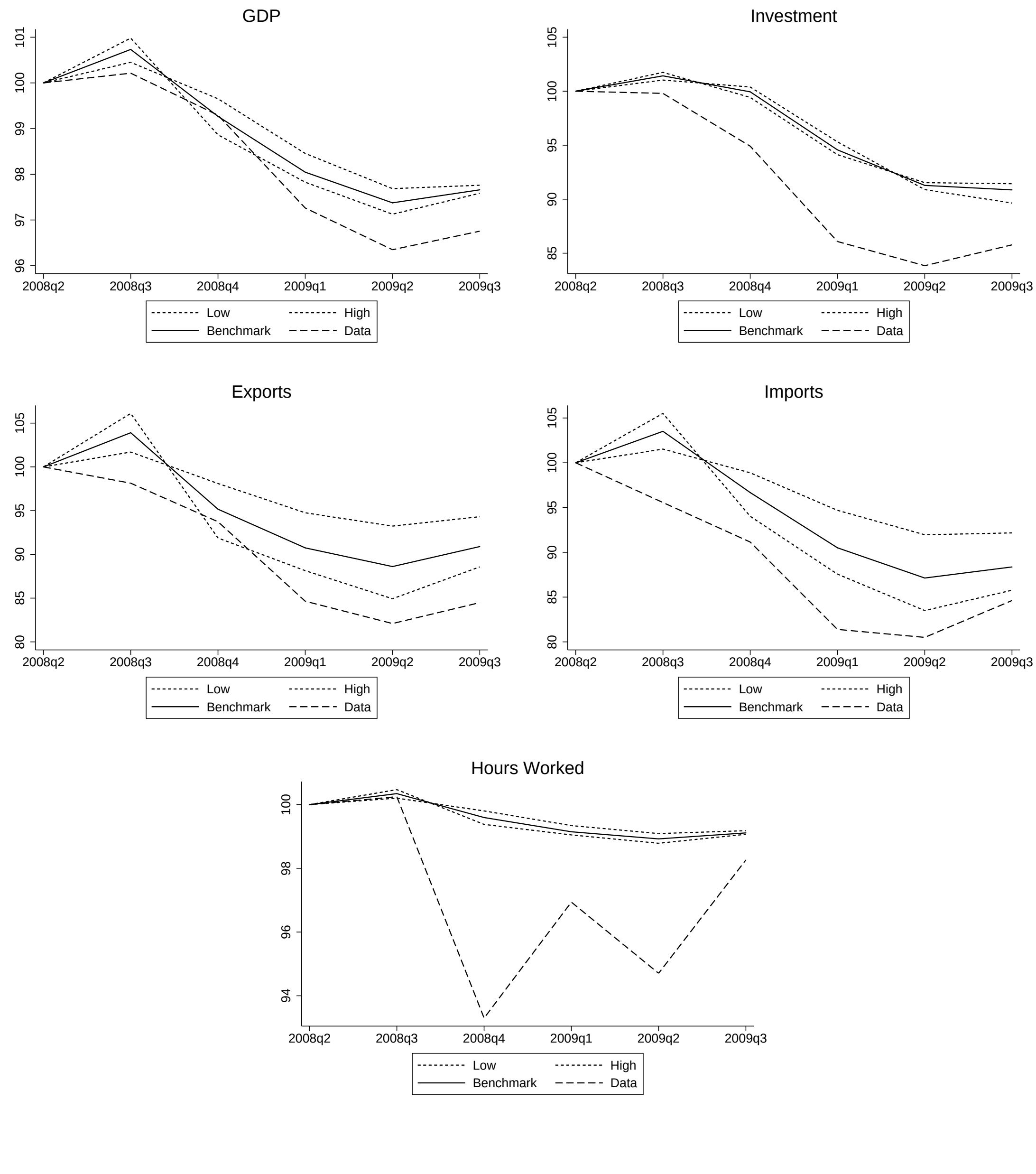
Levchenko (2010) estimate that vertical linkages can account for about 30% of the impact of bilateral trade on aggregate comovement, and Burstein, Kurz, and Tesar (2008) suggest that the production sharing intensity is at least as important as trade volume in accounting for bilateral manufacturing output correlations. In this experiment I quantify the relative contribution of production sharing in trade transmission for Canada. I use the Canadian calibration and vary the share of production sharing exports in total exports. I recalibrate the model when setting the production sharing share of exports to zero, and to 39%, a 50% increase relative to the benchmark.

The results are displayed in Figure 2.12. Comparing the zero production sharing case (labeled 'low') to the benchmark the results suggest that production sharing can account for 12% of the fall in GDP, and about 40% of the fall in trade in Canada. The impact on investment and hours worked is negligible.

My benchmark results suggest that international production sharing is less important in explaining comovement in output, but more important for trade. This finding indicates that production sharing can be part of the explanation for the large fall in trade relative to output during the recession. However, my results are sensitive to the calibration of production sharing, capital adjustment costs, as well as the choices of Armington elasticity parameters.

In the model, production sharing and the capital adjustment costs amplify the effect of the demand shock because capital becomes 'stuck' in the production sharing sector. As explained in the previous section, in the production sharing

Figure 2.12: Experiment 1 - GDP, Exports, Imports, Investment, and Hours Worked



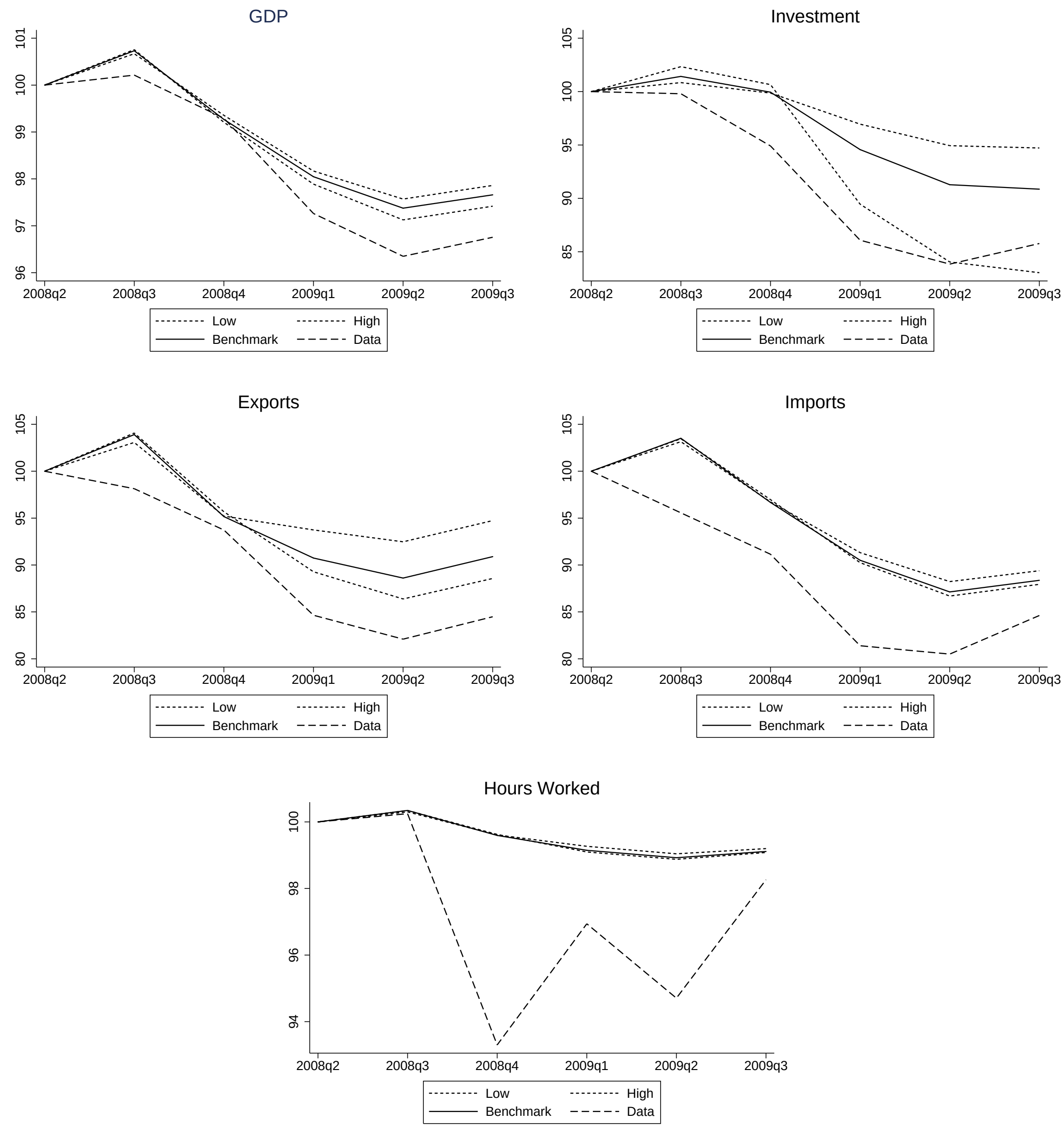
sector the shock can only be absorbed by reallocating productive factors. The capital adjustment costs restrict capital movement across sectors, and therefore the efficiency loss to the adjustment costs is greater when the production sharing sector is bigger.

When the production sharing share in exports is increased from 26% to 39% the trade channel explains 79% of the fall in GDP and 84% of the fall in trade for Canada.

2.5.4 Capital Adjustment Costs

In my model, the link between the capital adjustment costs and the production sharing sector plays an important role in generating the transmission dynamics. As all the goods produced in the production sharing sector are exported, the model can only absorb shocks to this sector by reallocating productive factors. The capital adjustment costs slow the reallocation of capital, and the impact of external shocks is exacerbated. In this experiment I quantify the impact of the capital adjustment costs on the transmission of the demand shock in the model. In the Canadian calibration I vary the capital adjustment costs while holding the production sharing share of exports constant at the benchmark level. I recalibrate the model for capital adjustment costs reduced to half, and double that of the benchmark value. This implies volatilities for Investment relative to GDP of 1.98 and 1.03 respectively, compared to the benchmark value of 1.46.

Figure 2.13: Experiment 2 - GDP, Exports, Imports, Investment, and Hours Worked



The results are displayed in Figure 2.13. The results show relatively small changes in GDP, aggregate hours worked, and imports in response to changing the capital adjustment costs. Exports on the other hand experience larger movements as the responsiveness of production sharing exports is directly linked to the mobility of productive factors.

With higher capital adjustment costs, capital movement is more restricted and the changes in hours worked across sectors are larger. That is, the labour allocation moves more across sectors in order to compensate for the less mobile capital input. The reallocation of labour results in a larger drop in production sharing output and exports.

With lower capital adjustment costs, capital has more freedom to reallocate and investment in the tradable sectors falls more relative to the benchmark. In response to the shock there is less forced reallocation of labour across sectors, and output in the production sharing sector and exports fall less.

2.6 Conclusion

The 2008-2009 recession had a large impact on GDP and trade in North America. The results of this chapter suggest that trade linkages played a significant role in the transmission of the US recession to its regional trading partners. In the benchmark calibration the model predictions can account for 72% of the fall in output for Canada, 19% for Mexico, and almost two-thirds of the fall in trade. The quantitative experiments suggest that production sharing accounts for about 40% of the fall in trade, but only 12% of the fall in output. Together these results indicate that production sharing may be an important factor in explaining why trade fell so much relative to output during the great recession, and in explaining trade comovement in general.

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Chapter 3

The Impact of Climate Change and Climate Policy on the Canadian Economy

3.1 Introduction

The emerging scientific consensus that the global climate is changing has sparked substantial debate over both the impact and effectiveness of policy targeted at mitigating greenhouse gas emissions (see e.g. Stern (2006) and Nordhaus (2008)). In this paper, we seek to quantify the net economic impact of climate change and climate change policy on the Canadian economy. In particular, we seek to quantify the economic costs and benefits from different emission reduction targets on the Canadian economy, and how this compares with the average economic impact in the rest of the world economy.

To tackle these questions, we combine a small open economy model of Canada with the ANEMI model. The ANEMI model is an integrated assessment model developed at Western University that incorporates an energy sector as well as fossil fuel production into a neoclassical growth model. We use the ANEMI framework to both develop our baseline analysis of the impact of carbon taxes on the world economy, and to generate a path of carbon emissions, climate, and (relative) price of fossil fuels which we feed into our small open economy model of Canada.[1]

The ANEMI model incorporates several key innovations that are absent from the influential DICE framework of Nordhaus (2008). First, the ANEMI model includes an explicit energy sector which produces a composite energy good used in the production of final output. This energy intermediate good is in turn produced using a composite of two broad energy sub-composites: heat energy (i.e. fuel energy burned for transportation or industrial purposes) and electrical energy. Each of these energy types is produced using different technologies for each of the major energy sources. This structure provides a useful mid-point between aggregate models (such as DICE) which abstract from detailed modeling of energy and more detailed bottom up models which typically abstract from key features of dynamics and optimal choice. The second innovation on the climate side is the inclusion of a simple production structure for fossil fuels. As a result, the path of fossil fuels evolves endogenously in the

[1]As a small economy, the direct impact of changes in Canadian greenhouse gas emissions on the level of global greenhouse stocks is relatively small, since Canada accounts for less than 3 percent of global GHG emissions This leads us to take the path of global greenhouse gas stocks as independent of Canadian emissions.

model, so that climate policy (such as carbon taxes which seek to lower demand for fossil fuels) and the negative impact of climate change on aggregate productivity (which tends to lower energy demand) both impact the temporal path of fossil fuel prices. In turn, the equilibrium prices of fossil fuels impact investment in capital stocks to produce energy using different types of fossil fuels.

To highlight how Canada differs from the global average, we compare the results from our Canadian economy to those of the ANEMI model for a carbon tax designed to maintain the level of CO2e below 550 ppm. We find that the economic benefits to Canada of this carbon tax are much smaller (in fact, negative) than they are for the rest of the world. This finding is mainly due to large differences in the calibrated damage function in the Canadian and world model ANEMI economies. These differences reflect significant differences in estimated impact of small temperature increases on the Canadian and global economies. In addition, our benchmark simulation results highlight the large impacts that carbon taxes can have on long run shifts in fossil fuel prices by shifting the temporal path of consumption.

There is a large and growing literature that seeks to quantify the economic impact of climate change as well as the costs of lowering greenhouse gas emissions (e.g. see Stern (2006) and Nordhaus (2008)). While our modeling structure builds upon the heavily cited DICE model of Nordhaus, the ANEMI model differs in how we model the energy sector.

Most of the literature with a Canadian focus has used static CGE models used to examine the impacts of climate policy on Canada (see e.g. Hamilton and Cameron (1994), Jaccard and Montgomery (1996), Ab Iorwerth, Bagnoli, Dissou, Peluso, and Rudin (2010), Dissou (2005), Wigle and Snoddon (2007), Boehringer and Rutherford (2010). Several papers have also used sectoral models: Jaccard and Montgomery (1996), Jaccard, Loulou, Kanudia, Nyboer, Bailie, and Labriet (2003), Simpson, Jaccard, and Rivers (2007). Our model differs both in the details of how we model the interaction between energy and economic output, and in our focus on comparing the net economic benefits of climate policy in Canada versus the rest of the world.

The remainder of this paper is organized as follows. Section 3.2 describes the calibration of the Canadian damage function. Section 3.3 outlines the key features of the model, while Section 3.4 reviews the calibration of key model parameters and the baseline simulation. Section 3.5 discusses our carbon tax experiment, while Section 3.6 provides a brief conclusion.

3.2 A Canadian Climate Damage Function

A key element in assessing the impact of climate change and climate policy in Canada is the economic damages associated with changes in mean temperature. This is especially important when comparing Canada to global averages, given our geographical location.

In constructing a climate change damage function, we adopt the approach of Nordhaus (2008) and model damages as a quadratic in global mean temperature. To construct estimates for Canada, we draw on regional damage estimates for the U.S. from Mendelsohn (2001). Mendelsohn presents estimated damages for seven U.S. regions for five sectors (Agriculture, Forestry, Energy, Coastal Structures, and Water Resources) at varying degrees of warming (1.5, 2.5, and 5.0 degrees Celsius) and varying levels of precipitation (0%, 7%, and 15% over 1990 levels) in 2060. We fit these estimates to our quadratic using estimated damages at $T = 2.5^\circ$ and $T = 5^\circ$ warming and 0% increase in precipitation above preindustrial levels for the four northern U.S. regions.

Figure 3.1 plots the U.S. regions for which Mendelsohn reports detailed estimates of the potential impact of climate change.

Table 3.1 summarizes the mapping we follow between U.S. regions and Canadian regions.

Table 3.1: Mapping U.S. Regions into Canadian Regions

Canadian Region	U.S. Region
Atlantic	North-East
Quebec	North-East
Ontario	North-East, Mid-West
Prairies	Northern Plains
B.C.	Pacific North-West

The estimates in Mendelsohn (2001) are based on studies employing both simulation models and empirical models examining cross-sectional differences

Figure 3.1: Mendelsohn's Regions

Source: Mendelsohn (2001, p. 8)

across climate zones. The climate benefits (damages) are estimated separately for each sector and region, relative to a baseline scenario of the economic conditions in 2060.

Tables 3.2 and 3.3 show estimated market damages from Mendelsohn at 0% increase in precipitation.[2] At 2.5 degrees of warming all regions are experiencing net benefits in the Agriculture, Forestry, and Energy sectors, except for the Northwest region, which have damages of 0.6 billion. Damages to coastal structures are negligible, but the water systems sector see some damages, particularly in the Northwest region. Overall, the Northeast, Midwest, and Northern Plains regions have net benefits as a result of a 2.5 degree warming, whereas

[2]Appendix B provides a comparison of the 7% and 15% precipitation scenarios.

the Northwest region experience small damages.

Table 3.2: Mendelsohn's Damage Estimates for $T = 2.5°$ Warming

	Agriculture	Forestry	Energy	Coast	Water	Total
Northeast	2.8	2.6	0.2	-0.1	0.0	5.5
Midwest	6.3	1.0	0.3	0.0	-0.2	7.4
Northern Plains	4.3	0.5	0.1	0.0	-0.6	4.4
Northwest	2.1	-0.6	1.4	0.0	-3.2	-0.3

Note: Estimated regional impacts of climate change in 2060 (billions of 1998 USD/year). Coastal damages assumes 67 cm of sea level rise in 2.5 degree scenario. Impacts are beneficial if positive, harmful if negative.

At 5 degrees of warming the impact is more pronounced. The energy sector now experiences damages in three regions, and the damages to the water sector are higher. The total impact from warming is still positive in three regions, though the benefits have declined compared to the 2.5 degree estimates.

Table 3.3: Mendelsohn's Damage Estimates for $T = 5°$ Warming

	Agriculture	Forestry	Energy	Coast	Water	Total
Northeast	1.8	2.6	-2.6	-0.2	-0.1	1.6
Midwest	3.6	1.0	-1.6	0.0	-0.5	2.4
Northern Plains	2.7	0.5	-1.2	0.0	-1.2	0.8
Northwest	1.7	-0.6	1.6	0.0	-5.7	-3.1

Note: Estimated regional impacts of climate change in 2060 (billions of 1998 USD/year). Coastal damages assumes 100 cm of sea level rise in 5.0 degree scenario. Impacts are beneficial if positive, harmful if negative.

Figure 3.2 plots the calibrated damage function. Damages are measured on the vertical axis as a share of output, and the horizontal axis shows average temperature in degrees Celsius. It is worth noting that we find very small damages for moderate changes in Canadian temperatures.

This is very different from the global average used in Nordhaus (2008), as can be seen from Figure 3.3 which plots both our calibrated damage function and that used in Nordhaus. However, Nordhaus takes into account damages to market sectors, as well as damages from increased incidence of catastrophic events, and damages to health, human settlements, and ecosystems. The estimates from Mendelsohn do not take into account catastrophic events, and damages to health and ecosystems. Therefore, it may be that the Canadian damage function in 3.2 reflects a lower bound, and that Canadian damages from warming are higher.[3]

As Canada lies to the north of the U.S., the market benefits to Canadian Agriculture and Forestry may be higher than for the U.S. regions. However, in a recent report,[4] the Canadian National Roundtable on the Environment and the Economy (NRTEE) suggested that the Canadian Forestry sector may actually experience damages from warming. Figure 3.4 shows the Canadian damage function re-estimated using the Canadian climate damage estimates from the Roundtable.[5] The initial benefits from warming are much smaller for the NRTEE damage function, but the climate damages are still small compared to the global average.

[3]Appendix B add catastrophic events into the damage function, following Nordhaus and Boyer (2000).

[4]Paying the Price: the Economic Impacts of Climate Change for Canada (2011)

[5]Appendix B provides a description of the NRTEE forestry damage estimates.

Figure 3.2: Calibrated Damage Function for Canada

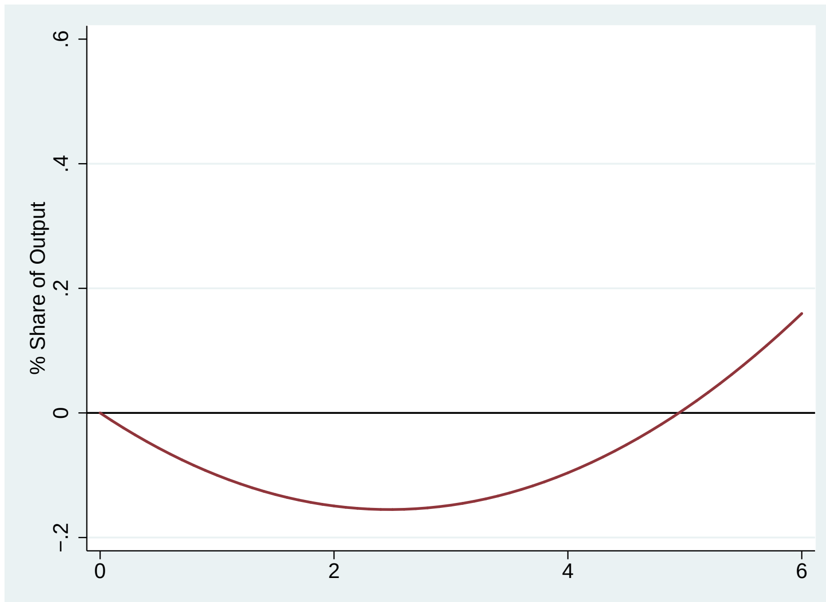


Figure 3.3: Climate Damage Functions: Canada vs. the World

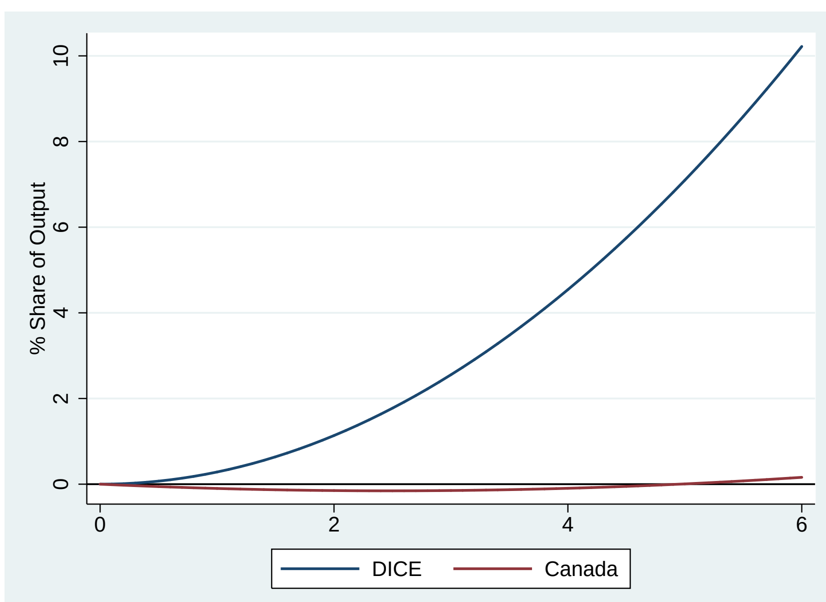
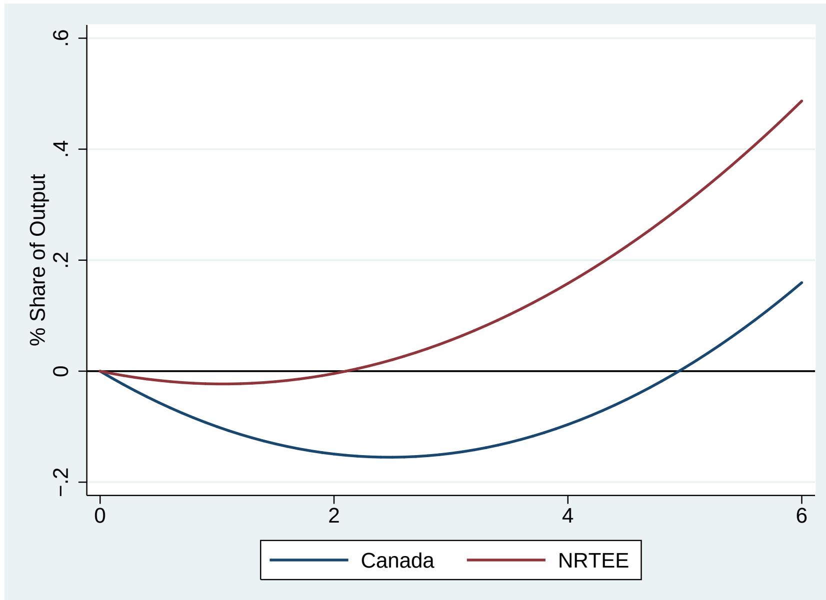


Figure 3.4: Damage Function for Canada: NRTEE Forestry Estimates



3.3 The Model

The model is based on ANEMI, an integrated assessment model developed at Western University. We model Canada as a small open economy that takes energy prices and the global stock of atmospheric carbon as given. That is, fossil fuel prices and the global mean temperature are endogenous variables in the ROW region, but exogenous to the Canadian energy economy. The paths for both of these variables (energy prices and temperature) are taken from simulations of the global version of the ANEMI model.[6]

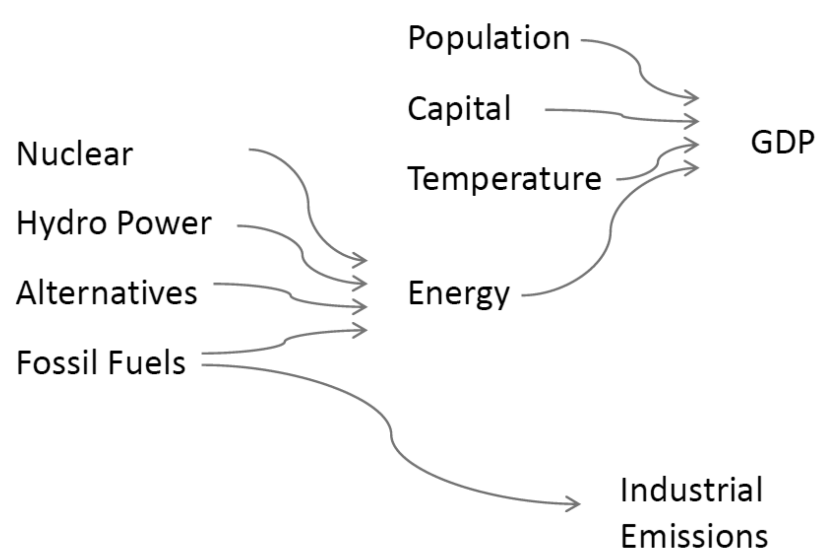
The world energy-economy model extends the neoclassical (Solow) growth model to include an energy sector as well as the production of fossil fuels. A key

[6] A complete description of the global ANEMI model is available in Akhtar (2011).

feature of the model is the endogenous allocation of energy production across fossil fuels, hydro, nuclear, and alternative energy sources. This results in industrial green house emissions responding endogenously to both carbon taxes and to shifts in the relative prices of fossil fuels.

Figure 3.5 outlines the causal structure diagram for the energy economy-sector. In the model, the energy-economy sector takes Canadian mean temperature and population as inputs, as well as an exogenously specified path for fossil fuel endowments and the technology available to produce nuclear, hydro, and alternative energy. The climate damage relationship (which is a function of temperature) is similar to that of Nordhaus and Boyer (2000), and is represented by a quadratic function in global mean temperature.

Figure 3.5: Causal Diagram for Energy-Economy Sector



The energy-economy sector produces the final consumption/investment good as well as industrial emissions. Industrial emissions are calculated from the burning of fossil fuels in producing energy services. Gross domestic product is equal to final output, and depends on the world's capital stock, labour force, and energy resources.[7] We assume that aggregate investment is equal to a fraction s of output.

'Energy services' used in the production of the final good is a composite good aggregated from heat energy and electric energy. Heat energy is produced from fossil fuels and alternative energy sources. Electric energy is produced from fossil fuels, nuclear, and hydro power.

The production of output is negatively affected by climate damages. The global mean temperature represents a negative feedback to the economic system from industrial emissions through climate damages.

3.3.1 Government

Climate policies are implemented by a government. The government can implement carbon taxes on energy consumption, and rebates these tax revenues lump-sum to the household. We assume a set of fuel specific taxes, τ_i, which depend on the emission intensity of each fuel type i. Finally, $\overline{T}$ is the sum of tax revenues from carbon. Then, $P_E E - \overline{T}$ is the household's income from selling energy services to the firm net of taxes.

[7] Note that energy production in the model is an intermediate good.

3.3.2 The Representative Household

The model economy is populated by a stand-in household. The household has preferences over an aggregate consumption good, which can be represented by the utility function:

$$U(C) = ln(C) \tag{3.1}$$

where C is the final consumption good. The household supplies labour, L, inelastically to the market. We assume that the household owns the world's capital stock and natural resources. Thus, the consumer rents the capital to the firm, earning income rK, where r is the interest rate and K is the aggregate capital stock in the economy. The consumer also sells energy services to the firm, earning income $P_E E - \overline{T}$, where E is aggregate energy services, and P_E is the price of aggregate energy services. Given prices, the household maximizes utility subject to its budget constraint:

$$rK + wL + P_E E - \overline{T} \geq C + I \tag{3.2}$$

where government transfers are given by:

$$\overline{T} = \sum_i \tau_i F_i \tag{3.3}$$

Note that since the price of energy services P_E is a final price, it includes the effect of taxes on intermediate fossil fuels. Hence, one has to subtract the value of taxes from household income.

Investment, I, is assumed to follow a Solow investment rule where a fraction s of output, Y, is invested into new capital each period:

$$I = sY \tag{3.4}$$

3.3.3 Final Good Production

Production of final output is represented by a stand-in firm which employs a CES production technology. The firm hires labour, capital, and energy services from the stand in household and produces the final consumption/investment good. The aggregate production function is:

$$Y = \Omega A \left(\omega (K^{\alpha} L^{(1-\alpha)})^{\gamma} + (1-\omega) E^{\gamma} \right)^{\frac{1}{\gamma}} \tag{3.5}$$

where A is total factor productivity (TFP), and $1/(1-\gamma)$ is the elasticity of substitution between value added and the energy composite. We follow Nordhaus (2008), and model the damage coefficient, Ω, as a function of, T, global mean temperature:

$$\Omega = \frac{1}{1 + \theta_1 T + \theta_2 T^2} \tag{3.6}$$

3.3.4 Energy Production

Aggregate energy services, E, is modeled as a composite good produced from heat energy and electric energy:

$$E = \left(\lambda E_H^{\theta} + (1-\lambda) E_{El}^{\theta}\right)^{\frac{1}{\theta}} \tag{3.7}$$

Here, E_H is total heat energy produced, and E_{El} is total electricity produced. The elasticity of substitution is determined by the parameter θ, and λ is the CES share parameter.

3.3.5 Electric Energy Production

Electric energy is produced from fossil fuels, nuclear and hydro power. Nuclear and hydro power are assumed to follow an exogenous path, as both depend heavily on policy and regulatory decisions. Each period, the representative firm solves the following problem:

$$\min_{F_{El,i}} ATC_{El}\left(F_{El,Coal}, F_{El,Oil}, F_{El,Nat.Gas}\right) \quad s.t. \tag{3.8}$$

$$E_{El} \geq \overline{E}_{El}$$

$$P_{El} = ATC_{El}$$

$$K_{Coal},\ K_{Oil},\ K_{Nat.Gas} \quad \text{given.}$$

where

$$E_{El} = A_{El}\left(\alpha_1 F^{\vartheta}_{El,Coal} + \alpha_2 F^{\vartheta}_{El,Oil} + \alpha_3 F^{\vartheta}_{El,Nat.Gas.} + \alpha_4 \overline{F}^{\vartheta}_{El,Nucl.} + \alpha_5 \overline{F}^{\vartheta}_{Hydro.}\right)^{\frac{1}{\vartheta}} \tag{3.9}$$

and

$$a_i = \left(\frac{1}{\omega}\right)\left(g_i - \left(\frac{F_{El,i}}{K_i}\right)^2\right), \text{ for } i = 1, 2, 3. \tag{3.10}$$

That is, given the capital stocks for fossil fuels and the nuclear and hydro power available, the representative firm chooses $F_{El,Coal}$, $F_{El,Oil}$, and $F_{El,Nat.Gas}$ to minimize the average total cost of electricity. Here, A_{El} is a productivity term specific to electricity production, $F_{El,i}$ is the fuel input used for fuel type i in electricity production, and ϑ is the CES elasticity parameter.

The functions α_i, for the fossil fuels, are decreasing in the fuel-to-capital ratio. Inside a period this assumption implies diminishing returns, as capital is a fixed factor. The parameters a_4 and a_5 are fixed. The parameters ω and g_i are used to calibrate the relative levels of fossil fuels in electricity production.

3.3.6 Heat Energy Production

The structure for production of heat energy is symmetric to the production of electric energy. We assume that heat energy is produced from fossil fuels and alternative energy sources. Each period the representative firm solves the following problem:

$$\min_{F_{H,i}} ATC_H \left(F_{H,Coal}, F_{H,Oil}, F_{H,Nat.Gas}, F_{H,Alt.}\right) \quad s.t. \tag{3.11}$$

$$E_H \geq \overline{E}_H$$

$$P_H = ATC_H$$

where

$$E_H = A_H \left(\beta_1 F^{\vartheta}_{H,Coal} + \beta_2 F^{\vartheta}_{H,Oil} + \beta_3 F^{\vartheta}_{H,Nat.Gas.} + \beta_4 F^{\vartheta}_{El,Alt.}\right)^{\frac{1}{\vartheta}} \tag{3.12}$$

There is no capital in the heat energy sector. The capital for heat energy comprises part of the aggregate capital for the economy. The firm chooses $F_{H,Coal}$, $F_{H,Oil}$, $F_{H,Nat.Gas}$, and $F_{H,Alt.}$ to minimize the average total cost of heat energy. Here, A_H is a productivity term specific to heat energy production, $F_{H,i}$ is the input of fuel type i for heat energy production, β_i is the CES weight for fuel type i, and ϑ pins down the elasticity of substitution.

3.3.7 Fossil Fuel Price Functions

The fossil fuel price functions are increasing in the ratio of the reserve value at its base year relative to its current value.

$$P_{F_{i,t}} = \tau_{i,t} + P_{F_{i,t=1980}} \left(\frac{R_{i,t} + D_{i,t} - F_{El_{i,t}} - F_{H_{i,t}}}{R_{i,t=1980}} \right)^{\frac{1}{\rho}} \tag{3.13}$$

Here, subscripts i and t refer to the fossil fuel type and the year respectively. $P_{F_{i,t}}$ is the fuel price, $\tau_{i,t}$ is the fuel specific carbon tax, $P_{F_{i,t=1980}}$ is the price of fuel at the base year , $R_{i,t}$ is the current reserve level, $R_{i,t=1980}$, is the base year reserve level, and $D_{i,t}$ is the new discovery value. $F_{El_{i,t}}$ and $F_{H_{i,t}}$ is extraction of fuel for electricity and heat energy production respectively.[8] $\rho < 0$ is an elasticity parameter.

This specification includes two key channels which impact the extraction cost of fuel. First, the model assumes that marginal extraction costs increase as the current reserves ($R_{i,t}$) falls relative to the base year. That is, higher levels of extraction results in higher future prices. This upward pressure on prices can be offset by new discoveries, which are assumed to have lower marginal extraction costs than remaining stocks of known reserves. The paths for new fossil fuel discoveries are taken as exogenous in the model.

[8]For the calibration we have chosen 1980 as our base year.

3.3.8 Alternative Heat Energy Price Function

The price of alternative heat energy is represented by the function:

$$P_{F_{Alt.,t}} = \mu_{1,t} + F_{H_{Alt.,t}}^{\mu_{2,t}} \tag{3.14}$$

$P_{F_{Alt.,t}}$ is the price, and $F_{H_{Alt.,t}}$ is the quantity of alternative fuel used in heat energy production. $\mu_{1,t}$ and $\mu_{2,t}$ are parameters. We assume that they are decreasing, representing that the price alternative fuel is falling over time.

3.3.9 Extraction and Trade in Fossil Fuels

The structure for the production of energy in the regional model is the same as in the global ANEMI model. However, since the prices of fossil fuels are exogenous, there is no mechanism to clear the market for fossil fuels in the regional energy economy. Demand and supply is determined separately. If supply is greater than demand, the excess supply is exported. Vice versa, the excess demand is met with imports. Extraction decision in the Canadian energy economy depends on the fossil fuel price, and are given by the inverse of the price functions:

$$F_{TE,i,t} = R_{i,t} + D_{i,t} - R_{i,t=1980} \left(\frac{\nu_i + \overline{P}_{F_{i,t}}}{P_{F_{i,t=1980}}} \right)^{\frac{1}{\rho}} \tag{3.15}$$

Here, $F_{TE,i}$ is the total extraction of fossil fuel type i at time t, given the current world price $\overline{P}_{F_{i,t}}$. $R_{i,t}$ is the current reserve value, $R_{i,t=1980}$ is the reserve value at the base year, $D_{i,t}$ is new discoveries, and $P_{F_{i,t=1980}}$ is the world price of fossil fuel i at the base year. ρ is an elasticity parameter, and ν_i is a calibration parameter adjusting the level of extraction.

Given the exogenous world price, demand for fossil fuels in the regional model is given. We assume that net exports of fossil fuel i, $NX_{i,t}$, is the difference between demand and total extraction each period. That is, net exports of fossil fuel type i is equal to total extraction minus fuel used for the production of heat energy and electric energy:

$$NX_{i,t} = F_{TE,i,t} - F_{H,i,t} - F_{El,i,t} \tag{3.16}$$

3.3.10 Energy Demand

In the model, final energy demand is from the final good producer. We assume that the final good producer is competitive, and takes the price of the energy composite as given when deciding how much to purchase. Thus, we solve for the equilibrium price within each period such that final energy demand equals final energy supply. At period t, capital and labour inputs are fixed. At period t, capital and labour inputs are fixed. Thus, equilibrium demand for aggregate energy services can be expressed as:

$$E = \left(\frac{(1 - \alpha - \beta) A K^{\alpha} L^{\beta}}{P_E} \right)^{\frac{1}{(\alpha + \beta)}} \tag{3.17}$$

E is the representative firm's demand for aggregate energy services, K is aggregate capital, L is the world's labour force, and P_E is the price of aggregate energy services. α and β are the share parameters from the aggregate production function.

3.3.11 Investment in Capital for Electricity Production

The available supply of investment funds for electricity production is assumed to follow a Solow rule. That is, each period I_{El} is available to invest in new electricity capital:

$$I_{El} = sY \left(\frac{\sum_i K_i}{K + \sum_i K_i} \right) \tag{3.18}$$

Here K_i is the current capital stock used to produce electricity from energy source i, which could be either a fossil fuel, nuclear or hydro power. K without a subscript i is the aggregate capital stock for the economy.

Investment into new capital for electricity production follows an average cost investment rule and is allocated by a built-in Vensim function called 'Allocate-by-priority'. For investment into electricity capital in the energy sector, the allocate-by-priority (ABP) function serves the purpose of a market clearing mechanism. The ABP function in Vensim is based on the Wood algorithm for allocating a resource in scarce supply to competing orders or 'requests'.[9] The ABP function takes as inputs the supply of available investment funds to be allocated, and the 'capacity' and the 'priority' of each order, representing the size and competitiveness of the orders respectively.

As explained above, given the fixed quantity of investment funds available inside a period, the market allocation depends on the size of the request and relative priority given to each sector, and the width parameter. After testing multiple approaches we decided to set the priorities for the sectors equal to each other, and only focus on the request dimension. The intention behind this decision is to simplify the calibration and to make the investment function more transparent.

3.3.12 Average Cost Investment Rule

The demand for new investment funds for each energy source used in electricity production is based on an average cost investment rule where the allocation is determined by the ABP function. Given a fixed priority across energy sources, the 'request' function takes the following form:

$$Req_i = \varphi_i \delta_i K_i + \left(\frac{K_i}{\sum_i K_i}\right)\left(\frac{ATC_{El}}{ATC_i}\right) \tag{3.19}$$

The request for new investment funds is a function of "replacement capital"

[9]The Wood algorithm was invented by William T. Wood.

and the current capital share of the sector scaled by its relative average total cost. Each period a share δ of existing capital depreciates, and we assume that all sectors will ask for that capital to be replaced. The parameter φ is a weighting factor that will reduce the request for replacement capital if the average total cost exceeds some threshold value. The second term is the relative size of the current capital stock for energy source i multiplied by its relative average cost. This implies that sectors with a lower average cost will have higher requests. ATC_{El} is the average total cost of electricity, and ATC_i is the average total cost of energy source i.

Since the path for nuclear and hydro power is exogenous, the capital stock used in production of nuclear and hydro power is also prescribed. The amount needed for new capital for nuclear and hydro power is subtracted from the total available for investment into electricity capital; what is left over is allocated to the fossil fuel capital stocks using the ABP function.

3.4 Calibration of Energy Economy

To calibrate the model, we choose parameters to match the level and trend in energy consumption, industrial emissions of GHGs, and economic activity from 1980 to 2005. Historical energy data was collected from the Energy Information Administration (EIA), the World Bank's World Development Indicators (WDI), and Statistics Canada.

3.4.1 Calibration Strategy

We calibrate the model in two steps. First, we choose initial conditions, exogenous variables, and parameters. Given those assumption, we calibrate the energy sector of the model to match fossil fuel consumption for the period 1980-2005.

For each year in the calibration period we solve a system of equations where $\{g_i, \beta_i\}_{i=1,2,3}$ is chosen to minimize the distance between fossil fuel consumption in the model and the historical trend lines in the data.

The g_i are parameters from the functional forms for the CES-weights in electricity production function (equation 3.10), and the β_i are the CES-weights in the heat energy production function (equation 3.12). For the calibration period we solve for these six parameters as part of the non-linear system of equations that make up the energy economy. The calibration targets are the observed trend lines of fossil fuel consumption in heat energy and electricity production.

The calibration implies the relative quantities of fossil fuels used in production of energy. Given these values, the productivity parameters are chosen so as to match the levels of energy and economic output for the calibration period.

For 2006 and after, $\{g_i, \beta_i\}_{i=1,2,3}$ is extrapolated following a nave updating rule, where

$$x_{i,t+1} = x_{i,t} \left(1 + \nu_i \left(\frac{x_{i,t} - x_{i,t-1}}{x_{i,t-1}}\right)\right) \tag{3.20}$$

The set of parameters $\{\nu_i\}$ are chosen to minimize the change in the trend for each of the fossil fuels in the period immediately following the calibration stage.

3.4.2 Calibration of Global Model

The energy data for the global energy economy is from the U.S. Energy Information Administration (EIA) and the World Bank's World Development Indicators (WDI). From the EIA we collected data on fossil fuel reserves, fossil fuel discoveries, total energy produced from fossil fuels, and total electricity produced from nuclear and hydro power. From WDI we collected data on the production of electricity from fossil fuels.

Energy stock variables are denoted in Gigajoules (GJ) and energy flow variables are denoted in GJ/year. The energy stock variables are the fossil fuel reserves. The flow variables are fossil fuel discoveries, fossil fuel inputs into production of heat and electric energy, alternative energy input into heat energy production, and nuclear and hydro power used to produce electricity. We use conversion factors from the EIA to convert cubic feet of natural gas, short tons of coal, and barrels of oil into GJ of energy.[10]

[10] 1cubic foot of natural gas = 0.001.0846 GJ, 1short ton of coal = 21.279 GJ, and 1 barrel of oil = 6.119 GJ.

3.4.3 Fossil Fuel Reserves and Discoveries

A key factor in our simulations is the projected path for future discovery of fossil fuels in Canada.

The Canadian oil sands are a vast resource; however, economical, political, and technological constraints make it very difficult to make a prediction about what share of the oil sands will actually be extracted. Given these constraints, we assume here that the total recoverable oil in Canada is about 410 billion barrels. That is approximately 25% of the oil estimated to be in the Alberta oil sands. In 2007, the Alberta Energy and Utilities Board estimated that about 10% of the oil was recoverable given the economic conditions and technology available at that time.

For simplicity, we assume that future fossil fuel discoveries are known at the beginning of time. Thus, the initial model reserves are the sum of expected discoveries and the reported reserves in the base year. Thus, the initial reserves used in the model (column 1) are equal to the sum of the remaining three columns in in Table 3.4 below.

The natural gas discoveries follow a similar assumption about improvement in technology or increase in prices.

Table 3.4: Fossil Fuel Reserves

Fuel Type (Billion GJ)	1980 Assumed Initial Reserves Model	1980 (EIA & Stat. Canada)	1980 - 2005 Disc. (EIA & Stat. Canada)	2006 - Assumed Discoveries
Conventional Oil	50	40	10	
Oil Sands	2500		1180	1320
Conventional Natural Gas	530	77	133	320
Shale Gas	1120			1120
Coal	140	90	50	

3.4.4 Energy Production

In energy production, the important parameters to consider are the elasticity parameters from energy production functions and aggregation, and the parameters in the price functions.

In the production functions for heat energy and electric energy, the CES elasticity parameters η and ϑ are set equal to 0.5, which implies an elasticity of substation of 2. The elasticity parameter in aggregation of electricity and heat energy, θ, is also set to 0.5.

The elasticity of substitution between fossil fuels, nuclear and hydro power in the production of electricity captures differences in the ease with which generation can respond to short term fluctuating demand. Intuitively, it seems that a unit of electricity produced from nuclear power is perfectly substitutable with a unit of electricity produced from coal. However, different sources vary in their ability to respond to demand fluctuations, thus it is not clear how substitutable energy sources are in the short run. Currently, we set μ and ϑ equal to 0.5 A similar argument can be made for the elasticity of substitution in heat energy production, and the aggregation of heat energy and electricity.

The share parameter γ in the CES aggregator for heat and electric energy is set to point 0.9.

The elasticity parameter for the fossil fuel price functions, ρ, is set to -0.4. A lower value would make fossil fuel prices more responsive to depletion of the fossil fuel reserves. The parameter value and the functional form for the price functions are from an earlier version of the ANEMI energy sector (see Davies and Simonovic (2009)).

The initial values for the parameters for the alternative energy price function, μ_1 and μ_2, were set equal to 3 and 5 respectively. The parameters decrease linearly over time representing that alternative energy is becoming cheaper over time as technology improves. For the calibration we had a target of 3% alternative heat energy in 2005.

3.4.5 Investment

The relevant parameters for investment are the aggregate savings rate s, the depreciation rate δ, and the replacement capital weighing factor φ. The aggregate savings rate is set to 0.25, which means that 25% of the generic consumption good produced is used for investment into new capital. The depreciation rate is set to 0.1, which correspond to an annual depreciation rate of 10%.

The weighting factor for replacement capital is triggered when the average total cost of producing electricity from a fossil fuel type is twice the weighted average total cost of electricity. The value of φ is set to 0.5 which means that if the condition is true, then the request for replacement capital is only half of the depreciated capital. The intuition behind this parameter is to improve the adjustment process of the capital stock in electricity production from fossil fuels in response to average cost changes.

3.4.6 Productivity Parameters

The model productivity parameters are the total factor productivity (TFP) A, and the energy specific productivity terms for electricity and heat energy, A_{El} and A_H. The model also has several assumptions that can be interpreted as implicit increases in productivity.

TFP is assumed to increase at a decreasing rate. TFP growth is 1.6% in 2005, 0.9% in 2050, and 0.6% in 2100. A_{El} and A_H is assumed to grow linearly. The assumption implies that they increase by approximately 1.35% in 2005, 0.9% in 2005, and 0.6% in 2100.

Implicit productivity increases are embedded in the assumptions on fossil fuel discoveries, the price function of alternative heat energy, and the share parameters in the aggregate production function.

Fossil fuel reserves are most commonly defined as the quantity that can be extracted given the current price and available technology. In the assumptions we have made about future discoveries of fossil fuels is an underlying assumption about improvements in extraction technology which comes in addition to our choice of A, A_{El} and A_H.

The parameter paths for the price function for alternative heat energy have similar assumptions embedded in them as they are decreasing over time.

The sum of the share parameters from the aggregate production function, α and β, are assumed to decrease over time. The assumption implies that the share of energy services in final output is decreasing. The assumption here is that technology improvements reduce the energy intensity of the economy as a whole

3.5 Results

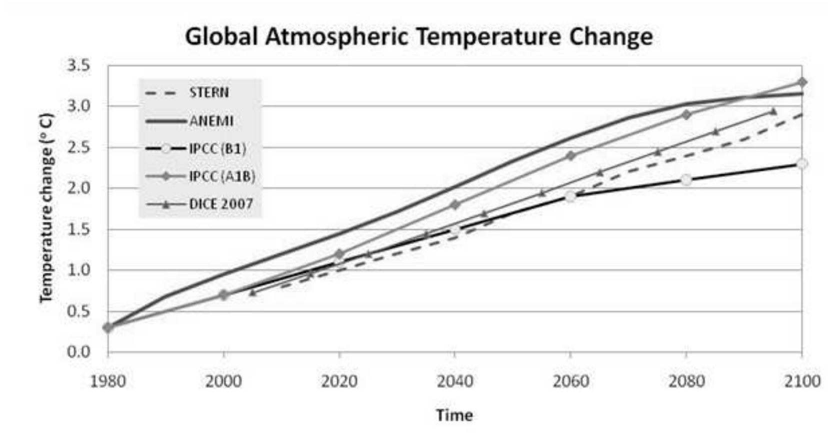
In this section we discuss the results of an illustrative experiment. To highlight how Canada differs from the global average, we compare the results from our Canadian economy to those of the ANEMI model for the same carbon tax policy. A key message of the experiment is while there are significant benefits to the world in moving to mitigate GHG emissions, the direct benefits to Canada are much smaller.

3.5.1 Global Baseline from ANEMI

Before turning to the Canadian economy, it is worthwhile briefly discussing the global projections that we take from the ANEMI model.

As Figure 3.6 shows, the baseline temperature projections implied by the ANEMI model are comparable with a number of well known estimates of future temperature change. This suggests that the global path of emissions and temperature changes that we feed into our model are reasonable.

Figure 3.6: Baseline Temperature Projections from ANEMI

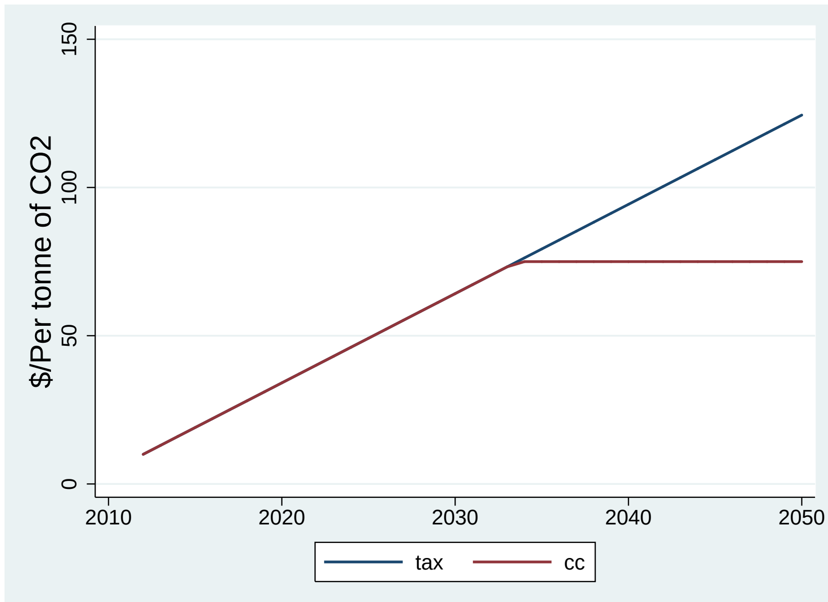


3.5.2 Carbon Tax Impact on Canada

The thought experiment we focus on is based on the carbon tax required to maintain the level of CO2e below 550 ppm. The path of the tax we consider is computed using two additional restrictions. First, we assume that a carbon capture and storage technology for coal fired electricity is available at a real cost of $75 per tonne CO2e . Second, we assume that the tax is introduced in 2012 and is increased linearly until 2080. The resulting tax is plotted in Figure 3.7.

Figure 3.8 shows the difference between GDP per capita for the business as usual case (the baseline run) and the carbon tax experiment for Canada and the world economy. Initially, the carbon tax results in a lower level of GDP, as higher energy prices result in lower energy consumption and thus GDP. In Canada, this effect is not offset by reduced climate damages, since the calibrated damage function for Canada initially features small positive effects.

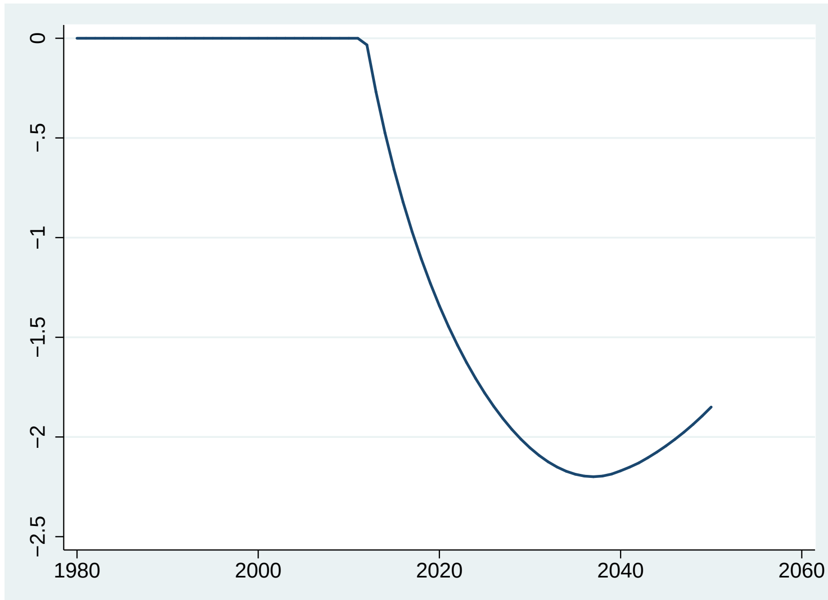
Figure 3.7: Carbon Tax in Experiment



As a result, this carbon tax policy results in a much larger decline in the level of GDP in Canada, with the trough in Canada in 2050 roughly 2.5% below the business as usual case. In contrast, the largest decline in the global economy is at less than 1% in 2020, with the carbon tax economy resulting in higher levels of GDP per capita by 2045 than the business as usual case.

As an alternative way of highlighting the differential impact of this carbon tax policy, we also compute the present value of this policy over 2012-2080 for Canada and the world in trillions of 2005 Canadian dollars. Table 3.5 highlights two key messages. First, from a global perspective, a carbon tax that keeps the stock of GHG below the 550 ppm mark yields positive net present value even if one truncates the calculations in 2050 (the end of our simulation). While the magnitude of the gains are decreasing in the discount rate

Figure 3.8: Impact of Carbon Tax on GDP as % of GDP in BAU Case



used, even for a relatively high value of 5% the gains remain positive. However, the second message from Table 3.5 is less positive. From a Canadian perspective, this carbon tax policy actually has a negative net present value. This highlights the potentially different incentives facing Canada versus other countries in adopting policies to mitigate GHG emissions.

Table 3.5: Cumulative Loss Benefit from Tax, 2012 - 2080 (2005 $ Trill.)

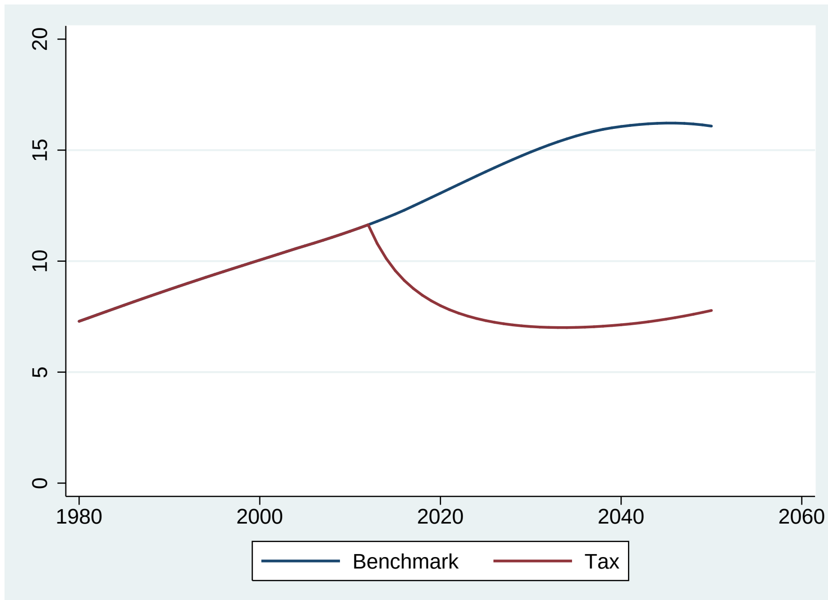
Discount Rate	Canada	The World
1%	-2.5	51.2
3%	-1.3	11.6
5%	-0.8	0.2

These differences are driven by two key forces. First, the climate damage functions for Canada and the world are very different. As discussed above, the Canada damage function actually yields small benefits for slight increases in temperature, whereas the global damage function features negative effects that increase relatively quickly with temperature. The second key force is a differential impact of a shift in the price of fossil fuels in Canada versus the world economy. Since Canada is a net exporter of fossil fuels, the initial reduction in fossil fuel prices due to the carbon tax lowers fossil fuel exports and this Canadian GDP. However, over time this effect is partially undone as the reduced level of fossil fuel consumption leads to slightly lower fossil fuel prices over the longer term than the business as usual case.

To better understand these mechanics, it is worthwhile to examine how both total energy use and fossil fuel use respond to the carbon tax in the model. The large decline in total energy used in the production of aggregate energy services in the Canadian economy is visible in Figure 3.9. For the baseline, the hump shape in total energy input is a result of increasing fossil fuel prices, which are exogenously given, from the global model. Not surprisingly, the path of industrial GHG emissions closely resembles that of total energy, with emissions declining even faster than energy use as the carbon tax induces a shift away from relatively more expensive fossil fuels towards alternative energy sources (see Figure 3.10). As a result, energy intensity (energy per dollar of GDP) declines significantly in response to the carbon tax (Figure 3.11).

The results in Figures 3.9 - 3.11 focus on the simulation up to 2050. After 2050, fossil fuel prices in the business as usual case begin to increase rapidly as the stock of remaining reserves declines in size. This rapid increase in price

Figure 3.9: Total Energy Used in the Production of Aggregate Energy Services in Canada



leads to a similar effect of a carbon tax, and results in a significant reduction in energy intensity. In contrast, the carbon tax economy features a much smaller secular trend in the price of fossil fuels, as the reduction in fossil fuel consumption induced by the carbon tax slows the depletion of reserves and thus delays the market driven increase in their price. As a result, the level of energy intensity in the business as usual case and the carbon tax tends to converge to a similar level by 2080.

Figure 3.10: Industrial Emissions in Canada

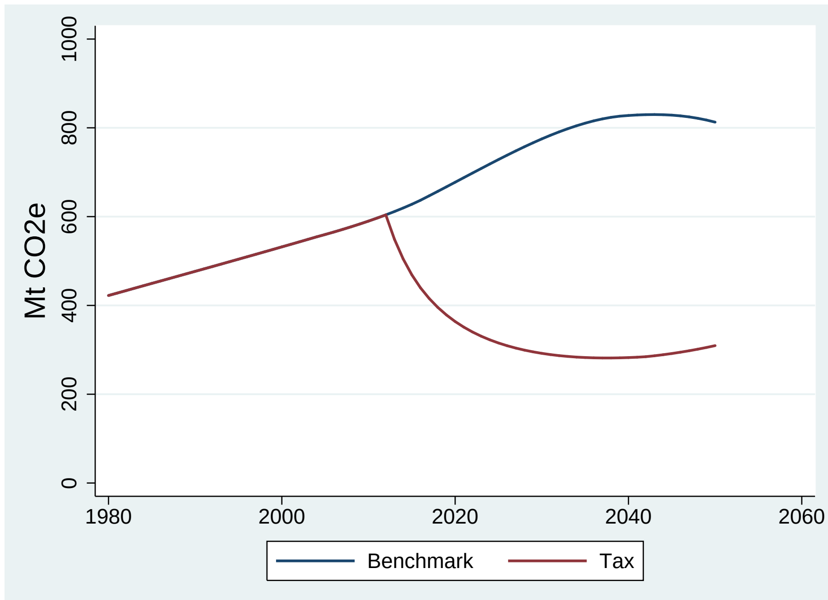
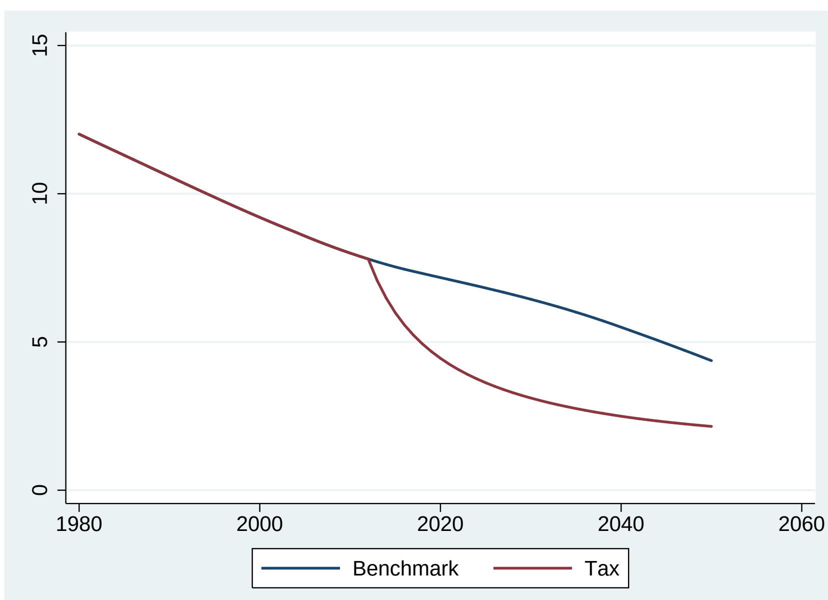


Figure 3.11: Energy intensity in Canada



3.6 Conclusion

We examine the relative benefits of policy aimed at mitigating GHG emissions in Canada and globally. We find that while a carbon tax that holds the stock of global emissions below the 550 ppm level would yield positive net benefits for the world economy, the impact of such a tax on the Canadian economy would be negative. This result is largely driven by our finding that the damages from small increases in temperature are much smaller in Canada than in the rest of the world.

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Chapter 4

Remittances and Sectoral Factor Allocation in Latin America

4.1 Introduction

Remittance payments to many developing economies are large. Net remittances to Latin America and the Caribbean reached US 53 billion in 2009, about 1.5% of the region's gross national income.[1] Indeed, for many countries, remittance flows exceed international aid and foreign direct investment.

Recent empirical studies have found that these remittance flows are large enough to impact (i.e. appreciate) the real exchange rate in remittance receiving countries, suggesting the presence of a *Dutch Disease effect*.[2] (For example Lartey, Mandelman, and Acosta (2012), Acosta, Lartey, and Mandelman (2009), and Amuedo-Dorantes and Pozo (2004)). The Dutch Disease effect generated by remittance inflows leads to a reallocation of productive factors from

[1] World Bank, "Migration and Remittances Factbook" (2011).

[2] The term 'Dutch disease' was originally used to describe the difficulties faced by the manufacturing sector in the Netherlands following the development of natural gas on a large scale which triggered a major appreciation of the real exchange rate.

the tradable to the non-tradable sector, which for many developing economies may have significant implications for aggregate productivity and welfare.

The Dutch Disease mechanism works through the real exchange rate. Remittance inflows increase household income and generally increase aggregate demand, putting upward pressure on prices and wages. As the price of tradable goods is restricted by the world price for tradables, the relative price of non-tradable goods increases (i.e. the real exchange rate increases). With higher prices in the non-tradable sector, remittance receiving economies experience a shift of productive factors from the tradable to the non-tradable sector. This shift of productive factors may cause a deterioration of the economy's aggregate productivity, and therefore a significant reduction of the benefits from remittance inflows, if the productivity in the non-tradable sector is relatively low.

Duarte and Restuccia (2010) suggest that differences in labour productivity levels between rich and poor countries are larger in services than in manufacturing, and low relative productivity in services explain all the experiences of slowdown, stagnation, and decline in relative aggregate productivity across countries. Thus, if the transfers are large, the Dutch Disease effect may substantially reduce the benefit from remittances for many developing countries. In this paper I analyze how the aggregate productivity and welfare in the Latin American and Caribbean economies are affected by remittance inflows.

To quantify the impact of remittance transfers on aggregate productivity and welfare I develop a two-sector, small open economy model where remittances are a function of migration. Linking remittance inflows to the migration decision is important because remittances are not a random process, but transfers to family members from workers who migrated in order to obtain better economic opportunities abroad. In the model, the allocation of productive factors between sectors is affected by the remittance process through two channels. First, out-migration reduces the size of the domestic labour force. Second, the households experience an income effect associated with received remittances. The increase in income induces an increase in aggregate demand, and since the non-traded good can only be produced domestically, by definition, the home country shifts productive factors from the traded sector and into the non-traded sector. The associated fall in production of the traded good is offset by running a trade balance deficit through increasing imports of the traded good. In the model, the trade balance deficit is matched exactly by the inflow of remittance payments.

I calibrate my model to 33 Latin American and Caribbean Economies. The year 2000 is the calibration base year, and I use CES share parameters to calibrate the debt-to-gdp ratio, investment-to-gdp ratio, and tradable sector share for each country. To calibrate migration I use data from the U.S. census on permanent migrants to estimate a migration gravity equation and derive country specific migration cost parameters. I find that relative wages and migrant networks are important in predicting migration shares in Latin American and the Caribbean.

In the quantitative experiments I compare the benchmark calibration to a counterfactual where there is no incentive to migrate. That is, for each country I compare the benchmark steady state equilibrium to a recalibrated steady state with zero migration and zero remittance inflows. The results suggest that

Latin American and the Caribbean economies have experienced an increase in consumption per capita by 9.1% on average as a result of remittance transfers.

My results further suggest that the benefits from remittance transfers could be 33% higher in terms of increased GDP per capita, and 27% in terms of increased consumption per capita, if the non-tradable sector productivity increased to the tradable sector level. The benefit is mitigated by the shift of productive resources into the less productive non-tradable sector. The remittance transfers generate a Dutch Disease effect where the non-tradable sector share increases by 6% on average, and by 15-20% for the high remittance countries.[3]

The rest of the chapter is organized as follows: The remainder of Section 4.1 summarizes the relevant literature. Section 4.2 describes the model framework in detail. In section 4.3 I discuss the calibration of the model, including the estimation of a migration gravity equation. Section 4.4 describes the benchmark results and quantitative exercises. Section 4.5 concludes.

4.1.1 Literature Review

For workers' remittances, recent research has focused on several aspects of the receiving economies.[4] Related to my work are Lartey, Mandelman, and

[3]In the sample, 10 out of the 33 countries are what I consider high remittance economies. In 2000, they received remittance transfers in excess of 5% of GDP.

[4]For example Adams and Page (2005), Page and Plaza (2006) and Acosta, Calderon, Fajnzylber, and Lopez (2006, 2008) who explored the relationship between remittances and poverty, Giuliano and Ruiz-Arranz (2006) and Calderon, Fajnzylber, and Lopez (2008) who investigated remittance payments' impact on growth, Rodrigues and Tiongson (2001) studying labour supply; and Cox-Edwards and Ureta (1998) looking at education.

Acosta (2012), Amuedo-Dorantes and Pozo (2004), and Rajan and Subramanian (2005), investigating the relationship between remittances and the Dutch Disease.

Lartey, Mandelman, and Acosta use cross sectional data disaggregated by sector to test for Dutch Disease effects. The authors consider data for the agriculture, manufacturing, and services sector and estimate a GMM in differences distributed lag model, employing lagged values of explanatory variables as instruments to control for endogeneity. The authors find support for the existence of Dutch Disease effects resulting from workers' remittances.

Amuedo-Dorantes and Pozo examine the effect of remittance inflows on the real exchange rate. Using a panel of 13 Latin American and Caribbean countries, they find that a doubling of remittance payments leads to an average overvaluation of the real exchange rate of about 22 percent. They suggest that the appreciation of the real exchange rate following a transfer can occur through an income effect for leisure, and by raising the relative price of non-traded goods. Interestingly, they also find that aid does not lead to the same overvaluation of the real exchange rate. This suggests that public and private transfers work through different mechanisms, and have different impacts on recipient economies.

Rajan and Subramanian tests Dutch Disease channels using panel data on real exchange rates and wages disaggregated by sector. The methodology exploits within and between country variations in industry sector growth. The intuition is that if certain sectors are more affected by a mechanism, one way to check if the mechanism is active is to see whether industries that might be more affected grow differentially. Thus, they rank industries by tradability to explore if the wage pressure in given industries are higher in countries that receive higher transfers. The industry level data is taken from the Industrial Statistics Database (2003) of the United Nations Industrial Development Organization (UNIDO). Contrary to Amuedo-Dorantes and Pozo, Rajan and Subramanian find that aid causes an appreciation in the real exchange rate, while remittances on the other hand do not. As an explanation, the authors suggest that aid appreciates the real exchange rate through increased spending, causing an increase in prices on non-tradable goods. They further argue that wages of worker types in limited supply (likely skilled labour in most developing countries) will increase. This effect will squeeze profits in the tradable sector, making the country less competitive in international markets. For remittances they find no effect, and speculate that remittances increase the demand for unskilled labour and traded goods, thus not appreciating the real exchange rate.

More closely related to this chapter is Acosta, Lartey, and Mandelman (2009), who develop and estimate a two-sector Dynamic Stochastic General Equilibrium (DSGE) open economy model to analyze the effect of remittances on developing economies. They test three approaches to the remittance process; first leaving remittance inflows independent of conditions in the domestic economy, second, a case where remittances are counter-cyclical, and third, a scenario where remittances act like capital inflows and are driven by the remitter's desire to invest in the home country. The authors estimate their model using a

Bayesian approach with macroeconomic data for El Salvador and find that remittances generally lead to a Dutch Disease phenomenon. The most important distinction between their paper and my work is the treatment of the remittance transfer process. Acosta, Lartey, and Mandelman let remittances follow exogenous processes, whereas I model the link between migration and remittances endogenously. The benefit of my approach is that it allows for analysis of the relationship between migration and remittances, and highlights how differences in this relationship manifests themselves in different patterns of factor allocation across countries.

4.2 The Model

To quantify the impact of remittance transfers on factor allocation, aggregate productivity, and welfare, I develop a two-sector small open economy model with an endogenous migration decision. Labour is mobile across sectors and between countries (i.e. endogenous migration). The economy produces a non-tradable good, and a tradable composite good by aggregating domestic intermediate goods with imported intermediate goods. The model is populated by a representative household and representative firms in each sector. Time is discrete, and the economic agents live forever.

4.2.1 Household Behavior

Household preferences are represented by a period utility function in the form of a CES function nested in a CRRA function. Each period the representative household chooses tradable and non-tradable consumption, the labour and migration allocation, investment, and foreign debt to maximize:

$$E_0 \left(\sum_{t=0}^{\infty} \beta^t \frac{\left(\omega c_{T,t}^{\theta} + (1-\omega) c_{N,t}^{\theta}\right)^{\frac{(1-\sigma)}{\theta}}}{(1-\sigma)} \right), \quad \theta < 1, 0 < \beta < 1, 0 < \omega < 1, 0 < \sigma \quad \textbf{(4.1)}$$

where $c_{T,t}$ and $c_{N,t}$ is consumption of tradable and non-tradable goods, ω is the intratemporal share parameter and $1/(1-\theta)$ is the elasticity of substitution for tradable and non-tradable consumption, σ pins down the intertemporal elasticity of substitution, and β is the discount factor. The household has a fixed time endowment each period, which is perfectly divisible between working at home and migrating. The household's time endowment is normalized to 1, and I abstract from any labour-leisure choice.

The household chooses the stock of migrants optimally, taking into account the relative foreign wage and costs associated with migrating. When abroad, the migrants send remittance transfers to family and relatives in the small open economy. Net remittances, $R(m_t)$, appear as real tradable goods, and the remittance function takes the following form:

$$R(m_t) = \psi(1-\tau)\left(\overline{w}_t^* m_t - \kappa m_t^{\phi}\right) \quad \textbf{(4.2)}$$

where m_t is the share of the household's labour supply that migrates and $\overline{w_t^*}$ is the exogenous foreign wage. The parameter τ captures the cost of international transfers of capital. For each unit of remittances sent to the home country, a fraction τ 'melts' on the way. κ and ϕ are country specific cost and curvature parameters which are calibrated employing a migration gravity equation. ψ is a calibration parameter to match the share of remittances in GDP.

The household can borrow or lend in the international financial market by a risk-free bond. The law of motion for debt, d_t, takes the following form:

$$d_{t+1} + tb_t + q_t^* R(m_t) = (1 + r_t^d) d_t \tag{4.3}$$

Here, d_t is current debt with interest rate r_t^d, d_{t+1} is next period's debt, and tb_t is the current period's trade balance. q_t^* is the price per unit of the tradable good received as remittances.

The above equation is the Balance of Payments Identity in the model. One way to interpret this equation is that current debt and interest payments can be satisfied by new debt, a trade surplus, or remittance transfers. However, since $d_{t+1} - (1 + r_t^d)d_t$ is relatively small in the data, the more appropriate interpretation is that remittance inflows finance the economy's trade deficit.

I assume that the representative household owns the capital stock and rents capital to the firms. Capital depreciates at rate δ each period. For each period t, investment in sector j follows:

$$i_{t,j} = k_{t+1,j} - (1 - \delta) k_{t,j}, \quad j = T, N \tag{4.4}$$

The household's period budget constraint can be expressed as:

$$p_{T,t}(c_{T,t} + i_{T,t}) + p_{N,t}(c_{N,t} + i_{N,t}) + (1 + r_t^d)d_t \leq \sum_j \left(r_{j,t}^k k_{j,t} + w_{j,t}n_{j,t}\right) \tag{4.5}$$

$$+ q_t^* R(m_t) + d_{t+1}, \quad j = T, N$$

Here, the subscript j indicates either the tradable or non-tradable sector. $n_{t,j}$ are labour services supplied to the firms, $w_{t,j}$ is the wage, and $r_{t,j}$ is the rental rate of capital in sector j. $p_{T,t}$ and $p_{N,t}$ are the prices of the consumption goods in the tradable and the non-tradable sectors.

4.2.2 Production

The economy produces two final goods, tradable and non-tradable, for consumption and investment by the household. Each good is produced by competitive firms. The tradable good is produced from domestic and imported intermediate goods, aggregated by a CES function:

$$y_{T,t} = \left(\gamma x_{H,t}^{\eta} + (1-\gamma)x_{IM,t}^{\eta}\right)^{1/\eta}, \quad 0 \leq \gamma \leq 1, \eta_{\leq}1 \tag{4.6}$$

$x_{H,t}$ is the amount of the domestically produced intermediate good and $x_{IM,t}$ the imported intermediate good used to produce the tradable composite. γ is the CES share parameter, and $1/(1-\eta)$ is the elasticity of substitution between the domestic and imported intermediate goods. The domestic intermediate good is produced from capital and labour by a Cobb-Douglas production technology:

$$x_t = k_{T,t}^{\alpha}(A_T n_{T,t})^{(1-\alpha)}, \quad 0 < \alpha < 1, \quad A_T > 0 \tag{4.7}$$

Here, α is capital's share in output, and A_T is the sector specific labour productivity. The representative firm maximizes profits:

$$\max_{k_{T,t},n_{T,t}} q_t x_t - r^k_{T,t} k_{T,t} - w_{T,t} n_{T,t} \tag{4.8}$$

where q_t is the price of the domestic intermediate good.

The non-tradable good is produced from capital and labour by a Cobb-Douglas production technology:

$$y_{N,t} = k^{\alpha}_{N,t} (A_N n_{N,t})^{(1-\alpha)} \, , \quad 0 < \alpha < 1 \, , \quad A_N > 0 \tag{4.9}$$

where α is again capital's share in output, and A_N is the sector specific labour productivity. Each period the representative firm maximizes profits:

$$\max_{k_{N,t},n_{N,t}} p_{N,t} y_{N,t} - r^k_{N,t} k_{N,t} - w_{N,t} n_{N,t} \tag{4.10}$$

4.2.3 Trade and Market Clearing Conditions

The foreign demand for exports is given by a CES import demand function:

$$\frac{\overline{q}^*_t}{q_t} = \left(\frac{\gamma^*}{1-\gamma^*}\right) \left(\frac{x^*_{IM,t}}{\overline{x}^*_t - x^*_{EX,t}}\right)^{1-\eta^*} \quad , \quad 0 \le \gamma^* \le 1, \, \eta^* \le 1 \tag{4.11}$$

Here, $\overline{q}^*_t / q_t$ is the terms of trade for the intermediate goods in the tradable sector. From the perspective of the foreign economy, γ^* is the CES share parameter, while $1/(1-\eta^*)$ is the elasticity of substitution between domestic and imported intermediate goods. The size of the foreign economy, $\overline{x_t^*}$, and the foreign price of the intermediate good, $\overline{q}_t^*$, are exogenous.

In the small open economy, market clearing for the tradable intermediate good implies:

$$x_t = x_{H,t} + x_{EX,t} \tag{4.12}$$

That is, $x_{H,t}$ units are used to produce the tradable good at home, and $x_{EX,t}$ units are exported.

Each period, the household has a time endowment normalized to 1. Market clearing implies:

$$n_{T,t} + n_{N,t} + m_t = 1 \tag{4.13}$$

4.2.4 Steady State Equilibrium

The model represents a small open economy which takes the price of the imported intermediate good, q_t^*, and the foreign wage, $\overline{w_t^*}$, as given. The interest rate, r_t^d, is pinned down by the discount factor from the utility function. Dropping the time subscripts we can define the steady state equilibrium:

Definition 1. *Given ($\overline{q}^*$, $\overline{w^*}$, r^d), a Steady State Equilibrium is an allocation for the households ($\overline{c}_T$, $\overline{c}_N$, $\overline{i}_T$, $\overline{i}_N$, $\overline{m}$, $\overline{d}$), an allocation for the firms ($\overline{y}_T$, $\overline{y}_N$, $\overline{x}$, $\overline{x}_H$, $\overline{x}_{EX}$, $\overline{x}_{IM}$, $\overline{n}_T$, $\overline{n}_N$, $\overline{k}_T$, $\overline{k}_N$), and prices ($\overline{p}_T$, $\overline{p}_N$, $\overline{q}$, $\overline{w}$, $\overline{r}^k$) such that:*

1. *The household's allocation is the solution to the household's problem*

2. *The firms' allocation is the solution to the firms' problems*

3. *Markets Clear:*

Tradable Goods Market: $\bar{c}_T + \bar{i}_T = \bar{y}_T$

Non-Tradable Goods Market: $\bar{c}_N + \bar{i}_N = \bar{y}_N$

Intermediate Goods Market: $\bar{x} = \bar{x}_H + \bar{x}_{EX}$

Balance of Payments: $\overline{q x}_{EX} - q^* \bar{x}_{IM} + R(\overline{m}) = \bar{r}^d \bar{d}$

Labour Market: $\bar{n}_T + \bar{n}_N + \overline{m} = 1$

4.3 Parameterization & Calibration Strategy

This section summarizes the model parameter values and the calibration strategy employed in the paper. I calibrate the model to 33 Latin American and Caribbean Economies. Each period corresponds to a year, and the benchmark corresponds to the year 2000. Below, I outline the calibration of parameters commonly found in the literature and the parameters specific to my model. Next, I explain the estimation of the migration gravity equation.

4.3.1 Parameterization & Calibration

For parameters typically found in open economy models I use values from the literature. Table 4.1 lists the benchmark values for the parameters. α, capital's share of output,[5] is set to 0.33 and σ, the coefficient of relative risk aversion, is set to 2.0. $\beta = 0.96$ implies an annual risk-free interest rate of 4%. Similarly $\delta = 0.1$ implies an annual depreciation rate of 10%. θ, the elasticity of substitution between tradable and non-tradable goods in the period utility function, follows Stockman and Tesar (1995), and is set to 0.44. The other Armington elasticity parameters are set to 2.0 which is within the typical range for this class of models.

Table 4.1: Benchmark Parameter Values

Parameter	Value	Description
α	0.33	Capital share in output
β	0.96	Discount factor
δ	0.1	Depreciation rate
σ	2.0	Risk aversion parameter
$1/(1-\theta)$	0.44	E_s tradable and non-tradable goods
$1/(1-\eta)$	2.0	E_s domestic and imported intermediates
$1/(1-\eta^*)$	2.0	E_s foreign import demand

[5] Income shares to capital and labour differ across countries. Unfortunately, data availability is a problem for many countries in Latin American and the Caribbean. However, Gollin (2002) finds that after accounting for labour income of the self-employed, income shares are similar across countries.

4.3.2 Calibrated Parameters

The CES share parameters from the period utility function, ω_j, the CES aggregator for the tradable composite good, γ_j, and the CES share parameter from the foreign import demand equation, γ_j^*, are included as variables when solving for the steady state to match three country specific moments. Table 4.2 lists the net external debt as a share of GDP, the gross investment as a share of GDP, and the tradable sector as a share of GDP for each country. Data on net external debt, investment, and GDP are 9-year averages around the year 2000, and are from the World Bank's World Development Indicators (WDI). Data on the tradable sector are from the United Nations' National Income and Product Accounts for the year 2000. The tradable sectors are *Agriculture, hunting, forestry, and fishing, Mining and quarrying, and Manufacturing*. The relative U.S. wage $\overline{w}_t^*/w_t$ is calculated using real GDP per capita in constant 2000 $US from the World Bank's WDI.

For many of the Latin American and Caribbean economies, data on productivity by sector is not readily available. I use data from the World Bank's WDI on value added by sector and employment shares by sector to construct A_N/A_T. As expected, the productivity in the non-tradable sector is lower than the tradable sector productivity for most of the countries in the sample. However, there are a few outliers (i.e. Peru and Venezuela), where the productivity in the non-tradable sector appears to be twice that of the tradable sector. But, because Peru and Venezuela receive relatively small remittance inflows as a share of GDP, they will only have a negligible impact on the overall results.

Table 4.2: Calibrated Moments

Country	$\frac{Debt}{GDP}$	$\frac{Inv.}{GDP}$	$\frac{Tr.Sector}{GDP}$	$\overline{w}^*/w$	A_N/A_T
Antigua & Barbuda	0.55	0.22	0.12	1.46	0.88
Argentina	0.50	0.22	0.23	1.61	1.55
Aruba	0.55	0.24	0.27	0.85	0.94
Barbados	0.55	0.23	0.16	1.50	0.68
Belize	0.74	0.29	0.25	1.87	0.75
Bolivia	0.69	0.18	0.40	2.00	0.57
Brazil	0.37	0.17	0.20	1.85	0.72
Chile	0.50	0.21	0.29	1.78	1.34
Colombia	0.34	0.14	0.29	1.92	0.91
Costa Rica	0.29	0.18	0.35	1.82	0.92
Cuba	0.55	0.12	0.21	1.90	0.73
Dominica	0.50	0.21	0.19	1.79	0.64
Dominican Republic	0.19	0.20	0.37	1.90	1.17
Ecuador	0.83	0.20	0.41	1.99	0.93
El Salvador	0.34	0.17	0.36	1.93	0.88
Grenada	0.39	0.35	0.13	1.76	0.63
Guatemala	0.20	0.16	0.37	1.96	0.52
Guyana	1.91	0.22	0.51	2.01	1.38
Haiti	0.32	0.13	0.27	2.04	0.94
Honduras	0.76	0.26	0.35	2.00	0.57
Jamaica	0.52	0.23	0.26	1.86	0.78
Mexico	0.26	0.21	0.26	1.72	0.59
Nicaragua	1.71	0.29	0.39	2.02	0.63
Panama	0.57	0.21	0.17	1.83	0.52
Paraguay	0.44	0.17	0.38	1.99	0.68
Peru	0.54	0.20	0.31	1.94	2.30
St. Kitts & Nevis	0.41	0.49	0.18	1.56	0.37
St. Lucia	0.31	0.30	0.12	1.79	0.53
St. Vincent	0.49	0.23	0.16	1.85	0.63
Suriname	0.55	0.22	0.21	1.95	1.62
Trinidad & Tobago	0.55	0.16	0.37	1.69	1.62
Uruguay	0.37	0.14	0.19	1.66	1.16
Venezuela	0.36	0.21	0.42	1.78	2.21

The iceberg transaction cost, τ, is set to 0.1. That is, if a person wants to send \$100 from the U.S. to his family somewhere in Latin America, the financial intermediary takes \$10. The World Bank has collected data on the cost of sending remittances, and in 2011, the average fee for sending \$200 from the U.S. to a selected sample of Latin American countries was around 5 percent depending on method of transfer and recipient country.[6] I choose $\tau = 0.1$ because the model is calibrated to the year 2000, and the cost of sending remittances has decreased over time.

4.3.3 Estimating the Migration Gravity Equation

To calibrate the migration cost parameters I use the structure of my model to inform the estimation equation. Given the migration-remittance relationship in the model, I choose a specific functional form for the cost function κ.

The net remittance flows in the model follow:

$$R(m_t) = \psi(1-\tau)\left(\overline{w}_t^* m_t - \kappa m_t^{\phi}\right) \tag{4.14}$$

Here, $R(m_t)$ is the net remittance inflow, m_t is the stock of migrants residing abroad, $\overline{w}_t^*$ is the exogenously given foreign wage, κ and ϕ are country specific cost parameters to be estimated. Now, let $\kappa_t = \alpha_0 X_{1,t}^{\alpha_1} X_{2,t}^{\alpha_2} ... X_{N-1,t}^{\alpha_{N-1}} \varepsilon_t$, then, in the household's problem, by taking first order conditions with respect to m_t, taking

[6]The World Bank provides information on the cost of sending remittances from the U.S. to Brazil, Colombia, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, and Peru. Their data is available quarterly from 2009 to 2012, however, several countries have missing data. The data is available on their website: http://remittanceprices.worldbank.org/.

logs and rearranging, we obtain:

$$ln(m_t) = \beta_0 + \beta_1 ln(\psi(1-\tau)\overline{w}_t^* - w_t) + \beta_2 ln(X_{1,t}) + ... + \beta_N ln(X_{N-1,t}) + \hat{\varepsilon}_t \quad (4.15)$$

Where

$$\beta_0 = -\frac{1}{(\phi - 1)}\left(ln(\phi) + ln(\alpha_0)\right) \quad (4.16)$$

$$\beta_1 = \frac{1}{(\phi - 1)} \quad (4.17)$$

$$\beta_i = -\frac{1}{(\phi - 1)}\alpha_{i-1}, \quad \text{for } i = 2, ..., N \quad (4.18)$$

$$\hat{\varepsilon}_t = ln(\varepsilon_t) \quad (4.19)$$

To estimate 4.15 I use data on immigrants from 33 Latin American countries to the U.S. from 1960 to 2000. The stock of migrants variable, m_t, is the foreign born population in the U.S. as a share of the domestic population. The data on foreign born nationals is from the U.S. Census and the population data is from the World Bank's WDI. I use data in 10 year period intervals due to the availability of the U.S. census.

The explanatory variables in the gravity equation are the wage gap between the domestic country and the U.S., and the country specific migration costs represented by the X_is in the functional form chosen for κ. Here, I include the size of the migrants' network in the U.S., plus a set of typical gravity equation variables such as distance, and indicators representing English, Spanish, and Portuguese language, borders, island, inflation, and unemployment. The distance variable is geodesic distance between nations' capitals, collected from a gravity data set available from the World Bank.[7] The migrant network variable is the 10-year lagged value of m_t. For the wage differential, $\overline{w}_t^* - w_t$, I use data on real GDP per capita in constant 2000 $US from the World Bank's WDI.

Due to the lack of data for some countries in 1960 and 1970 I have an unbalanced panel. I run a pooled OLS regression with year and country dummies for sensitivity. Table 4.3 presents the estimation results. For the full sample, the sub-sample for the year 2000, and with time fixed effects the results are fairly consistent. The estimation results with country fixed effects differ from the other columns, likely because the panel is unbalanced or because of the small sample size.

As expected, the coefficients on the Wage Differential, Migrant Network, and English Language variables are positive, and the coefficient on the Distance variable negative. Spanish and Portuguese language indicator variables were tested, but did not have a statistically significant impact on the estimation results. Similarly, border and island indicators did not influence the results. Inflation and unemployment controls were also found insignificant.

After obtaining (β_0, β_1, β_2, ..., β_N), I use equations (4.16), (4.17), and (4.18) to solve for (α_0, α_1, ..., α_{N-1}, ϕ). With these values I compute the country specific cost parameter κ. The results are presented in Tables 4.4 and 4.5.

Two main observations stand out in Table 4.5. The first is that non-English speaking countries in South America, such as Argentina, Bolivia, Brazil, Chile,

[7]The data set is described in detail in Nicita and Olarreaga (2006).

Table 4.3: Gravity Equation Estimation Results

	OLS Full Sample	OLS Year 2000	OLS Full Sample	OLS Full Sample
Wage Differential	0.9618 (0.1673)	0.7996 (0.2756)	0.5358 (0.2752)	1.9791 (0.2032)
Migrant Network	0.6830 (0.0520)	0.8542 (0.0548)	0.7320 (0.0550)	0.1729 (0.0806)
Distance	-0.7429 (0.1646)	-0.3689 (0.1507)	-0.6046 (0.1447)	-4.8099 (0.7135)
English Language	0.6973 (0.1716)	0.3097 (0.1381)	0.6403 (0.1569)	5.9059 (0.8472)
Constant	-4.6794 (1.8264)	-5.0745 (2.8055)	-1.3822 (3.0464)	14.836 (4.7012)
Time F. E.	NO	NO	YES	NO
Country F. E.	NO	NO	NO	YES
Observations	123	32	123	123
Adj. R-squared	0.9027	0.9758	0.9214	0.9301

Table 4.4: Phi: Calculated Migration Curvature Parameter

Full Sample	Year 2000	Time F.E.	Country F.E.
2.04	2.32	1.51	2.87

Table 4.5: Kappa: Calculated Migration Cost Parameters

Country	Full Sample	Year 2000	Time F.E.	Country F.E.
Antigua & Barbuda	0.59	0.10	2.03	0.02
Argentina	32.78	26.06	45.27	25.40
Aruba	2.84	1.14	3.13	0.33
Barbados	1.02	0.21	3.42	0.04
Belize	0.95	0.23	1.93	0.04
Bolivia	17.91	12.48	20.89	8.83
Brazil	88.49	146.89	31.19	185.25
Chile	25.22	17.70	40.05	15.55
Colombia	8.19	5.15	6.19	2.33
Costa Rica	5.72	2.89	6.09	1.16
Cuba	1.05	0.35	0.85	0.06
Dominica	0.80	0.15	2.68	0.03
Dominican Republic	1.88	0.71	1.72	0.16
Ecuador	6.75	3.46	8.04	1.54
El Salvador	1.38	0.36	2.89	0.08
Grenada	1.14	0.25	3.51	0.06
Guatemala	3.30	1.46	3.16	0.44
Guyana	1.55	0.24	18.56	0.08
Haiti	2.46	1.11	1.67	0.28
Honduras	3.37	1.54	2.96	0.46
Jamaica	0.84	0.20	1.45	0.03
Mexico	1.89	0.60	3.00	0.15
Nicaragua	2.25	0.78	3.24	0.21
Panama	2.25	0.73	3.92	0.20
Paraguay	50.71	56.94	35.88	61.46
Peru	14.59	9.65	16.46	6.15
St. Kitts & Nevis	0.83	0.18	2.18	0.03
St. Lucia	2.02	0.65	3.36	0.17
St. Vincent	1.38	0.35	3.33	0.08
Suriname	18.87	17.73	8.99	11.13
Trinidad & Tobago	1.57	0.40	4.15	0.10
Uruguay	16.10	8.40	42.31	6.45
Venezuela	18.42	20.61	4.93	11.65

Colombia, Paraguay, Peru, Suriname, Uruguay, and Venezuela have high migration costs. This is not surprising as these countries are relatively far away from the U.S., do not speak English, and they have relatively large populations, reducing the positive impact of the network variable. Second, English speaking countries with relatively small populations have very low migration costs according to this estimation. This applies primarily to the British West Indies.

Given the values for κ and ϕ, the parameter ψ is set to match the share of remittances in GDP for each country.

In the quantitative exercises that follow I will use parameters estimated from the Year 2000 sub-sample. I choose these parameters because the estimation results had the best fit, and because the rest of the model is calibrated to the year 2000.

4.4 Model Results

This section uses the model to quantitatively assess the impact of remittance inflows on receiving economies. I restrict attention to Latin America and the Caribbean due to the relative homogeneity in geography, demographics, and migration patterns. The U.S. is the main destination for migrants from this region, and data on foreign-born residents is available from the U.S. census.

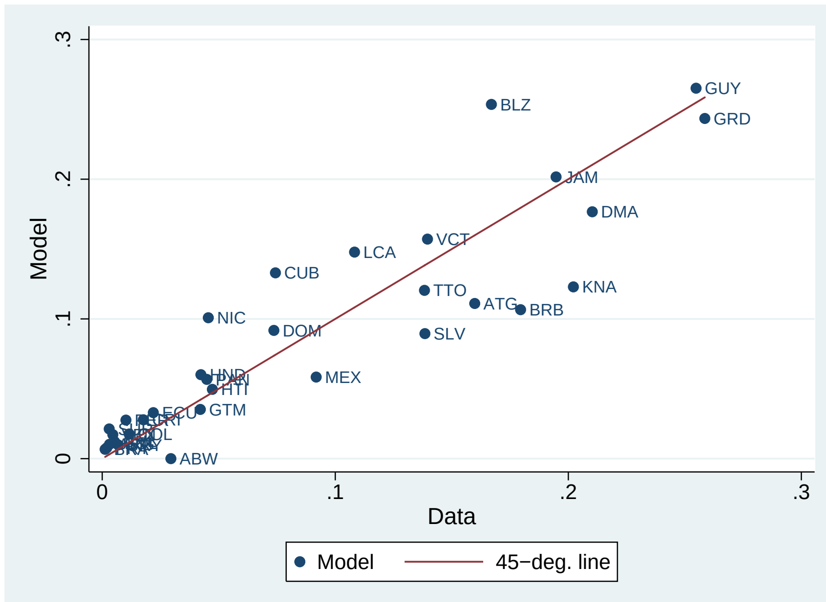
I first present the benchmark model results for the sample of 33 Latin American and Caribbean countries, and discuss the model's predictions. I then present counterfactual experiments to quantify the impact of migration and remittance inflows on factor allocation, aggregate productivity, and welfare for each country. Finally, I simulate the model to examine how benefits from remittance inflows vary with the relative non-tradable sector productivity.

4.4.1 Model Benchmark

Figure 4.1 shows the model's predicted migration stock in the U.S. relative to the domestic population compared to data. Each dot represents a Latin American or Caribbean economy. A perfect model fit would have each point lie exactly on the 45° line. Despite the simple migration cost function, the benchmark values are clustered along the 45° line. The corresponding values are presented in table 4.6 together with the remittance share of GDP which is matched exactly by the model.

Table 4.2 lists the benchmark debt-to-GDP ratio, investment-to-GDP ratio, tradable sector share, and the relative productivity of the non-tradable sector for all the countries in the sample. In 2000, the average debt-to-GDP ratio for Latin America and the Caribbean is 0.55, and the average investment-to-GDP ratio is 0.22. The debt and investment ratios are fairly uniform across the region, except for Guyana and Nicaragua which have debt problems, with debt amounting to almost double their GDP. There is some variation in the tradable sector share, depending on the reliance on tourism which is an important industry for many countries in the region. A handful of the island economies have tradable sector shares around 15%.

Figure 4.1: Stock of Migrants in the U.S.



Source: U.S. Census - Foreign-born population in the U.S. as a share of domestic population, 2000

For the region, the average relative non-tradable productivity is 0.95, meaning that the productivity in the non-tradable sector is 5% lower than the tradable sector productivity. Leaving out the outliers Peru and Venezuela, the average drops to 0.86, and for the group of high remittance countries (Rem./GDP > 0.05) the average is 0.75. This is an important point when considering the impact of remittances on recipient economies, as one of the effects of remittance transfers is a reallocation of productive factors from the tradable sector to the non-tradable sector.

Table 4.6: Benchmark Remittances and Migration

Country	Rem/GDP	Migration Model	Migration Data
Antigua & Barbuda	2.6	11.6	16.0
Argentina	0.0	1.1	0.3
Aruba	0.4	1.1	2.9
Barbados	4.5	11.2	18.0
Belize	3.2	27.1	16.7
Bolivia	1.5	1.3	0.6
Brazil	0.3	0.4	0.1
Chile	0.0	1.5	0.5
Colombia	1.6	2.0	1.2
Costa Rica	0.9	3.3	1.8
Cuba	2.5	5.9	7.4
Dominica	5.0	14.9	21.0
Dominican Republic	7.7	10.3	7.4
Ecuador	8.3	3.7	2.2
El Salvador	13.4	9.9	13.8
Grenada	8.9	24.9	25.9
Guatemala	3.1	3.6	4.2
Guyana	3.8	25.6	25.5
Haiti	15.8	5.3	4.7
Honduras	6.8	6.5	4.2
Jamaica	9.9	21.5	19.5
Mexico	1.3	6.3	9.2
Nicaragua	8.1	10.7	4.6
Panama	0.1	5.4	4.5
Paraguay	3.9	0.6	0.2
Peru	1.3	3.3	1.0
St. Kitts & Nevis	7.1	20.0	20.2
St. Lucia	3.7	13.9	10.8
St. Vincent	5.7	16.3	14.0
Suriname	0.1	2.6	0.3
Trinidad & Tobago	0.5	15.0	13.8
Uruguay	0.0	1.1	0.7
Venezuela	0.0	2.0	0.5

4.4.2 Remittances and Factor Allocation

In this section I use the model to quantitatively examine the impact of remittance inflows on the Latin American and Caribbean economies. For each country I take the benchmark steady state equilibrium and compare it to the steady state where the exogenous foreign wage is set to zero. With no incentive to migrate, migration and remittances are zero, and the differences between the steady states can be attributed to the joint effect of migration and remittance transfers. I focus on the changes in the allocation of labour across sectors, GDP, GNP, and the components of GDP per capita.

The first column in table 4.7 shows the remittance share in GDP in the benchmark calibration. The following three columns show the percentage change in the non-tradable labour share, GDP, and GNP, going from the zero remittance steady state to the benchmark. I assume that migration is permanent, and only net remittances received are counted in GNP.

The first important observation is that every country experiences a relative shift of productive factors from the tradable sector into the non-tradable sector. Figure 4.2 shows that there is a nearly perfect linear relationship between the percentage increase in the non-tradable labour share and remittances relative to GDP in the benchmark. This is consistent with the Dutch Disease mechanism, predicting real exchange rate appreciation and factor reallocation as a result of capital inflows.

The second observation to take away from table 4.7 is that GDP, and in

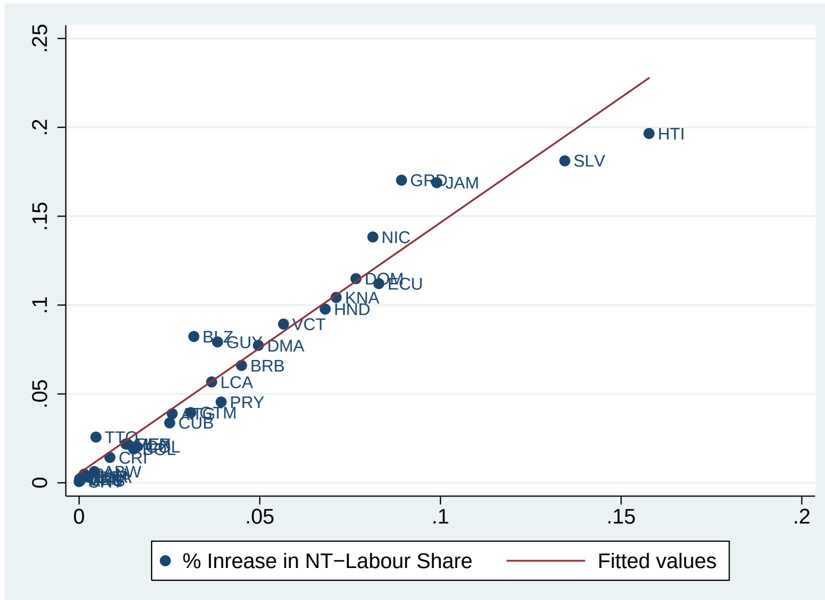
Table 4.7: %Δ in Non-Tradable labour share, GDP, and GNP

Country	Rem/GDP	Non-Tradable Labour-Share	GDP	GNP
Antigua & Barbuda	2.6	3.9	-7.7	-5.3
Argentina	0.0	0.1	-0.9	-0.8
Aruba	0.4	0.6	-0.9	-0.4
Barbados	4.5	6.6	-7.4	-3.2
Belize	3.2	8.2	-20.3	-17.7
Bolivia	1.5	1.9	-1.0	0.4
Brazil	0.3	0.3	-0.3	0.0
Chile	0.0	0.2	-1.1	-1.1
Colombia	1.6	2.0	-1.5	0.0
Costa Rica	0.9	1.4	-2.6	-1.7
Cuba	2.5	3.4	-4.1	-1.7
Dominica	5.0	7.7	-10.4	-5.9
Dominican Republic	7.7	11.5	-7.5	-0.4
Ecuador	8.3	11.2	-2.7	5.3
El Salvador	13.4	18.1	-7.1	5.4
Grenada	8.9	17.0	-14.6	-6.9
Guatemala	3.1	4.0	-2.9	0.1
Guyana	3.8	7.9	-19.4	-16.3
Haiti	15.8	19.7	-2.6	12.8
Honduras	6.8	9.8	-4.8	1.6
Jamaica	9.9	16.9	-14.9	-6.4
Mexico	1.3	2.2	-4.9	-3.6
Nicaragua	8.1	13.8	-7.6	-0.1
Panama	0.1	0.5	-4.2	-4.0
Paraguay	3.9	4.5	-0.6	3.3
Peru	1.3	2.2	-2.3	-1.0
St. Kitts & Nevis	7.1	10.4	-18.7	-13.0
St. Lucia	3.7	5.7	-9.6	-6.3
St. Vincent	5.7	8.9	-10.6	-5.6
Suriname	0.1	0.4	-2.0	-1.8
Trinidad & Tobago	0.5	2.6	-11.3	-10.9
Uruguay	0.0	0.1	-0.8	-0.8
Venezuela	0.0	0.2	-1.5	-1.4

Table 4.8: %Δ in GDP Per Capita

Country	GDP_{pc}	C_{pc}	I_{pc}	EXP_{pc}	IMP_{pc}
Antigua & Barbuda	4.5	6.3	16.2	-19.3	8.3
Argentina	0.3	0.3	0.9	-0.1	0.6
Aruba	0.3	0.8	1.0	-1.5	0.7
Barbados	4.3	9.1	17.0	-22.5	10.3
Belize	9.4	11.8	34.8	-10.5	23.1
Bolivia	0.2	2.1	1.3	-2.7	1.7
Brazil	0.1	0.4	0.5	-1.2	0.4
Chile	0.4	0.4	1.2	0.0	0.8
Colombia	0.5	2.5	2.1	-4.3	2.3
Costa Rica	0.8	2.1	2.9	-1.8	2.4
Cuba	1.9	5.1	6.8	-10.1	5.7
Dominica	5.3	11.4	20.6	-19.7	14.1
Dominican Republic	3.2	14.2	10.5	-16.3	14.9
Ecuador	1.0	12.0	4.0	-15.9	9.2
El Salvador	3.1	21.4	12.4	-23.4	20.2
Grenada	13.8	20.0	60.3	-46.4	30.2
Guatemala	0.8	4.6	3.8	-5.9	4.3
Guyana	8.3	14.9	25.7	1.4	38.9
Haiti	2.8	23.1	12.1	-31.4	20.9
Honduras	1.7	10.6	8.6	-15.5	9.1
Jamaica	8.5	23.0	33.5	-26.4	29.7
Mexico	1.6	3.1	5.8	-4.4	3.9
Nicaragua	3.5	15.1	14.0	-18.5	15.8
Panama	1.3	1.2	4.2	-0.9	2.3
Paraguay	0.0	4.5	1.3	-7.5	3.1
Peru	1.0	2.9	2.8	-4.5	3.1
St. Kitts & Nevis	1.5	8.4	10.8	-35.1	2.7
St. Lucia	5.0	7.0	19.7	-26.8	8.8
St. Vincent	6.8	12.9	27.1	-27.1	16.5
Suriname	0.6	0.7	2.0	-0.6	1.3
Trinidad & Tobago	4.3	6.6	13.6	0.9	11.3
Uruguay	0.3	0.3	0.8	0.0	0.5
Venezuela	0.5	0.6	1.5	0.5	1.6
Average	3.0	7.9	11.5	-12.1	9.7

Figure 4.2: Increase in Non-Tradable Labour Share



most cases GNP decrease. Naturally because parts of the labour force have migrated. However, GNP increases for a few high remittance countries, for example Ecuador, El Salvador, and Haiti. This means that net remittance transfers exceed the aggregate income loss from migration. Part of the explanation is that these countries are relatively poor, Haiti in particular. But it could also be that migrants from these countries are more likely to send remittances to their families.

Table 4.8 presents the percentage change in GDP per capita and its components, going from the zero remittances steady state to the benchmark. On average, GDP per capita increases by 3%, consumption per capita by 7.9% and investment per capita increases by 11.5%.

Figure 4.3 shows the increase in GDP per capita plotted against the remittances-to-GDP ratio. There is significant variation in the increase in GDP per capita across countries, depending on the level of remittance transfers, as well as differences in productivity, tradable sector share, investment-to-GDP and debt-to-GDP ratios. Figure 4.4 shows how there is less variation in consumption per capita, relative to GDP per capita. Generally, consumption and investment per capita increase as the households have higher per capita income from the remittance transfers.

Finally, the last two columns in table 4.8 show that on average, exports per capita decrease, and imports per capita increase. This is also consistent with Dutch Disease predictions. For the benchmark steady state equilibrium, in the Balance of Payment Identity, remittance inflows are offset by trade balance deficits. Whereas, in the zero migration, zero remittances steady state, each country is running a trade surplus to cover the interest payments on the national debt. Holding the debt and interest payments constant, this means that exports must fall relative to imports.

4.4.3 Increasing Non-Tradable Productivity

The results in the previous section suggest that remittance transfers benefit recipient countries in terms of higher GDP and consumption per capita. In this section, I quantify the benefits from increasing the non-tradable sector productivity in remittance receiving countries.

Obviously, increasing the productivity in any sector will increase output

Figure 4.3: Increase in GDP Per Capita

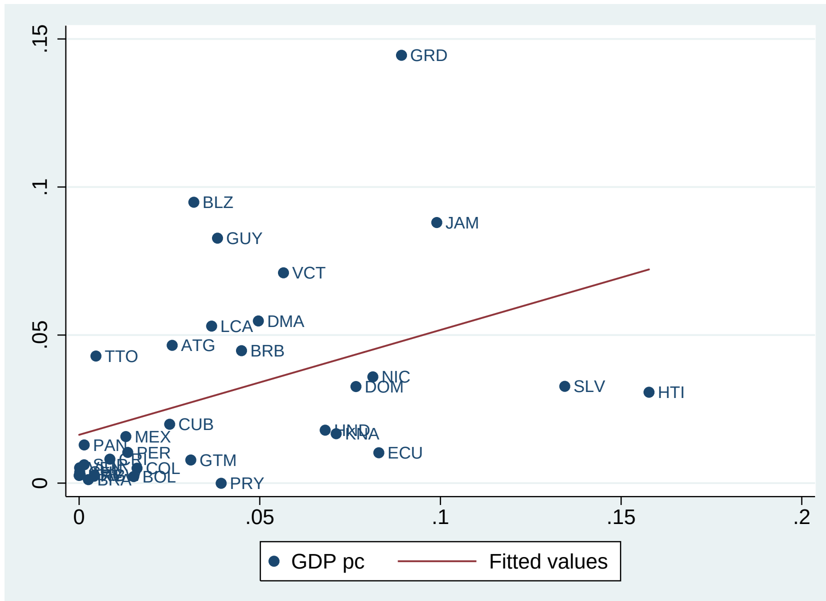
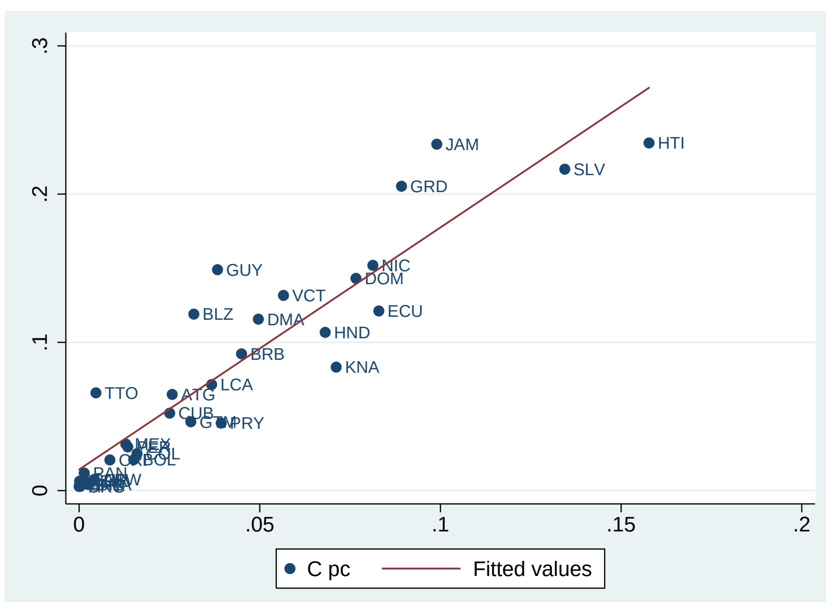


Figure 4.4: Increase in Consumption Per Capita



and likely consumption. In this experiment, I would like to isolate the benefits from remittance inflows. To achieve this I recalibrate the model and repeat the experiment from the previous section for all countries where the non-tradable sector productivity is less than the tradable sector productivity. That is, when $A_{NT} < A_T$, I increase A_{NT}, until $A_{NT} = A_T$. I hold constant the level of migration, the remittance share of GDP, and the debt-to-GDP ratio, so that they exactly match the Benchmark calibration levels. Next, I compare this new steady state equilibrium to the zero migration, zero remittances steady state, keeping $A_{NT} = A_T$.

Tables 4.9 and 4.10 present the results for GDP and consumption per capita, respectively. In table 4.9, the first column shows the percentage increase in GDP per capita comparing the Benchmark to the zero remittances steady state (the results from the previous section), and the second column shows the results from the same experiment when the model is recalibrated such that $A_{NT} = A_T$. As a reference, the third column shows the Benchmark non-tradable sector productivity.

The important observation here is that the increase in GDP and consumption per capita from remittance inflows is greater when the productivity in the non-tradable sector matches that of the tradable sector. The averages suggest that increasing the non-tradable sector productivity could increase the benefits from remittance inflows by 33% in terms of higher GDP per capita, 27% in terms of higher consumption per capita.

Figures 4.5 and 4.6 plot the relative increase in GDP and consumption per

Table 4.9: Counterfactual: Increasing Non-Tradable Sector Productivity

Country	GDP_{pc} Benchmark	GDP_{pc} $A_{NT} = A_T$	Benchmark A_{NT}/A_T
Antigua & Barbuda	4.5	5.1	0.88
Aruba	0.3	0.3	0.94
Barbados	4.3	5.3	0.68
Belize	9.4	10.7	0.75
Bolivia	0.2	0.3	0.57
Brazil	0.1	0.1	0.72
Colombia	0.5	0.5	0.91
Costa Rica	0.8	0.8	0.92
Cuba	1.9	2.3	0.73
Dominica	5.3	6.4	0.64
Ecuador	1.0	1.0	0.93
El Salvador	3.1	3.2	0.88
Grenada	13.8	17.5	0.63
Guatemala	0.8	0.9	0.52
Haiti	2.8	3.0	0.94
Honduras	1.7	1.9	0.57
Jamaica	8.5	9.1	0.78
Mexico	1.6	2.0	0.59
Nicaragua	3.5	3.5	0.63
Panama	1.3	1.9	0.52
St. Kitts & Nevis	1.5	11.8	0.37
St. Lucia	5.0	8.2	0.53
St. Vincent	6.8	8.4	0.63
Average	3.3	4.4	0.71

Table 4.10: Counterfactual: Increasing Non-Tradable Sector Productivity

Country	C_{pc} Benchmark	C_{pc} $A_{NT} = A_T$	Benchmark A_{NT}/A_T
Antigua & Barbuda	6.3	7.2	0.88
Aruba	0.8	0.8	0.94
Barbados	9.1	11.4	0.68
Belize	11.8	15.8	0.75
Bolivia	2.1	2.2	0.57
Brazil	0.4	0.5	0.72
Colombia	2.5	2.5	0.91
Costa Rica	2.1	2.1	0.92
Cuba	5.1	5.9	0.73
Dominica	11.4	14.4	0.64
Ecuador	12.0	12.1	0.93
El Salvador	21.4	21.9	0.88
Grenada	20.0	32.8	0.63
Guatemala	4.6	5.1	0.52
Haiti	23.1	23.5	0.94
Honduras	10.6	11.6	0.57
Jamaica	23.0	25.5	0.78
Mexico	3.1	4.3	0.59
Nicaragua	15.1	16.4	0.63
Panama	1.2	2.4	0.52
St. Kitts & Nevis	8.4	27.3	0.37
St. Lucia	7.0	13.5	0.53
St. Vincent	12.9	17.2	0.63
Average	9.1	11.7	0.71

Figure 4.5: Relative Increase in GDP Per Capita

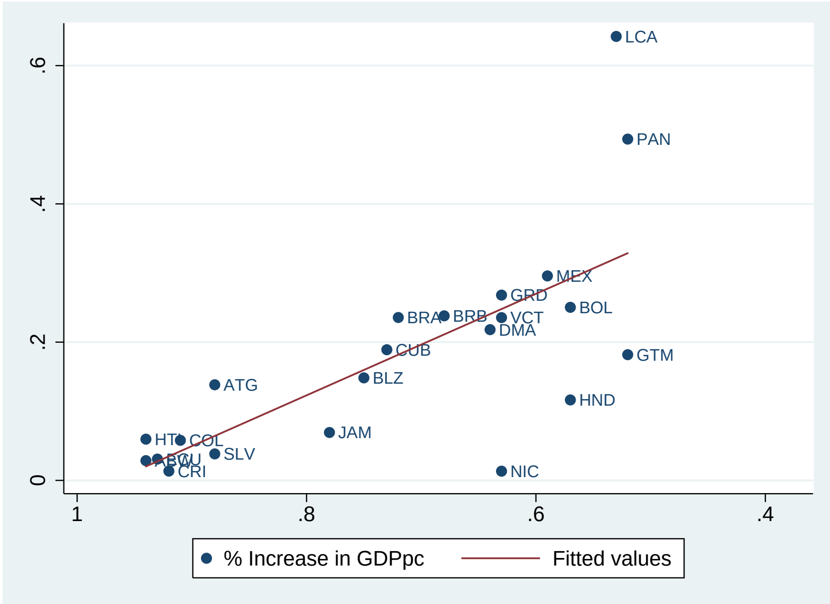
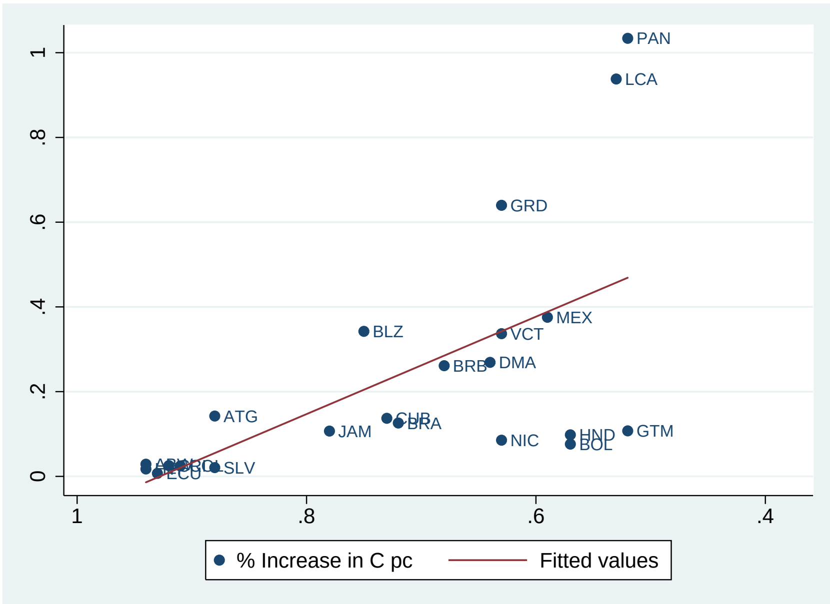


Figure 4.6: Relative Increase in Consumption Per Capita



capita against the non-tradable productivity levels in the Benchmark calibration.[8] Both figures show that the potential increase in benefits from remittance transfers are larger for countries with relatively low non-tradable sector productivity. St. Lucia (LCA) and Panama (PAN) could potentially increase the benefits from remittance inflows by about 50% in terms of higher GDP per capita, and about double the benefits in terms of higher consumption per capita.

4.4.4 Sensitivity Analysis: ψ

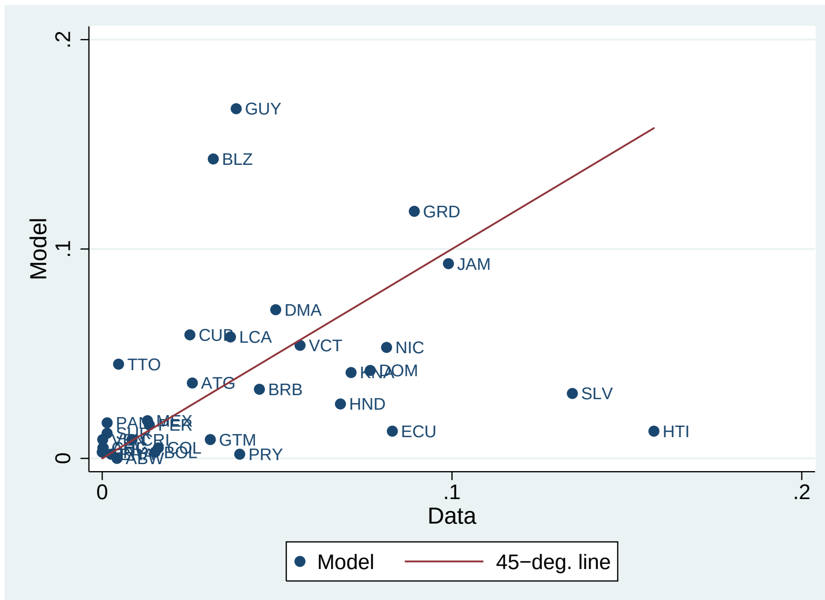
In the benchmark calibration ψ is set to exactly match the share of remittances in GDP for each country.

Figure 4.7 shows a plot of remittance inflows over GDP compared to the data when $\psi = 1$. As in the corresponding migration plot in figure 4.1, a perfect fit would have the points line up exactly on the 45° line. When $\psi = 1$ the discrepancy between the model and data appears larger than for migration, because the model is now only calibrated to match the migration stocks, but not the remittance inflows. Outliers to the left have remittance inflows that are over-predicted by the model. Guyana, Belize, Dominica, Trinidad and Tobago are all island economies which have high migration stocks relative to their domestic population, yet the number of people sending remittances, or the average size of remittances sent back to these countries is smaller than for the rest of the sample. Alternatively, it could be that remittances sent to these countries for some reason follow more informal channels, and therefore not recorded in the

[8] St. Kitts & Nevis is an outlier and does not appear in the plot.

data.

Figure 4.7: Remittance Inflows as a Share of GDP



It is also important to mention that the remittance data shown in Figure 4.7 are total remittance inflows, whereas the migration data used in the calibration only takes into account migrants in the U.S. that responded to the U.S. census. It is likely that some temporary migrants send remittances back to their home countries, but were not included in the U.S. census. The migration data is also missing information on migrants to other countries. According to Ratha and Shaw (2007), significant migration takes place between developing economies, and estimates of south-south remittances range from 10 to 29 percent of developing economies' total remittances. With this information in mind, it may be the case that the model overstates the remittance inflows for some economies, and that some of the points to the right of the 45° line in Figure 4.7 actually shows an accurate representation of the remittances coming from permanent residents in the United States.

4.5 Conclusion

Remittance payments to Latin America and the Caribbean are an important source of income for households in the region. For some countries, aggregate remittance transfers exceed international aid and foreign direct investment, and a growing literature has set out to investigate the potential impacts from such large capital inflows. This paper examines the impact of remittance transfers on the sectoral factor allocation and the accompanying welfare implications for Latin American and Caribbean Economies.

The paper develops a quantitative model where remittance transfers are a function of an endogenous migration decision. It is important to capture the intimate relationship between migration and remittances in order to properly account for the impact of remittance transfers on the sectoral factor allocation.

My results suggest that remittance inflows have increased the non-tradable sector share by 6% on average, and by 15-20% for high remittance countries. This supports the finding by for example Lartey, Mandelman, and Acosta that remittance transfers generate a Dutch Disease effect.

My results further suggest that Latin American and the Caribbean economies have experienced an increase in consumption per capita, on average 9.1%, as a result of remittance transfers; however, the benefit is mitigated by the shift of productive resources into the less productive non-tradable sector. The quantitative experiments suggest that the benefits from remittance transfers could be 27% higher in terms of increased consumption per capita, if the non-tradable sector productivity increased to the tradable sector level. This is a novel finding in the development and remittance transfer literature which has important policy implications for economies receiving large remittance inflows.

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Chapter 5

Conclusion

My thesis consists of three chapters investigating topics in international and environmental economics. Although the topics are different, they are all examined within the context of quantitative open economy models.

Chapter 2 examined the role of production sharing and trade in the transmission of the 2008-2009 recession. The results of this chapter suggest that the recession had a large impact on GDP and trade in North America, where trade linkages played a significant role in the transmission of the US recession to its regional trading partners. In the benchmark calibration the model predictions can account for 72% of the fall in output for Canada, 19% for Mexico, and almost two-thirds of the fall in trade. The quantitative experiments suggest that production sharing accounts for about 40% of the fall in trade, but only 12% of the fall in output. Together these results indicate that production sharing may be an important factor in explaining why trade fell so much relative to output during the great recession, and in explaining trade comovement in general.

Chapter 3 quantified the net economic impact of climate change and climate change policy on the Canadian economy. We find that while a carbon tax that holds the stock of global emissions below the 550 ppm level would yield positive net benefits for the world economy, the impact of such a tax on the Canadian economy would be negative. This result is largely driven by our finding that the damages from small increases in temperature are much smaller in Canada than in the rest of the world.

In addition, our benchmark simulation results highlight the large impacts that carbon taxes can have on long run shifts in fossil fuel prices by shifting the temporal path of consumption.

The final essay in Chapter 4 examined the impact of remittance transfers on the allocation of productive factors across sectors in Latin American and Caribbean economies. The results suggest that countries in the region have experienced an increase in consumption per capita by 9.1% on average as a result of remittance transfers.

My results further suggest that the benefits from remittance transfers could be 33% higher in terms of increased GDP per capita, and 27% in terms of increased consumption per capita, if the non-tradable sector productivity increased to the tradable sector level. The benefit is mitigated by the shift of productive resources into the less productive non-tradable sector. The remittance transfers generate a Dutch Disease effect where the non-tradable sector share increases by 6% on average, and by 15-20% for the high remittance countries.

Appendix A

Chapter 2 Appendix

Let $c_t + \sum_j i_{j,t} + \Phi_d(d_{t+1}) = \Gamma_t$.

For each period t, the budget constraint holds with equality in equilibrium:

$$\Gamma_t + (1 + r_t^d)d_t - d_{t+1} = \sum_j \left(r_{j,t}^k k_{j,t} + w_{j,t} n_{j,t}\right) \quad \text{, for } j = 1, 2, nt$$

$$\Gamma_t + (1 + r_t^d)d_t - d_{t+1} = q_{1,t}^x x_{1,t} + q_{2,t}^x x_{2,t} + q_{nt,t} y_{nt,t}$$

Substitute for the trade balance, $d_{t+1} = d_t(1 + r_{d,t}) - tb_t$, and drop time subscripts:

$$\Gamma + tb = q_1^x x_1 + q_2^x x_2 + q_{nt} y_{nt}$$

Substitute for $exports = q_1^x x_{1,ex} + q_2^v v_{2,ex}$ and $imports = q_1^{x^*} x_{1,im} + q_2^{x^*} x_{2,im}$:

$$\Gamma = q_1^x x_1 + q_2^x x_2 + q_{nt} y_{nt} - q_1^x x_{1,ex} - q_2^v v_{2,ex} + q_1^{x^*} x_{1,im} + q_2^{v^*} x_{2,im}$$

Note that:

$$q_2^v v_{2,ex} = q_2^x x_2 + q_2^{x^*} x_{2,im}$$

$$q_1^x x_{1,h} = q_1^x x_1 - q_1^x x_{1,ex}$$

$$q_1^v v_1 = q_1^x x_1 + q_1^{x^*} x_{1,im}$$

Cancel terms and substitute for $q_1^x x_1 + q_1^{x^*} x_{1,im}$:

$$\Gamma = q_1^v v_1 + q_{nt} y_{nt} = y$$

Thus, the period t resource constraint is:

$$c_t + \sum_j i_{j,t} + \Phi_d(d_{t+1}) = y_t$$

Appendix B

Chapter 3 Appendix

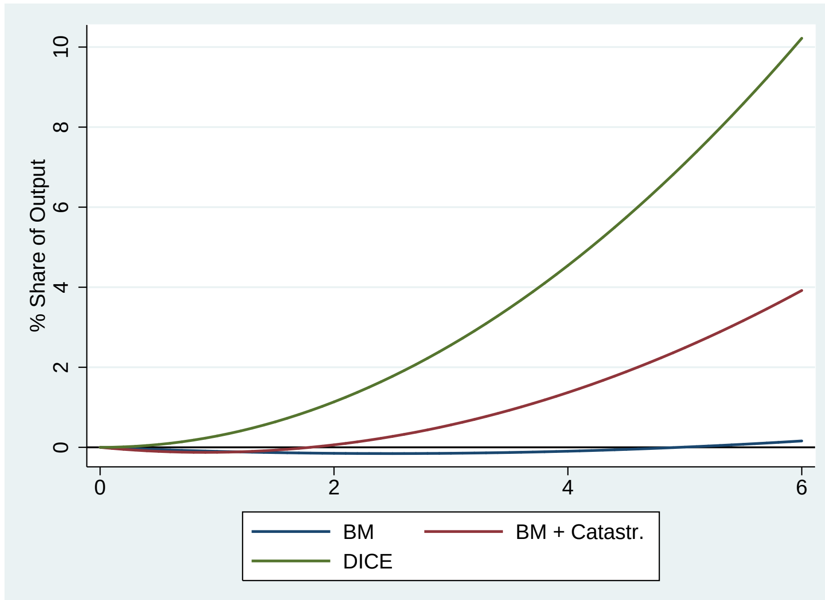
B.1 Catastrophic Damages

Nordhaus and Boyer (2000) estimate the catastrophic impact from climate change based on survey responses from experts in the scientific community. Survey respondents were asked about the likelihood of low-probability, "high consequence" events resulting from climate change. (Here, "high consequence" means a 25 percent loss in global income indefinitely). They find that:

- For the US, the Willingness to Pay (WTP) to avoid catastrophic risk of climate change is 0.45% of GDP at $T = 2.5^\circ$ of warming, and 2.53% at $T = 6^\circ$ of warming.
- For the world, the WTP to avoid catastrophic risk of climate change is about 1% of GDP at $T = 2.5^\circ$ of warming, and 7% at $T = 6^\circ$ of warming (depending on use of output or population weights)

Using the estimates for the U.S. catastrophic impact I re-estimate our Canadian damage function. In figure B.1, the new damage function is displayed together with our old (Benchmark) damage function and the global damage function from Nordhaus (2008).

Figure B.1: Adding Catastrophic Damages



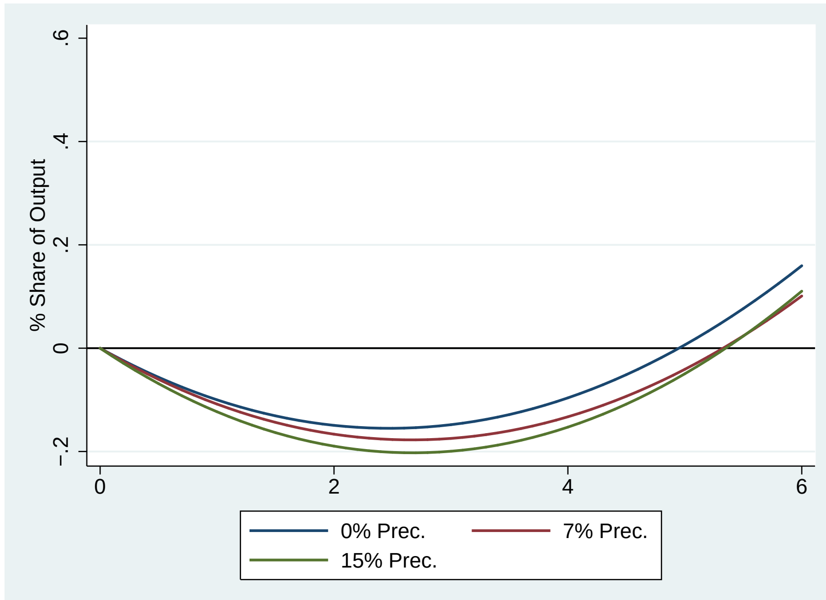
Interestingly, Mendelsohn's estimates of market damages seem negligible compared to potential catastrophic damages suggested by Nordhaus and Boyer (2000).

B.2 Precipitation Sensitivity Analysis

Mendelsohn (2001) reports regional climate damages for five sectors (Agriculture, Forestry, Energy, Coastal Structures, and Water Resources) at varying degrees of warming (1.5, 2.5, and 5.0 degrees Celsius) and varying levels of precipitation (0%, 7%, and 15% over 1990 levels) in 2060.

Our damage function was constructed using the damage estimates at 2.5 and 5.0 degrees of warming and 0% increase in precipitation for the four northern U.S. regions. Figure B.2 shows the calibrated damage functions for 7% and 15% increase in precipitation from Mendelsohn's scenario analysis. At 7% and 15% increase in precipitation, almost all of the regions experience either higher benefits (or lower damages), and consequently, the damage functions for these scenarios fall below the benchmark calibration. See pages 193 and 203

Figure B.2: Damage Functions for Canada: Precipitation



in Mendelsohn (2001) for details.

B.3 NRTEE Forestry Damage Estimates

In a recent report published by the National Roundtable on the Environment and the Economy (NRTEE, 2011), regional damages to the forestry sector are estimated based on impacts of climate change on fires, forest productivity, and pests such as the pine beetle. Table B.1 shows the estimated damages.

The estimates were drawn primarily from research conducted by the Canadian Forest Service at Natural Resources Canada. Damage estimates from forest fires are based on forecasts of forest ares burned in different regions due to climate change. Damage estimates from forest productivity and pests are based on qualitative assessments stemming from judgments based on existing literature.

Overall, damages of $2 - 17 billion for Canada in 2050 are high compared to Mendelsohn's estimated benefits to the forestry sector in the Northern United States.

Table B.1: NRTEE Forestry Damages

Region	Low Climate Change Slow Growth		High Climate Change Rapid Growth	
B.C.	-0.5B	0.18%	-3.1B	0.44%
Alberta	-0.2B	0.06%	-1.0B	0.14%
Prairies	-0.5B	0.33%	-3.3B	0.85%
Ontario	-1.0B	0.11%	-7.4B	0.31%
Quebec	-0.3B	0.08%	-2.1B	0.23%
Atlantic	-0.1B	0.07%	-0.5B	0.21%
Canada	-2.4B	0.12%	-17.4B	0.33%

Notes: $ 2008
Source: Table 4, Paying the Price, page 53, (NRTEE, 2011).

B.4 Bibliography

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Appendix C

Chapter 4 Appendix

There is no government in the model, and GDP can therefore be expressed as:

$$GDP_t = C_t + I_t + NX_t \tag{C.1}$$

$$= p_{T,t}(c_{T,t} + i_{T,t}) + p_{N,t}(c_{N,t} + i_{N,t}) + q_t x_{EX,t} - q_t^* x_{IM,t} \tag{C.2}$$

$$= p_{T,t} y_{T,t} + p_{N,t} y_{N,t} + q_t x_{EX,t} - q_t^* x_{IM,t} \tag{C.3}$$

$$= p_{T,t} y_{T,t} + p_{N,t} y_{N,t} + q_t x_t - q_t x_{H,t} - q_t^* x_{IM,t} \tag{C.4}$$

$$= p_{T,t} y_{T,t} + p_{N,t} y_{N,t} + q_t x_t - p_{T,t} y_{T,t} \tag{C.5}$$

$$= p_{N,t} y_{N,t} + q_t x_t \tag{C.6}$$

$$= \sum_j \left(r_{j,t}^k k_{j,t} + w_{j,t} n_{j,t} \right) \tag{C.7}$$

The first step, from (C.1) to (C.2), follows from the definitions of tradable and non-tradable consumption and investment, exports and imports. Next, from (C.2) to (C.3), follows from the resource constraints $c_{T,t} + i_{T,t} = y_{T,t}$ and $c_{N,t} + i_{N,t} = y_{N,t}$. Then, the step from (C.3) to (C.4) follows from the resource constraint for the domestic intermediate good x_t, where $x_t = x_{H,t} + x_{EX,t}$. Finally, the step from (C.3) to (C.4) uses the zero profit condition for the tradable composite good, where $p_{T,t}y_{T,t} = q_t x_{H,t} + q_t^* x_{IM,t}$.

The Balance of Payment Identity, (C.8), can be stated as (C.9). Then, (C.2), (C.7), and (C.9) implies the household's period t budget constraint, (C.10). $p_{T,t}$ is normalized to 1.

$$d_{t+1} + NX_t + q_t^* R(m_t) = (1 + r_t^d) d_t \tag{C.8}$$

$$q_t x_{EX,t} - q_t^* x_{IM,t} = (1 + r_t^d) d_t - d_{t+1} - q_t^* R(m_t) \tag{C.9}$$

$$(c_{T,t} + i_{T,t}) + p_{N,t}(c_{N,t} + i_{N,t}) + (1 + r_t^d) d_t \leq \sum_j \left(r_{j,t}^k k_{j,t} + w_{j,t} n_{j,t} \right) \tag{C.10}$$

$$+ q_t^* R(m_t) + d_{t+1}, \quad j = T, N$$

Currirculum Vitae

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