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Honours Thesis

The Environmental Impact of Trade Liberalisation in Developing Countries:

A General Equilibrium Approach

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Declaration

I hereby declare that this thesis is my own original work, and to the best of my knowledge, does not contain material or content by other authors except where I have acknowledged otherwise. This Thesis has not been submitted for the award of any other degree or diploma at the University of New South Wales, or at any other educational institution.

Aidan Wood
October 28th 2016

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Abstract

The environmental impacts of increased trade activity is an increasingly contentious issue within economic literature. The debate has arisen in findings from the literature, especially from contrasting results from empirical studies and theoretical models of trade. The rapid process of tariff reduction which began in 1991 provides a unique opportunity to study how such policies can affect economic structure and externalities, and findings from such studies may be applicable to similarly developed economies. In this study we use a form of static general equilibrium modelling to analyse the impacts of quantitative tariff reduction on all potential sectors in a developing country, India. We conduct various policy experiments to simulate both the exact level of tariff reduction post-1995 as well as incremental tariff reductions in order to calculate both welfare and carbon optimal tariff levels. Given the lack of a pre-built model, we manually construct a Social Accounting Matrix in order to provide the required exogenous inputs for the model. After simulating the tariff-reductions impacts on the production plans for each sector, we disaggregate each corresponding carbon impact into income, sectoral and technological impacts using a form of Laspeyres index. In lieu of calibrating the amount of energy used for each sector we use intermediate inputs as well as an estimated carbon factor for each sector as the required inputs. We find a noticeable decrease in carbon emissions as a result of our initial experiment which then reverses with increasing tariff reductions, as well as some mitigating effects from forms of environmental regulation.

2
Introduction

The economic and environmental effects from trade liberalization invokes two of the most politically sensitive topics surrounding the effectiveness of the free market and potentially unaccounted for social costs. At the core of the debate lies an assumption as to whether the increased economic activity resulting from globalization must inevitably result in increased environmental costs. This is amplified by the additional factors of huge variations in environmental quality and in regulatory controls between the developed and developing world, with the potential of much greater externality related costs within the latter. Accordingly, much of the debate is intensely focused on lowering tariff rates within developing type economies. At worst the removal of barriers to globalization could create the presence of so-called "pollution havens", in which dirty industries are able to thrive in relatively poorer sections of the global economy in the absence of sufficient environmental regulation. The simultaneous emergence of increased public awareness of anthropologic climate change and increased World Trade Organization (WTO) membership inclusion amplified this debate during the early 90's. As the majority of inclusion efforts were focused on transitioning countries, trade liberalization had a much larger potential impact on their respective economic structures: mainly on the transition from an agricultural based-economy to the initial stages of industrialization. Typically this involved a significant increase in environmental effluents due to the relative harm of manufacturing sectors compared to agriculture. At the same time, economic connectivity with the developed world was seen as necessary in order to access capital and production technology, and transition away from such harmful industries.

India retained a status as a relatively closed economy until as recently as the early 2000's, whilst maintaining a high rate of economic growth and resulting environmental effluents. These qualities offer a unique case for the study of relationships between environment and trade. Up until the mid 1990's its economy was in the early stages of industrialization with agricultural products occupying 23.35% of total economic activity. After 1995, manufacturing increased to more than a third of total economic output as sectoral primaries became less proportionally significant (World Input-Output Database 1995). As a result of its 1991 bargain with the International Monetary Fund (IMF), its tariff rates were dramatically reduced over the next decade from an economy wide average of 128% in the 1990/91 period to 40% in 1995/96, and then to 34% a few years later. This tariff reduction occurred systematically across all consumption, intermediate and investment sectors with little proportional difference between sectors. Over the same period India experienced a sharp increase in annual growth from 5.5% in 1992 to a post-crisis peak of 7.5% in 1996, much of it a result of the simultaneous increase in both exportation and importation, which contributed to India's output. Over the same period its air effluent production increased at a similarly significant rate. Total carbon emissions increased by an average of 4% p.a. post 1995, from a per-capita average of 0.8 tonnes in 1990 to 1.2 tonnes in 2005, to as much as 1.6 tons in 2010.

The current empirical framework surrounding the environmental effects of international trade was pioneered in the work of Grossman & Krueger with their 1993 contribution examining the effects of the North America Free-Trade Agreement (NAFTA). Their approach differentiated between environmental effects as a result of increased growth, changing sectoral composition and technological effects, and found that empirically each individual effect often acted independently of each other. As a result it became more plausible that increased trade activity could actually improve environmental outcomes, that increased carbon output from higher production could potentially be offset by an increased sectoral presence in cleaner industries and less harmful production processes. Further empirical approaches such as Krueger (1995), Dean (1995) & Bussolo (1998) which analysed developing countries such as Costa Rica and Mexico found extremely variable outcomes, as the unique comparative advantages in each country resulted in shifts towards industries with varying pollution outcomes. In the vast majority of cases regarding developing countries, the net carbon impact is determined by whether the sectoral changes and improved production technology can overcome the increased emissions from the shift from agricultural based products to manufacturing. Going into the 21st century, further empirical research began to focus on the effect in transitioning countries, with equally variable results. Gale and Lewis(Gale IV, Lewis R 1995), using an input-output model not unlike general equilibrium used in this thesis, found that Mexico's comparative advantage in cleaner than average industries would help offset the growth carbon impact from the effects of the NAFTA, in contrast to Krueger's findings (Krueger 1995). Using an alternative approach Roland and others (Roland, Beghin & Mensbrugge 1990) calculated that by measuring emissions using inputs rather than outputs, the technological improvements resulted in a net-overall reduction in emissions in spite of an increase in overall emission-relevant output.

Due to a previous lack of relevant economic and environmental data, few papers have used India as a test subject for modelling the environment-trade relationship. The one key contribution from Jha et al (Jha, Gamper-Rabindran 2005), forgoes comprehensive macroeconomic modelling in favour of a Heckman two-step regression approach. Separating data both pre- and post-1991 (the starting point of India's mass tariff reduction process), they measure the change in composition and quantity of India's exports, imports and foreign direct investment, as well as a subsequent estimation of the carbon intensity of the entire economy. They find a significant impact on both the amount and intensity of carbon-producing activities via changes in trade activity. Given that their model only assumes a linear impact on trade given macroeconomic and autoregressive factors, we cannot use it to account for specific impacts on the production patterns that would permit a more precise environmental impact estimate. The contribution of our study will be to thus determine how firms domestically and abroad react to a change in trade regulation in terms of the types and quantities of each input.

In this thesis we employ a variation of static general equilibrium modelling in order to estimate the quantitative increase in specific environmental effluents as a result of trade liberalization. These were largely in the form of a reduction in import tariffs not unlike those employed in the post-1991 India reforms. This particular form of macroeconomic modelling is used to capture the effects of specific policy changes in the form of exogenous changes on various economic agents. The interconnectedness between different sections of the model means that the calculated effects of a policy change are more complete than even an equivalently complex regression model. As a primer, it is simultaneously and predominantly used to analyze the effects of major free trade agreements such as NAFTA, as well as governmental policy targeting various environmental externalities. Within it we test several tariff simulations: the first one analyses the exact tariff reductions that took place the first year of data availability (1995). We then also run the model at each incremental 10% reduction in all tariff levels towards zero tariffs. Finally we test the simultaneous effect of trade liberalization, and a form of environmental policy mitigating the potential cost. The latter takes the form of taxation which is proportional to the amount of carbon-intensive intermediate product usage for each production plan. In the first case we find that even in the case of an matching reduction in foreign tariff rates, the resultant production pattern results in an increased proportion of inputs dedicated to foreign components and a subsequent shifting of carbon-intensive activity towards foreign economies. A simultaneous shift towards less intensive industries means that trade liberalization results in less overall carbon emissions in both scale and composite terms. In order to quantify the disaggregated effects of scale, composition and technology, we use a variation of Laspeyres's Index (Yang

2001). Yang's methodology uses a linear approximation of the actual changes in emissions as a sum of each three separate effects. In addition, given the lack of a pre-built model, we calibrate our own Social Accounting Matrix (SAM) for the Indian setting in 1995 to provide the necessary exogenous inputs.

Our results aim to build upon the sole contribution to date on how India's rapid integration process has contributed to parallel changes in environmental externalities. Our General Equilibrium modelling should provide a better framework for understanding how tariff reduction alters a firm's optimal production process in each sector, and in turn how it affects corresponding carbon activity. The latter result means it is paramount that our methodology differentiates between each sector's activity. This is also one of the strengths of an Applied General Equilibrium approach. By analysing the specific movements in India's sectoral output and carbon productivity we can estimate its theoretical position on the Environmental Kuznet's curve; if the effects from an improved carbon factor outweigh the negative carbon impacts from increased economic activity, then we can theorize that in 1995 India was at a stage where increased openness could potentially improve environmental outcomes. We can also make a rough estimation of India's comparative advantages and disadvantages at that time by comparing the share of production performed domestically across all sectors.

Initial results show that India's nominal domestic production falls in the majority of sectors even as overall final output increases across the board. Increases of 3.5% in the share of production by foreign economies of the total outputs is associated with the first policy change of a tariff reduction of around 30%. The sectoral proportions also change: as primaries and the majority of selected dirty industries decrease in domestic output, the remaining manufacturing and tertiary sectors increase. The environmental implications mean that there is a shift in carbon related activity from India's economy towards foreign production as well as a shift away from more carbon intensive industries towards cleaner manufacturing and services. Both trends result in a net negative emissions impact. The limitations of our model however, means that we cannot assume that a significant change in carbon productivity is the result of the policy change. The end result nevertheless is an overall reduction in carbon output. When simulating this result across incremental tariff level reductions down towards zero, all of the aforementioned trends in production change at a somewhat exponential rate. Domestic and final output and trade activity increase at a somewhat accelerated rate after tariffs are reduced below 50% of their original amount. We also find evidence of a U-turn in emissions where between a 80% to 90% reduction in tariff rates; as India experiences a net gain in carbon output, domestic production begins to increase in sectors with a lesser comparative disadvantage.

3
Policy Background

3.1 Trade Reforms

Before the initial process of trade liberalization in the 1980's, India's government largely relied on import substitution as it provided the infrastructure and capital needed to develop its industries in the face of foreign competition. It was not until the early 1980's, after a period of stagnant economic growth at around 3% per annum, there was a change in philosophy as to how to address external goods provision. The first steps taken were primarily to replace trade quotas with specified levels of tariffs and to ease import restrictions in the form of product licensing and canalization. These reforms however did not bring India towards adopting similar trade policies with countries at a similar level of development. At the beginning of the 1990's the average tariff level remained high at an ad valorem rate around 90%.

One of the major effects of this reform, however, was the massive rise in macroeconomic imbalances. This was seen in both the fiscal and balance-of-payments deficit, which made the country much more vulnerable to economic and political shocks such the first Gulf War in 1991 and subsequent oil shocks. The government thus arranged a stabilization plan with the IMF which compensated for much of the economic deficit. However, this was conditional on India reforming much of its regulation and taxation on foreign trade and investment. This wave of policy changes began in 1992, which reduced the share of products subject to quotas from 87% in 1987-88 to 45% in 1994-95. Average tariff levels fell from 80% in 1990 to 39% in 1996 (Figure 3.1). This trend was universal across the main primary sectors: agriculture and mining, and across consumer, intermediate and capital goods. The ratio of total trade in manufacturing to GDP rose from 13% in the 1980s to 20% in 2000. Export and import volumes also increased sharply from the early 1990's with a growth rate far outpacing the actual GDP rate. From a base year of 1980, exports more than doubled by 1990, and increased by more than seven times their original amount after 2000, whilst total imports took a similar growth path to over six times their original amount by 2002. Both of these trends developed alongside a background of real GDP tripling over the same period (Figure 3.2).

Even as tariff reduction slowed at the start of the 21st century, trade activity still grew at a rate that either matched or exceeded the rate of economic growth. Both averaged a year-on-year growth average of 14% for the next half-decade (WIOD-India Input-Output Table-1995). Only the composition of exports reflected changes in India's specialization, with increased trade in services at the expense of agriculture and manufacturing, whilst import composition remained unchanged. The former trend largely followed a corresponding change in the composition of India's economy, with Services increasing from 41.8% to 51.7% (of total activity) over the same period. In contrast, India's import activity had largely remained with the same partners across the turn of the century; UK, Germany, US and Hong Kong. Thus the sectoral composition of import activity remained largely static. Given that India's carbon activity is largely concentrated in its dirtier industries such as chemicals and petroleum, and to a lesser extent its agriculture, initial empirical evidence suggests a higher carbon impact due to sectoral changes via tariff reduction post-1995.

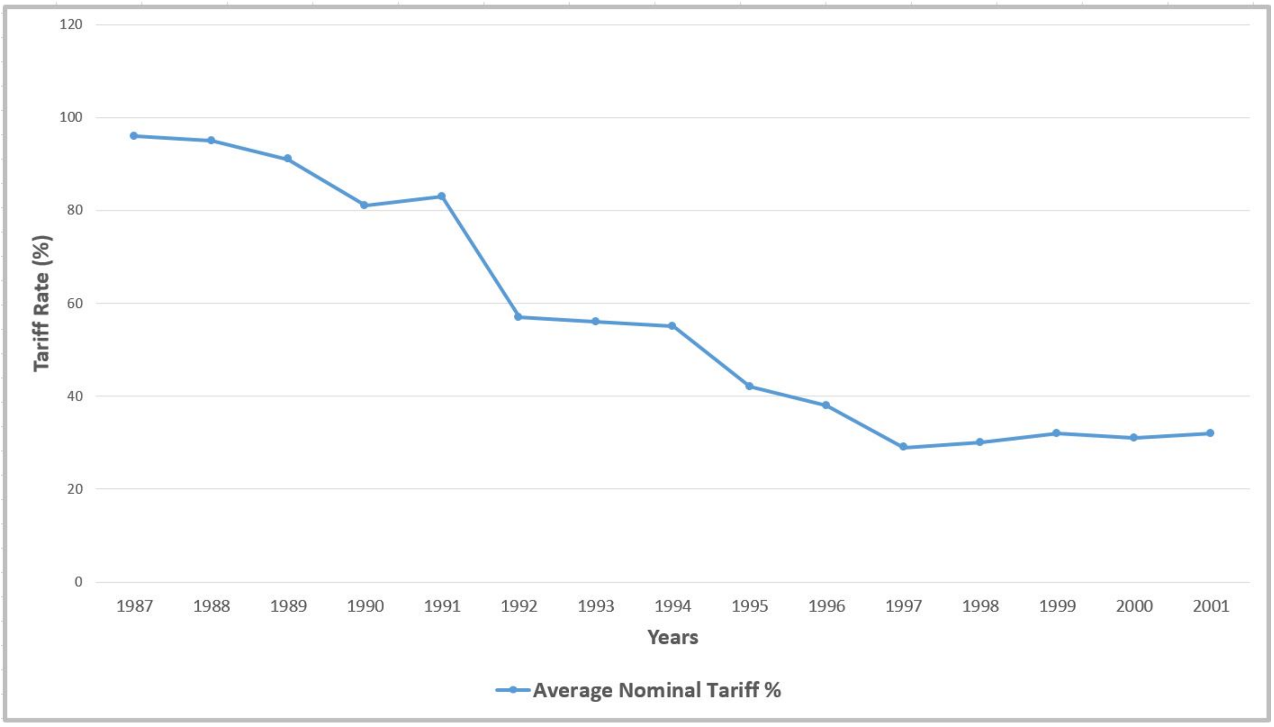

Fig. 3.1: **Average Nominal Tariff Rate (%) India 1987-2001**

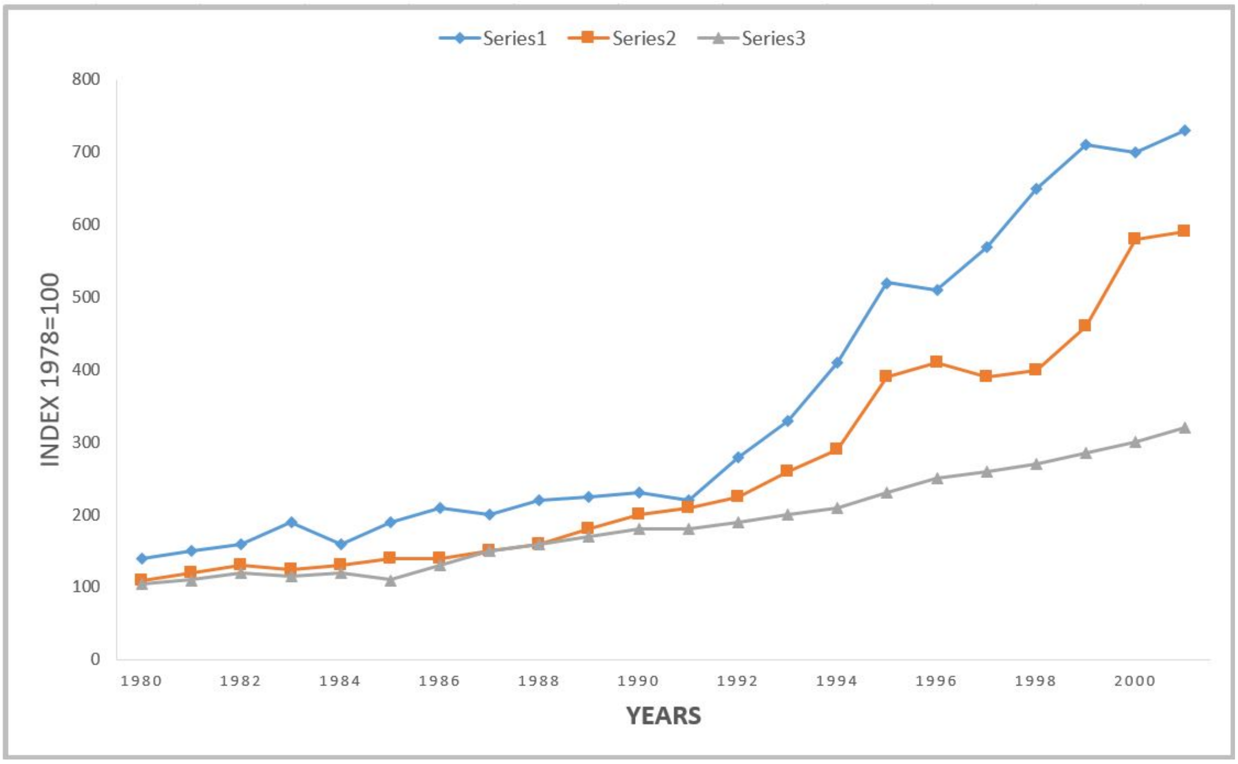

Fig. 3.2: **Growth Rates and Trade Activity India 1980-2001**

3.2 Indian Environmental Policy

India possessed minimal national environmental policy in the 1990's both before and after widespread trade liberalization. Whatever potential for minimizing environmental harm was often extremely hampered by bureaucratic conflict. Prior to the trade liberalization of 1991 the main mechanisms of regulation were the Central Pollution Control Board and the State Pollution Control Board, which were mainly responsible for data collection and policy enforcement. The turning point began with the Bhopal Disaster of 1984, which triggered a large scale re-evaluation of the environmental regulation system in the face of intense of public pressure. This eventually led to the enactment of two air pollution policies: the Supreme Court Action Plans (1995) and the mandatory requirement for catalytic converters. The former is a broad collection of policies aimed at stemming air pollution levels in areas considered critically polluted. These generally included infrastructure projects aimed at shifting environmentally harmful activity away from these areas, as well as regulatory controls on certain fuels. The second was a mandatory extra regulation for motor vehicle usage in order to reduce their toxic outputs. The main water pollution policy was the National River Conservation Plan, which sought to reduce the spread of water effluents and acidity in the main Ganga river area through a sewage treatment plan.

The overall effect of these policies was minimal, with changes in emissions activity still largely the result of changes in economic activity. Overall output somewhat outpaced growth in carbon emissions during the 1995-2009 period. This was as a result of agricultural sectors experiencing similar growth in both areas, whilst both Indian manufacturing and services experienced significantly more growth in output than in carbon emissions. This trend was almost identical for other non-carbon effluents such as sulfur oxides, nitro oxides and methane, despite being produced in significantly lesser quantities (WIOD Environmental Accounts-India 1995).

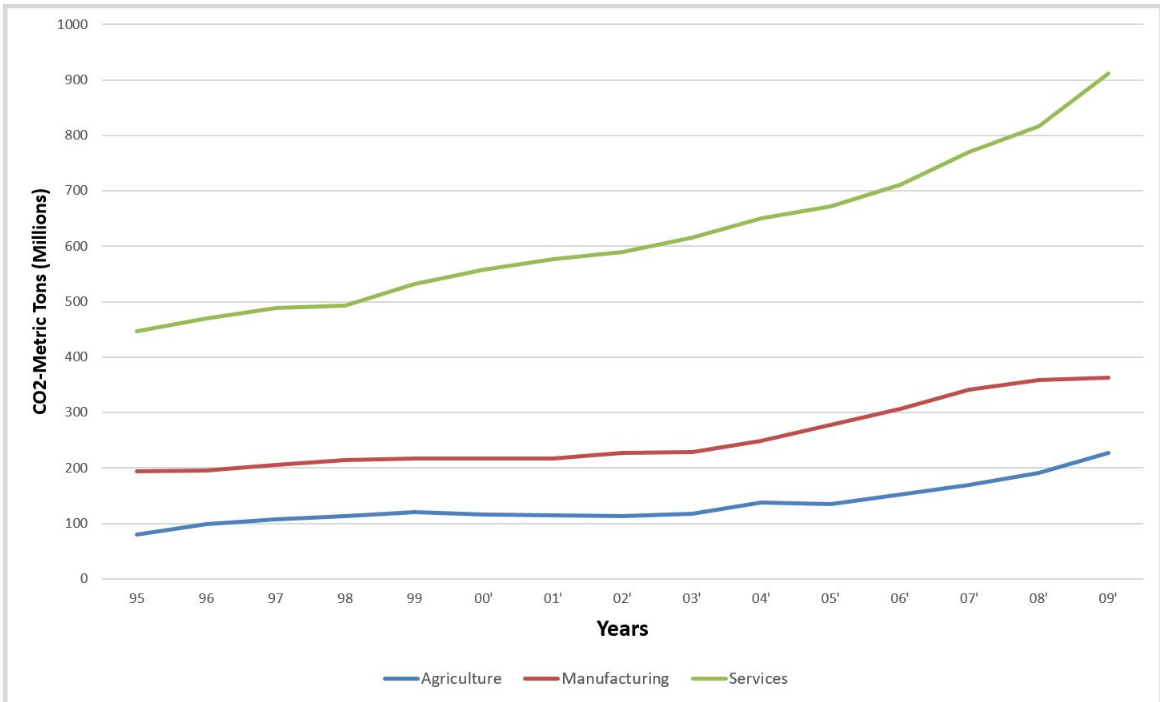

Fig. 3.3: **Carbon Emissions by Sector India 1995-2009**

4
Literature Review

4.1 Applied General Equilibrium Models

The Applied General Equilibrium (AGE) model in its static form is primarily used to evaluate the effects of economic policy on a macroeconomic scale via emphasizing the interactions between its various sectors and agents. Its theoretical foundation lies with several separate strands of research that eventually cumulated into a framework for equilibrium analysis. The first contribution was the work of Leontief (1936) which was an empirical study in Input-Output analysis. In this work, the interactions between different sectors of the economy are the primary endogenous mechanisms for how an Applied General Equilibrium reaches its equilibrium. His techniques were subsequently combined with linear programming models during the early 50's, which would eventually help develop AGE methods. The second strand was the discovery of the Walrasian General Equilibrium by Arrow & Debreu (1954). This provided an abstract representation of the macroeconomy that would eventually be combined with empirical data. Finally, Arrow & Debreu's work was developed into simple 2-sector general equilibrium models that were predominantly used to evaluate the effects of international trade such as by Samuleson (1948) & Meade (1955). The first numerical application came with Johanson (1960) who specified the utility/profit maximizing behaviour of various agents that previous models lacked. This was used to analyze the causes of Norway's economic growth. Our particular specification by Shoven & Walley (1972) involves fixed proportion requirements of intermediate goods, and Cobb-Douglas productivity for primary factor usage. This specification remains the primary simplified form for a general equilibrium model for the purpose of evaluating a static policy change. The Johanson model provided the foundations for the ORANI models of the 1970's which particularly focussed on the employment and welfare effects of international trade on disadvantaged sectors. The AGE studies of Taylor (1983) and Adelman & Robinson (1978) analyzed the redistributional effects of macroeconomic policy changes in developing countries.

Like any model, the AGE is an abstract representation of an economy with various conceptual agents: households, firms and government. These conduct transactions based on their real-world counterparts. It is flexible enough to allow for different sets of assumptions regarding these agents, including returns to scale, elasticities of substitution between factors and aggregation of domestic and foreign components. Given their ability to differentiate economic activity and effects between sectors, AGE models are increasingly useful for investigation such as in our study where carbon factors are extremely different between different settings. The innate complexity in which exogenous changes affect each sector's production pattern and consumption means it has been historically more useful at analysing policy changes than regression techniques. Regression techniques typically only consider a few relevant macroeconomic variables in a linear relationship. The strength of general equilibrium modelling is its capacity to elucidate the relationships by which exogenous changes affect various economic agents rather than their forecasting ability. Regression models have traditionally had mixed results depending on the specific assumptions they make.

In an environmental context (in which it is more usually referred to as a 'Computable General Equilibrium' (CGE), the abstract foundation places greater emphasis on the environment as an economic factor and the effects of its usage from economic agents. In the event of unpriced natural resources, consumption by both firms and households results in diminished ecological functioning. This in turn affects its marginal productivity as an input within relevant sectors. This is a classic case of negative externalities for which the private and social costs of economic activity diverge. The vast majority of CGE studies attempt to quantify the effect on environmental quality from either natural endogenous processes or governmental attempts to improve it through defined policies. The three archetypal research areas for CGE models are the impact of endogenous economic growth on externalities and other unpriced natural capital, the impact of policies designed to alleviate such social costs, and the impact of an exogenous change in environmental quality on the equilibrium status of an economy. Given our topic of trade liberalization, this paper falls into the second category (despite trade liberalization not being a strictly environmental policy). There are however some methodological differences between the two specifications: AGE models work through an Arrow-Debreu style equilibrium which formulates a price/demand vector in order to satisfy an Arrow-Debreu equilibrium given various sector data. In contrast, CGE models balance several macroeconomic equations as simultaneous results. We refer to our model as an AGE given that it largely follows the former process.

4.2 Theoretical and Empirical Approaches

Prior to Grossman and Krueger's influential 1993 contribution, most research on trade and environment only considered the externalities of international trade in the context of equivalent domestically produced market failures. Namely, the harmful externalities that result from international trade were seen as a market imperfections to be treated with the same solutions as in a domestic scenario. An example is Pigouvian taxation and other market oriented actions to bring the level of effluents to a socially optimal level. Contributions from Siebert (Siebert 1977) and from Baumol and Oates (Baumol & Oates 1989) suggested that without the presence of some environmental central planner such as the Environmental Protection Agency, international trade would produce a suboptimal scenario, resulting in the likely production of environmental externalities. The models proposed by these authors, which typically involve homogenous goods, constant returns to scale and two countries with comparative (dis)advantages in clean and dirty goods respectively, suggest a combined solution of low barriers to trade and market-based environmental regulation. Without the latter the gains from international trade would likely be offset by environmental damages, which is stated as a loss of household welfare under normal preferences.

Other theoretical models from around the same period also build upon traditional models of international trade; that patterns of trade are determined by either differences in technology/productivity (Ricardian Model) or factor endowments (Heckscher Ohlin). Due to increasing elasticities of substitution, international trade results in a net increase in environmental effluents. This is because as one country ends up specializing in dirty goods, the net overall production for both types increases. Most of these studies also reach identical conclusions about the necessity of environmental regulation. They conclude that without some form of market regulation and openness to international trade, increased negative externalities will result in countries with a comparative advantage in dirty goods. Baumol and Oates (Baumol & Oates 1988) used a typical model of international trade with homogenous goods in two countries with respective comparative (dis)advantages in dirty or clean goods. They found that environmental central planners such as the Environmental Protection Agency can mitigate a country's relative advantage in polluting goods and/or disadvantage in cleaner goods by way of market oriented actions.

Grossman and Krueger's 1993 Mexico study separated the income effects of trade liberalization, and found that compositional and technological effects were instrumental in setting up much of the uncertainty in the trade-environment link post-NAFTA. The theoretical framework analyzing the latters effect on Mexico meant that the environmental impact of globalization depended far more on a country's current stage of economic development. This was in comparison to previous theoretical constructs which only differentiated countries via comparative advantage. Widely accepted macroeconomic thinking on international trade suggests that it should lead to a universal increase in per-capita income. This in turn should increase demand for environmentally harmful capital, creating a cycle of suboptimal economic growth. Eventually this would be offset by advances in technological capital, leading to reduced effluents per output, as reduction in trade barriers would lead to an increased flow of capital as much as the consumption of goods. The combination of these two phenomena would eventually lead to the formation of the Kuznet's curve. This states that a country's environmental externalities will initially increase with income per capita as an economy transitions from agriculture to secondary industries. However, this effect should eventually reverse following technological improvements due to globalization.

Grossman & Krueger's initial finding cast doubt on the mainstream view at the time, being that trade liberalization was consistently environmentally harmful. It was found that the technological changes from trade could potentially outweigh the increased emissions due to increased economic activity. The majority of studies following Grossman & Krueger attempted to emulate the exact shape of the yield curve, attempting to determine the point in per capita income when the impact of trade liberalization begins to positively impact on the environment. In most cases, determining the net environmental impact of trade liberalization typically hinges on how effective increased openness to trade is in producing progressive technological change within countries. This would effectively counteract consistent increases in environmentally harmful economic activity, as well as determine whether its comparative advantage favoured "cleaner" goods. Following the mass reduction of tariffs driven by the World Trade Organisation expansion of the 1990's, many empirical papers found that scale effects were by far the most consistent of the three individual impacts, and international trade was universally considered to have resulted in an increase in economic activity along with a similar proportional increase in emission. Technique effects were only significant once a country progressed beyond the main stages of industrialisation, whilst composite effects were mostly independent of a country's developmental stage and extremely variable.

General Equilibrium in both AGE and CGE variations were increasingly used to calculate the effects of trade liberalization along with the simultaneous increase in tariff reduction in the early 1990's. The sectoral framework meant that they were useful in comparing gains and losses across different sectors and parties; a politically controversial topic for the time. Originally the environmental impacts of free trade were largely measured using production quantities as a linear proxy for emissions (Ugelow 1982) using a corresponding exogenous carbon factor. The use of the alternative CGE model, used by contributions such as Lopez (1994) & Mcguire (1982) instead calibrated the environment as a factor directly. As a result comparative advantages occur due to differences in endowments or productivity relating to natural capital. Yang (2001), calibrated fossil fuel usage by sector using Constant Elasticity of Scale production parameters and a comparative shift towards chemicals, metals and other effluent intensive production. This effect was ultimately more significant than a weak technological progression. Dessus and Bussolo (1998) applied a similar model to Costa Rica of the base year 1988, finding that without the impact of environmental regulation, the increased economic activity from open trade would result in greater environmental effluents. It should also be noted that contributions which advocate environmental policy to counteract the effects of environmental harm emphasize the need to co-ordinate its design so that it is consistent with the specific economic cause of the externality. For example, emissions increases due to compositional change rather than income growth are better addressed by policies which target such sectors as opposed to universal emission taxation.

Post Krueger, theoretical models often reached conclusions at odds with simultaneously conducted empirical studies. One of the most common models used was the North-South model of trade, pioneered by Copeland & Taylor (1994). This expanded upon the basic Heckscher-Ohlin model of comparative advantage via endowments by framing the environment as a factor in itself of production, with its own value and productivity. The asymmetries between the two sample countries in terms of capital endowments and absorbative capacities of externalities means that the environment as a factor is relatively devalued in one country (the "South"). This in turn induces a relative difference in the pricing of the environment. The South then produces less environmental regulation than the North, and accordingly suffers from the many market imperfections of ill-defined property rights. This results in a welfare advantage for the North. Theoretical works such as this motivated more empirical investigations into the so called "Pollution Haven Hypothesis" (PHH). This proposed that global competitiveness in dirty goods would lead to worldwide reduction in environmental regulation as a country's firms end up disadvantaged internationally. Further research confirmed that while environmental regulation indeed has a negative impact on dirty firms' productivity, its overall effect is relatively minimal compared to alternative factors (e.g. factor productivity, domestic competitiveness). That is, the main tenets of the PHH did not in fact come to pass.

India has remained relatively under-researched as to how its post-1991 trade reforms have impacted on its environmental quality. As noted the one key contribution (Jha, Gamper-Rabindran 2005) uses a two-stage regression model of sectoral and emissions output. Their paper tests three hypotheses about the effect of trade liberalization on domestic effluents output in both air and water form and about the change in the composition of exports and Foreign Direct Investment (FDI). Using linear regression of sector output over a period of time as a fraction of value added against labour and capital productivity and pollution output, they found that trade liberalization results in a significant environmental impact across all three criteria. There is a shift in exports and FDI towards sectors that are more effluent intensive, and increased carbon factors across all sectors. In order to extend these findings, our methodology analyzes the combined impact of overall economic output and sectoral change, as well as offering the advantages of using general equilibrium modelling over linear regression.

4.3 Laspeyres Index

Energy decomposition analysis is a mixture of methods used to isolate the individual causes of energy usage. The main applications actually extend into energy demand and supply, material flows, energy efficiency monitoring and cross-country comparisons, although its primary purpose is within the first category. Originally developed in the 1970's to study the emissions impact of structural change, this type of analysis takes empirical inputs regarding the energy usage across the economy to differentiate between income and sectoral effects. Most of the formulae used are simple and intuitive involving relatively fewer algebrae than most economic models. The Laspeyres additive decomposition has been one of the most common methods used over the last decade in part due to its simplicity. In its most basic form it differentiates energy use and intensity between sectors, and aggregates the two variables across all the sectors.

$$S_{i,t} = \frac{Y_{i,t}}{Y_t} = \text{Production share of sector } i$$
$$I_{i,t} = \frac{E_{i,t}}{Y_{i,t}} = \text{Energy share of sector } i$$
$$I_t = \sum_i S_{i,t} I_{i,t} = \text{Aggregate Energy Intensity}$$

The actual decomposition comes from splitting the total change in emissions into a sum of three individual effects: the effect from changes in overall activity, the effect from changing sectoral propotions and the effect from changing emissions intensity. This is a perfect analogy for the aforementioned scale, composite and technique effects detailed in Grossman and Krueger (1993) that have dominated the empirical literature since.

$$A_t = \text{Total Activity}$$
$$S_{i,t} = \text{Sector } i \text{ Proportion of Total Activity}$$
$$I_{i,t} = \text{Energy Intensity of sector } i$$
$$\Delta E = E_t - E_{t-1} = \Delta A + \Delta S + \Delta I + \epsilon$$

5
Methodology

5.1 Overview

In this empirical study we use a variation of macroeconomic equilibrium modelling known as the Applied General Equilibrium model in a static form. It provides a more sophisticated analysis than the regression based approach such as used by Jha et al (Jha, Gamper-Rabindran 2004) to analyse the environmental impact of India's tariff reduction policies. The calibration process largely follows the process specified by Kehoe (Kehoe 1994) while also taking account of the analytical approach used by Yang (Yang 2001). In order to quantify the economic, and thus environmental, impacts of India's trade reform we disaggregate the available sectoral data into seven sectors. These are selected on the basis of their respective environmental impact and the nature of tariff reduction. Each agent in our model economy is classified in accordance with their respective role: households which derive welfare from consumption of various goods, firms which gain from the sale and produce of goods and services for various purposes both domestically and overseas, and the government sector with its own specific welfare agenda. The static nature of the model means a competitive equilibrium is derived at a fixed temporal point and only adjusts in response to an exogenous alteration.

5.2 Households

We assume that all households derive utility from consumption in exactly the same ways; we can thus use a representative household in order to calibrate the behaviour of all households. The utility function specified is of a Cobb-Douglas form:

$$\begin{array}{c} \max_{c_i} \sum_i \theta_i \ln c_i + \theta_{inv} \ln c_i nv \\ \text{s.t. } \sum_i p_{c,i} c_i + p_{inv} c_{inv} = (1-\tau_d)(\bar{w}\bar{l} + \bar{r}\bar{k}) \end{array}$$

where households derive utility from a weighted average of each good, with diminishing returns in accordance with a logarithmic utility function. Each good is specified as either consumption goods c_i which are used purely for the final consumption by households, and domestic investment goods c_{inv} which are the primary form of household saving in our model. The respective prices for each good: where $p_{c,i}$ equals the domestic price of consumption good i and p_{inv} equals the domestic price of the representative investment good are endogenously derived through the formation of an equilibrium. The quantity of consumption is restricted via the amount of disposable income available. Given the primary factors labour and capital, $\bar{l}$ and $\bar{k}$, and their respective compensation rates, wage and rental: w & r, the market value of consumption cannot exceed the total value of factor compensation times the disposable income rate: $1 - \tau_d$. Given that our Social Accounting Matrix displays a trade deficit, there is no need for the inclusion of a foreign investment good in order to maintain a balanced trade account.

5.3 Government

In our model the government sector gains utility in a similar fashion to domestic households; it gains utility from consumption of both final consumption and investment goods, albeit with different preferences. Given the net negative revenues, the specification of a fiscal deficit in our SAM means that the inclusion of investment goods in our model is interpreted as a borrowing of financial capital. The government derives income from both direct and indirect taxation, the latter of which is separated into tariff and non-tariff revenue. The utility function is also of a similar Cobb-Douglas specification:

$$\begin{gathered}\max_{c_i^g} \sum_i \theta_i^g \ln {c_i}^g + {\theta_{inv}}^g \ln {c_{inv}}^g \\ \text{s.t. } \sum_i p_i c_i^g + p_{inv} c_{inv}^g = \tau_d(\bar{w}\bar{l} + \bar{r}\bar{k}) \\ + \sum_i T_{c,i} + \sum_f \sum_i \tau_{i,f} e_f p_{i,f} y_{i,f}\end{gathered}$$

The government utility equals a weighted average of the consumption of final goods c_i^g and investment goods c_{inv}^g in accordance with its own preferences. The government budget constraint means that value of its total consumption basket cannot exceed the sum of its three revenue sources: income taxation, indirect taxation by sector and tariffs on imports. These are the first, second and third terms of the budget constraint respectively.

5.4 Welfare Index

Whilst utility maximization determines the exact consumption patterns of both households and government, we use a nominal index to determine how much well off each party will be within each simulation. Since welfare is a more abstract concept than most economic measures, the results are measured using an index based on income in lieu of any natural units of measurement. We use an index based on consumption across all sectors i for both households c_j and government $c_{g,j}$, such that the social welfare index is an aggregation of the two separate indexes. The intuition behind this index is known as equivalence variation, which calculates the additional income required to achieve the same level of utility when purchasing in the benchmark simulation.

$$\text{Consumer Welfare Index} = \prod_j {c_j}^{\theta_j} \text{ where } \theta_j = \frac{c_j}{\sum_j c_j}$$
$$\text{Government Welfare Index} = \prod_j {c_{g,j}}^{\theta_{g,j}} \text{ where } \theta_{g,j} = \frac{c_{g,j}}{\sum_j c_{g,j}}$$
$$\text{Social Welfare Index} = \prod_j {c_j}^{\theta_j} + {c_{g,j}}^{\theta_{g,j}}$$

5.5 Domestic Production

The production of final goods involves the input of primary factors: labour and capital, various intermediate goods which are produced by each sector, as well as specific foreign components. The domestic component involves the input of the first two factors and the intermediate produce, which are eventually combined with the respective foreign component to produce the final good. Within the former, the marginal value of both primary factors is calibrated in accordance with a Cobb-Douglas production function, meaning there exists constant returns to scale for each factor. The inclusion of intermediate inputs is done in accordance with fixed proportions, that is, the ratio of each intermediate good used per final good production remains identical regardless of the quantity of production. This means there must exist a minimum proportion of each intermediate good in order to produce a certain positive quantity of the domestic component:

$$(\hat{y},_{j,d}\,, \hat{x}_{i,j}, \hat{l}_j, \hat{k}_j) \text{ satisfy:}$$
$$\hat{y}_{j,d} = \max[\hat{x}_{1,j}/a_{1,j}, ..., \hat{x}_{i,j}/a_{i,j}, \beta_j \hat{k}_j^{\alpha_j} \hat{l}_j^{1-\alpha_j}]$$
$$\hat{p}_{j,d}\hat{y}_{j,d} - \textstyle\sum_i \hat{p}_i \hat{x}_{i,j} - \hat{r}\hat{k}_j - \hat{w}\hat{l}_j = 0$$
$$\hat{l}_j, \hat{k}_j \geq 0$$

The quantity of domestic component production $\hat{y}_{j,d}$ for each sector j is determined by a maximum utilization of both primary factors in accordance with its production weights α_j and technological parameter β_j as long as there remains an appropiate proportion of intermediate goods available given a select quantity of production. The unit requirement of intermediate good $\hat{x}_{i,j}$ for the production of component

$\hat{y}_{j,d}$ equals $a_{i,j}$, and the fixed proportions requirement means that in order to utilize the maximum value of the primary factors, these ratios must be equal across all the relevant sectors. The quantity produced is calibrated in accordance with zero economic profit for all sector/firms, a condition for a competitive equilibrium to exist in a static equilibrium. The firm's criteria for production is defined as the market value of final production $\hat{p}_{j,d}\hat{y}_{j,d}$ subtracting the market value of all relevant intermediate goods used $\sum_i \hat{p}_i\hat{x}_{i,j}$ as well as the total factor compensation given $\hat{r}\hat{k}_j - \hat{w}\hat{l}_j$. The quantities for production and factor usage are calibrated such that the profit generated equals zero, else the shifting of production from differing sectors from firms to take advantage of the differing profit levels.

In addition, the quantities of primary factor usage must satisfy cost minimization given their compensation rates: $\hat{w}, \hat{r}$ given that all available factors must be utilized, even if there remains insufficient intermediate goods to satisfy the maximum potential production of the corresponding Cobb-Douglas:

$$\begin{gathered}\min \hat{r}k_j + \hat{w}l_j \\ \text{s.t. } \beta_j k_{j_j}^{\alpha} l_{j_j}^{1-\alpha} = \hat{y}_{j,d} \\ k_j, l_j \geq 0\end{gathered}$$

The identical principle applies for the production of investment goods, although it is not used as a component for final goods that are still produced under the same fixed proportions principle as their respective domestic components. Since investment goods do not utilize primary factors, only the intermediate good/unit-requirement ratios for each sector must be equal in order to utilize their maximum production potential, without the additional requirement of cost-minimization/total-usage of the primary factors. That is, given a calibrated amount of unit requirement $a_{i,inv}$ for sector 'i', there must exist a satisfactory ratio of intermediate goods $\hat{x}_{i,inv}$ to produce an amount of final investment goods $\hat{y}_{inv}$. In a competitive equilibrium the market value of these inputs must exactly equal the corresponding market value of the final investment goods.

$$\begin{gathered}(\hat{y}_{inv}, \hat{x}_{i,inv}) \text{ satisfy:} \\ \hat{y}_i = \min[\hat{x}_{i,inv}/a_{i,inv}] \\ \hat{p}_{inv}\hat{y}_{inv} - \hat{p}_i\hat{x}_{i,inv} = 0 \\ \forall i \in j\end{gathered}$$

5.6 Final Production

In this general equilibrium, the final goods produced are the product of a weighted combination of a domestically produced component, described in the aforementioned Cobb-Douglas, as a foreign component which is produced exogenously. The proportions are aggregated through an Armington specification:

$$y_i = \gamma_i[\delta_{i,d} y_{i,d}^{\rho_{m,i}} + \delta_{i,f} y_{i,f}^{\rho_{m,i}}]^{\frac{1}{\rho_{m,i}}}$$

where the elasticity of substitution between the domestic and foreign components equals $\sigma_{m,i} = \frac{1}{1-\rho_{m,i}}$ for sector i and $-1 < \sigma_{m,i} < 1$ between the domestic component $y_{i,d}$ and the foreign component $y_{i,f}$. There also exists a unique technological parameter δ_i for both components. The conditions of a competitive equilibrium also ensure that the quantitative allocation between domestic and foreign components ensures that the combined market value of the domestic and foreign components given their respective prices $\hat{p}_{j,d}$ and $\hat{p}_{j,f}$, an ad valorem tariff rate τ_j and an exchange rate for the unspecified foreign entity $\hat{e}$ equals the market value of the resultant final good.

$$\hat{y}_{,j}\ , \hat{y}_{,j,d}\ , \hat{y}_{,j,f} \text{ satisfy:}$$
$$\hat{p}_j \hat{y}_j - \hat{p}_{j,d}\hat{y}_{j,d} - (1+\tau_j)\hat{e}\bar{p}_{j,f}\hat{y}_{j,f} = 0$$

They also must satisfy a cost-minimization condition given a specified level of final output. Unlike the price of the final good $\hat{p}_j$ and the domestic good, the price of the foreign component is taken exogenously. The alteration of tariff rates on imported components will be the primary method of simulating policy experiments via trade liberalization.

$$\hat{y}_{,j,d}\ , \hat{y}_{,j,f} \text{ solve:}$$
$$\min \hat{p}_{j,d}\hat{y}_{j,d} + (1+\tau_j)\hat{e}\bar{p}_{j,f}\hat{y}_{j,f}$$
$$s.t. \gamma_j \hat{y}_{j,d}^{\gamma_j} \hat{y}_{j,f}^{1-\gamma_j} = \hat{y}_j$$
$$\hat{y}_{j,d}, \hat{y}_{j,f} \geq 0$$

5.7 Foreign Households

Foreign household behaviour is determined in much the same way as their domestic counterparts. They derive utility from the consumption of final goods either being produced within their own economic boundaries or being imported from the subject country (India). We also take each foreign household to possess identical preferences and thus can construct a representative household, which consumes goods from its own production entities $x_{f,f}$ and imports from India $x_{i,f}$ for each sector i, in accordance with its own preferences: $\theta_{i,f}$, and an elasticity of substitution between purchases and exports. The latter is calibrated from the same utility maximization principle as the domestic households, given a budget constraint where the total value of consumption can't exceed their respective income: I_f. In the presence of a domestic trade deficit/foreign trade surplus, we also include the purchases of investment goods: $x_{inv,f}$ to ensure the foreign balance between India and it equals zero.

$$\begin{gathered}\hat{x}_{i,f} \text{ solve:}\\ \max[\textstyle\sum_i \theta_{i,f} x_{i,f}^{\rho_x} + \theta_{inv,f} x_{inv,f}^{\rho_x} + \theta_{f,f} x_{f,f}^{\rho_x}]^{-\frac{1}{\rho_x}}\\ \text{s.t.} \textstyle\sum_i \hat{p}_i (1+\tau_{i,f}) x_{i,f} + p_{inv} x_{inv,f} + \hat{e}\hat{x}_{f,f} = \hat{e}_f I_f\\ x_{i,f}, x_{f,f} \geq 0\\ \textstyle\sum_j e_f \bar{p}_{j,f} y_{j,f} + \sum_j e_f \bar{p}_{inv,f} c_{inv,j} = \sum_j p_j x_{j,f} + p_{inv} x_{inv,f}\end{gathered}$$

5.8 Market Clearing Conditions

During calibration there also exists further market clearing conditions in order to ensure a static equilibrium exists within our framework. There are respectively:

The goods market must clear for all domestic goods $x_{i,j}$ as well as exports $x_{i,f}$:

$$\begin{gathered}\hat{y}_j = \textstyle\sum_i x_{i,j} + x_{inv,j} + c_i + c_i^g + x_{i,f}\\ \hat{y}_{inv} = c_{inv} + c_{inv}^g + x_{inv,f}\end{gathered}$$

All available factors must also be used in the production of the domestic components:

$$\begin{gathered}\textstyle\sum_j l_j = \bar{l}\\ \textstyle\sum_j k_j = \bar{k}\end{gathered}$$

5.9 Policy Simulations

Our initial policy experiment attempts to simulate the actual tariff reduction that took place from the 1994-95 measuring period across five years to the corresponding 1999-2000 point. The majority of this change occurs in 1995-96 with tariff rates reducing by a few percentage points for a few years afterwards. Using the WTO Trade Policy Review of India (both 1993 and 1998) versions, we universally reduce each domestic tariff rate by the ratio of rates between 1999/2000 and 1994/95 for intermediate goods, as well as foreign tariff rates by the same ratio regarding consumer goods. Our model specifies importation of foreign components for the produce of final goods and the exportation of the latter for the consumption of foreign households. Ordinarily we would simply insert the corresponding weighted averages of the 2000 level tariff rates from the WTO database, but data anomalies means that the 5 year change is actually an increase in regulation for some sectors, as our initial results should emphasize the effect of a roughly universal reduction across all sectors whilst tying into the actual policy changes that took place. This means that domestic tariff rates on imported foreign components are reduced by 30.2% and foreign tariff rates on exported final goods are reduced by 27.3%.

Following that we simulate the effects across 10% incremental reductions in domestic tariff levels whilst maintaining foreign tariffs at their original levels. This comprises ten additional policy experiments all the way down to a complete elimination of tariff levels. By aggregating the simulation results across each tariff level, we establish a rate of change amongst each economic variable, although with a particular focus on production patterns and inputs, as this will directly impact the models implied carbon output. The economy's rate of increased output will determine how quickly the scale effects of emissions increase along the same experiments. That is, whether it increases linearly with tariff reduction or it contains a slightly exponential and/or logarithmic trend as foreign components and exports become cheaper. The composite effects on the other hand may not maintain such a steady rate of change. Potentially more or less polluting sectors may reverse their original trends if their comparative advantage favours open trade. In that case we evaluate the tipping point both when composite effects begin to improve environmental quality, and when that begins to exceed the scale effects to the point where trade liberalization reduces carbon emissions.

5.10 Carbon Measurement and Laspeyres Index

While we can observe the general changes in overall economic production and the proportional shifts between sectors in terms of output and trade activity, a more precise mathematical index is required for a direct differentiation between the scale and composite environmental effects of trade liberalization. In general terms the Laspeyres Index takes exogenous data regarding the carbon factor for each sector and the level of economic activity both before and after the economic simulation, and then calculates the changes in carbon output of each sector as a product of the two values. The Laspeyres Index is additive, meaning the total carbon impact can be decomposed into the sum of the three individual emissions effects:

$$\Delta e_{Total} = \Delta e_{scale} + \Delta e_{composite} + \Delta e_{technique}$$

Initially we adapt the specifc formula used by Yang(2000) which uses data regarding each sectors energy use ($X_{f,i}$) from each individual emission relevant energy source/fossil fuel (f) and its respective carbon factor (ϕ_f).

f = energy source
X_i = output for sector 'i'
$X_{f,i}$ = energy usage from source 'f' for sector 'i'
ϕ_f = carbon factor for energy source 'f'

$$\Delta e_{scale} = \sum_f (\frac{\phi_f X^0_{f,i}}{X^0_i})(\frac{X^0_i}{\sum_i X^0_i})\Delta(\sum_i X_i)$$
$$\Delta e_{composite} = \sum_f (\frac{\phi_f X^0_{j,i}}{X^0_i})(\sum_i X^0_i)\Delta(\frac{X_i}{\sum_i X_i})$$
$$\Delta e_{technique} = X^0_i \sum_f \Delta(\frac{\phi_f X_{f,i}}{X_i})$$

As a total carbon change before and after the simulation for each sector equals the sum of the products of each energy source's carbon factor and the intermediate quantitative usage of each energy source:

$$e_i{}^0 = \text{baseline result } e_i{}^1 = \text{simulation result}$$
$$e_i{}^1 = \sum_f \phi_f X^1_{f,i} \text{ and } e_i{}^0 = \sum_f \phi_f X^0_{f,i}$$

Since the Laspeyres Index is an additive index, the total estimated carbon impact can simply be taken as the sum of each three individual effects:

$e_i{}^1 - e_i{}^0 = \Delta e_i = \Delta e_{scale} + \Delta e_{composite} + \Delta e_{technique} +$ residual

The income, component and technical effects are represented by the first, second and third terms respectively. The first term equals a sectors total emissions (across all energy sources) as a proportion of total output (across all sectors) times the change in total output, yielding the emissions effects of a change in overall activity. The second term equals the sectors overall emissions as a proportion of its specific output, times both overall output as well as the change in its proportion of output, equalling the impact due to comparative dis/advantages across countries. The third term equals a sectors output multiplied by the sum of all the changes in energy specific emissions as a proportion of sector output.

$e_i{}^1 - e_i{}^0 =$(Sector Carbon Factor)*(Sector Proportion)*(Δ Total Output) + (Sector Carbon Factor)*(Total Output)*(Δ Sector Output) + (Sector Output)*(Δ Sector Carbon Factor)

Note that the total emission impact before and after the simulation will not exactly equal the sum of the three components, thus it requires the use of a residual term analogous to its purpose in a linear regression model. Given the nature of the estimation index however, the sum of three terms should typically equal a value very close to the actual change in output (*residual* $\leq$ 5%*Model Impacts).

Our general equilibrium model however only includes two primary factors: labour and capital, along with intermediate inputs, as part of the production process. It does not like Yang(2001) or Bussolo(1998) include energy/electricity inputs themselves as another primary factor. The input values for each sector are calibrated via the same principles as the labour and capital supply, which in our case is Cobb-Douglas. Implicitly these values are included in the intermediate usage from the services aggregated sector given its inclusion of utility generation, but they cannot be differentiated from the usage of other tertiaries such as transportation or recreational services.

Therefore as a general tool for measuring the overall carbon impact of production we use intermediate demand for each sector as a substitute for measuring the carbon cost of production. This effectively means we attribute the production of domestic components rather than final production. This runs counter to other general equilibrium applications, however it is more accurate substitute for methods that directly calibrate energy usage, given that intermediate demand from the services sector includes electricity and utility usage. Additionally the merging of domestic and foreign components only adds a small portion of value and typically involves the merging of mechanical components that involves relatively little emissions. In order to estimate a carbon factor for each sector we use exogenous energy usage data for each sector (taken from the 1995 World Input Output Database Environmental Accounts) to observe the exact quantitative electricity input and the proportions as a result of each source (fossil fuels, renewables etc.). From this we can calculate an exogenous estimation of the carbon output of each sector. We then divide this value by the calibrated level of production to estimate a value for the carbon factor for each sector:

$$g = \text{energy source}$$
$$X_{g,i} = \text{energy usage by sector 'i' from source 'g'}$$
$$\phi_g = \text{carbon factor for energy source 'g'}$$

Carbon Factor for intermediate input 'i' $CF_i = \frac{\sum_g \phi_g X_{g,i}}{X_i^0}$

The carbon factor measured above is now inputed as ϕ_f in the original Laspeyres formula used by Yang(2001) where f now represents the index of intermediate inputs rather than energy sources. We then take the quantity of each intermediate input $X_{i,f}$ both before and after our simulated trade liberalization and its product with its respective carbon factor to measure carbon output as a result of production. These values are then combined with the changes in the quantities of domestic production for each sector to calculate exact carbon changes due to either scale or composite effects.

5.11 Effluents Taxation

In line with other environment-trade studies such as (Dessus-Bussolo 1998) we apply some form of ad-valorem taxation that raise the cost of production dependent on how much carbon it is responsible for; i.e. we have a separate tax rate for each sector, dependent on the carbon factors calculated from the previous Laspeyres Index method. Given a sectors respective carbon output per production we impose a rate of value-added production costs proportional to that exact carbon factor.

A sector generates carbon via the amount of intermediate inputs it uses per production process, and is thus proportional to the amount of domestic components produced. We calibrate the endogenous carbon factor (different from the exogenous carbon factor applied to each intermediate input in the later section) by taking a linear sum of the intermediate requirement $a_{i,j}$ times by its own exogenous carbon factor CF_i, which represents the amount of carbon as a result of one unit of production from sector j.

$$CF_j = \sum_i a_{i,j} * CF_i$$

We then apply a value-added taxation by effectively raising the price of the domestic component for each sector proportional to the afore calculated carbon factor, making it more expensive in terms of both overall production and the relative costs of producing domestic components versus foreign alternatives. The tax rate π_j raises the cost of producing good j by π_j times its carbon factor CF_j.

In accordance with previous environment-trade papers such as Dessus-Bussolo (1998) we compare production and emissions results between having trade liberalisation, having emissions taxation and having both simultaneously. These three results are then compared across both the initial policy experiment (which the reflects the actual reforms that took place). We also initially set our tax rate pi_j at 0.001(USD per Ton) but increase it out to 0.01 to observe at what rate the model results change across different levels.

$$(\hat{p}_{j,d} + \pi_j * CF_j)\hat{y}_{j,d} - \sum_i \hat{p}_i \hat{x}_{i,j} - \hat{r}\hat{k}_j - \hat{w}\hat{l}_j = 0$$

6
Data and Exogenous Inputs

6.1 Sectoral Disaggregation

In order minimize unnecessary complexity we limit our analysis to include only seven sectors, including four specific manufacturing sub-sectors and three aggregated primary, manufacturing and tertiary sectors. The four specific sectors are chosen based on a criterion relative to our topic of the environmental impact of trade. These include: the relative contribution of that sector to overall economic output, the relative contribution of that sector to overall carbon emissions, whether that sector's specific tariff alterations differed greatly from the rest of the manufacturing sub-sectors in both domestic and foreign laws, or whether its production pattern regarding factors and intermediates is unique amongst its peers.

The sectors which are disaggregated have the most potential to change their respective inputs and outputs to a greater extent than their aggregated peers and thus increase their environmental impact. Given India's tariff reduction process was largely uniform amongst all of its sectors, the primary criteria was the amount of emissions within that sector. The amount of non-carbon emissions such as methane and sulfur oxides is relatively miniscule in comparison, so only carbon dioxide was considered. The four disaggregated sectors are Chemical products, Petroleum products, Basic metal production and Non-metallic mineral products. We thus aggregate primaries, services and the remaining manufacturing sectors into the other three sectors (Table 6.1).

For selecting our sectors we use emissions and energy data from the WIOD, which

Tab. 6.1: **Sectoral Dissaggregation**

Primaries
Chemical Products
Petroleum Products
Basic Metals
Non-Metallic Mineral Products
Aggregated Manufacturing
Services

***Tab. 6.2:* Carbon Output SAM-Sectors India 1995**

Sector	CO2(KiloTons)
Primaries	80326
Chemical Products	39297
Petroleum Products	15259
Basic Metals	54825
Non-Metallic Mineral Products	56254
Aggregated Manufacturing	28016
Services	446849
Total	720826

***Tab. 6.3:* Trade Activity SAM-Sectors India 1995**

Sector	Exports(USD Millions)	Imports(USD Millions)
Primaries	6897	3666
Chemical Products	3294	2462
Petroleum Products	284	3418
Basic Metals	1391	2932
Non-Metallic Mineral Products	3612	1267
Aggregated Manufacturing	20980	8634
Services	5733	9538
Total	42191	31917

includes both carbon emissions and energy usage by source for each sector as well as tariff data from the WTO database, both from our baseline year of 1995. According to the former source our four selected sectors are the largest in terms of carbon output. Despite only comprising 41% of total manufacturing they are responsible for 85.5% of its aggregated carbon output. In particular Basic Metal production and Non-Metallic Mineral Products occupy 28.3% and 29% of manufacturing carbon output respectively. In terms of energy usage across all sources (coal, natural gas, fuel oil etc) these four sectors occupy just over half of total manufacturing energy input in terms of kilojoules. This indicates that while there is some disproportional increase of fossil fuel usage, the majority of the impact from these sectors' carbon arises from the way their specific production patterns generate effluents from their respective inputs; capital and intermediates, including energy. Services occupy the largest sector component of carbon output with just under 62% of economy wide emissions whilst primaries only occupy 11.14%, largely from agricultural products and mining (WIOD Environmental Accounts 1995)(Table 6.2). Given that tariffs do not apply normally to the former and were not reduced as much in the latter, together with its lower carbon output, we keep the two classifications aggregated.

6.2 Social Accounting Matrix

The Social Accounting Matrix (SAM) is required for the exogenous input for our general equilibrium model. At its core it is a rearrangement of exogenous macroeconomic data in order to make it feasible as an input for a general equilibrium model. The SAM details all of the economic transactions that take place in a given year including both the source and destination. The visual design of a SAM is so that rows represent the incomes of a particular agent whilst the columns represent the expenditures. Given the macroeconomic rule of each transaction having an equal part expenditure and income component, the corresponding totals of each row and column must equal.

The AGE model works such that parameters regarding demand to and from each sector, production patterns and trade activity are calibrated from the data that the SAM provides as well as optimality and market clearing conditions. For example the inter-sectoral transactions provide the necessary data as to the required intermediate inputs, and household consumption by sector indicates their respective preferences for goods in those corresponding areas. As such most of the model's parameters can be directly calibrated from the SAM inputs.

Given there is no readily pre-built SAM for India's economy, let alone one that applies to our specific sectoral aggregation, we must construct one using macroeconomic data from various data sources. The vast majority of the latter comes in the form of supply and use tables which detail both the origin and usage of goods and services for each sector. That is, the supply table describes the quantity of goods and services that are supplied to each sector from either other sectors or importation. In contrast, the use table describes how those supplies of goods are utilised across all sectors, whether they be intermediate inputs for other sectors or consumed as final products by either households or government agencies. The former source also includes information as to the amount of indirect taxation and commercial margins, information that is crucial to balance the values within the SAM. The supply and use information is then combined to form a table of total transactions to and from each sector in the form of intermediate goods and payments for them, otherwise known as a balanced input-output matrix. To construct the SAM in its complete form this matrix is combined with additional information about expenditures including final consumption, generation of capital, exportation and income, taxation, commercial margins, and the added value via primary factor input. To further analyze the sources of income, the value added for each sector was split into contributions from either labour or capital sources, again using data from the WIOD database.

It should also be noted that in its final form, the Indian 1995 version of the SAM displayed negative values in the intermediate transactions between sectors. This does not invalidate either the sources of the data or the representation itself. Rather it means that in some sectoral interactions there is an excess of supply of goods ahead of the quantity actually used. Our model however requires that all of the transactions between intermediate sectors be non-negative, lest the calibrated values of the required ratio of intermediate goods $a_{i,j}$ be below zero. To alleviate this we simply add its absolute value back to its sector, changing it to zero, but also to an input on its diagonal. As well, we subtract it from the two inputs that share a row/column with either of them, so that the value of the affected row and column totals remains identical as well as the expenditure/income equality.

Whilst we did have the option to directly incorporate India's corresponding 1995 direct tax rate into the SAM, it may have resulted in values of revenue/taxation that differed greatly from their real world counterparts. While the simplification process of constructing a SAM as a static representation of an economy will always differ somewhat from the actual one, in order to best simulate the effects of policy we adjust our inputs so that government expenditure and income is proportional to the actual values rather than equalling them exactly. We thus adjust the direct tax rate such that the ratio of total government revenue to the calibrated GDP exactly equals its 1995 counterpart of 9.1%, resulting in an income tax policy of 1.46%.

As a result governments' direct contribution to GDP in the model equals 7.64%; the bulk of its revenue comes from indirect taxation (which was inputed from the supply table) equalling 4.27% of GDP, with tariffs (3.37%) and direct taxation (1.46%) making up the rest of its 9.1% total. The difference between the total revenues and expenditures results in a very small government deficit of -0.365%.

6.3 International Income

The level of economic output for foreign entities is required to calibrate the level of foreign consumption and exportation per sector. Our model does not distinguish between the different trading partners and thus foreign parties are represented by just a single outside economy, meaning foreign income in this case equals Gross World Product (GWP) minus India's output. The lack of a common currency between countries means we convert GWP into US dollars: the currency measurement in our SAM, adjusted for per purchasing parity across countries. As

Tab. 6.4: **Calculated Indian Domestic Tariff Rates 1995**

Sector	Ad Valorem Tariff Rate (%)
Primaries	35.86
Chemical Products	40.03
Petroleum Products	43.97
Basic Metals	30.48
NMM-Products	28.76
Aggregated Manufacturing	34.25
Services	0

of 1995 the GWP equalled 43 trillion US PPP dollars. Subtracting India's output of 1.056 trillion USD results in a foreign income of 41.944 trillion.

6.4 Determination of Tariff Rates

The adjustment of the tariff rates are the primary method of policy experimentation in our thesis, thus it is the core component of our counterfactual analysis. In contrast to their real world counterparts, domestic tariffs measure the extra cost of importing foreign produced components to be combined with domestic components in the final good production process, whereas foreign tariff levels measure the extra cost that foreign economies bear to import final goods produced domestically. In our data source for tariff rate, the WTO Database, there is no distinction between tariffs on intermediate, capital or final goods in the Harmonised System 2 classification. We thus input these values as exogenous data and adjust the domestic and foreign rates separately according to their real-world reduction rate.

The WTO database only possesses tariff rates from 1996, which thus becomes our measurement year. It measures nominal tariff rates via Most Favoured Nation (MFN), and classifies their corresponding sectors using the Harmonised System (HS). For simplification we use tariff rates on a HS 2-digit level, which differentiates the economy into 96 sub-sectors. This is somewhat more detailed than the classification used in the WIOD Input-Output/Supply and Use tables. The fact that we are using a 7-sector SAM eliminates the need to specify tariff rates between different types of the same product, or the same product but for different production purposes. A concordance was made in order to adjust these rates to fit our seven sector SAM. We took weighted averages of each of the seven sectors according to corresponding average ad valorem rate as well as the value of importation in US dollars (Table 6.4).

***Tab. 6.5:* Calculated Foreign Tariff Rates 1995**

Sector	Ad Valorem Tariff Rate(%)
Primaries	6.34
Chemical Products	2.89
Petroleum Products	2.82
Basic Metals	2.89
NMM Products	3.03
Aggregated Manufacturing	4.78
Services	0

Given the lack of distinction between foreign trading partners, for simplification we only use India's top export partners as calculation for a weighted average of rates. As of 1995 they were the US, Germany, UK and Hong Kong. The WTO database unfortunately does not distinguish between tariff rates between members of the European Union (EU), so we take the rates of both the UK and Germany as a combined average. The foreign tariff rate for each sector is calculated from each export partners' weighted average from each of the 96 sub-sectors within the 7 selected sectors. This is then aggregated into another weighted average of each partners export value as a % of India's exports and its corresponding tariff rate (Table 6.5).

6.5 Elasticities of Substitution

The Armington Aggregators between the domestic and foreign components require an exogenous input of the elasticity of substitution between the two goods in order to find a solution. Our AGE specification is static, so we cannot directly calibrate the values of these parameters by measuring the change in trade activity across different sets of prices. Therefore we arbitrarily apply values based on similar AGE contributions as well as calibration methods applied to specific sectors. The benchmark case is taken from Cho & Diaz's (2011) work analysing Slovenias entry into the EU and its subsequent trade liberalization, where the import and export elasticity for all sectors are 5 and 10 respectively, meaning the exogenous inputs $\rho_m \forall$ and $\rho_x \forall$ are 0.8 and 0.9 respectively. The static nature of the model also allows us to perform sensitivity analysis across multiple elasticity values. That is, we analyse the change in calibrated parameters, in particular trade activity, as preferences for imported components and exported consumption goods change.

$$\sigma_{i,m} = \frac{1}{1-\rho_{i,m}}$$

***Tab. 6.6:* IPCC Carbon Factors by Commodity (tons/TJ)**

Energy Source	Carbon Factor (Metric Ton/TeraJoule)
Coal	26
Diesel	20
Light Fuel Oil	20
Residual Fuel Oil	21
Natural Gas	15
Other Oil	20

6.6 Carbon Factors by Intermediates

The Laspeyres Index requires that we have some form of measurement of environmental externalities that is endogenously calibrated before and after policy experimentation. Contributions that use Laspeyres or an alternative to differentiate between scale, composite and technique effects in a general equilibrium methodology typically use some direct measurement/calibration of emissions. They usually calibrate fossil fuel usage via each emission relevant energy source as CES inputs for production as a primary factor in of itself (Yang 2001) or as an energy relevant capital bundle (Dessus, Bussolo 1994). Given the limitations of our model, which only calibrates labour and capital per Cobb-Douglas along with intermediates, we use an indirect measurement of carbon output via demand for intermediate goods. This is because energy usage is implicitly included in intermediate usage from the services sector, and much of the carbon output is likely captured in the middle of the production process. Implicitly this means we are effectively measuring carbon emissions via the amount of domestic production instead of final production, which carries several implications for the conclusions we make about free trade's environmental impact.

There exists no direct exogenous measurement of each of India's sectors carbon factor. The WIOD however contains data on each sectors energy input by source (e.g. coal, fuel oil, diesel) as well as carbon emissions alone by sector. The latter however relies on outdated values of carbon factors for each energy commodity which is likely to underestimate the actual carbon outputs. We thus use information from the International Panel on Climate Change (IPCC) guidelines, which contains a universal measurement of each commoditys carbon impact in metric tons per kilojoule used (Table 6.6). In order to comparably analyse the two data sources we aggregate the WIOD data into six energy source types.

From these 1995 values we obtain a linear sum which equals the total carbon emissions by sector via exogenous 1995 data. We then divide them by the baseline

Tab. 6.7: **Baseline Carbon Output India 1995 (Millions of Tons)**

Sector	1995 Carbon Output
Primaries	80,326
Chemical Products	39,297
Petroleum Products	15,259
Basic Metals	54,825
Non-Metallic Mineral Products	54,825
Aggregated Manufacturing	28,017
Services	446,849

Tab. 6.8: **Exogenous Carbon Factors by Intermediate Input**

Energy Source	Carbon Factor (Metric Ton/$x_{i,j}$)
Primaries	3.00
Chemical Products	7.43
Petroleum Products	3.85
Basic Metals	5.74
Non-Metallic Mineral Products	18.27
Aggregated Manufacturing	1.48
Services	11.40

calibrated final output of each corresponding sector. This includes both domestic component production and aggregation of domestic and final components, in order to get an estimate for a carbon factor for each intermediate good (Table 6.8). Since our counterfactual experiments only involve alteration of tariff levels and not technological production processes we use these values to calculate the amount of carbon emissions that is implied by the model itself. These implied carbon factors are then multiplied by each sectors demand for intermediate goods. This is calibrated via each level of tariff reduction in order to get to a corresponding calibrated level of carbon output. Those values are then dissected into scale, composite and technique effects via our Laspeyres specification (although our models assumptions do not permit the reliable measurement of the latter).

6.7 Carbon Factors for Taxation

The carbon factors that represent how much emissions are produced via domestic production are different from the ones via intermediate inputs, given that different sectors have different intermediate requirements $a_{i,j}$. The values below (Table 6.9) are used to calculate the rate of ad-valorem taxation used in additional policy experiments.

Tab. 6.9: **Endogenous Carbon Factors by Domestic Output**

Energy Source	Carbon Factor(Metric Tons/$y_{d,j}$)
Primaries	3.96
Chemical Products	7.04
Petroleum Products	3.63
Basic Metals	4.81
Non-Metallic Mineral Products	4.90
Aggregated Manufacturing	3.95
Services	3.50

6.8 Diagnostic Checking

To further ensure the stability of our results of our model we also incrementally alter the import elasticity (an exogenous value) in order to make sure that the production, welfare and carbon values are not products of a specific elasticity value tailored to suit those results. In other words, whether the model results spike as a result of a small deviation of the exogenous input. We thus make small changes to both increase and decrease this value to make sure that our main takeaways from the model do not change drastically. We run multiple simulations with $\rho_{m,i}$ incrementally changing by 0.1 from 0.5 to 0.8, such that the elasticity value $\sigma_{m,i}$ ranges from 2 to 5. We compare the results in both our baseline simulation and our initial tariff change where domestic tariffs are reduced by 30.2% and foreign tariffs are reduced by 27.3%.

7
Empirical Results

7.1 Overview

Our primary form of measurement is comparison of the simulated results both before and after some form of tariff reduction to either domestic or foreign levels of tariffs. Our baseline experiment involves reducing both domestic and foreign tariffs by corresponding actual change from a five-year period from 1994-95 (from the start of the data) to 1999-2000. This simulates the exact effect of India's trade liberalization process, which was partly driven by its WTO membership as of 1995. Next, we run subsequent simulations by changing only the domestic tariff levels incrementally by 10% from its original levels all the way to a complete elimination of trade barriers. Within both of these simulations we use Laspeyres Index to disseminate the calibrated changes in carbon output as a result of either overall changes in economic output or changes in sectoral proportions. Finally we also implement an ad valorem tax rate on domestic production proportional to the level of intermediate good usage, which in our model corresponds to the level of carbon output. It is determined whether the simultaneous effect of trade liberalization and environmental regulation results in a net increase or decrease in carbon output.

The primary measurement is changes in carbon output, although alternative data on changes in consumption and production plans go hand-in-hand with explaining the individual mechanics through which trade liberalization affects equilibrium. We analyze firms changes in inputs between the primary factors of labour and capital, and intermediate inputs as a proportion from each sector as changes in tariff policy to alter the relative costs of each. Consumption and investment demand, both domestic and abroad, is also analyzed in response to a cheapening of production components and final goods. However, this is a secondary measurement in terms of the paper's purpose of analyzing changes in the production process and its externalities. Changes in welfare are used as a measurement for utility, which in this context are used as the corresponding benefits to short-term environmental degradation. Given the lack of universal measurement units for welfare and/or utility, it is measured in relative terms with respect to the baseline experiment (no tariff alterations) in an index based on income. The overall changes in welfare as measured by changes in the social welfare index are disaggregated into a sum of changes in household welfare and government welfare indexes.

We also use our calibrated values of import elasticities to perform sensitivity analysis, which tests the robustness of the models equilibrium adjustment. This will naturally go hand-in-hand with the tariff adjustment experiments; both will incrementally change their respective values and observe the rate-of-change of production and emissions quantities over the various simulations.

7.2 Baseline Experiment

7.2.1 Changes in Domestic and Final Production

Our most relevant economic determinant of carbon are the changes in production process both before and after our simulation, as this will affect the level of factors and intermediates used. This in turn directly affects the level of carbon output. The baseline changes in domestic and foreign tariffs show mixed changes amongst the multiple sectors, but with a net negative impact of -0.157% in domestic component production (Table 7.1). This is largely the result of the combined impact of tariff reduction in both Indian and foreign economies; the former reduces the cost of importing foreign components while the latter reduces the cost of importing Indian final goods. Subsequently there is both decreased incentive in the form of cheaper foreign alternatives and increased incentives in the form of higher foreign demand. Non-Metallic Mineral Products experienced a distinctive increase in production in contrast to other uniquely polluting sectors (which all experienced decreases) and to aggregated manufacturing (which had a small increase). While it was the least protected sector in the baseline scenario, it also experienced a similar strong increase in final output ahead of other sectors. This suggests that it has an inherent comparative advantage in the Indian structural economy ahead of its manufacturing peers.

The changes in final production which result from aggregating domestic and foreign components reveal more as to how firms altered their production plans in response to cheaper components and final goods. Trade liberalization results in an average increase of 2.16%, with similar heterogenous changes across the different sectors with regards to domestic production (Table 7.2). The simultaneous decrease in domestic components and increase in production of final goods means that the overall proportion of production value within domestic components reduces across all sectors, effectively outsourcing economic activity from Indian production. Emissions intensive sectors barring Non-Metallic Mineral products show

Tab. 7.1: **Trade Liberalization Impact on Domestic Production by Sector**

Sector	%Δ-Domestic Production
Primaries	-0.8
Chemical Products	-3.9
Petroleum Products	-7.7
Basic Metals	-1.9
Non-Metallic Mineral Products	+4.2
Other Manufacturing	+1.9
Services	+0.4
Total	-0.16

Tab. 7.2: **Trade Liberalization Impact on Final Production by Sector**

Sector	%Δ-Final Goods Production
Primaries	+1.0
Chemical Products	+3.7
Petroleum Products	+0.7
Basic Metals	+1.0
Non-Metallic Mineral Products	+8.0
Other Manufacturing	+6.9
Services	+0.3
Total	+2.16

a comparative disadvantage relative to other aggregated manufacturing sectors. The previously most heavily protected industries in chemicals and petroleum share the biggest shift in economic activity outwards.

7.2.2 Changes in Trade Activity

Trade liberalization results in a significant increase in trade activity in almost all sectors, although the increase in overall imported products outweighs the increase in export. This is partially the result of a slightly stronger tariff reduction amongst domestic sectors. The baseline experiment change in tariffs reduces the "competitiveness" of domestic components in the production process compared to foreign counterparts, whereas reduction in export barriers increases competitiveness in Indian produced goods. Sectors that were previously the most protected, such as chemical and petroleum products, agricultural products and aggregated other manufacturing experienced the highest increase in importation of foreign components. The small increase in importation of services components is largely due to a substitution effect where intermediate services become relatively more expensive than sectoral alternatives. The increase and cheapening of imports will also have a follow-on effect of reducing the final goods price and subsequent increase in demand.

Tab. 7.3: **Trade Liberalization impact on Exportation level**

Sector	%Δ in Export Activity
Primaries	+43.52
Chemical Products	+38.14
Petroleum Products	+41.85
Basic Metals	+30.35
Non-Metallic Mineral Products	+38.46
Other Manufacturing	+39.56
Services	-4.41
Total	+38.15

Tab. 7.4: **Trade Liberalization impact on Importation level**

Sector	%Δ in Import Activity
Primaries	+33.88
Chemical Products	+49.97
Petroleum Products	+43.59
Basic Metals	+34.72
Non-Metallic Mineral Products	+32.53
Other Manufacturing	+48.19
Services	+10.08
Total	+33.44

Exports show a greater counterfactual change in overall totals than imports, with a total increase of 38.15% compared to 33.44% (Table 7.3 & Table 7.4). This means that while sectors have greater amounts of foreign production components to work with, they have a greater proportional demand increase from foreign households. This places upward pressure on production levels either at the domestic or foreign level. Given domestic production falls overall, production of foreign components increases by a more significant level in order to accommodate for the increasing demand. Thus, the proportion of overall component input has increased towards foreign components and away from domestic from an average of 93.17% to 91.05% (Table 7.5). This is a minimal change relative to the nominal changes in either individual component, implying the efficiency differences between sectors has far more influence than efficiency differences between domestic and foreign components when it comes to trade policy changes.

Primary factor proportional usage shows effectively zero change in response to tariff reduction. Changes in factor intensity towards either labour or capital are the likely result of changes in factor prices as trade liberalization alters the relative pricing between different production components. The baseline tariff reduction shows that the capital/labour ratio remains identical across policies (76.55% or 43.36% of total factor usage), with nominal changes in either factor being exactly proportional to

***Tab. 7.5:* Change in the Relative Contribution of Domestic Components in the production of Final Goods**

Sector	Δ(Dom./Final) Prod. Ratio)
Primaries	-1.7
Chemical Products	-5.9
Petroleum Products	-6.9
Basic Metals	-2.6
Non-Metallic Mineral Products	-3.1
Other Manufacturing	-4.0
Services	0
Total	-2.12

***Tab. 7.6:* Trade Liberalization Impact on Economic Welfare**

Variable	ΔHousehold Welfare	ΔGovernment Welfare	ΔSocial Welfare
-	+1.12%	-1.12%	+0.88%

the changes in sector growth.

By our model's specification, the ratio requirements of intermediate goods needed to produce a fixed amount of domestic components remains homogenous, regardless of the quantity produced. Subsequently, given market-clearing conditions there must be no primary factors that are unused in all sectors. The proportional weights to intermediate goods to each sector also remain identical. The increase in demand for each intermediate good thus also remains identical. The only meaningful measurement related to the domestic production process is thus the change in overall production itself.

7.2.3 Welfare Changes

The direct impact of tariff reduction is a reduction of government revenue, which will have an immediate negative impact on the government's aggregate welfare level. Despite the fact that government only experiences a less than 1% fall in direct revenue, its overall consumption of final and investment goods falls by more than 1.2%, reflecting the extra impact tariff reduction has on optimal government behaviour. As a result, government welfare also falls by more than 1.2%. Conversely, consumer welfare increases by 1.1% as the reduced production costs feed into reduced prices for final goods, allowing greater consumption. The net effect shows a slight increase in overall welfare of 0.88% (Table 7.6). Given that households occupy a larger proportion of all economic agents in the model than government, more weight is placed on it in the calculation of social welfare.

***Tab. 7.7:* Trade Liberalization Impact on Factor Compensation**

Variable	ΔRental	ΔWages
-	+1.04%	+1.18%

As well as the reduced prices, the change in factor prices adjusts the level of disposal income available to households, further changing their possible consumption budgets. The baseline trade reform increases both rental on capital and the nominal wage by more than 1% (Table 7.7). The combined effect of the latter as well as decreased prices allows household consumption to increase at a percentage higher than the change in goods prices. The increase in factor compensation is an effect of an increased budget constraint from lower tariff levels.

7.2.4 Carbon Emissions and Laspeyres Disaggregation

According to the Laspeyres linear approximation, the baseline policy experiment shows carbon emissions reducing as a result of both scale and composite effects, with a slight weighting towards the former. Trade liberalization has resulted in a reduction in domestic production across all sectors as a result of shifting priorities towards foreign components, so carbon emissions have fallen by 0.157% via scale effects (Table 7.8). Despite being less affected by tariffs than their manufacturing counterparts, both primaries and services sectors have the biggest income related carbon reduction due to their size and carbon intensity. The composite effects are far more volatile between sectors; the vast majority of nominal changes in emissions are due to alterations in sector proportions, but the contrasting changes between the increased weight towards services, non-metallic products and aggregated manufacturing is balanced out by the reductions in primaries and the more carbon intensive manufacturing. Given the relatively higher carbon factors of the latter sectors, the net result is a reduction of 0.135% of overall carbon emissions due to composite effects: significantly down from the sum of absolute value of changes across sectors of 20.674%. Given our model specification of maintaining fixed proportions of intermediate inputs, we cannot measure significant technique effects.

Tab. 7.8: **Laspeyres Index Results-Carbon Emissions (Metric Tons)**

Sectors	Scale Effects(%)	Composite Effects(%)	Total Impacts(%)
Primaries	-0.157	-0.658	-0.815
Chemicals	-0.157	-3.764	-3.921
Petroleum	-0.157	-7.521	-7.678
Basic Metals	-0.157	-1.698	1.855
NMM Products	-0.157	4.318	4.161
Other Manufacturing	-0.157	2.053	1.896
Services	-0.157	0.527	0.371
Total	-0.157	-0.135	-0.291

Tab. 7.9: **Laspeyres Index-Proportion between Scale and Composite**

Sectors	Scale/Total Effects(%)	Composite/Total Effects(%)	Residual
Primaries	19.26	80.86	-0.13
Chemicals	4.00	96.15	-0.15
Petroleum	2.04	98.11	-0.15
Basic Metals	8.46	91.68	-0.14
Non-Metallic	-3.77	103.94	-0.16
Other Manufacturing	-8.28	108.45	-0.17
Services	-42.39	142.61	-0.22
Total	53.82	46.25	-0.07

7.3 Results across Incremental Tariff Levels

7.3.1 Production Levels across Tariff Levels

While most of the economic variables measured either increase or decrease along a steady rate with tariff reduction, parts of the production process have the potential to reverse their original trend if the income effects of reduced costs on both production and consumption costs have a drastic enough effect on economic activity. In particular the level of domestic production reduces by an average of 0.04% per 10% tariff reduction until domestic tariffs reach between (60 and 50)% of their original levels (Table 7.10). This is where it begins to increase with increased trade liberalization. Similar to the previous composite effects, Non-Metallic Mineral Products and Aggregated manufacturing increase at an exponential rate after tariffs are reduced below 50% until they reach zero. In contrast, the rate of increase of primaries and intensive manufacturing is lower past a tariff rate of 50%. This is lower than their counterparts, resulting in net increases.

Production of a final goods rate of change only increases as tariffs decrease below 50% of their levels, averaging an exponential trend of 1.14% per tariff level across the

***Tab. 7.10:* Production by Tariff Levels**

-	Tariff Reduction Policy				
Variable	-10%	-20%	-30%	-40%	-50%
%Δ Total Domestic Production	-0.07	-0.14	-0.19	-0.22	-0.22
%Δ Total Final Production	+0.52	+1.11	+1.80	+2.60	+3.54
Δ (Domestic/Final) Prod. Ratio	-0.55	-1.15	-1.82	-2.56	-3.38
Variable	-60%	-70%	-80%	-90%	Tariff Elimination
%Δ Total Domestic Production	-0.19	-0.11	+0.04	+0.27	+0.16
%Δ Total Final Production	+4.65	+5.97	+7.55	+9.48	+11.48
Delta (Domestic/Final) Prod. Ratio	-4.3	-5.34	-6.51	-7.84	-9.36

entire simulation. The fact that this largely exceeds the corresponding rate of change in domestic production means the proportion of Armington final goods production in domestic goods also decreases with increased openness. The rate of change is largely a result of the way tariff rates incorporate into the first-order conditions of final production. i.e.:

$$\hat{p_{j,d}} y_{j,d} + (1+\tau_j)\hat{e}\bar{p_{j,f}} y_{j,f}$$
$$\text{s.t. } \gamma_j[\Delta_j y_{j,d}^{\rho} + (1-\Delta_j) y_{j,f}^{\rho}]^{\frac{1}{\rho}} = \hat{y_j}$$
$$y_{j,d}, y_{j,f} \geq 0$$
$$\frac{(1+\tau_j)\hat{e}\bar{p_{j,f}}}{\hat{p_{j,d}}} = \frac{(1-\Delta_j) y_{j,f}^{\rho-1}}{\Delta_j y_{j,d}^{\rho-1}}$$
$$y_{j,d}^{\rho-1} = \frac{(1-\Delta_j) y_{j,f}^{\rho-1}}{\Delta_j} \frac{\hat{p_{j,d}}}{(1+\tau_j)\hat{e}\bar{p_{j,f}}}$$
$$\frac{\hat{y_{j,d}}}{\hat{y_{j,f}}}^{\rho-1} = \frac{\hat{p_{j,d}}}{(1+\tau_j)\hat{e}\bar{p_{j,f}}} \frac{(1-\Delta_j)}{\Delta_j}$$

The effect of the domestic tariff rate τ_j on the corresponding sector j domestic production is of a hyperbolic nature; the rate of increase increases as $(1+\tau_j)$ decreases with policy. Similarly the proportion of production value in domestic goods is also inversely proportional. This effect is somewhat reduced when the price level of the corresponding sectors good decreases as a result of lower production costs.

7.3.2 Carbon Emissions across Tariff Levels

The turning point in the nominal amounts of domestic production also equals the tariff level turning point for scale effects across the relevant sectors. However, the differing carbon factors among the different sectors means that it is not quite at the same point across sectors. Scale effects begin to result in an increase in carbon emissions at an 80% tariff reduction as opposed to 50% for nominal production. This is due to intensive sectors such as chemical products and basic

.

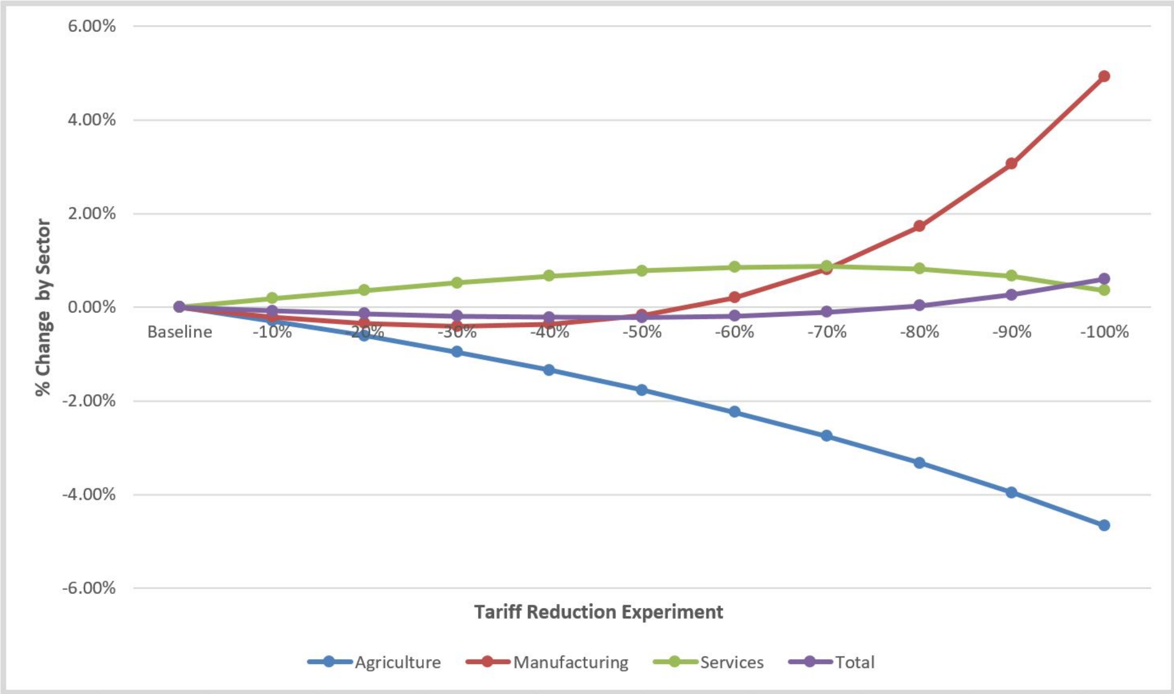

Fig. 7.1: **Domestic Production Changes over Tariff Rates**

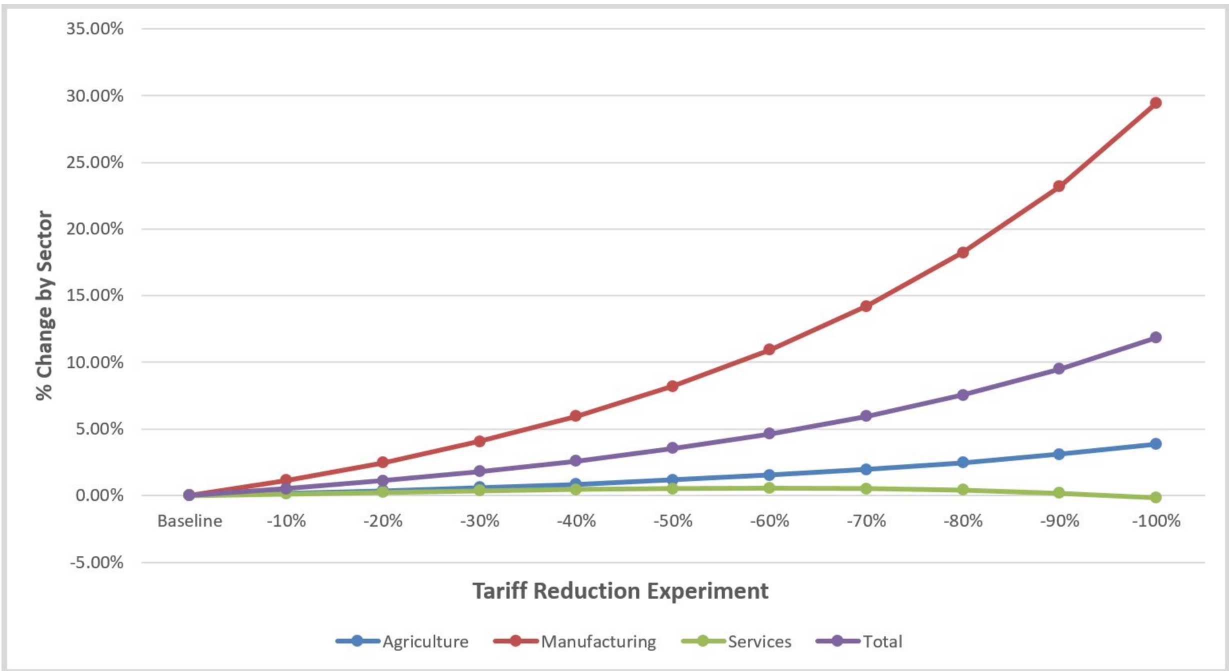

Fig. 7.2: **Final Production Changes over Tariff Rates**

***Tab. 7.11:* Average Rate of Sector Size Change(Final Output) via Incremental Tariff Reductions**

Variable	Average Rate of Change(%)	Average Nominal Change(%)
Primaries	-0.465	-0.465
Chemical Products	-0.473	-0.367
Petroleum Products	-3.166	-3.182
Basic Metals	-0.217	-0.176
NMM-Products	2.388	2.453
Aggregated Man.	1.244	1.324
Services	0.054	0.036
Total	0.127	0.158

***Tab. 7.12:* Laspeyres Index Results via Incremental Tariff Reductions**

Variable	-10%	-20%	-30%	-40%	-50%
Scale Effects(%)	-0.075	-0.139	-0.188	-0.217	-0.219
Composite Effects(%)	-0.045	-0.087	-0.124	-0.154	-0.175
Total Index Carbon Changes(%)	-0.12	-0.225	-0.311	-0.371	-0.394
Variable	-60%	-70%	-80%	-90%	Tariff Elimination
Scale Effects(%)	-0.186	-0.105	0.039	0.267	0.606
Composite Effects(%)	-0.184	-0.177	-0.147	-0.088	0.012
Total Index Carbon Changes(%)	-0.37	-0.282	-0.109	0.179	0.618

metals beginning to increase in domestic output much later than the turning point for services and other manufacturing. Overall composite effects are initially carbon negative as activity shifts from agriculture and intensive industries towards services and cleaner industries. But like scale effects, chemicals and basic metals begin to reduce in proportion whilst non-metallic and other manufacturing begin to increase exponentially.

The net result is that overall carbon begins to increase in output as tariffs are reduced below half of their original value, roughly in the middle of the turning point for both scale and composite effects. Again, this is due to the accelerated growth in India's comparatively advantaged sectors; services, aggregated manufacturing and non-metallic mineral products. After an 80% reduction in tariffs, the overall level of carbon emissions begins to rise above the baseline level, and grows by 0.44% in the last incremental reduction from 10% to 0% after an average nominal change of 0.08% (Table 7.12). Emissions reach their lowest when tariffs are halved from their original levels, with a reduction of -0.394%.

Tab. 7.13: **Welfare Change via Incremental Tariff Reductions**

Tariff Reduction	-10%	-20%	-30%	-40%	-50%
%Δ Household Welfare	0.292	0.613	0.968	1.360	1.795
%Δ Government Welfare	-0.358	-1.081	-2.263	-4.024	-6.521
%Δ Social Welfare	0.226	0.443	0.643	0.819	0.958
% Tariff Reduction	-60%	-70%	-80%	-90%	Tariff Elimination
%Δ Household Welfare	2.278	2.817	3.418	4.090	4.845
%Δ Government Welfare	-9.956	-14.594	-20.791	-29.029	-39.969
%Δ Social Welfare	1.043	1.048	0.939	0.662	0.133

Tab. 7.14: **Welfare Rate-of-Change via Incremental Tariff Reductions**

Variable	Household Welfare	Government Welfare	Social Welfare
Average Rate of Increase	0.477	-3.675	0.045
Average Nominal Change	0.485	-3.997	0.013

7.3.3 Welfare across Tariff Levels

Both household and government welfare continue increasing and decreasing respectively as reduced tariff rates both reduce goods prices for the former and decrease revenue for the latter. The rate of change between them however differs as government welfare deteriorates exponentially, while consumer welfare only increases at slightly above a linear rate. This is because tariff revenue comprises a far larger proportion of government revenue; nearly half of indirect taxation, rather than the price reduction impact on household budgets. The policy change constricts the available consumption baskets for government agents considerably more. As a result social welfare begins to decline after tariffs reach 20% of their original value. In terms of possible consumption based welfare, the optimal policy in terms of domestic tariffs is therefore to reduce them by 70% of their original value.

7.4 Emissions Taxation

7.4.1 Production Changes via Emissions Taxation

Total Domestic Production mostly follows a linear trend as the emissions tax rate increases, with a slightly decreasing rate-of-change as the tax rate increases. The initial tax rate of 0.001 USD/ton results in a 1.05% decrease in overall production, compared with a rate of 0.01 USD/ton causing a 9.88% decrease. As expected there is also a proportional shift away from the more carbon intensive manufacturing

***Tab. 7.15:* Domestic Production Changes across Taxation Levels and Trade Policies**

Carbon Tax Rate(USD/Ton)	0.001	0.002	0.003	0.005	0.01
%Δ Total Production wout/ Tariff Reduction	-1.05	-2.09	-3.12	-5.12	-9.88
%Δ Total Production w/ Tariff Reduction	-1.22	-2.27	-3.30	-5.32	-10.11

***Tab. 7.16:* Laspeyres Index across Taxation Levels and Trade Policies**

-	No Tariff Reduction				
Carbon Tax Rate(USD/Ton)	0.001	0.002	0.003	0.005	0.01
Change via Total Scale Effects	-1.05	-2.09	-2.47	-4.17	-7.44
Change via Total Composite Effects	-0.04	-0.09	-0.21	-0.34	-0.74
Change via Total Carbon Change	-1.10	-2.18	-2.68	-4.51	-8.18
-	Initial Tariff Reduction				
Carbon Tax Rate(USD/Ton)	0.001	0.002	0.003	0.005	0.01
Change via Total Scale Effects	-1.22	-2.27	-3.30	-5.32	-10.11
Change via Total Composite Effects	-0.18	-0.23	-0.28	-0.38	-0.62
Change via Total Carbon Change	-1.40	-2.50	-3.58	-5.70	-10.73

sectors, but not so much that the primary effect of a higher tax rate is still the change in total domestic production. The effect of trade liberalization, that of both less overall domestic production and a shift towards services and aggregated manufacturing, also remains largely unchanged with only a slightly increased effect as the tax rate increases.

7.4.2 Carbon/Laspeyres Results via Emissions Taxation

The aforementioned combined effect on production is such that scale effects are now responsible for a much higher proportion in carbon emissions changes as opposed to sectoral shifts: carbon taxation does a poor job at moving an economy's position on the Kuznet's curve. Without trade liberalization carbon taxation results in significant carbon reductions, with around 90% of it coming from falls in overall production, and 10% from composite effects. Like production, the rate of change along different tax rates is mostly linear with some concavity: a tax rate of 0.001 USD/ton causes less than 8 times the carbon drop than a rate of 0.01 USD/ton. The initial tariff reforms amplify the total effects by around (20-30)% for each sector but also vastly increase the share of reduction going to composite effects.

7.5 Import Elasticity Ranges

There is a slight gradual change in production quantities over the course of decreasing import elasticities, but no sudden spikes such that the baseline results of $rho_{i,m} = 0.8$ can be considered tailored to specific exogenous inputs. The change

***Tab. 7.17:* Production Levels across Multiple Import Elasticities (USD)**

$\rho_{i,m}$	0.8	0.7	0.6	0.5
$\sigma_{i,m}$	5	3.33	2.5	2
Total Dom. Prod.(Baseline)	27,169,195	27,199,466	27,214,885	27,224,213
Total Dom. Prod.(Policy)	27,126,604	27,211,436	27,253,490	27,278,476
Total Final Prod.(Baseline)	29,161,876	29,187,573	29,201,867	29,210,997
Total Final Prod.(Policy)	29,791,945	29,695,098	29,635,283	29,594,970

in import elasticity shifts the production priorities across from domestic to foreign components as it alters the relative costs between them. In addition the combined effect of tariff reduction reverses the impact of changing import elasticity on the quantity of final production (Refer to Appendix B).

8
Discussion

8.1 Literature Context

In a majority of empirical papers linking trade liberalization and environmental effluents, the net carbon effect is ultimately a result of the conflict between increased overall production and the environmental externalities that come with it, and potential structural shifts away from carbon-intensive manufacturing sectors. Our model's simulation results in a fall in emissions due to both income and sectoral effects as a result of India's comparative disadvantages across most of its sectors. This is in contrast to the vast majority of general equilibrium studies of trade in developing countries and also to the actual empirical outcomes of India's growth, which increased rapidly during the peak of the liberalization process of the late 1990's. In our thesis, the domestic production value for the majority of sectors actually decreases, although the production and proportion of foreign components in those same sectors increases by a greater amount, which almost universally results in an increase in final goods production. The caveat in terms of an implied environmental benefit is that we lack a direct representation of externalities. Rather, we are assuming that they are generated in a linear fashion as a result of domestic component production. As well as implicitly assuming that emissions change in the exact same proportions as economic activity (effectively assuming zero technique effects), this also eliminates the possibility of emissions being drawn from other sources such as the aggregation of domestic and final components, and certain forms of capital. Given the nature of manufacturing products, it is likely that the vast majority of generated emissions will result from the early stages of production. This means that within the limitations of our model, domestic components are the most accurate proxy we have. Yet this aspect is still one of the more likely reasons that our simulation's findings contrast that with most other empirical works involving environment and trade.

The simulation results contain several implications for analyzing India's potential comparative disadvantages in terms of both sectoral structure and outsourcing. At the turn of the 21st century India's relative economic advantages lay in both agricultural products and services, its growth pattern appeared to skip much of the industrialization phase that developing countries traditionally undergo in the process towards developed status. Our simulated changes appear to support this empirical trend, with Indian production deprioritizing certain harmful manufacturing in favour of services, agriculture and other aggregated manufacturing that is less carbon responsible. On another level, India is also comparatively disadvantaged with regards to foreign inputs, with the share of the latter as a proportion of total inputs increasing from 6.83% to 16.2% from the baseline scenario to tariff elimination, maintaining a positive trend throughout the whole tariff reduction process. This was the primary reason the Laspeyres index indicated negative scale effects in terms of emissions changes. According to the model, allowing cheaper foreign components permits greater production and growth levels by reducing overall costs; India's rapid growth rate post-trade reforms appears to validate this conclusion. In terms of emissions however the fall in domestically produced carbon may be compensated or even eclipsed by foreign produced carbon via increased components. Since the SAM data (and therefore the model) does not differentiate trade activity by country, we cannot reliably estimate a carbon factor for these economies and thus cannot quantitatively conclude whether trade liberalization results in either an increase or decrease in carbon emissions.

Another important caveat is the limitation of a general equilibrium model with only seven sectors, in contrast to the vast majority of empirical papers which make very few sector aggregations in modelling the effects of trade liberalization. In our case, the nature of India's liberalization process such that tariff rates were reduced at almost identical rates across sectors in the post-1991 period, means that the effects of such non-distinctions remain minimal within the manufacturing sectors. The carbon output between the three main subsectors in the aggregated primaries (agriculture, food and mining) is extremely high as of 1995. Whilst the direct effects of trade liberalization are likely to be identical given the universal rate of reduction, the differing purposes of goods between the sub-sectors means that there are potential differences in carbon output as a result of changes between final consumption and intermediate usage. Food products are primarily used for household consumption whilst the vast majority of its intermediate usage are utilized within the same sector. Mineral products are almost exclusively used for intermediate production for various manufacturing products, and agricultural products are roughly divided evenly between both directions. The most likely impact in terms of empirical results will be the compression of all the tertiary sub-sectors and the subsequent containment of electricity generation within all of the other sectors.

The almost negligible impact of technique effects is an inevitable result of our limited definition of energy usage by sector. In our case this is defined as the intermediate product inputs across each sector, whilst primary factor inputs are assumed to have zero carbon input. Most applications of the Laspeyres methodology in an environmental context use a direct measurement of energy usage per sector in order to calibrate a carbon factor for each sector. This is either an exogenous measurement for each relevant sector or as a primary factor in itself. The usage between sectors is calibrated as part of profit maximization/zero profit conditions of the model. This ensures that there remains a significant change in carbon intensity before and after a major exogenous change such as in the case of trade liberalization. In the cases such as Taiwan's post-WTO membership period, energy usage from fossil fuel intensive sources such as coal and oil decreased by a non-negligible amount to the point where technique effects reduced carbon output by a sixth of the combined effects of scale and composite effects (Yang 2001). Given our assumptions of a Cobb-Douglas production function for all sectors with constant returns to scale, the proportional inputs between primary and intermediate sources remain almost identical. The constant marginal productivity of each input means there is almost no economic motivation to alter the proportions across each production plan. This stands in contrast to most applications of Applied General Equilibrium models which use Constant Elasticity of Substitution production functions. Yang (2001) applies this function to both the composition of energy inputs by sector as well as to the composition of labour, capital and electricity inputs by sector. Were such an adjustment to be made to India's 1995 case, it is likely that we would observe a carbon reduction as a result of productivity effects for both empirical reasons (India's status as a relatively developing country in both welfare and technology) as well as theoretical reasons. India's proportional labour input and intermediate input from carbon intensive sectors remains relatively high compared to more developed economies.

8.2 Simulation vs. Actual Results

The changes in both trade activity and carbon emissions from our counterfactual experiment differ from their real world counterparts in somewhat different ways. By comparing the two sets we should receive a rough estimation as to what proportion of overall change was due to either trade reform or other policy changes such as privatisation, finance and infrastructure. The data showing actual trade activity from Comtrade differs from our simulation although not consistently. The model both overestimates exports and underestimates imports, with an extremely high variance of difference between the two sets. Our model theoretically should underestimate the increase in trade activity given its inclusion of one type of policy. The models simplifying nature should result in divergences that

Tab. 8.1: **Exportation Level (USD): Model vs Real**

Sector	%Δ from Baseline-Model	%Δ from Baseline-Real
Primaries	43.52	-10.56
Chemical Products	38.14	40.38
Petroleum Products	41.85	173.37
Basic Metals	30.35	47.87
Non-Metallic Mineral Products	38.46	62.64
Other Manufacturing	39.56	22.55
Total	38.15	26.63

Tab. 8.2: **Importation Level (USD): Model vs Real**

Sector	%Δ from Baseline-Model	%Δ from Baseline-Real
Primaries	33.88	31.9
Chemical Products	49.97	-0.1
Petroleum Products	43.59	68.79
Basic Metals	34.72	-33.68
Non-Metallic Mineral Products	32.53	147.09
Other Manufacturing	48.19	2.97
Total	33.44	35.39

average themselves out over the variables. Trade activity in non-metallic mineral products and petroleum is highly underestimated, whilst the opposite holds true for aggregated manufacturing, and to some extent, primaries and chemicals. The actual measurements of 2000 levels also contain no anomalies, relative to the growth trend from 1995 onwards. It should be noted that AGE models are not primarily designed for forecasting but rather, the elucidation of mechanisms. The predicted changes in trade activity here are very similar to other general equilibrium studies of trade liberalization. Our results support the established belief that AGE models have poor forecasting ability without exhaustive inclusion of exogenous changes, particularly in India's case of widespread microeconomic reform.

In the model, counterfactual changes in emissions due to trade liberalization only comprise a small percentage of the actual changes. This reflects both the rapid rate of economic growth and reform during the post-1991 period. Theoretically, trade liberalization should change carbon emissions via sectors most comparatively dis/advantaged, especially relative to major trading partners. The biggest differences between the two sets occur in primaries and petroleum, largely a reflection of how these sectors have grown independently of the effects of

Tab. 8.3: **Final Production (USD): Model vs Real**

Sector	%Δ in F. Prod.-Model	%Δ in F. Prod.-Actual
Primaries	-0.82	+44.76
Chemical Products	-3.92	+3.56
Petroleum Products	-7.68	+86.82
Basic Metals	-1.85	-9.37
Non-Metallic Mineral Products	+4.16	+28.16
Other Manufacturing	+1.89	-8.35
Services	+0.37	+24.91
Total	-0.29	+23.62

Tab. 8.4: **Carbon Levels (Tons): Model vs Real**

Sector	%Δ in Carbon-Model	%Δ in Carbon-Actual
Primaries	-0.82	+44.76
Chemical Products	-3.92	+3.56
Petroleum Products	-7.68	+86.82
Basic Metals	-1.85	-9.37
Non-Metallic Mineral Products	+4.16	+28.16
Other Manufacturing	+1.89	-8.35
Services	+0.37	+24.91
Total	-0.29	+23.62

trade liberalisation. Otherwise the predicted effects of trade liberalisation vastly underestimate the actual increases in carbon emissions, even taking into account the corresponding differences between the model and actual production changes. This is likely due to the simplification as to how higher volumes of trade components affects the decisions firms make about those respective inputs.

Most of the measurable variables in the model grow exponentially over the rate of tariff reduction. This is especially observable as the tariff rate approaches zero. This relationship is mostly explicable through the mathematics of the cost minimization conditions, but imply optimal policies that often contrast with alternative economic theories. Our AGE model states that in this case the optimal domestic tariff policy to maximise social welfare equals 30%. At this point, the decline in government revenue outpaces the increases in potential household consumption. Orthodox trade theories conclude that the optimal tariff level should only be above zero should the host country influence the global market if it occupies a significant enough share (Dean 2002). Yet our model specifies that foreign prices are exogenously inputed that remain homogeneous irrespective of other potentially relevant prices or quantities, and it is socially optimal to have a tariff rate above zero despite India being a price taker in the global market.

8.3 Carbon and Welfare Optimal Tariff Levels

Carbon emissions are at their lowest when domestic tariffs are halved from their original amount as this lies in between the lowest emissions due to income growth/decline (50%) and composite effects (40%). This runs contrary to traditional theories of trade that predict trade activity according to differences in economic features between trading partners. The most prominent economic models dealing with the trade-environment relationship, such the North-South model, conclude that trade liberalization increases environmental effluents through an overall increase in production. Countries with comparative advantages in dirty goods gain increased production synchronization, and produce a higher amount than the previous autarkized countries combined. This results in higher emissions depending on where the effluents are made along the vertical integration of production. If there are other differentiating factors such as natural capital and heterogenous preferences for environmental quality, then the net changes could be greater. As such, in a static framework, reduced taxation on trade activity should theoretically only result in greater emissions.

The body of empirical works regarding countries at similar developmental levels to India suggest scale effects are the most consistent in causing increased emissions. Conversely, composite effects are often unique to a country's economic features, and technique effects are often only significant towards the latter half of the developmental stage. Unless there was an immediate large disparity between its dirty and clean industries, the increase in production should typically exceed any potential reductions in emissions due to the other mechanisms. Our model shows scale effects actually troughing at the halving of tariffs before exponentially rising towards zero, although with consistent proportional shifts towards cleaner industries.

Compared to theoretical models of trade, our different conclusions are largely due to differences in production specification. Our model like most other AGE specifications requires international integration to produce final goods, and India's implied comparative disadvantages result in a proportional decrease in Armington inputs. The latter change of increased scale effects due to decreased production costs is far more explicable via neoclassical theory. It is possible that previous applications of AGE models had different international integration specifications to produce final goods, thus eliminating potential substitution effects from domestic to foreign production plans.

The caveat in terms of policy evaluation is that the optimal tariff policy in terms of immediate welfare does not match the optimum in terms of minimizing environmental effluents. In our model, we do not assign household preferences to environmental quality, such as with the consumption of final goods, which could potentially produce a different optimal policy which balances the two criteria. As well as arbitrary preferences we also do not include a separate entity for environmental capital that potentially depreciates with usage, thus providing a tangible economic incentive to reduce effluents. It should be noted that either of the two changes would also affect household and firm behaviour at their consumption and/or production choices, making a ceteris parabus analysis impossible without re-running the model using different specifications. In papers where households did assign preferences to environmental quality the optimal trade policy more often satisfied both maximizing utility and minimizing effluents.

8.4 Effectiveness of Carbon Value-Added Taxation

Previous papers that modeled the simultaneous effects of carbon-based ad valorem taxation and trade liberalization found that it was significantly more socially desirable than either one of them in isolation; i.e. much of the additional effluents as a result of freer trade could be mitigated via fiscal policy with minimal impact on production and welfare. Our simulations suggest that fiscal based environmental policy is effective only as much as its impact on overall production, rather than specifically targeting the most harmful sectors. A high enough tax rate could potentially reduce carbon by an amount far exceeding any tariff-based policy, but not necessarily in a way that is more production and/or welfare efficient. The maximum tax rate tested of 0.01(USD/Ton) under the initial trade liberalization scenario reduces total domestic component production by 8.6% as well as carbon emissions by 10.73%. The vast majority of this resulted from scale effects ($\geq$ 94%), compared to an only trade-policy scenario with a 0.16% fall in production and a 0.3% fall in emissions, with a more even split between scale and composite effects. Even with radically different tax rates per sector, fiscal-environmental policy is very ineffective at targeting sectors according to their carbon factors. It is also not much more production efficient compared to tariff reduction policies, even as the latter traditionally performs poorly as environmental policy (Brian & Taylor 2003). The carbon optimal tariff policy of a 50% across the board reduction results in a 0.22% fall in domestic production causing an 0.39% drop in carbon; the ratio of (change in production)/(change in emissions) is much smaller than even the smallest carbon-tax rate tested. Fiscal based environmental policy would thus be recommended if developing countries of similar economic positions needed to rapidly reduce emissions in the short-term, in a way that other policies could not.

The caveat, similar as with the discussion around tariff policies, is the relatively simplified way as to how carbon emissions are assumed to be generated. In our model they are generated linearly from domestic production rather than occupying a separate production factor (Yang 2001). So taxation effectively penalizes the production of the whole good rather than the use of any specific input (also since the proportion of intermediate inputs to production remains identical regardless of quantity). There is no substitution effect between production inputs with different carbon factors in papers such as Dessus & Bussolo (1998), that allow firms to respond to taxation with more efficient production methods that would allow for much higher tax rates with a much lower welfare impact.

9

Concluding Remarks

In this modelling paper we have quantified the counterfactual effect of the version of trade policy completed in India in the post-1995 period, as well as the effects of incremental tariff reduction. The aim was to discover how production and emissions change with changes in tariff rates and the optimal policy in terms of both welfare and environment. We use a form of static general equilibrium modelling known as AGE, that incorporates exogenous data about the Indian economy pre 1995 as well as various assumptions as to the behaviour of its economic agents. Trade liberalization is applied through an exogenous change to domestic tariff levels as well as foreign ones in simulations. We also employ a form of Laspeyres Index in order to differentiate between the scale and composite effects of emissions changes.

Our initial simulation reflects the five-year period change in tariffs to 2000. It shows a non-insignificant decrease in emissions, with a reduction of 314,134 metric tons of carbon dioxide, or just over 0.2% of the original amount. Half of this impact is attributed to scale effects where India experiences an overall reduction in domestic output of 0.2% . This decrease is not uniformly experienced across all sectors however, with the biggest impacts being on primaries and carbon intensive manufacturing sectors, simultaneously with a lesser increase in services and less harmful aggregated manufacturing. The result is that composite effects account for the other portion of carbon reductions, although the polarizing changes between sectors means the sum of individual composite effects is far higher than the net total.

The way domestic and foreign components are aggregated via an Armington specification means the loss in domestic production is more than made up for in foreign components. While different sectors grow and reduce at different rates, India's proportional contribution towards final goods remains identical, and production of final goods increases with lower tariff policies. These results conflict with other general equilibrium studies regarding the environmental impact of trade. These conclude that reduced trade costs reliably result in increased production (and thus scale effects) as well as ambiguous composite effects, although they had potentially different specifications of aggregating domestic and foreign production patterns.

Secondarily the trade policy enacted had a net positive impact on social welfare, as determined by the utility preferences specified by the representative household. The fall in government revenue had a much higher proportional impact on the baseline government welfare (-1.03%) than the fall in household budget did on household welfare (+1.12%) However the latter occupies a far higher proportion of social welfare, and as such it rose by (0.88%) following trade liberalization. The change in government revenue (-0.9%) is also much proportionally smaller than the increase in factor returns: wages (+1.18%) and rental (1.04%).

Running simulations across incremental tariff levels, production levels eventually peak at the complete reduction of tariffs, but not before troughing at 50% tariff levels. Thereafter, losses occur in comparatively disadvantaged sectors; primaries and intensive manufacturing peak before other sectors such as Chemical Products and Basic Metals begin to recover. India's relatively internationally advantaged sectors of services and other manufacturing grow exponentially along the entire process. The Armington proportion for domestic components decreases slightly as tariffs are eliminated, meaning that final production increases reliably as costs are reduced so that production peaks as tariffs are eliminated. Carbon emissions are at their lowest when tariffs are halved, the scale effects trough at -0.2191%. Composite effects are slightly more persistent; they trough at 40% tariff values at -0.1844%. This means that at tariffs are halved, carbon emissions are lowered by -0.3944%. Beyond that, the income effects of lower production costs mean that domestic production rises again, to a point where carbon increases by 0.6179% if tariffs are totally eliminated. Social welfare peaks at a greater level of reduction than this (30%), with the exponential decrease in government revenue outpacing the gradual increases in household consumption.

We conclude that for a country with India's economic structure trade liberalization may potentially improve environmental quality. This is because it is comparatively disadvantaged in its most effluent intensive sectors, shifting carbon relevant activity both overseas and towards cleaner sectors. This lies in contrast to other general equilibrium studies of trade liberalization which conclude that the reduced production costs effects should reliably increase production and resulting carbon emissions to varying degrees, with composite and technique effects being relatively arbitrary. India is unique in that it appears to have skipped the industrialization process from agriculture to manufacturing. Services may have contributed, although the rapid growth of intensive manufacturing in the 2000's may mitigate its effects. Nevertheless, we have shown that a country can potentially reduce harmful externalities by opening up to trade. This is dependent on appropriate economic differences with its trading partners so that the shifting priorities between both sectors and countries can outweigh the impact of increased economic activity. Theoretically this implies that a country like India can exist on the latter half of the Kuznet's curve and simultaneously improve living standards and environmental quality despite not being fully developed.

The model specifications for measuring how carbon emissions are generated limit the amount of conclusions we can draw; specifically how emissions change due to either changes in production technology or a shift of activity from India to foreign countries. Final goods production requires endogenously combined domestic and foreign components. For certain intensive manufacturing products which only rely on natural capital such as petroleum and basic metals, this does not apply. It may increase domestic production far beyond than what is simulated here. This represents significant outsourcing to foreign components. We also assume that a sector's carbon emissions is proportional to all of its intermediate demand, in lieu of a carbon factor for the primary factors. Implicitly this means electricity/fossil fuel usage is part of intermediate goods from aggregated services. This specification implies that proportional inputs from intermediate goods remain the same regardless of output. This is contrary to the principle of technique effects espoused by Grossman and Krueger. The Laspyeres method thus appropriately measures technique effects to be zero. Were the model to either include more flexible production processes or to calibrate energy usage as an economic factor in itself, it is likely it would predict a greater reduction in carbon emissions. In addition, the static nature of the model removes any endogenous growth dynamics that would re-optimize the production process at each temporal point, potentially adding significant technique effects.

Whilst our model comprehensively evaluates domestically produced effluents, it does not specify any carbon-related measurements for foreign countries. This means that we cannot evaluate as to whether Indian trade-liberalization in the mid-1990's increased global carbon emissions. Empirically we know that India's main manufacturing production partners of that period were major economic players: USA, UK and China as well as geographically favourable smaller countries like Hong Kong. It is likely that each of these countries, especially the major Western economies will have far cleaner production processes, potentially amplifying the reduction in carbon via changes in Indian specific production.

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Appendix A

	Primaries	Chemicals	Petroleum	Basic Metals	NMM Prod.	Agg. Man.	Services	Labour	Capital	C	I	G	X	**Total**
Primaries	1,449,790	93,851	353,312	170,689	99,319	399,110	455,738	0	0	4,064,774	156,865	19,649	218,663	7,481,762
Chemical Products	196,295	367,927	0	13,071	13,109	320,710	120,259	0	0	120,066	124,093	12,764	109,199	1,397,494
Petroleum Products	72,542	13,356	5,670	113,565	25,490	60,805	455,780	0	0	186,466	23,067	26,866	4,226	987,834
Basic Metals	22,692	12,717	6,141	760,872	0	776,393	204,136	0	0	65,630	126,072	911	42,747	2,018,311
Non-Metallic Mineral Prod.	15,561	6,124	456	3,982	28,179	20,004	317,732	0	0	12,921	4,808	1	114,436	524,205
Agg. Manufacturing	143,748	79,507	5,628	33,440	40,604	1,394,113	725,209	0	0	1,103,668	1,595,301	161,288	649,762	5,932,268
Services	1,877,572	408,449	155,207	298,116	113,396	858,996	2,221,307	0	0	2,196,282	1,437,520	1,094,051	226,354	10,887,249
Labour	2,057,369	55,264	6,322	141,795	56,833	575,191	3,517,877	0	0	0	0	0	0	6,410,651
Capital	1,315,586	161,174	84,268	172,470	73,224	563,261	2,537,526	0	0	0	0	0	0	4,907,509
Households	0	0	0	0	0	0	0	6,410,651	4,907,509	0	0	0	0	11,318,160
Tariffs	26,908	14,722	236,060	191,115	43,675	417,802	131,480	0	0	0	0	0	0	1,061,763
Direct Tax	0	0	0	0	0	0	0	0	0	202,996	0	0	0	202,996
Indirect Tax	-58,127	-59,039	182,152	149,397	31,221	215,826	131,480	0	0	0	0	0	0	592,909
Government	85,035	73,761	53,908	41,719	12,454	201,977	0	0	0	0	0	0	0	468,854
Capital(Saving)	0	0	0	0	0	0	0	0	0	3,365,356	0	-50,772	153,144	3,467,728
Imports	303,698	184,403	134,771	119,196	30,376	545,883	200,205	0	0	0	0	0	0	1,518,531
Total	7,481,762	1,397,494	987,834	2,018,311	524,205	5,932,268	10,887,249	6,410,651	4,907,509	11,318,160	3,467,727	1,264,759	1,518,531	

Fig. 10.1: **Social Accounting Matrix Full Version India 1995**

11
Appendix B

Tab. 11.1: **Domestic Production Parameters** (α, β)

Sector	α	β
Primaries	0.391	4.105
Chemical Products	0.745	9.291
Petroleum Products	0.930	11.362
Basic Metals	0.549	11.764
Non-Metallic Mineral Products	0.563	7.344
Agg. Manufacturing	0.495	9.107
Services	0.419	3.484

Tab. 11.2: **Preference Parameters-Households(Domestic and Foreign) + Government ($\theta_i, \theta_{i,f}, \theta_i^g$)**

Sector	θ_i	$\theta_{i,f}$	θ_i^g
Primaries	0.366	0.074	0.016
Chemical Products	0.011	0.067	0.010
Petroleum Products	0.017	0.048	0.021
Basic Metals	0.006	0.061	0
Non-Metallic Mineral Products	0.001	0.067	0
Agg. Manufacturing	0.099	0.128	0.128
Services	0.198	0.069	0.865
Investment Goods	0.303	0.467	-0.04
Foreign Produced Goods	N/A	0.067	N/A

Tab. 11.3: **Laspeyres Results across Multiple Import Elasticities**

$\rho_{i,m}$	0.8	0.7	0.6	0.5
$\sigma_{i,m}$	5	3.33	2.5	2
Baseline				
Total Scale Effects(%)	0	+0.11	+0.17	+0.2
Total Composite Effects(%)	0	+0.03	+0.04	+0.05
Total Simulated Carbon Change(%)	0	+0.14	+0.21	+0.25
Experiment				
Total Scale Effects(%)	-0.16	+0.16	+0.31	+0.40
Total Composite Effects(%)	-0.13	-0.02	+0.04	+0.08
Total Simulated Carbon Change(%)	-0.29	+0.14	+0.35	+0.48

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