UNIVERSITY OF CAPE COAST

A DSGE MODEL ON CLIMATE CHANGE, INTEREST RATE, AND WELFARE IN GHANA

BISMARK MINTAH

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BY

BISMARK MINTAH

Thesis submitted to the Department of Economic Studies of the School of Economics, College of Humanities and Legal Studies, University of Cape Coast, in partial fulfillment of the requirements for the award of a Master of Philosophy degree in Economics

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature ……………….…………… Date ………………

Name: Bismark Mintah

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid on by the University of Cape Coast.

Principal Supervisor's Signature ……………………… Date ………………

Name: Dr. Adams Sorekuong Yakubu Adama

Co-Supervisor's Signature …………………………….. Date ………………

Name: Dr. Eric Amoo Bondzie

ABSTRACT

Given the scientific consensus that climate change is largely anthropogenic, it is essential to understand how human-induced activities are driving the externality of the century. To this effect, using a Dynamic Stochastic General Equilibrium (DSGE) model, this study sought to investigate the impact of economic activities and policies on climate change in Ghana. Despite its low emission levels, Ghana faces substantial climate change impacts, including flooding, earth trembling, and rising sea levels, necessitating immediate investment in sea defenses. The study's objectives were to examine the effects of monetary policy on climate change, find the link between environmental policy and climate change, understand the effects of a change in productivity on climate change, and to analyze the welfare implications of interest rate and environmental policy shocks on the average Ghanaian consumer. The findings reveal that changes in interest rates affect climate change through various transmission mechanisms, with lower interest rates leading to increased emissions. Positive environmental policies were found to effectively reduce climate change and improve mitigation efforts by incentivizing green technologies and sustainable industries. However, increased productivity, while economically beneficial, exacerbates climate change due to increased energy use. The study concludes that while positive environmental policy shocks improve consumer welfare, positive monetary policy shocks have the opposite effect, resulting in a 3 percent extra welfare loss compared to the gains from environmental shocks. These findings underscore the need for a balanced approach to economic growth and environmental sustainability in Ghana.

KEYWORDS

Climate Change

Monetary Policy

Interest Rate

Environmental Policies

Productivity

CO_2 Emissions

Dynamic Stochastic General Equilibrium

Welfare

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DEDICATION

To myself, good friends, and family

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LIST OF ACRONYMS

ARDL	Auto Regressive Distributed Lags
BoG	Bank of Ghana
CCDR	Country Climate and Development Report
CES	Constant Elasticity of Substitution
CGE	Computable General Equilibrium
CO_2	Carbon dioxide
COP	Conference of Parties
DFI	Development Financial Institution
DSGE	Dynamic Stochastic General Equilibrium
E-DSGE	Environmental Dynamic Stochastic General Equilibrium
EKC	Environmental Kuznets Curve
EUEST	European Union Emission Trading Scheme
FDI	Foreign Direct Investment
FINSAP	Financial Sector Adjustment Programme
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GMM	Generalized Method of Moments
GoG	Government of Ghana
GSGDA	Ghana Shared Growth Development Agenda
HFA	Hyogo Framework for Action
HGR	High Growth rate
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
KIF	Key Impact Factor

MESTI	Ministry of Environment, Science, Technology and Innovation
MGS	Macroeconomic Graphical Sensor
NCCAS	National Climate Change Adaptation Strategy
NCCP	National Climate Change Policy
NGFS	Network of Central Banks and Supervisors for Greening the Financial Systems
NK	New Keynesian
NOAA	National Oceanic and Atmospheric Admiration
PSTR	Panel Smooth Transition Regression
ROW	Rest of the World
SAARC	South Asian Association for Regional Cooperation
SDG	Sustainable Development Goals
SSA	Sub-Saharan Africa
STIRPAT	Stochastic Impacts by Regression on Population, Affluence, and Technology
UN	United Nations
UNFCCC	United Nations Framework on Climate Change

CHAPTER ONE

INTRODUCTION

Carbon dioxide emissions have surged since the industrial revolution in the 1950s. This has caused global temperature to rise exponentially and not showing any signs of slowing down. As a result, the climate as we know it is changing rapidly alongside its associated risks. Climate change is perhaps the central economic and social challenge of the 21st century (Economides & Xepapadeas, 2018). According to the assessment report of the Intergovernmental Panel on Climate Change (2014), scientists believe that the expansion of the greenhouse effect as a result of human activities is the cause of the global warming trend that has been noted since the middle of the 20th century.

Ghana is named in the World Bank Group's Climate Change Knowledge Portal (CCKP) as highly vulnerable to climate variability implying the need for studies that will improve mitigation effort. Given the consensus that climate change is anthropogenic, it is prudent to understand how economic policies influences human activities which influences climate change. Interest rate is known to have an impact on both consumption and production through money demand and cost of investment respectively. If there is a real impact of real interest rate on economic performance, it will affect consumption, production, and prices (Almahadin & Tuna 2019) which in turn affect climate change through CO_2 emissions.

The few climate-related studies in Ghana such as (Asante & Amuakwa-Mensah, 2014; Thurlow et al, 2015) have been on the impacts climate change exerts on key economic variables and indicators such as transportation, agriculture, health, and economic growth and sustainability in general.

In terms of welfare, the negative impacts of climate change and variability predominantly worsens the plight of the poor, who are mostly women and children (Asante & Amuakwa, 2014). However, welfare in terms of discounted future utility in the context of interest rate and climate change has not been studied.

A study on how interest rate affects climate change, and how climate change mitigation affect household discounted welfare will give unappareled insights to policymakers in Ghana on climate policy formulation. Therefore, this study seeks to examine how interest rate affect climate change, and how mitigation effort from this perspective affect household welfare in Ghana using a Dynamic Stochastic General Equilibrium (DSGE) Modeling approach.

Background to the Study

In the post 2015-development agenda, the discussions concerning sustainable development now includes the topic of climate change. (Dafermos, Nikolaidi, & Galanis, 2018). Global development at present seems to be operating under a non-negotiable paradigm as the stability of the climate and future emission reductions seem to be the most important challenges of the twenty-first century.

According to Abidoye and Odusola (2015), GDP growth in Africa decreases by 0.67 percentage points for every 1°C increase in temperature and Bernard (2012) emphasizes that although only 4 percent of the global annual greenhouse gas emissions is generated in Sub-Saharan Africa, the region is extremely prone to the devastating impacts of climate change, some of which are currently being experienced and reported.

The story of the effects of climate change on the Ghanaian economy and social structures is not different from the global trend if not worse as projected by the IPCC (2016) for developing economies. In a nation whose economy is based on climate-sensitive sectors like agriculture and mineral extraction, climate change is likely to impede economic development and poverty reduction efforts and exacerbate already pressing difficulties (Diao X, 2010). Millions of impoverished people now face a greater chance of severe crop failures, decreased agricultural output, hunger and malnourishment, water shortages, and the proliferation of infectious diseases due to climate change.

According to the Network for Greening Financial Systems (NGFS, 2018), the relationship between climate change and interest rate is bi-directional. This means climate change influences the conduct of interest rate while the setting interest rate also affect climate change. While the effect of climate change on interest rate has been widely studied globally, it is yet to be researched in the Ghanaian context. The effects of interest rate on climate change on the other hand is yet to receive the needed academic attention even though it is established that climate change is a human induced phenomenon. Given the anthropogenic nature of climate change and Ghana's vulnerability to the phenomenon, it is more prudent to understand how interest rate affect climate change through consumption and production to enable better policy formulation.

Academic enquiry on the subject of climate change in Ghana has largely been on how it affects welfare. Asante & Amuakwa-Mensah (2014) showed that the negative impacts of climate change and variability worsens the plight of the poor, who are mostly women and children. Thurlow et al (2015) also using a computable general equilibrium concluded that Climate change is found to always reduce national welfare, with poor and urban households and the northern Savannah zone of Ghana being the worst affected. Climate change and variability leads to an increase in gender welfare gap by 64.62 percent in northern Ghana (Adzawla et al, 2019). These studies however lacked the micro foundation-based nature of the phenomenon as data on emissions were employed to arrive at these conclusions.

For the Ghanaian government, determining the optimal way to address the adverse consequences of climate change and achieving low-carbon growth and development would be a challenging task. To evaluate climate change scenarios, uncertain policy options, and context-based solutions that take into account local and region al concerns and aspirations, a prompt reaction including all stakeholders in a collaborative process is required.

Statement of the Problem

Climate change is an externality that is unprecedentedly huge, intricate, and unpredictable for Ghana and continuing with business as usual could have detrimental effects on household welfare. Since the nation ratified the United Nations Framework Convention on Climate Change (UNFCCC) in the 1990s the nation has implemented a number of policies and infrastructures such the National Climate Change Policy (NCCP), the Green Ghana Agenda, and the sea defense along the coastal stretch of the country to mitigate the effect of climate change. With the exception of the Ghana Sustainable Banking Principles (2019) which incorporates environmental issues into financial stability discussions, all other climate adaptation and mitigation policies have largely been fiscal and geared towards welfare loss mitigation. This is partly due to the plausibility that central bank's primary objective of price stability and output growth are short-term whiles climate change is a long-term phenomenon. However, climate concerns are immediate concerns and they are also a source of financial risk and therefore falls under the purview of central banks (NGFS, 2018).

In line with national policy perspectives, studies on climate change in Ghana has also largely been fiscal and welfare centered with the findings all being negative (Asante & Amankwah-Mensah, 2014; Issahaku & Addulai, 2017; Adzawla & Kane, 2019; Koomson et al, 2022). The obvious question is, will a climate-induced study from the monetary perspective produce the same findings and if so, to what extent?

The real interest rate assumes an essential role in the economy, and its impact on CO_2 emissions is contingent upon how it influences real income, prices, and the potential for increasing or decreasing energy consumption, which in consequently affects CO_2 emissions (Çelik & Kaya, 2010). Sehrawat and Giri (2017) also showed that by altering the exchange rate, interest rate affect consumption through trade. Thus, interest rate affect economy through channels such as wages, prices, trade, and exchange rate. However, the degree to which such changes in aggregate consumption affect the level of CO_2 emissions and consequently climate change is yet to be answered, especially in a vulnerable economy like Ghana.

The effects of productivity on firm production have been vigorously studied since the classical ages, with both theories and empirical results showing a strong and positive correlation (Moomaw & Williams, 1991;

Limam & Miller, 2004; Tamura et al, 2006; Baltabaey, 2014; Foster-Mcgregor & Verspagen, 2017). With the consensus that climate is a human-induced phenomenon (Santini et al., 2018; Winter et al., 2010) stemming from production to meet consumption, the question again rises that, will increases in production due to increasing productivity levels have the same effect on climate change?

Against the backdrop discussed, a few questions rise?

1. To what extent will changes in interest rate affect climate change in Ghana?
2. Have government policies been effective in mitigating the effects of climate change?
3. Does changes in production levels due to changes in productivity affect climate change?
4. Will what be the implications of the changes in the environmental and interest rate policies on household welfare in Ghana?

This study therefore seeks to fill the research gap by investigating the effect of central bank's interest rate on climate change in Ghana by investigating how interest rate affect production and household consumption and also investigate how productivity and environmental policies will affect climate change using a Dynamic Stochastic General Equilibrium (DSGE) model. The study will also discuss how changes in the aforementioned policies affect household welfare? DSGE is preferred because it allows for the integration of forward-looking expectations, rational agents, and various types of shocks (e.g., monetary, fiscal, technology) into a dynamic framework. It is also micro founded in nature which means that they are grounded in individual economic behaviour and preferences which provide a more robust theoretical basis for macroeconomic analysis.

Purpose of the Study

The central objective of the study is to investigate how changes in interest rate affects climate change, and how such changes affect welfare in Ghana using a DSGE approach.

Research Objectives

The specific objectives of the study are to:

1. investigate the effects of interest rate on climate change in Ghana,
2. examine the effectiveness of environmental policies on climate change,
3. investigate the effects of a change in productivity on climate change,
4. analyze the welfare implications of changes in interest rate, and environmental policy on the Ghanaian consumer.

Research Questions

To achieve the objectives and purpose of the study, the research will be guided by the following queries:

1. How does interest rate affect climate change?
2. How effective are environmental policies on climate change?
3. How does changes in productivity affect climate change?
4. What is the impact of changes interest rate and environmental policies on household welfare?

Significance of the Study

It is anticipated that the findings of the study will be advantageous to Ghanaian economic policymakers and analysts. The result of the study will give cognizance to Ghana's climate change and clear direction for its mitigation which will affect the very fabric of the economy. In addition, the findings of the study will serve as a guide to the central bank's decisions on interest rate and inflation targeting as they provide some guidelines in policy formulation regarding the economy in relation to climate change. Given that inflation is also dependent on the interest rate, the study will help policymakers understand how interest rates mediate inflation targeting and climate change and how it affects the economy. All over, as climate change continues to receive the needed attention on the global stage, the findings of the study will serve as reference material that will provide guidelines for the central bank and economic policymakers in our country and the world at large. The study will add to the body of literature by serving as a basis for further research in the subject area.

Organization of the study

The study is organized into five main sections/chapters. The first chapter of the study gives a background of monetary policy and climate change. It also entails the statement of the problem, research questions and the objectives on which the study is built. The second section also gives a detailed review of the literature on monetary policy, climate change and other relevant variables. This will include both theoretical and empirical literature and how the relationship is peculiar to Africa and Ghana in particular. The third chapter gives an overview of the methodology used to analyze the work. It outlines the technique of estimations and also describes variables and sources of the study used for the study. The fourth section gives a detailed analysis the results and discussions. The last section gives a summary of results, study implications and also makes recommendations based on the analyzed results and discussions.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This section discusses the various definition, terms, conceptual framework and perspectives of literature existing on energy consumption, monetary policy and carbon dioxide emission. It analyzes the theoretical and empirical researches and previous evidence relating to monetary policy and climate change consistent or opposed to theory.

Theoretical review

The New Keynesian Models

The New Keynesian school of thought merged in the 1980s as a response to some perceived limitations of the traditional Keynesian economics. It sought to integrate microeconomic foundations into macroeconomic models while retaining Keynesian perspectives on the position of aggregate demand in shaping economic outcomes. One of the defining features of New Keynesian models is the incorporation of microeconomic foundations.

These models assume that economic agents, such as consumers and firms, are rational decision-makers who act to optimize their objectives subject to various constraints. Rational agents use available information, including knowledge of the underlying economic model, to form expectations about future economic conditions. This assumption of rational expectations allows for consistent predictions in the face of policy changes and economic shocks.

These models depart from the neoclassical assumption of flexible prices and wages. Instead, they assume that prices and wages are sticky, meaning they do not adjust immediately in response to changes in demand or supply conditions. The presence of sticky prices and wages gives rise to nominal rigidities, which contribute to economic inertia. These rigidities introduce short-term market imperfections, leading to fluctuations in output, employment, and inflation. As firms and workers adjust their prices and wages gradually, rather than instantaneously, output and employment may deviate from their long-run equilibrium levels. This feature explains why economies can experience short-run fluctuations, including periods of unemployment and suboptimal resource allocation. To model the process of price and wage adjustments, NK models often utilize various theoretical frameworks.

For instance, Calvo pricing and Taylor contracts are commonly used to represent the sluggishness of price and wage adjustments in response to economic shocks. Calvo pricing assumes that a fixed proportion of firms can reset their prices in each period, while Taylor contracts imply that wages are adjusted in proportion to changes in the aggregate price level. Another major proponent of these models is the incorporation of monetary policy in economic analysis. Central banks influence the economy by adjusting the nominal interest rate. However, the effectiveness of monetary policy is affected by the forward-looking behaviour of economic agents. This is because rational expectations allow individuals and firms to incorporate their expectations about future policy actions, which may influence their economic decisions.

Climate change is fundamentally driven by environmental externalities, where certain economic activities generate negative effects on the environment that are not directly accounted for in market transactions. It is also characterized by significant uncertainty, both in terms of the extent of future climate impacts and the effectiveness of mitigation and adaptation measures. Integrating climate change into NK models is essential to effectively address the challenges posed by global warming and the transition to a more sustainable economy. By incorporating environmental externalities, green investment, climate policies, and uncertainties, these models can provide insights into the complex interactions between climate change macroeconomic outcomes. Such efforts will aid policymakers in designing effective climate policies that promote both environmental and economic stability.

The G-Cubed model

With a focus on global warming policies, the G-Cubed model was developed to add to the ongoing policy debate on environmental regulation and international trade. However, it has many features that makes it useful for addressing a variety of issues in environmental regulation and macroeconomic and microeconomic policy questions. It is a global model that includes sectoral detail and significant regional disaggregation. Furthermore, trade and financial markets bind nations and regions together both temporally and intertemporally.

Similar to MSG2, G-Cubed has a solid basis for analyzing macroeconomic policies for the immediate term as well as long-term growth and alternative macroeconomic policies. Intertemporal fiscal constraints are imposed on individuals, governments, and countries (the latter due to the accumulation of foreign debt). Forward-looking behavior is integrated into investment and consumption choices to account for these limitations. Moreover, G-Cubed has a significant amount of sectoral detail, unlike MSG2. This makes it possible to analyze environmental regulations, which typically affect tiny economic segments the most.

G-Cubed can be used to analyze the long-term costs of alternative environmental laws while also taking the macroeconomic effects of these policies into account over time. This is achieved by combining sectoral detail with the macroeconomic aspects of MSG2.

The reaction of fiscal and monetary authorities across nations can have significant implications in the short to medium term, which can be a long time recognizing the long lags in the accumulation of physical capital and other assets. All things considered, the model aims to bridge the gap between macroeconomic models and computable general equilibrium models by combining the best aspects of both methodologies.

Cap-and-trade theory

In many political jurisdictions, cap-and-trade has been the focal point of policy discussions over how to lower greenhouse gas emissions. The government sets a ceiling, or "cap," on the total emissions of one or more pollutants from a group of regulated organizations for a predetermined compliance period in a cap-and-trade regulation. (McAllister, 2009).

Next, through auction or allocation, the government issues tradable allowances, each of which represents the right to emit one unit of pollution, to regulated organizations. Regulated enterprises are required to demonstrate that they have enough allowances in place to offset the pollution units they have released at the end of the compliance period. To help reach its emissions reduction targets under the Kyoto Protocol, the European Union implemented a cap-and-trade program known as the EU Emissions Trading Scheme (EU ETS), which covers its largest carbon dioxide emitters.

In addition, China, New Zealand, Australia, and South Korea have implemented cap-and-trade schemes to cut greenhouse gas emissions. Polluters have market incentives to lower their carbon emissions in order to sell emissions permits or refrain from purchasing more ones when there is a "price on carbon." Theoretically, cap-and-trade regulations are more economical than direct regulations, which frequently call for similar-type polluters to cut their emissions to a comparable extent or using comparable methods (Burtraw & Swift 1996).

Individual polluters have flexibility in choosing whether, when, and how to cut their emissions by using cap-and-trade. An organization facing high costs for reducing emissions may opt to acquire allowances from another with more affordable charges, therefore decreasing the total compliance costs per unit of pollution. Pollution taxes, like cap-and-trade, impose a cost on pollution and force polluters to pay for each unit of emissions they create. However, a significant distinction is that in a cap-and-trade system, the government establishes the maximum pollution level (the cap) and market participants respond by discouraging pollution.

The Environmental Kuznet Curve (EKC)

The Environmental Kuznet Curve (EKC) is a theoretical concept that suggests a relationship between economic development (measured by per capita income or GDP) and environmental degradation (Kijima et al. 2010). Kuznets (1955) serves as its foundation. Since Panayotou (1993) first used the term "Environmental Kuznets Curve," Kuznets' theory has become progressively apparent. According to the EKC theory, environmental quality first declines as a nation grows economically until reaching an optimum level, at which time it starts to increase. The environmental effects of the early phases of economic development will be corrected and offset once economic growth reaches a certain level (Sun, 1999).

The EKC suggests that environmental quality initially worsens as a country's income and economic development increase but then improves after reaching a certain level of economic growth. In other words, it proposes an inverted U-shaped curve depicting the environmental impact as a function of economic development. The general idea behind the EKC is that in the early stages of economic development, countries prioritize economic growth and industrialization, often leading to higher pollution levels and environmental degradation. It demonstrates how, at some point, economic expansion may improve environmental quality. (Niu et al., 2014). The following components according to Stern (2004) may be employed to explain the EKC;

1. Output scale input rates are the expansion of output in relation to production range and technological state
2. The degree of pollution intensity varies throughout industries, and production range usually fluctuates as economies expand
3. Variations in input heterogeneity result in the substitution of less ecologically damaging inputs for more destructive ones, and vice versa
4. Technology advancements may lead to reductions in pollution through specific emission modifications in input per unit.

However, as countries reach higher levels of income and development, they become more aware of environmental issues, invest in cleaner technologies, and implement more stringent environmental regulations. These efforts ultimately lead to improvements in environmental quality, as measured by indicators such as air and water pollution levels or carbon emissions. In the present study, the EKC implies that global economy has developed to a point where environmental concerns are now incorporated into developmental issues.

The relationship between the EKC and climate change has been a subject of debate. While the EKC suggests that environmental degradation should eventually decrease with economic growth, it is crucial to understand that climate change is a global issue and cannot be addressed by relying on the EKC hypothesis. Critics argue that the EKC does not adequately capture the complexity and urgency of climate change. Climate change is a global problem that requires collective and immediate action from all countries, regardless of their economic development stage. Waiting for wealth to increase before taking substantial climate action may lead to irreversible damage and severe consequences for future generations.

Potters Theory

The Porter hypothesis also postulates that innovation can have a positive influence on emission reduction. This is not because of FDI inflows, but because of regulations, that bring cost reducing innovation (Levinson and Taylor 2008). So, if you take the developed countries which have more stringent regulations, there are incentives for innovation.

These innovations reduce the costs for production by improving productivity and therefore outweigh the comparative advantage between developed and developing countries, created by the difference in the stringency of environmental regulations (Porter and van der Linde 1995). Porter and van der Linde (1995) call this the 'innovation offsets', which means that these innovations "can not only lower the net cost of meeting environmental regulations, but can even lead to absolute advantages over firms in foreign countries not subject to similar regulations" (Porter and van der Linde 1995).

Overview of Ghana's Monetary Policy

Just as with central banks from other countries and economies, the implementation of monetary policy has evolved through various phases over time. The evolution of monetary policy in Ghana has gone from monetary targeting regimes, where both direct and indirect instruments are used, to the current inflation targeting regime. Price stability has always been the primary goal of monetary policy over the last decades, even if the level of commitment to achieving monetary policy's overall goals has shifted little over time. There has been a substantial shift in monetary policy instruments in reaction to developments in the financial sector as well as global challenges.

As monetary policy capabilities have improved, more indirect and market-oriented instruments have been invented and used (Yahya, 2001). In 1992, Ghana's central bank switched from using direct monetary policy instruments to using indirect monetary policy instruments. In 1988, as part of a Financial Sector Adjustment Program (FINSAP), a deliberate shift in methodology was implemented. By 1992, institutional structures for the indirect monetary management system had been established, along with the deregulation of interest rates and credit. The framework for monetary policy activities served as the foundation for the IMF's financial programming approach. Broad money served as the intermediate goal and high-powered money as the operational goal.

The definition of the money supply was modified in a number of ways to take into consideration new financial assets that surfaced as a result of the liberalization and innovation process and functioned as close substitutes for monetary assets. The main assumption which underlies this framework was that there should be a stable velocity of money and money multiplier (there should exist a stable relationship between ultimate targets and intermediate targets of monetary policy and also between the intermediate targets and operational targets of monetary policy). The different monetary policy measures implemented in Ghana since the Economic Recovery Program/Structural Adjustment Program have shown mixed results. For the majority of the review period, the principal limitation to monetary policy has been the need to meet unanticipated fiscal demand.

Yahya (2001), for instance, indicated that there were a series of seasonal injections of liquidity from cocoa loans since the latter quarter of 1994, which became one of the main setbacks to the dictation of a disciplined monetary policy in Ghana. Major alterations in the financial space of Ghana immediately after the FINSAP, coupled with the introduction and spread of technology, assisted in deepening the financial system with a supply of financial instruments (Bawumia et al. 2008). The money market became unstable due to the introduction of new financial instruments, transaction types, or market players.

As a result, the linkages between intermediate (monetary aggregate) and final (inflation) aims are becoming less predictable and reliable. The Bank of Ghana Act 2002 was passed to offer the central bank operational independence as a result of the cost of inflation and a greater commitment to fighting inflation. This is predicated on the notion that price stability is monetary policy's best long-term contribution. The Bank of Ghana adopted the current inflation targeting regime as a result of the reorientation of the Bank of Ghana Act toward price stability as well as the poor performance of the previous monetary targeting policy framework. Ghana was the second country in Sub-Saharan Africa to adopt an inflation-targeting framework, following South Africa.

Climate change in Ghana

Ghana's economy is based mostly on agriculture, with smallholder farming providing the majority of the country's income. Because these farmers mostly use antiquated technology, crop yields are low and rural poverty is prevalent. Gold and offshore crude oil are among the abundant mineral resources found in Ghana. However, mining does not create a lot of jobs in Ghana, even if it contributes significantly to export revenues. The majority of nonfarm sector workers are employed in light industries and informal services and reside in the nation's rapidly developing metropolitan regions.

Ghana's economy is growing rapidly, and the majority of the nation's higher-value, expanding industries are concentrated around or close to Accra, the coastal capital. The nation's energy resources, which mostly rely on the Akosombo hydropower dam located inside the Volta River Basin, are under a great deal of strain due to urban expansion. Ghana's agricultural landscape is highly variable, with rainfall often decreasing from south to north. The extreme southwest has the highest annual rainfall, with over 2000 mm falling in the forests area. In contrast, less than 1100mm of rain fall annually in the far Northen savannah region. Ghana is divided into four agroclimatic zones;

the coastal, forest, transitional, and savannah zones, which run from the south to the north of the nation The Forest Zone produces almost all of Ghana's main agricultural products, such as lumber and cocoa, and here farmers typically earn more than they would elsewhere in the nation.

On the other hand, the drier northern Savannah zone is home to certain higher value crops like irrigated vegetables as well as subsistence staples like drought-resistant sorghum. In the far north, pastoralists also depend on their livestock. Ghana's primary food-producing region is the Transitional Zone, which is situated between the savannah and forest regions. Lastly, the coastal zone primarily cultivates horticulture and cereals for the metropolitan markets in the south. Due to the diversity of agroclimatic conditions in the nation, it is anticipated that the effects of climate change will differ significantly amongst regions.

Definition of Terms

Interest rate

The monetary value of resources used over a given period of time by a borrower or debtor to a lender or creditor is measured by interest rates. (Fabozzi & Modigliani, 2003). According to Goedhuys (1994), interest rates are the overall sum of all financial claims and assets, including bills of exchange, government bonds, corporate shares, call loans, and debentures. There are two types of interest rates: nominal and real. The rate without an inflation adjustment is known as the nominal interest rate. The relationship between the interest rate and the amount lent is known as the nominal interest rate on loans; on the other hand, the real interest rate takes inflation into account. The unit of measurement for the real interest rate is purchasing power.

Climate change

Climate change pertains to the rise in mean worldwide surface temperatures primarily resulting from human activity-induced increases in greenhouse gas concentrations, specifically carbon dioxide (CO_2), within the earth's atmosphere. (Kankam-Yeboah, Amisigio, & Obuobi, 2013). According to Barros et al. (2016), climate change can also be defined as the average weather or, to put it more scientifically, as the statistical depiction of pertinent quantities' mean and variability over time spans varying from months to millions or thousands of years.

Greenhouse

The ability of greenhouse gases in the atmosphere to retain heat released from the earth's surface is known as the greenhouse effect (Pidwimy, 2006). The average temperature of the world would be 3ºC lower without the greenhouse effect, which functions as a thermal blanket to regulate the planet's surface temperature (Pidwimy, 2006). The current rapid warming of the earth and changes in global weather patterns, especially the rise in temperature of the earth's atmosphere, increased precipitation, rising sea levels, and windy activities, are the results of anthropogenic modification of this natural process, which raises the levels of heat-trapping gases (greenhouse gases) in the atmosphere. This phenomenon is known as climate change. By absorbing and re-emitting long wave energy or radiation, the greenhouse effect causes the atmosphere to trap more heat energy at the earth's surface and within the atmosphere.

Productivity

Productivity is the quantity relationship between input and output, according to Iyaniwura and Osoba (1983). This implies that, in production, output depends on what inputs are used in the production process. The resources that are invested to produce an output, such as capital and human resources, are called inputs. In general, productivity is the efficacy and efficiency with which resources are employed in the production of goods and services.

Household Welfare

Household welfare refers to the economic and social well-being of a household or a family unit. It encompasses various factors that contribute to the overall quality of life and standard of living of the people within that household. Key components of household welfare include: income and employment, basic needs, healthcare, education, housing, social services, safety and security, financial security, nutrition, social and community integration, etc. Household welfare is a multidimensional concept that varies from one household to another and from one country to another. However, in the context of this study, welfare refers to consumption discounted utility. The principle discounted utility provides a framework for understanding how individuals value consumption over time and make choices that balance present and future preferences and needs. Thus, how better off is the average individual over time not just in the present period.

Empirical Studies on the Effects of some Macroeconomic Variables and CO_2 Emissions

Though essentially a physical process involving fluctuations in climatic variables, climate change has an impact on social, economic, and environmental systems as well as the security of food, water, and health. (Christensen, Carter, Rummukainen, Amanatidis, 2007). Household welfare is ultimately affected by the impact of climate change on these socioeconomic outcomes, albeit indirectly. Indeed, a variety of welfare variables, including consumption, productivity, and health, have been used in studies on the impact of climate change on welfare (Skoufias & Vinha, 2013). This is rational particularly for agrarian economies like those in northern Ghana, where erratic and unpredictable weather patterns are a prominent characteristic of the world's most productive agricultural region and a significant source of danger to the long-term economic viability of these countries (IPCC, 2007).

Globally, about 100 million people are expected to fall back into poverty by 2030 as a direct result of climate change (Hallegate, Bangalore, Bonzanigo, Fay, Kane, Narloch, & Vogt-Schib 2016). The majority of these in SSA are expected to be the marginalized who live in the driest and wetted parts (Azzari and Signorelli, 2020). When assessing the impact of climate change on productivity, production, and farm income, econometric estimations, the Ricardian model, and the hedonic model are typically employed.

According to Skoufias and Vinha's (2013) analysis of the impact of climate shock on the welfare of Mexican households, individual residing in dry localities are the only ones impacted by climate change. The research reveals a non-significant effect of climate change on food and non-food consumption when all the samples are examined combined. They therefore draw the conclusion that the impact of climate change on household welfare is correlated with the characteristics of the local climate.

Kabubo-mariara, Malwa and Falco (2017) investigate the effects of climate change on food production and poverty in Kenya using panel data. Their analysis showed a nonlinear relationship between weather conditions, food production, and the likelihood of food insecurity. Up to an ideal point, their research also reveals a beneficial relationship between humidity and food output. Additionally, they demonstrate that adopting new technologies and gaining access to new markets are viable approaches for mitigating and adapting to climate change.

Mulatu, Eshete, and Gatiso (2016) find that global warming has a detrimental influence on Ethiopian households' welfare and agricultural productivity using a Computable General Equilibrium (CGE) model. They do find that Ethiopia's GDP will decline by 4.5 percent as a result of climate change. A panel data analysis is used by Schlenker, Lobell, and Res (2010) to show that climate change will have a negative impact on Sub-Saharan Africa's agricultural output. As an illustration, their findings show that by the middle of the century, the production of crops like corn, millet, sorghum, cassava, and groundnuts will decline at rates of -22, -17, -18, -8, and -17, respectively. Furthermore, their analysis suggests most of the impact will be felt on African nations with large agricultural yields. Hirvonen (2016) investigates the impact of per capita temperature. He discloses that a 1 percent rise in the mean monthly temperature in Tanzania is associated with a 4.9 to 5.5 percent decrease in the country's average per capita consumption.

Marx and Espagne (2019) employ a non-linear model to investigate how climate variability affects Vietnamese households' income. They show that there is a negative correlation between annual income and the number of days with a temperature above 33 percent. The researchers demonstrated that a household's annual income diminishes by 1.3 percent for every additional day that the temperature rises beyond 33 degrees Celsius. They demonstrate how, in some parts of Vietnam, global warming could result in a 100 percent loss of household income by 2009 using a climate change scenario. Using a CGE model, Amdt, Asante, and Thurlow (2015) assess the implications of climate change in Ghana. They conclude that Ghana's economy is negatively impacted by climate change, especially in the agriculture sector. In fact, their models indicate that Ghana's GDP will decline by 1.9 percent due to climate change. Still, they show that these effects differ significantly between scenarios and geographical areas.

According to Yaro's (2010) study, the effects of climate change on livelihoods are more severe and frequent than in the past. The northern savannah is particularly affected, as agriculture suffers greatly and activities that rely on natural resources are put at risk due to the resulting degradation. The production of food, the cultivation of cocoa, oil palm, cattle, fisheries, and irrigated farming are the primary uses of agricultural land in Ghana (Benneh et al., 1994). As a result, the effects of climate change on the agricultural sector could be substantial.

Despite the fact that climate change poses a threat to every region of Ghana, its effects on households in the north may be particularly severe because of the region's increased economic and physical susceptibility. The area is classified as part of the savannah ecological zone, which is distinguished by a unimodal distribution of rainfall, an annual average rainfall of 1000 mm, and a mean monthly temperature that varies from 36 °C in March to 27 °C in August. The main sources of income for the people living in the savannah belt include agriculture, raising livestock, dry season gardening, processing Parkia biglobosa (dawadawa) and Vitellaria paradoxa (shea) nuts, small-scale trading, and the manufacture of charcoal (Yaro, 2010). These studies show that the welfare of households is predominantly negatively impacted by climate change.

Numerous academics have studied the relationship between GDP and CO_2 emissions. Since some studies have a very narrow focus and some of the nations included in the study have extremely variable data, the agreement regarding a definitive relationship is not entirely unambiguous. Moreover, as previously mentioned, part of the research finds correlations between energy use and CO_2 emissions in addition to looking for a relationship between GDP and CO_2 emissions. A few findings regarding classifications of nations are looked at below;

Khochiani and Nademi (2020) aimed to investigate, using the wavelet correlation and partial wavelet coherence techniques, the connection between CO_2 emissions, energy use, and economic expansion in the three most polluting countries in the world: the United States, China, and India between 1971 and 2013. According to the analysis, there is a positive correlation between the GDP and energy consumption and CO_2 emissions for the United States across all frequencies. For China, there is a strong positive correlation between GDP and short-term energy consumption and CO_2 emissions. The study did discover a substantial positive correlation between India's GDP and CO_2 emissions; however, it is unclear how the country's energy consumption and GDP are related. Despite the ambiguity, the data obtained empirical results supported the pollution haven theory.

Based on an array of annual data from 1997 to 2014, Mitić et al. (2017) investigated the relationship for 17 transitional economies between real GDP and CO_2 emissions. Both the Dynamic Ordinary Least Squares (DOLS) and Fully Modified OLS (FMOLS) were the methods used for the analysis. The findings show that there is a statistically significant long-run cointegrating relationship between CO_2 emissions and real GDP. The robustness of the estimated results was validated by close values of the long-run coefficients for every estimation. The authors suggested that in order to achieve simultaneously economic growth and future reductions in CO_2 emissions, transitional economies should try to implement new mechanisms and instruments for the purpose of reducing CO_2 emissions, such as environmental taxes, emissions-trading schemes, and carbon capture and storage. They should also follow global policy incentives in this regard.

In order to forecast Africa's total CO_2 emissions using non-assumption driven bidirectional long short-term memory based on a panel data model, Ameyaw and Yao (2018) conducted a study that examined the relationship between GDP and CO_2 emissions. According to the study's causality analysis, there is a unidirectional causal relationship between GDP and CO_2 emissions.

The study suggests that the chosen West African nations diversify into alternate energy sources with reduced greenhouse gas emissions in line with the results obtained. This will support long-term economic growth while also helping to reduce CO_2 emissions. Additionally, considering the long-term co-integration links shown by this study, recommendations for the development of clean renewable energy and energy efficiency should be at the center of African nations' efforts to achieve sustainable economic growth. Ameyaw and Yao (2018) further close a gap in the literature by developing an algorithm that projects future emissions in the chosen nations and demonstrates that emissions will climb in tandem with GDP growth.

Jebli and Hadhri (2018) looked at the dynamic causation relationship between real gross domestic product, energy use, and transportation-related carbon dioxide (CO_2) emissions in a different study. The study looked into these relationships for the top ten international tourist destinations between 1995 and 2013 using the Granger causality test technique and the vector error correction model. The study's conclusions show that there is a unidirectional causal relationship between CO_2 emissions and economic growth without feedback, as well as bidirectional relationships between energy use and economic growth, international tourism and economic growth, and energy use and economic growth. The study appears to indicate that tourism boosts GDP and energy consumption, which in turn raises CO_2 emissions. This suggests that tourist destinations should switch to greener energy sources.

Also, Andreoni and Galmarini (2016) used data from the 1995–2007 period to do a decomposition study of energy-related CO_2 emissions for 33 different world countries. The study examined the effects of modifications to abatement technologies, fuel quality, and fuel switching; adjustments to the structure and efficiency of the energy system; the relative ranking of a nation with respect to the generation of its total GDP (Gross Domestic Product); and variations to the overall economic activity specific to the nation using the Index Decomposition Analysis. According to the report, the primary cause of the rise in energy-related CO_2 emissions has been economic expansion. However, the rapidly expanding roles that these economies are playing in the global economic landscape have also played a significant impact in rapidly developing nations like China and India. It was discovered that increases in energy efficiency were the primary factor lowering the overall rise in CO_2 emissions across all of the study's nations involved.

Dong et al. (2019) examined the key impact factors (KIFs) of carbon dioxide (CO_2) emissions at the regional and global levels using an unbalanced panel dataset of 128 nations and the stochastic effects by regression on population, affluence, and technology (STIRPAT) model covering the years 1990–2014 to assess the efficacy of renewable and non-renewable energy sources. The study used a number of econometric methodologies which provide a slope heterogeneity and cross-sectional dependence due to the potential for these phenomena. According to the study's overall estimations, the factors that have the greatest influence on CO_2 emissions globally are economic growth, population density, non-renewable energy, and energy intensity; on the other hand, the factors that have the greatest influence at the regional level differ depending on the region and the estimator. The study's findings also demonstrated that using renewable energy can lower global CO_2 emissions. Renewable energy had a significant and negative impact on CO_2

emissions only in two regions at the regional level: South and Central America and Europe and Eurasia. These results may have been influenced by the proportion of renewable energy consumed in the primary energy mix. Eventually, the study's conclusions showed that different regions had different causal correlations between the factors.

In a similar vein, Saleh and Abedi (2014) looked at the reciprocating causal relationship that exists between the the per capita carbon dioxide emissions and the real gross domestic product per person of various nations. In order to conduct the study, the World Bank member nations were split up into various groups and the Vector Auto-Regression Model with the micro panel application was utilized. The findings showed a bidirectional causal link for three groups of nations between GDP and CO_2. Also, for subgroups of nations with high average economic growth rate (HGR) and the rest of the world (ROW), there was a single causal effect from GDP on carbon dioxide volume. It follows that cooperation between the HGR and ROW group of the countries with industrialized countries is essential to achieving the global goals of reducing the emissions of polluting gases. Moreover, Iran's heterogeneous non-causality test revealed that the nation's economic activities are having an increasingly destructive effect on the environment.

Over the annual period 1995–2013, Chaabouni and Saidi (2017) examined the causal relationship between health spending, GDP growth, and carbon dioxide (CO_2) emissions for 51 countries (categorized into three groups: low-income countries, lower- and upper-middle-income countries, and middle-income countries). This relationship was examined using the generalized method of moments (GMM) and dynamic simultaneous-equations models. The study's primary findings demonstrated a causal connection between the three factors. The research findings further indicated that, for the three sets of estimates, there was a bidirectional causal relationship between GDP per capita and CO_2 emissions as well as between health spending and economic growth. The study also discovered that, with the exception of low-income nations, there is a unidirectional causal relationship between CO_2 emissions and health spending.

Numerous research included in this review of the literature have looked at the correlation between GDP and energy usage. As was previously indicated, some of these studies discovered multivariate correlations between GDP, CO_2 emissions, and energy consumption, suggesting that rising GDP may result in higher energy use. In particular, a study by Afridi et al. (2019) looked at the effects of energy consumption, urbanization, trade openness, and per capita income on CO_2 emissions among nations that are members of the South Asian Association for Regional Cooperation (SAARC). The study found that there is a positive correlation between energy consumption and CO_2 in the SAARC countries, utilizing annual data from 1980 to 2016 and panel data methodologies. The study's findings additionally show that GDP and CO_2 have an N-shaped relationship, which may indicate that SAARC nations' ongoing reliance on inefficient and environmentally harmful energy sources could lead to higher CO_2 emissions even in the absence of GDP development.

Likewise, Mouhd Saudi et al. (2019) used yearly data spanning the years 1980–2017 in an effort to examine the roles played by non-renewable energy, renewable energy, and technological innovation in evaluating the environmental Kuznets Curve in Malaysia. Their study used advanced econometrics to support their research objectives, and as a result, they employed the auto regressive distributed lags (ARDLs) bound testing technique to determine whether the variables had a long-term relationship. Their study's findings support the long-term validity of the relationship between Malaysia's carbon dioxide emissions and economic growth, non-renewable energy sources, and technological innovation. The study's empirical results also show that, whereas the use of nonrenewable energy and economic expansion significantly and favorably affect carbon dioxide emissions, consumption of renewable energy and technological innovation have a significant and negative impact on carbon dioxide emissions. The findings also validate the presence of an inverted U-shaped curve in Malaysia.

A study on the existence of the environmental Kuznets curve (EKC) was conducted by Nazir et al. (2018) from Pakistan's perspective between 1970 and 2016. The autoregressive distributed lagged (ARDL) bound test was utilized in the study to examine the long-term relationship between the variables. The study used the dynamic ordinary least squares technique to test for robustness. To probe into the short- and long-term causal relationships between the variables, the Granger causality test was used. Pakistan's EKC theory is supported by the experimental findings of the ARDL bound test method. The results of the causality test demonstrate that although the relationship between CO_2 emissions and the other variables is unidirectional, the relationship between energy use and CO_2 emissions is bidirectional. The EKC hypothesis appears to be confirmed in the nations where it is validated, as seen by the unidirectional causality from other variables toward CO_2 emissions. According to these results, the regulatory bodies should increase their funding for various innovative energy initiatives that could aid in mitigating the effects of climate change.

Azlina et al. (2014) examined the dynamic link between income, energy use, and carbon dioxide (CO_2) emissions in Malaysia using time-series data spanning from 1975 to 2011. The EKC hypothesis was further attempted to be validated in this investigation. By using a multivariate model that included income, carbon emissions, energy consumption in the transportation sector, structural changes in the economy, and the use of renewable energy, the empirical evidence verified the co-integration analysis result, which indicated a long-term relationship between the variables. The study also discovered that income, energy use, and the utilization of renewable energy are all Granger-caused by emissions. Additionally, income is a Granger-cause of both energy consumption and renewable energy usage.

In the case of road transportation, Granger-causes of energy consumption are structural change and renewable energy use. Chiu (2017) examined the relationship between the CO_2-income nexus and real income, energy, and investment for 99 nations spanning the years 1971 to 2010 using the panel smooth transition regression (PSTR) model. The study observed that, in the entire sample, CO_2 emissions rise first and more quickly as real income increases, but after that, their rate of increase begins to slow down. The composite results of three income groups also confirm the EKC theory for CO_2 emissions. The study's findings also suggested that reducing energy consumption, improving the use of clean energy, and increasing energy efficiency might all help to mitigate the effects of real income on CO_2 emissions. In addition, the study found that CO_2-income interactions varied throughout nations with distinct energy trading conditions and income levels, suggesting that there is no one-size-fits-all solution.

A stock-flow-fund ecological macroeconomic model was used by Dafermos, Nikolaidi, and Galanis (2018) to study the relationship between climate change, financial stability, and monetary policy. The study found that damages from climate change decreases;

i. consumption and investment
ii. consumers' desire for regular corporate bonds
iii. the potential output derived from labor (influenced by labor force and labor productivity) and
iv. potential output elasticity of capital (which is affected by capital stock and capital productivity)

The findings also suggested that climate change damages directly affect the rate of capacity utilization (because the growth rate of output is not always the same as the growth rate of capital-determined output) and the profitability of firms (since profits are affected by economic growth and the climate-induced depreciation of capital). Both variables affect the desired investment of firms. Added to that, since the growth rate of output does not always correspond with the potential output elasticity of labour, climate change affects the rate of employment.

The relationship between and combination of monetary and climate policy was studied by Chen, Pan, Huang, and Bleischwitz (2021) using an Environmental Dynamic Stochastic General Equilibrium (E-DSGE), offering insights to central banks contemplating their involvement in the climate change issue. First, the main conclusions were that monetary policy can be influenced by climate policy because price level and inflation, which are monetary policy's primary targets change when monetary policy is combined with various forms and degrees of effectiveness (stringency) of climate policy. Second, when the current climate policy is taken into account within the framework of analysis, the reaction coefficient in the conventional Taylor rule of monetary policy can always be better calibrated to enhance welfare. Optional coefficients exist if the economy is dominated by the cost-push shock. The ideal coefficients' value can be influenced by the nature and efficacy of climate policies. Lastly, by including the emission gap objective in the monetary policy rule and placing the new target's reaction coefficient within a certain range, the economy's well-being can be improved.

In all of these discussions, a key question is how can climate change be mitigated and key insights from literature includes;

Determining a carbon price: Due to negative externalities and other market imperfections, markets are unable to fairly value the consequences of greenhouse gas emissions on the environment. In line with the polluter pays concept, changing market pricing through the introduction of a Pigovian tax that internalizes the external costs of greenhouse gas emissions may help the necessary reduction of these emissions in a way that is both cost-effective and technologically neutral. In actuality, this result could be attained by enacting an emissions trading scheme or a carbon tax. In order to address market failures, both policies might increase the price of emissions to the point where they fully pay the societal costs of their negative externality. A trading plan defines a limited volume of items per period and lets the market determine their price, whereas a tax sets higher prices and lets the market determine the desired volumes.

However, it is important to note that pricing externalities will not serve as a panacea for all of the socioeconomic issues caused by climate change. As stated by Stern and Stiglitz (2021), it is a fundamental error to start the study of climate change with the assumption that the economy is efficient aside from the mispricing of pollution, They make reference to a number of issues, including imperfect capital markets with credit rationing that results in underinvestment in climate-neutral technologies because these only offer uncertain returns, and moral hazard, which arises when economic agents expect that large climate-related losses might be covered by the government. Again, there ought to be experimental means of incorporating carbon markets into the mainstream economy and making them accessible to traditional banking and legal frameworks.

One way to lessen climate change has also been identified: global economic disparities. Climate change is influenced by global economic imbalances. Bowen, Mattia, and Stern (2010) have succinctly argued that the biggest challenge of the twenty-first century is climate change, and that the root of the problem is global marker failure, which needs to be addressed in tandem with global economic imbalances and debt. The authors argued that the world should transition to a low-carbon economy in order to reduce carbon emissions. They pointed out that if things continued as they are, there will probably be a concentration of greenhouse gases that cause temperatures not seen in tens of millions of years, with obviously dire consequences.

According to the researchers, the current annual emissions of greenhouse gases amount to roughly 47 billion metric tons of carbon dioxide equivalent. They contended that in order to avoid climate change and have a 50 percent chance of keeping the global temperature increases below 2 degrees, emissions must decrease down to approximately 44 billion metric tons by 2020, well under 35 billion metric tons by 2030, and well under 20 billion metric tons by 2050. The authors emphasized that in order to address the market failure brought on by greenhouse gas emission externalities, significant and ongoing investment in emission reduction as well as carefully crafted policies are urgently required. Delays are risky because emission fluxes contribute to rising greenhouse gas concentrations, which are difficult to lower (Brown et al., 2010). Africa is a prominent example of negative external effects, or the externalization of costs, as its contribution of greenhouse gas emissions is less than 4 percent of the global average, despite the continent suffering the most from its impacts. This constitutes a paradox.

Utilizing agricultural technologies to lower or limit high food importation from foreign nations while also increasing domestic food production in order to minimize import taxes (World Business Council for Sustainable Development, 2009). Offering tax breaks and advantageous import duties on technologies to support emission-reducing initiatives.

Theoretical Framework

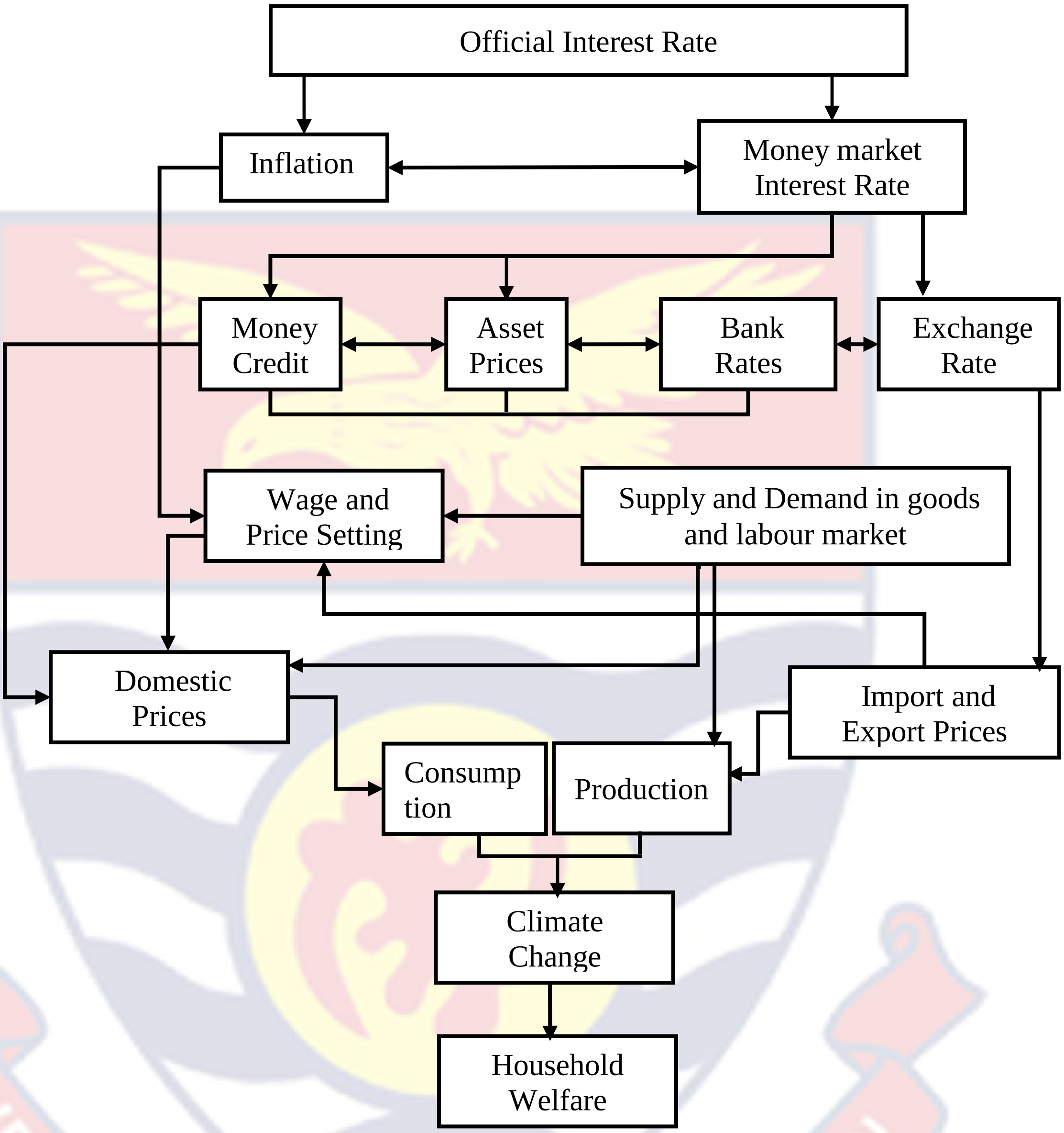


Figure 1: Theoretical framework showing the transmission mechanism of how interest rate affects climate change and welfare.
Source: Author's construct

Figure 1 above is the theoretical framework showing the transmission mechanism of how interest rate affects climate change and welfare in Ghana. The central bank levies interest and supplies money to the banking sector (Mayer & Schnabl, 2021). The central bank has complete control over this interest rate due to its monopoly on money issuance. Money-market interest rates are directly impacted by changes in official interest rates, while lending and deposit rates—which banks set for their clients—are indirectly impacted (Matemilola et al., 2015). This means that the policy rate serves as a key benchmark that influences the cost of borrowing and lending in the money market, leading to adjustments in short-term interest rates. In other words, medium- and long-term interest rates are influenced by expectation of upcoming official interest rate increases. Specifically, market assumptions regarding the future direction of short-term rates influence longer-term interest rates.

In addition to influencing price movements, monetary policy can also direct economic agents' expectations of future inflation. Hansen et al. (2019) suggest that inflation expectations are consistent with central banks' goals. Expectations of price stability are strongly anchored by a highly credible central bank. In this instance, economic agents are not required to lower their prices out of concern for deflation or increase them out of fear of rising inflation.

The effects of monetary policy operations on the financing conditions in the economy and on market expectations may lead to changes in the values of assets (such as stock market prices) and the exchange rate. Changes in the currency rate can directly affect inflation because imported goods are immediately consumed, but they can also have indirect consequences. Interest rate changes have an effect on the savings and investment decisions made by both individuals and companies. Interest rates have a favorable impact on savings, which in turn encourages investment, as demonstrated by Muntanga (2020). Higher interest rates, for instance, make borrowing money less desirable overall when it comes to investments or consumption.

Furthermore, investment and consumption are impacted by changes in asset values through wealth effects and collateral value effects. Nastansky et al. (2010) argue that changes in housing and stock values affect household wealth and may have a significant effect on household consumption. Furthermore, the corporate sector's investments may be impacted by stock prices, and construction activity may be impacted by property values. For instance, share-owning households grow wealthier as equity prices rise and may decide to raise their consumption. On the other hand, if stock values decline, households might cut back on spending.

Anderson and Puleo (2020) give evidence that the value of collateral, which allows borrowers to get more loans and/or lower the risk premia that banks and lenders require, can also influence aggregate demand through asset prices. Higher interest rates, for instance, increases the credit risk of default and banks may reduce the amount of money they loan to individuals and businesses. Additionally, this can result in lower household and business investment and consumption, respectively. The degree of domestic demand for goods and services in relation to domestic supply will fluctuate depending on changes in investment and consumption. There will probably be rising pricing pressure when supply cannot keep up with demand.

Again, shifts in aggregate demand could result in different labor and intermediate product market conditions. Price and wage setting in the relevant market may then be impacted by this. Changes in policy rates can impact banks' marginal cost of obtaining external financing in different ways, contingent on the quantity of internal resources, or bank capital, that the bank possesses (Maredza & Olamide, 2017). This route is especially important during severe economic conditions, such financial crises, when banks have a harder difficulty raising capital and cash is more limited.

Furthermore, in addition to the traditional bank lending channel, which is concentrated on the number of loans supplied, there may be a risk-taking channel if banks' incentives to assume risk associated with loan provision are influenced. The risk-taking channel is believed to function primarily through two methods. First, the values of assets and collateral are increased by low interest rates. (Borio et al., 2017). This encourages banks and borrowers to take on greater risk since they both think the rise in asset values is sustainable. Second, since agents look for larger yields, lower interest rates make riskier assets more appealing. (Djatche, 2019). These two factors typically result in banks easing their credit regulations, which can cause an uncontrollably high increase in the quantity of loans available, which has an immediate impact on consumer spending.

Inflations levels have a negative relationship with real income (Chiaraah & Nkegbe, 2014). With changes in inflation comes changes in purchasing power. Higher inflation levels reduce the purchasing power of consumers and they demand for higher wages to offset the loss in income. The higher wages paid by firms increases the cost of production which affect the supply and demand of labour as employers may choose to increase wages to retain skilled labour. Producers also pass on the increased cost of production to consumers in the form of higher prices. Thus, inflation is an important element in setting the wage and price levels in the economy.

Changes in the interest rate on the money market have an impact on import and export prices via the exchange rate. That is, inflation is negatively related to foreign price levels (Chiaraah & Nkegbe, 2014). This means that a worsening exchange rate increases the price of imports while making exports cheaper. Changes in import and export prices affect production dynamics and they cause a change in aggregate demand pattern. These changes, coupled with changes in the labour and capital market affect the level of production of firms.

The centrality of human consumption and production in climate change has already been confirmed by scientific consensus. Household consumption and firm level production patterns will therefore have an impact on CO_2 levels, which in turn will have an impact on climate change and consequently affect household welfare.

CHAPTER THREE

RESEARCH METHODS

Introduction

This chapter presents the methodological framework suitable for conducting the research study. The detailed form of the model's empirical description, study area, and estimation techniques are clearly presented in this section. This chapter focuses on the research paradigm, design, approach, study area, model development, and model calibrations. The chapter will end with a chapter summary

Research Design

According to Plonsky (2017) a research design is the overall plan of a study chosen to address a research question. Williams et al. (2011) indicated that the choice of a research design must base on the research setting, research problem, possible limitations and its underlying paradigm that informs the study. Research design can be either exploratory, descriptive and explanatory (Saunders, Lewis & Thornhill, 2007). Creswell and Creswell (2017) posited that exploratory research design is a crucial way of finding out "what exactly is happening, to identify new insight, to ask questions and to assess a phenomenon in a new light". It is particularly useful if the researcher wishes to understand the research problem and if he is unsure of the exact nature of the problem (Rahi, 2017).

The goal of the descriptive research design is to quantify these magnitudes in the broader population by evaluating people's knowledge, beliefs, preferences, and satisfaction. Research that establishes causal connections between variables is sometimes referred to as explanatory research. (Saunders et al., 2015). Considering the above discussion, the explanatory research design is the most appropriate to guide this study. That is, to investigate how changes in interest rate affects climate change, and how such changes affect welfare in Ghana. The explanatory research design would help to provide a detailed account of the phenomenon the researcher intends to study.

Research Approach

A researcher's types of beliefs based on these factors will mostly lead to adopting a strong qualitative, quantitative, or mixed-methods approach in their study (Creswell & Creswell, 2017). The research approach adopted by the researcher was the quantitative approach. The quantitative modelling of the nexus between interest rate and climate change and the nature of the study necessitated the adoption of a quantitative research approach. According to Leedy and Ormrod (2015), quantitative research includes measuring data collection and statistical analysis.

Quantitative research offers advantages over qualitative design in terms of replicability, objectivity, and generalizability of findings. This research approach guarantees that the researchers approach the study with objectivity. The quantitative approach is considered appropriate because the research objectives need rigorous, formal, deductive technique and systematic strategy to solve the problems (Tekdogan, 2022). However, there are disadvantages to quantitative research as well, including the disregard for critical human factors including responder behavior, emotions, and sentiments.

The Model Specification

The model structure is based on the basic small open economy New Keynesian models of (Justiniano & Preston, 2010; Monacelli, 2005), in which the economy is divided into five sectors: the government, the external sector, households, businesses, and the monetary authority. The household utilizes its financial resources: labor income, capital investments, and bond returns, to maximize the intertemporal utility function separable in labor and consumption in a quality environment. The production sector is made up of both domestic and foreign companies, and they set prices in accordance with Calvo (1983), whose mechanism permits partial indexation of import and domestic prices to the past inflation in order to add more nominal rigidities to the framework of staggered price-setting (Justiniano & Preston, 2010).

Also, it will be assumed that firms use energy and the by-product is carbon dioxide (Cao et al., 2022; Dafermos et al., 2018;). The study makes the assumption that the relative size of the foreign economy is so large that it is unaffected by changes in the Ghanaian economy and so approximates a closed economy because of the model's small open economy attributes. The study extend the Cao et al. (2022) model by including the external sector to make the study an open economy study whereas the study will move further on the work of Bangara (2019), on how firm production affects climate change. In order to introduce some monopoly control over wages, labour is differentiated across a continuum of households, which in turn permits the introduction of sticky wages. The energy used in production emits Green House Gases that affects the climate and in turn affects utility. The government aims for a balanced budget and uses pollution and lump-sum taxes to pay for public spending.

Household

The economy is characterized by identical households. The representative household maximizes utility given its consumption; which is dependent on domestic and foreign goods. working hours, investment, capital and domestic participation in bonds. The two most prevalent independent variables in the conventional utility function are consumption and labor. This study also presents the impact of CO_2 emissions on environmental quality as a factor influencing the utility function of the household. Therefore, using Fischer and Springborn (2011), Niu, Yao, Shao, Li, and Wang (2018), and Dissou and Karnizova (2016), the utility function of a typical household is therefore given as

$$\mathrm{Max}_{C_t N_t Q_t}\ E_0 \sum_{t=0}^{\infty} \beta^t [\theta \ln C_t + \varphi \ln(1 - N_t) + \gamma \ln Q_t],\ \theta, \varphi, \gamma, > 0 \qquad (1)$$

where C_t is consumption at time t, N_t is labor supply at time t and Q_t is environmental quality at time t. $\varphi > 0$ implies that leisure is preferred to working. $\theta > 0$ implies more consumption is preferred to less at time t. Also, $\gamma > 0$ implying that quality environment is preferred to a polluted environment. β^t and E_0 refers to the discount rate and expectation respectively.

Subject to:

$$P_t C_t + I_t + B_t + P_t^{e,D} Q_t = W_t N_t + R^k{}_t K_{t-1} + (1 + r_{t-1}) B_{t-1} \qquad (2)$$

where P_t and C_t refers to consumer price and aggregate consumption at time t. respectively. $P^e{}_t$ is the price for a unit of high-quality environment for period t. The household's holdings of one-period domestic bonds are indicated by B_t, $(1 + r_t)B_{t-1}$ is the return on bonds in purchased in period $t - 1$. I_t represent investment made in time t and ${R^k}_t$ shows the return on capital. W_t is the wage rate.

C_t is however a composite consumption constant elasticity of substitution (CES) function of foreign and domestic goods given as;

$$C_t = \left[(1-\sigma)^{\frac{1}{\eta}} {C_t^D}^{\frac{\eta-1}{\eta}} + \sigma^{\frac{1}{\eta}} {C_t^f}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{3}$$

where C_t^D and C_t^f are Dixit-Stiglitz aggregate of goods produce by domestic and foreign producers respectively (Dixit & Stiglitz, 1977). σ becomes the share of foreign goods in domestic consumption bundle (Trade openness); if σ is close to 1, the more open the economy is. However, if $\sigma = 0$, the model goes back to close economy. σ carries trade restrictions imposed by governments, geographical barriers such as distance and mountainous terrain, etc.

$\eta > 0$ is the elasticity of substitution between differentiated foreign and domestic goods, C_t^D is an index of consumption of domestic goods and C_t^f is an index of imported goods. Where,

$$C_t^D = \left[\int_0^1 C_t^D(i)^{\frac{\varepsilon^D-1}{\varepsilon^D}} di\right]^{\frac{\varepsilon^D}{\varepsilon^D-1}} \text{ and}$$

$$C_t^f = \left[\int_0^1 C_{j,t}^{\frac{\varepsilon^f-1}{\varepsilon^f}} dj\right]^{\frac{\varepsilon^f}{\varepsilon^f-1}}$$

$C_{j,t}$ is a measure of the quantity of commodities imported from nation j that are used by households in the home country. It is provided by an identical CES function followed from Galí (2008) as

$$C_{j,t} = \left[\int_0^1 C_{j,t}(i)^{\frac{\varepsilon^D-1}{\varepsilon^D}} di\right]^{\frac{\varepsilon^D}{\varepsilon^D-1}}$$

$\varepsilon^D > 1$ is elasticity of substitution between differentiated goods produced in the domestic country. $i \in [0,1]$ indicates the different types of goods. ε^f is elasticity of substitution between goods from differentiated foreign countries. Households maximize utility from both domestic and foreign good. Therefore, the demand functions are produced by the most feasible distribution of any given expenditure throughout each category of products.

$$C_t^D(i) = \left(\frac{P_t^D(i)}{P_t^D}\right)^{-\varepsilon^D} C_t^D;\ C_{j,t}(i) = \left(\frac{P_t^D(i)}{P_t^D}\right)^{-\varepsilon^D} C_{j,t}\ \forall\, j,i\ \in [0,1]$$

where $P_t^D \equiv \left[\int_0^1 P_t^D(i)^{1-\varepsilon^D} di\right]^{\frac{1}{1-\varepsilon^D}}$ is the index of domestic pricing, or the cost of items produced domestically and $P_{j,t} \equiv \left[\int_0^1 P_{J,t}(i)^{1-\varepsilon^D} di\right]^{\frac{1}{1-\varepsilon^D}}$ is an indicator of prices for items imported from country j, expressed in domestic currency. $\forall\ j \in [0,1]$. Combining the optimality conditions in $C_t^D(i)\ and\ C_{j,t}(i)$ with the definitions of price and quantity indexes $P_t^D, C_t^D, P_{j,t}, and\ C_{j,t}$ gives

$P_t^D = \int_0^1 P_t^D(i) C_t^D(i) di$ and $P_{j,t} = \int_0^1 P_{J,t}(i) C_{J,t}(i) di$ respectively. Therefore, it follows that the most efficient allocation of import expenditures by country of origin is

$$C_{j,t} = \left(\frac{P_{j,t}}{P_t^f}\right)^{-\varepsilon^f} C_t^f\ \forall\, j\ \in [0,1]$$

where $P_t^f \equiv \left[\int_0^1 P_{i,t}{}^{1-\varepsilon^f} di\right]^{\frac{1}{1-\varepsilon^f}}$ is the price index for imported goods, also expressed in domestic currency. Similarly, the information of P_t^f, and C_t^f implies that total expenditures on imported goods can be written as

$$P_t^f = \int_0^1 P_{J,t} C_{J,t} di$$

The demand functions are implied by the optimal distribution of expenditure between domestic and foreign goods

$$.C_t^D = (1-\sigma)\left(\frac{P_t^D}{P_t}\right)^{-\eta} C_t \quad (4)$$

$$C_t^f = \sigma\left(\frac{P_t^f}{P_t}\right)^{-\eta} C_t \quad (5)$$

Therefore, the overall consumer price index in the home country is written as

$$P_t = \left[(1-\sigma)(P_t^D)^{1-\eta} + \sigma\left(P_t^f\right)^{1-\eta}\right]^{\frac{1}{1-\eta}} \quad (6)$$

$P_t, P_t^D,\ P_t^f$, correspond to domestic CPI, domestic goods prices, and foreign price, respectively. The total expenditure becomes

$$P_t C_t = P_t^f C_t^f + P_t^D C_t^D \quad (7)$$

Environmental Quality

Environmental quality of the preceding period Q_{t-1} and the emissions of the current period CO_{2t} affect the environmental quality of the current period Q_t (Heutel, 2012). However, the state of the environment also depends on the environmental policies implemented to mitigate environmental degradation. Taking this into account, this study obtains:

$$\mathrm{Q}_t = (\tau^{CO_2} - 1)CO_{2t} + \mathrm{Q}_{t-1} + \mathrm{V}_t \quad (8)$$

where $0 \leq \tau^{CO_2} \leq 1$ denotes emission tax levied by the government to protect the natural environment and V_t is the non-tax fiscal policies (e.g., Green Ghana) initiated to help curb the effects of climate change.

Capital Accumulation

The relationship between investment and capital stock is expressed as:

$$\mathrm{K}_t = (1-\delta)\mathrm{K}_{t-1} + \mathrm{I}_t \quad (9)$$

where K_t is the stock of capital at time t, K_{t-1} is the stock of capital at time $t-1$, I_t is gross investment at time t, and δ is the depreciation rate of capital.

Cost of Energy Efficient Goods

Domestic consumers pay a price of $P_t^{e,D}$ for using foreign less energy consuming products. Where,

$$P_t^{e,D} = (1+\tau^{IM})RER_t \tag{10}$$

and $$RER_t = e_{n_t}\frac{P_t^D}{P_t^f} \tag{11}$$

where $P_t^{e,D}$ is the price for a unit of high-quality environmental consumable good in period t, RER is the real exchange rate in period t, e_{n_t} is the nominal exchange rate at time t. P_t^f and P_t^D are the foreign and domestic price respectively for the commodity, and τ^{IM} is the import duty levied on foreign products.

The typical maximization problem that households face is maximizing their estimated discounted sum of instantaneous utility (1) subject to equations (2), (8), (9) and (10). Letting λ_t denote the Lagrangian multiplier for the households' budget constraint, the study obtains the following first order conditions with respect to consumption (C_t), labour (N_t), environmental quality (Q_t), government bond (B_t), and capital (K_t), respectively given as:

Consumption

$$\lambda_t = \frac{\theta}{P_t C_t} \tag{12}$$

Labour

$$\lambda_t = \frac{\varphi}{W_t(1-N_t)} \tag{13}$$

Environmental Quality

$$\lambda_t = \frac{\gamma}{Q_t P_t^e} \tag{14}$$

Government Bonds

$$\lambda_t = E_t \beta \lambda_{t+1}(1 + r_t) \quad (15)$$

Capital

$$\lambda_t = E_t \beta \lambda_{t+1}[R^k{}_t + (1 - \delta)] \quad (16)$$

From equations (12) and (13), we obtain the real wage from the households as

$$\frac{W_t}{P_t} = \frac{\varphi C_t}{\theta(1-N_t)} \quad (17)$$

(12) and (14) produces a relationship between environmental quality and aggregate consumption given as

$$\frac{C_t}{Q_t} = \frac{\theta P_t^e}{\gamma P_t} \quad (18)$$

(12), (15) and (12), (16) produces the following consumption Euler equations respectively.

$$C_t^{-1} = \frac{P_t}{P_{t+1}} \beta E_t C_{t+1}^{-1}(1 + r_t) \quad (19)$$

$$C_t^{-1} = \frac{P_t}{P_{t+1}} \beta E_t C_{t+1}^{-1}[R^k{}_t + (1 - \delta)] \quad (20)$$

FIRMS

Production in this model is split into two; foreign and domestic good production. The first are those producing final and intermediate goods using labour and capital for consumption and export in the foreign economy. The second type relates to the domestic final goods producers who uses energy as an intermediate good from the foreign economy to produce homogeneous final goods that would eventually be consumed or invested by households.

Foreign Firms

The foreign final goods production "technology" is simply a constant elasticity Cobb Douglas production function that is used to produce carbon emitting consumables. Hence output in the foreign country is given as

$$Y_t^f = A_t^f K_t^{f^{\alpha}} N_t^{f^{(1-\alpha)}} \quad (21)$$

where Y_t^f is the total foreign output, A_t^f is the total factor productivity in the foreign economy, K_t^f is level of capital available, and N_t^f is the labour input used in the production process. Production in the foreign economy is constrained by total cost given as:

$$TC_t^f = \mathrm{W}_t^f \mathrm{N}_t^f + \mathrm{R^k}_t^f \mathrm{K}_t^f \quad (22)$$

Where TC_t^f is the total cost of production, W_t^f is the wage received by households, and $\mathrm{R^k}_t^f$ is the rent for using capital.

Domestic Firms

A typical domestic producer uses a common productivity shock A_t^D and a constant return to scale in labor and capital when producing goods and services. Nonetheless, this study also presents energy consumption as an input factor of firm's production function, given that it is the primary source of CO_2 emissions during the manufacturing process. (Dafermos et al., 2018). With that, the more firms produce, the more CO_2 is emitted into the atmosphere. The study also assumes that firm's pay for the energy, labour and capital employed in the production process. The study shall make the assumption that there will be considerable nominal rigidity (also known as price-stickiness) in the domestic products production sector which leads to significant non-neutralities.

As a result, the following Cobb-Douglas production function is obtained in this study.

$$Y_t = A_t K_t^{\alpha} N_t^{\vartheta} EN_t^{(1-\alpha-\vartheta)} \quad (23)$$

Where Y_t is the domestic output level, K_t is capital, N_t is labour, and EN_t is the energy consumed in the production process. A_t is technology at time. α is output elasticity of capital, θ is output elasticity of labour, and $(1-\alpha-\vartheta)$ is output elasticity of energy consumption. $\alpha > 0$, $\vartheta > 0$, $(1-\alpha-\vartheta) > 0$. Y_t is assumed to be constant returns to scale, i.e., $\alpha + \theta + (1-\alpha-\vartheta) = 1$. When $(1-\alpha-\vartheta)$ increases, the output elasticity of capital α *and labour* θ decreases and vice versa. When $(1-\alpha-\vartheta) = 0$, Y_t^D becomes the standard Cobb–Douglas production function given that energy consumption is not included in the production process of the firm. Productivity follows an AR (1) process:

$$\text{In}(A_t) = \rho_A \ln A_{t-1} + \mu_t{}^{A_t},\ \rho_{A^D} \in (0,1), \mu_t^A \sim N(0, \sigma_A^2) \tag{24}$$

$\mu_t^{A^D}$ represents the principal shock in the DSGE model and an exogenous sector-specific productivity shock, which are the most prevalent sources of uncertainty. (Annicchiarico & Di Dio, 2015; Dissou & Karnizova, 2016; Fischer & Springborn, 2011; Heutel, 2012).

The monopolistic domestic firm maximizes profit subject to its cost of production. Profit, which is a function of total revenue and total cost is given as

$$\prod_{D,t} = P_t Y_t - \left(\mathrm{W_t N_t} + \mathrm{R^k{}_t K_t} + P_t^{e,D} EN_t\right) \tag{25}$$

Where $TC_t = \mathrm{W_t N_t} + \mathrm{R^k{}_t K_t} + P_t^{e,D} EN_t$ is the total cost or production and $P_t Y_t$ is the total revenue accrued after production.

From (25), the first order conditions for the domestic firm with respect to Capital $(\mathrm{K_t})$, Labour $(\mathrm{N_t})$, and Energy use (EN_t) are given respectively as;

$$\frac{R_t^k}{P_t} = \frac{\alpha Y_t}{K_t} \tag{26}$$

$$\frac{W_t}{P_t} = \frac{\vartheta Y_t}{N_t} \tag{27}$$

$$\frac{P_t^{e,D}}{P_t} = (1-\alpha-\vartheta)\frac{Y_t}{EN_t} \quad (28)$$

From (26), (27), and (28) the study obtains a total marginal cost of

$$MC = rhov.\frac{\phi}{A_t} R_t^{k^{\alpha}} W_t^{\vartheta} P_t^{e,D^{(1-\alpha-\vartheta)}} \quad (29)$$

where $rhov = \frac{\vartheta+\alpha^2+\alpha(1-\alpha-\vartheta)}{\alpha(1-\alpha-\vartheta)}$

The study assumes a sticky price specification based on the Calvo Price setting. Firms have some market power and can set prices because of the downward sloping demand curve. It is presumed that they are unable to freely change prices at any time. Firms are especially vulnerable to two persistent risks: (1) the ability to change their pricing at any time with a probability of $1-\emptyset$, and (2) the risk of having to stick with their previous price with a probability of $\emptyset$. Calvo (1983) identified this type of pricing stickiness. Regardless of their ability to change prices, firms are nevertheless free to decide how much labor and capital to use each period. This produces the result

$$\mathrm{P_t} = \frac{\varepsilon}{\varepsilon-1}\frac{E_t\sum_{k=o}^{\infty}(\phi\beta)^k\Lambda_{t,t+k}\left(mc_{t+k}P_{t+1}^{\varepsilon-1}Y_{t+k}\right)}{E_t\sum_{k=o}^{\infty}(\phi\beta)^k\Lambda_{t,t+k}\left(P_{t+k}^{\varepsilon-1}Y_{t+k}\right)} \quad (30)$$

(30) is the optimal price level for the monopolistic firm. Since $\varepsilon > 0$, it implies that

$\frac{\varepsilon}{\varepsilon-1} > 0$. This means that the optimal price level is a markup above marginal cost.

Hence, in a symmetric equilibrium, the Calvo version of the linear New Keynesian Phillips Curve (NKPC) is derived as:

$$\hat{\pi}_t = \frac{(1-\phi)(1-\phi\beta)}{\phi}\widehat{mc}_t + \alpha\beta E_t\hat{\pi}_{t+1} \quad (31)$$

Carbon Emissions

CO_{2t} evolves as an increasing function of total energy use. Thus,

$$CO_{2t} = (1 - \tau^{CO_2} - V_t) \int_0^1 EN_{it} \, \mathrm{d}i \quad (32)$$

However, $\int_0^1 EN_{it} \, \mathrm{d}i = EN_t$

where τ^{CO_2} is CO_{2t} emission reduction tax, $0 \leq \tau^{CO_2} \leq 1$. Assuming that without levying emissions, firms have no intention of reducing emissions and where $\tau^{CO_2} = 0$. $(1 - \tau^{CO_2} - V_t)$ denotes carbon intensity. V_t represent low-carbon technologies and other non-tax policies employed by the government to control CO_{2t} emissions in time t. V_t follows the AR (1) process given as:

$$\text{In}(V_t) = \rho_v \ln V_{t-1} + \mu_t{}^V, \; \rho_V \in (0, 1), \mu_t^V \sim N(0, \sigma_V^2) \quad (33)$$

where $\mu_t{}^V$ represents the shock of exogenous low-carbon technological growth. The unanticipated result with negative externalities in the production process is the carbon emissions resulting from the production behavior of firms. While low-carbon technological innovation will be encouraged by appropriate environmental regulation, businesses should also financially assist the acceleration of emission reduction rates. According to Chen and Nie (2016) and Haites (2018), taxing the production process facilitates tax collection and the control of carbon emissions. This study aligns with the views of Zhang and Zhang (2018), who argued for the imposition of a carbon tax on production.

Fiscal Policy

An exogenous quantity of public goods (G_t) is provided by the government which is defined in terms of total government spending. Government expenditure is financed through emission taxes, import duties, and the issue of one-period bonds that are ostensibly risk-free. Other forms of government revenue such as income tax are assumed to be constant to highlight the effects of emission tax and import duties in the model. The government budget constraint is of the form:

$$G_t + (1 + r_{t-1})B_{t-1} = \tau^{CO_2} CO_{2t} + \tau^{IM} C_t^f + B_t \tag{34}$$

where G_t is government expenditure, $\tau^{CO_2} CO_{2t}$ is firms' environmental tax (i.e., CO_{2t} emissions tax), and $\tau^{IM} C_t^f$ is the revenue from taxing imports.

Monetary Policy

We conclude the model by outlining a straightforward framework for the monetary policy rule. The central bank pursues price stability and full employment. Monetary policy evolves according to

$$r_t = \phi_\pi(\pi_t) + \phi_y(y_t) + er_t \tag{35}$$

Where r_t is the real interest consistent with stable inflation, ϕ_π and ϕ_y denotes the weights of inflation and output respectively in the rule. π_t and y_t are inflation and output respectively. er_t is the stochastic shock to monetary policy given as:

$$\ln(er_t) = \rho_{er} \ln er_{t-1} + \mu_t^{er}, \rho_{er_t} \in (0, 1), \mu_t^{er} \sim N(0, \sigma_{er}^2) \tag{36}$$

Market Clearing

Finally, the market-clearing condition (equilibrium) is given as

$$Y_t = C_t + I_t + G_t + XM_t \tag{37}$$

Where Y_t is total output in the economy, I_t is the level of investment, G_t is government spending, and XM_t is the net export.

CHAPTER FOUR

ANALYSIS AND DISCUSSION

Introduction

With the baseline calibration to asymmetric shocks in relation to climate change, this section examines and discusses the various impulse response functions relating to specific important macroeconomic variables. Figures 2-5 represent the various responses following interest rate, environmental policy and productivity shocks and their effect on Climate change. Figure 5 shows the response to different levels of shocks to interest rate and environmental policies on household welfare. The study describes the current new Keynesian DSGE models in accordance with the baseline calibration results obtained in the current setup.

Model Calibrations

The structural parameters for the model's framework were mostly taken from literature and data pertaining to Ghana. Data and values on Ghana that do not exist are taken from the literature on developing countries that have similar characteristics with Ghana to calibrate the model. Parameters and steady-state ratios are also chosen to reflect levels often seen in developing nations. The complete list of parameters and their values are presented in Table 1.

Table 1: Parameter Calibration

Parameter	Value	Description
σ	0.71	Trade Openness
α	0.33	Output elasticity of capital
θ	0.71	Share of consumption in the utility function
γ	0.41	Proportion of environmental quality in the utility
ϑ	0.349	Output elasticity of labour
η	0.7	Rate of substitution between differentiated goods
δ	0.025	Depreciation Rate of Capital
φ	0.6	Ratio of work to free time
ϕ	0.6	Price parameter for nominal rigidities
β	0.97	Discount factor
τ^{CO_2}	0.2	Emission tax
τ^{IM}	0.1	Import tax
ρ_A	0.7	Stochastic productivity shock
ϕ_y	0.5	Weight of output in monetary policy stance
ϕ_π	0.5	Taylor's coefficient for inflation
ρ_V	0.7	Environmental policy shock
ρ_R	0.7	Monetary Policy Shock

Source: Author's Construct

Household preferences and public sector organizations employ consistent parameters for developing countries. For instance, the study chooses a subjective discount factor (β) of 0.97 to give a 3 percent monthly interest rate given that monetary policy rate in Ghana is 30 percent as given by the Bank of Ghana (BoG July, 2023). According to the Ghana Revenue Authority, the import tariff on Inputs and Intermediary Products (Semi-Finished Goods) is 10 percent (GRA, 2022) thus, a 0.1 import duty (τ^{IM}) is chosen for this study and is also consistent with Arinze et al. (2017).

Again, a 0.025 depreciation rate of capital is employed in this study to reflect a 25 percent capital allowance rate as stipulated by the income tax act 2015-Act 896 (GRA, 2022) in Ghana.

Ghana operates a relatively liberal trade openness regime. To limit the local market for Ghanaian producers, it also implements an import substitution program. Schmitt-Grohe (1998) who argued that the average developing economy has trade openness of up to 80 percent. However, data from (WDI, 2022) shows that trade as a percentage of GDP is 71 percent thus, the study set trade openness (σ) at 0.71.

To capture the intensity of the effect of climate change on household welfare, Fan et al. (2016), set the percentage of environmental quality (γ) in the utility function to 41. According to the Environmental Performance Index by Wendling *et al.* (2022), Ghana ranks 171 in terms of air quality with a score of 15.3 and a total EPI score of 170 with a score of 27.7. This implies an air quality to total environmental ratio of 0.552, leaving a desired level of 0.448. This study thus set (γ) to 0.45 given the extreme adverse effect of climate change on the economy of Ghana.

According to description of the utility function, the ratio of work to free time (φ) is 0.6 to reflect the higher preferences for leisure for the average household in the utility function as supported Sun and Jiang's (2012) in developing economies. The current study does not deviate from this figure given that out of the 18 hours available for work after the standard 6 hours of sleep, the average Ghanaian works 8 hours a day. This implies a 0.4 proportion of work given the available time, with 0.6 proportion of leisure.

The proportion of utility attributable to consumption (θ) is set at 0.82 given that Ghana's final consumption expenditure as a percentage of to GDP is 82 percent (WDI, 2022).

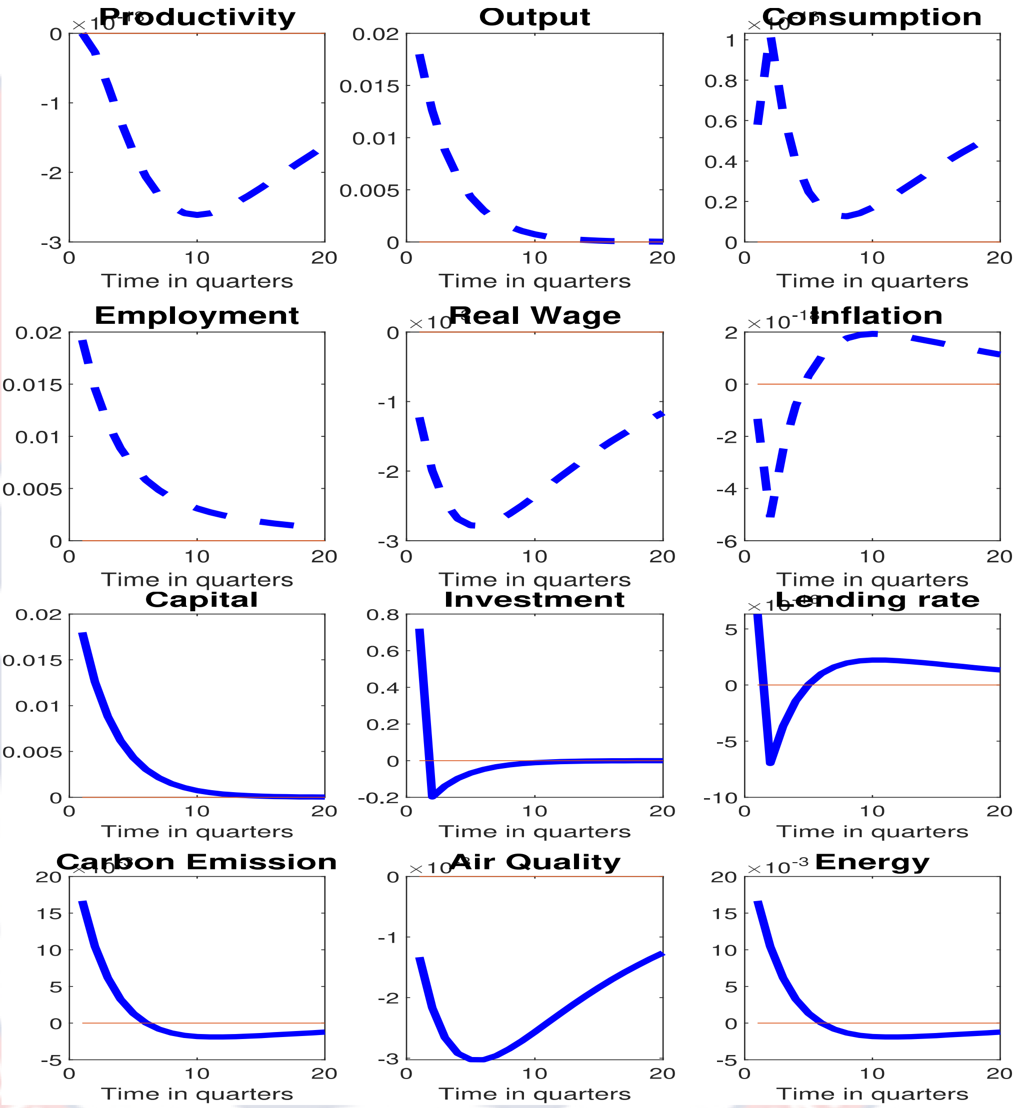
According to the recommendations of Ríos-Rull et al. (2012), the elasticity of substitution between imported and domestically produced goods, η is fixed at 0.7. Mendoza (1991), Schmitt-Grohe (1998), and Fan et al. (2016) all agree that the output elasticity of capital (α) is a constant of 0.33 and this is also consistent with the Ghanaian economy.

Per the African Center for Economic Research (ACET, 2020) report, the African continent has a very low labour productivity with Sub-Saharan Africa recording 35 percent working hour. Thus, this study follows Angelopoulos et al. (2010), to set the labor elasticity of output (ϑ) at 0.349 which is reflective of the developing economies like Ghana.

After gaining operational independence in March 2002, (BoG, 2022), the central bank officially adopted the inflation-targeting monetary policy. The central bank employs an inflation-targeting framework with market-oriented instruments, primarily short-term interest rate. Despite recent inflation hikes, the Bank of Ghana still pursue a balanced outlook of inflation and output growth as posited by Taylor (1993). Taylor (1993) posited that both ϕ_y and ϕ_π be set to 0.5 to give equal weight to both output gap and inflation parameters.

Finally, stochastic productivity shock, ρ_A, which happens to be persistence of shock is fixed at 0.7 as posited by Taylor (1993). According to Taylor (1993), the parameters low-carbon technology progress shock and monetary policy shock describing the shock processes are calibrated with the symbol ρ_R and ρ_V with fixed numerical values 0.7 and 0.7 respectively. Products' relative prices on the black market are greater than those in the legal market at steady state. The soaring cost of key inputs is the primary reason for the widening price gap. Calibration considering the other structural factors is used to get the remaining steady-state values.

Objective 1: Analyses on Monetary Policy Shock to Climate Change



Source: Author's construct

Figure 2: Impulse responses to a negative interest rate shock

Figure 2 shows the impulse responses to an expansionary monetary policy shock. This comes in the form of a negative interest rate shock by the central bank through lowering the interest rates to stimulate economic activity. Changes in official interest rates have an immediate impact on money-market rates, and they also have an indirect impact on lending and deposit rates that banks set for consumers. (Matemilola et al., 2015).

The reduction in the policy rate implies a reduction in the money market interest rate, lending and deposit rates as supported by the work of (Sääskilahti ,2018). Thus, the transmission mechanism involves increased economic activity through reduction the lending rate by commercial banks. This will ultimately result in the people having access to loans and holding more cash. This action should imply an increase in money demand for both consumption and investment purposes. This is because the cost of investment become cheaper as cost of debt financing reduces, and households also have less motivation to hold money for speculative purposes.

However, the response function of the investment graph shows that though the initial response to the shock was favourable, investment falls quickly. This could be because of the deteriorating level of exchange rate and the precarious levels of inflation in the Ghanaian economy. According to the Ghana statistical services (GSS, 2022), the year-on-year inflation for the 2022 was 54.1 percent with the policy rate of 22 percent (BoG, 2022). With inflation above the interest, the cost of investment increases exponentially thus business expansions slows down in the economy.

The depreciation of the domestic currency makes the cost of importing raw materials, equipment, other inputs needed for production expensive. The higher costs reduce the profit margin of firms, causing them to reconsider or delay investments. The weaker domestic currency can make exports more competitive in international markets by lowering their prices in foreign currencies. However, with global demand for Ghanaian products remaining fairly stable and the increasing levels of trade barriers on Ghanaian products, the boost in export competitiveness may not translate into increased sales volume, limiting the incentive for businesses to invest in expanding production capacity. Again, the exchange rate fluctuations affect both business confidence and capital flows through uncertainty. In the face of uncertainty, investors become more cautious about investment approaches and reduce investment until a proper trend is established.

The econometric exercise (Feijo et al, 2016) demonstrates that financialization has a detrimental effect on the physical accumulation of capital and that the interest rate is the key factor in explaining the investment rate giving cognizance to the fact that a fall in interest will increase capital accumulation. Thus, given the positive relationship between investment and capital accumulation, capital is also positive but at a decreasing rate. The increased capital accumulation has a positive influence on employment (Miaouli, 2001). Therefore, the marginal increase in capital accumulation cause employment to increase and they together cause and increase total output marginally. With output decreasing overtime in the economy, energy use in the production process also decreases and this is consistent with Kocaaslan (2013) who discovered that total energy use may be predicted by output growth.

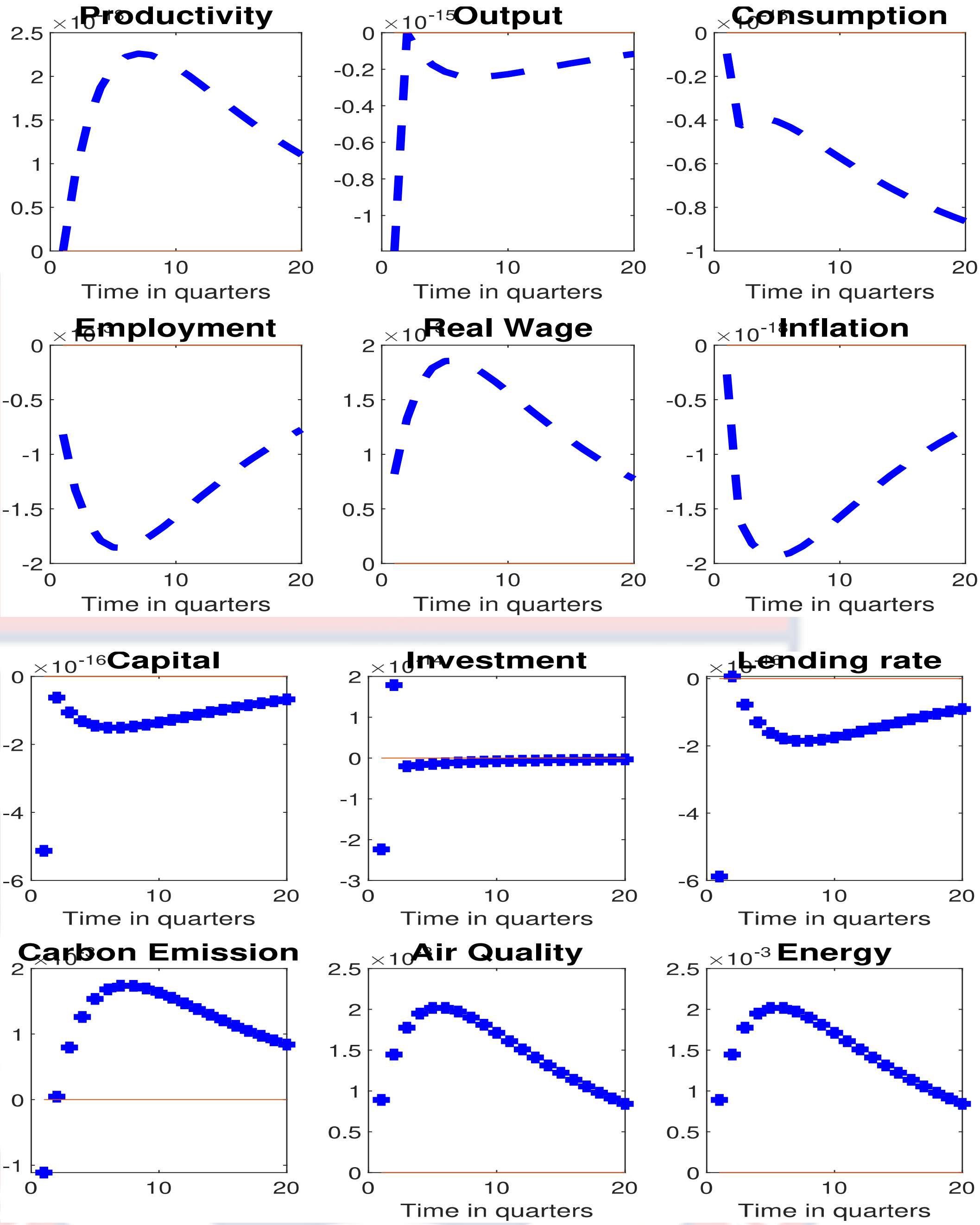
On impact of the shock, the lending rate remains high which is a reverse of desired outcome. This is due to the level of inflation in the economy. Prices are sticky and hence take longer periods to adjust compared to bank rates. Add a paper. Thus, with inflation being high, bank rates remain high because of in order to achieve a positive return on investment. However, as inflation begins to fall as shown by the inflation response graph, lending rates also fall. Money demand for transactionary purposes increase as households have less motivation to hold money for speculative purposes coupled with the cheap access to loans. The result is the initial increase in consumption on impact of the shock as shown by the consumption graph. The increase in money holding, consumption, and a declining production level cause inflation to rise which continuously reduce real wage as shown by the wage graph. The worsening of purchasing power of consumers through the reduction of the real wage causes consumption to fall after the initial rise.

Increased greenhouse gas (GHG) emissions result from a greater proportion of fossil fuels in the energy mix due to the rising energy demand (Alvarez-Herranz *et al.*, 2017). However, as shown by the impulse graph of carbon emission, the initial impact of the shock on both production and consumption resulted in carbon emission also being positive. As consumption and production reduced in the later periods, carbon emission also fell. The initial increase in carbon emissions caused air quality to reduce but became better as carbon emission reduced overtime.

In spite of the fluctuations in the exchange and inflation rate that exist in Ghana, an expansionary interest rate policy has negative repercussions on the quality of the environment through increases CO_2 emissions which is consistent with the work of (Bauer & Rudebusch, 2021).

Objective 2: Analyses on Environmental Policy Shock to Climate Change

This comes in the form of a deliberate spending by government to reduce carbon emission. Environmental policies such as renewable energy incentives (where the government provide financial incentives in the form of tax credits or subsidies, to encourage the adoption of renewable energy sources like solar, wind, and hydropower), public transportation expansion, investment in research and development of green technologies such as carbon capture and storage adopted by firms to accelerate the development and deployment of climate-friendly innovations. These policies set the stage for a proactive approach to climate change mitigation, emphasizing sustainability and emissions reduction as they encourage businesses and consumers to invest in energy-efficient products and renewable energy sources, thus reducing emissions and the overall carbon footprint (IPCC, 2021).



Source: Author's construct

Figure 3: Impulse responses to a positive shock to environmental policy

Figure 3 displays the impulse responses to a positive shock to environmental policy. Such a policy seeks to stimulate economic activity while also promoting environmental sustainability at the same time.

On impact of the shock, investment declines rapidly and this could be due to a number of reasons such as increased cost of production, reduced demand for carbon intensive products, and structural changes. When positive environmental policies impose additional cost to firms by requiring them to invest in cleaner technologies, reduce emissions, or pay taxes on carbon emissions, production cost increases and profitability is reduced which consequently reduced the level of investment. Positive environmental shock in the form of public education on the effects of carbon-intensive commodities on the environment may cause a shift in consumer preferences to environmentally friendly alternatives. Thus, high emitting firms like most companies in Ghana reduce investment due to low demand. Positive environmental shocks can lead to structural changes in the economy as firms adapt to new regulations. With such uncertainty, firms may delay expansions until the full impact of the shock is understood.

With investment falling, capital accumulation also falls on the impact of the shock confirming the classical relationship between investment and capital accumulation. As firms reduce investments and invariably capital accumulation, employment also falls on impact of the shock as labor is required to manage capital. Again, as firms shift to greener technologies, new industries are created as some become obsolete. These new firms require skilled labour and this creates structural unemployment further reducing employment.

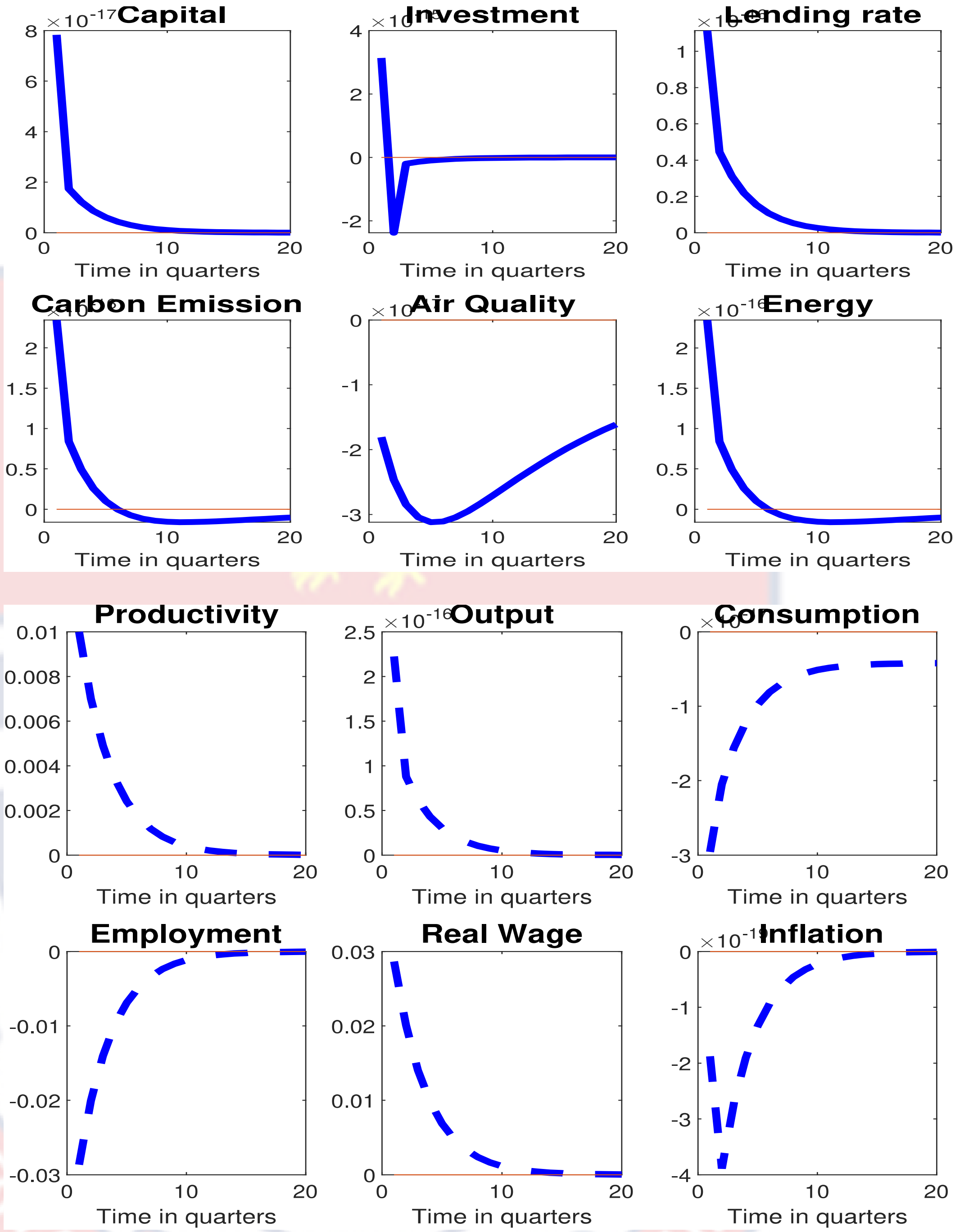
However, given the extremely low level of the lending rate due to the shock, investment increases along with capital accumulation and employment. Output, though worsens, it improves gradually but this is primarily due to improvement in productivity. As firms invest in new technologies, output per man hour increase and this drives output up even though investment and capital worsen.

On impact of the shock, the lower lending rate is unable to stimulate aggregate consumption given the low level of employment. The improvement in real wage is due to the high salaries of skilled labour and reduction in inflation stemming from production efficiency which translate into lower prices as production cost reduces. Consumption continues on the down trend as prices begin to rise which reduce the real wage overtime.

Though the output growth is primarily due to productivity, energy use in production rise steadily until firms begin to invest in greener technologies. Cabon emission thus rise faster in tandem with energy use and falls as energy use in production declines. As carbon emission reduces, air quality gets better and obtains a higher turning point compared to the emission level. This could be because emission is driven by firms' energy use and the decline in consumption help keep air quality better and longer.

Objective 3: Analyses on Productivity Shock to Climate Change

Figure 4 is the impulse responses to a positive productivity shock. This comes in the form of an improvement in innovation and production technologies. In response to the shock, output increases.



Source: Author's construct

Figure 4: Impulse responses to a positive productivity shock

The shock caused both investment and capital to accumulation to worsen overtime though they were both favourable initially. This is mainly due to the high lending rate evidenced by the lending response graph. Other reasons increased production efficiency which lowers cost of production and imply that firms may not need to invest in new machinery or technologies, avoidance of excess capacity in order to maintain profitability which may scale back investment plans. The improvement in output on impact of the shock is primarily due to the improvement in productivity which is significantly higher compared to the investment and capital accumulation levels.

Furthermore, the rise in return-on-investment causes consumption to fall on impact of the shock as money demand for speculative purposes increase. The fall in aggregate consumption causes the price of final output to fall thereby reducing inflation and making real wage favourable due to the shock. However, as lending rate falls to stimulate economic activities, both consumption and inflation begin to rise with inflation being the faster of the two. As productivity falls overtime, employment increases to maintain output.

This causes real wages to rise thereby increasing the real cost of labour. The result of the rise in real wages is a reduction in employment. The positive productivity shock results in an increase in output on impact of the shock, this in turn results in higher demand for energy as input in production. The increase in firms and household energy consumption leads to a sharp rise in carbon emission and consequently a worsening of air quality.

Emission levels, given that it is dependent on energy use takes the same trend as energy as energy also takes the trend of production. At higher output levels, energy use is higher, leading to higher carbon emission levels. The higher carbon emission levels due to the shock leads to air quality deteriorating in the early periods and gets better as carbon emission levels reduce.

economy to the 10 percent shocked economy is about 17 percent.

Similarly, considering the case of an expansionary interest rate policy shock, labour, output and consumption increased while air quality worsened. Intuitively, this resulted in household's welfare worsening as shown in column 2 in Figure 5. Again, comparing 10 and 8 percent expansionary monetary policy shocks to the economy, there was welfare loss from moving from the 8 shocked economy to the 10 percent shocked economy to about 20 percent.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The study's overview, conclusions, and recommendations are presented in this chapter. The first section contains a summary of the study that includes the objectives, methods, and primary findings. The next section presents the conclusion derived from the main findings. It also offers the foundation for evaluating the attainment of the study's specific objectives. Thus, a summary of the specific objectives and significance of the key findings is included at its conclusion. The recommendations in relation to the main conclusions, implications, and findings of the study are also included in this part. The final section provides suggestions for future studies.

Summary of Study

It is a well-established fact that climate change is indeed largely a human-induced phenomenon. This means that while natural factors have played a role in Earth's climate variations, the current rapid and unprecedented changes in the climate are primarily driven by human activities. Africa is the continent most affected by climate change, yet it only generates 4 percent of the world's carbon emissions. Ghana, being one of the strongest economies in Africa contributes minimal to global greenhouse gas emissions, with emissions on a per capita basis at 24 percent of the global average. However, the impact of climate change on Ghana is significant. According to the World Bank Group's latest Country Climate and Development Report (CCDR) for Ghana, by 2050, income for poor households might drop by as much as 40 percent, and at least one million more people could become impoverished as a result of climate shocks. This is in spite of current impacts mostly experienced in the form of flooding, earth trembling and rising sea levels prompting the immediate investment in sea defences. To this effect, this study sought to determine how economic activities caused by changes in interest rate affects climate change. Specifically, the study investigated the effects of monetary policy (interest rate) changes on climate change, the effectiveness of environmental policies on climate change, the effects of a change in productivity on climate change, and finally, analyze the welfare implications of interest rate and environmental policy shocks on the average Ghanaian consumer. The New Keynesian models, the Cap-and-trade theory and the Environmental Kuznet Curve (EKC) theory provided the theoretical underpinnings for the study. To determine the current trend and the position of the variables in relation to climate change, a number of empirical research were also thoroughly analyzed. The study employed the positivism research paradigm and the explanatory research design given that the DSGE methodology was used.

Summary of Findings

The first objective of the study investigated the effects of interest rate on climate change of which the findings showed evidence that changes in the interest rate goes through transmission mechanisms that affect the climate change. The result shows that a reduction in interest rate reduces the cost of borrowing and the cost of investment which increases money demand for both consumption and production purposes. The reduction in the interest rate also causes the exchange rate to depreciate making imports costly compared to export. This implies that the cost of imported energy-efficient goods increases causing domestic consumers to purchase high-emitting products and increasing emissions. The huge investment by firms also requires an in- increase energy use in the production process to increase output which also increases emissions. Thus, this study shows that interest has an inverse relationship with climate change.

The second objective of the study sought to determine the effectiveness environmental policies on climate change. The findings show that positive environmental policies are effective in reducing climate change and improves mitigation efforts. This is because such policies increase investment and incentivize green technologies and sustainable industries (Yu et al., 2022). With firms shifting to greener technologies, CO_2 emission also reduce and boost environmental quality.

On examining the effects of a change in productivity on climate change as the third objective, the study shows that economic efficiency plays a detrimental role in curbing climate change. This is because production efficiency increases output which requires more household energy use thereby increasing emissions and worsening the environment.

Finally, on the presumption that positive interest rate and environmental policy shocks will improve consumer welfare, it is worthy to note that favourable environmental policy shocks make consumers better off. On the contrary, positive monetary policy shocks have negative effects on household welfare. It is also important to note that, given equal shock parameters, there is a 3 percent extra welfare loss compared to the gains from the environmental shock.

Conclusions

In light of the research findings presented in the previous section, the following conclusions are arrived at.

The relationship between interest rates, consumption, production, and their impact on global warming in developing economies is complex, and there are several factors to consider when discussing the rationale for reducing interest rates, even if it may lead to increased consumption and production. Reducing interest rates stimulates economic growth by encouraging borrowing and spending which increases emissions and deteriorates the climate. There exists therefore an inverse relationship between interest rate and climate change. Lowering interest rates can be a short-term measure to address economic challenges, but it should ideally be complemented with policies aimed at mitigating environmental impacts.

Again, this study supports the theories and discussions that expansionary environmental policies should be promoted in the fight against climate change. This is because expansionary environmental policies are the mainly policy toolkit that tackles the issue of climate change directly. From emission tax to afforestation policies, environmental protection policies incentivize green technologies and sustainable industries which promote mitigation and adaptation efforts.

On analyzing the impact of enhanced productivity on climate change as the third objective, the study concludes that economic efficiency has a negative effect on mitigating climate change. This is due to the fact that increased production efficiency leads to higher output, which in turn demands more energy consumption, consequently elevating emissions and exacerbate environmental conditions.

Finally, in terms of welfare, which is the discounted future utility, assuming that positive interest rate and environmental policy shocks lead to enhanced consumer welfare, it's noteworthy that favorable environmental policy shocks positively impact consumers, while positive monetary policy shocks have negative effects on household welfare. This means consumers enjoy increased utility from positive environmental policies in the long run while utility worsen from positive interest rate policies. Additionally, it's crucial to highlight that, under equal shock parameters, there's a 3 percent additional welfare loss compared to the benefits derived from the environmental shock.

It is therefore essential that policymakers understand the trade-off between immediate economic concerns and long-term environmental sustainability. The overall conclusion is that, to achieve a sustainable and resilient economy, it is imperative that policymakers carefully balance immediate economic concerns with long-term environmental sustainability.

Recommendations

To address the complementary effect of a reduction in interest, positive productivity shocks, and favourable environmental policies expansions in the short and long term effectively, the following policy recommendations are proposed.

On the conclusion that expansionary interest rate worsens climate change, the following recommendations are made;

- Green financing initiatives. The government of Ghana should encourage and support green financing projects that promote sustainable investments in renewable energy, energy-efficient technologies, and eco-friendly infrastructure. This can be done through incentives such as tax breaks, subsidies, and preferential loan terms for green projects. It can also be achieved by allocating resources towards research and development of clean technologies and innovation that can reduce the carbon footprint of production processes and consumption patterns.

- Education and Awareness. Institutions like the National Commission for Civic Education (NCCE) should be adequately resourced to undertake public awareness campaigns, workshops, and educational programs that promote sustainable consumption lifestyles among consumers and businesses.
- Collaboration and Partnerships. Collaboration between government agencies, private sector entities, academia, and civil society organizations should be fostered to develop and implement comprehensive strategies for addressing both economic growth and environmental sustainability. Public-private partnerships can play a crucial role in driving sustainable development initiatives.

Based on the finding that expansionary environmental policies should be promoted in the fight against climate change, the following recommendations are made to strengthen this position.

- Promote renewable energy transition. The government of Ghana should accelerate the transition to renewable energy sources such as solar, wind, and hydroelectric power. This can be achieved by providing incentives, subsidies, and investment opportunities for renewable energy projects to reduce reliance on fossil fuels and decrease greenhouse gas emissions. Also, by expanding the use of emission pricing mechanisms such as carbon taxes and cap-and-trade systems, it will create economic incentives for firms to reduce carbon footprint and invest in cleaner technologies.

- Support sustainable agriculture practices. Sustainable agriculture practices that promote soil conservation, water efficiency, and reduced use of chemical inputs should be promoted the Ghanaian government. Methods such as agroforestry, organic farming, and regenerative agriculture techniques should be adopted to enhance carbon sequestration and resilience to climate impacts.

On the third conclusion that productivity leads to a destructive climate, it is important to note that changes in output as a result of changes in productivity is what influence climate change. This study thus concludes that production efficiency should match with energy efficiency in production process.

Given the impact of positive interest rate and environmental policy shocks on consumer welfare, the following recommendations are made;

- Adoption of green financial instruments. Financial instruments such as green bonding and sustainable investment funds provide capital for economic growth by investing towards environmentally beneficial projects. They provide a balanced approach in policymaking that considers both economic objectives (like interest rate adjustments) and environmental sustainability that promote economic growth while minimizing negative environmental impacts.

- Long-term planning. By emphasizing long-term planning in policymaking to account for the cumulative effects of environmental policies and interest rate adjustments on consumer welfare, future utility could be maximized.

Suggestions for Future Research

On the basis that this study is theoretical, future studies can extend the current study by employing data to better understand how this theory works out in the economy. Finally, in order to reach a broader consensus, future research could use different econometric models such autoregressive integrated moving average (ARIMA) and vector autoregression (VAR) to understand the changes of these variables over time.

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APPENDICES

Appendix 1: Symmetric Equilibrium of the Model

Setting up the Lagrange

$$L = E_0 \sum_{t=0}^{\infty} \beta^t \{[\theta \ln C_t + \varphi \ln(1 - N_t) + \gamma \ln Q_t + \lambda_t[(1 - \tau^w)W_t N_t + R^k{}_t K_{t-1} + (1 + r_{t-1})B_{t-1} - P_t(1 - \tau^c)C_t - [K_t - (1 - \delta)K_{t-1}] - B_t - P^e{}_t Q_t + T_t]\}$$

The FOCs are

$$\frac{\partial L}{\partial C_t} = \beta^t \left[\frac{\theta}{C_t} - \lambda_t(1 - \tau^c)P_t\right] = 0$$

$$\Rightarrow \lambda_t(1 - \tau^c)P_t = \frac{\theta}{C_t}$$

$$\Rightarrow \lambda_t = \frac{\theta}{(1 - \tau^c)P_t C_t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\frac{\partial L}{\partial N_t} = \beta^t \left[-\frac{\varphi}{1 - N_t} + \lambda_t(1 - \tau^w)W_t\right] = 0$$

$$\Rightarrow \lambda_t(1 - \tau^w)W_t = \frac{\varphi}{1 - N_t}$$

$$\Rightarrow \lambda_t = \frac{\varphi}{(1 - \tau^w)W_t(1 - N_t)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\frac{\partial L}{\partial Q_t} = \left(\frac{\gamma}{Q_t}\right) - \lambda_t P_t^e = 0$$

$$\Rightarrow \left(\frac{\gamma}{Q_t}\right) = \lambda_t P_t^e$$

$$\Rightarrow \frac{\gamma}{Q_t} = \beta \lambda_t P_t^e$$

$$\Rightarrow \lambda_t = \frac{\gamma}{Q_t P_t^e} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\frac{\partial L}{\partial B_t} = -\beta^t \lambda_t + E_t \beta^{t+1} \lambda_{t+1}(1 + r_t) = 0$$

$$\Rightarrow \lambda_t \beta^t = E_t \beta^{t+1} \lambda_{t+1}(1 + r_t)$$

$$\Rightarrow \lambda_t = E_t \beta \lambda_{t+1}(1 + r_t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\frac{\partial L}{\partial K_t} = -\beta^t \lambda_t + E_t \beta^{t+1} \lambda_{t+1}[R^k{}_t + (1 - \delta_t)] = 0$$

$$\Rightarrow \beta^t \lambda_t = E_t \beta^{t+1} \lambda_{t+1}[R^k{}_t + (1 - \delta_t)]$$

$$\Rightarrow \lambda_t = E_t \beta \lambda_{t+1}[R^k{}_t + (1 - \delta_t)] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

From equation (1)

$$\lambda_t = \frac{\theta}{(1 - \tau^c)P_t C_t} \qquad \Rightarrow \lambda_{t+1} = \frac{\theta}{(1 - \tau^c)P_{t+1} C_{t+1}}$$

Equation (1) and (2) implies that

$$\frac{\theta}{(1-\tau^{c})P_tC_t} = \frac{\varphi}{(1-\tau^{w})W_t(1-N_t)}$$

$$\Rightarrow \frac{W_t}{P_t} = \frac{\varphi(1-\tau^{c})C_t}{\theta(1-\tau^{w})(1-N_t)} \qquad \ldots\ldots\ldots\ldots (6)$$

From equations (1) and (3)

$$\frac{\theta}{(1-\tau^{c})P_tC_t} = \frac{\gamma}{\beta Q_tP_t^e}$$

$$\Rightarrow \gamma(1-\tau^{c})P_tC_t = \theta Q_tP_t^e$$

$$\Rightarrow \frac{C_t}{Q_t} = \frac{\theta P_t^e}{\gamma(1-\tau^{c})P_t} \qquad \ldots\ldots\ldots\ldots (7)$$

From equations (1) and (4)

$$\frac{\theta}{(1-\tau^{c})P_tC_t} = \beta\lambda_{t+1}E_t(1+r_t)$$

$$\Rightarrow \frac{\theta}{(1-\tau^{c})P_tC_t} = \frac{\beta\theta E_t(1+r_t)}{(1-\tau^{c})P_{t+1}C_{t+1}}$$

$$\Rightarrow \theta(1-\tau^{c})P_{t+1}C_{t+1} = \beta\theta E_t(1+r_t)(1-\tau^{c})P_tC_t$$

$$\Rightarrow \frac{C_{t+1}}{C_t} = \frac{\beta\theta E_t(1+r_t)(1-\tau^{c})P_t}{\theta(1-\tau^{c})P_{t+1}}$$

$$\Rightarrow C_t^{-1} = \frac{P_t}{P_{t+1}}\beta E_tC_{t+1}^{-1}(1+r_t) \qquad \ldots\ldots\ldots\ldots (8)$$

Equation (8) is the Euler equation linking consumption in adjacent periods.

From equation (8)

$$\beta^{-1}\frac{P_{t+1}C_{t+1}}{P_tC_t} = E_t(1+r_t)$$

Let $\Lambda_t = \frac{1}{1+r_t}$

$$\Rightarrow \Lambda_t^{-1} = \beta^{-1}\frac{P_{t+1}C_{t+1}}{P_tC_t}$$

$$\Rightarrow \Lambda_t = \beta E_t\left\{\frac{P_tC_t}{P_{t+1}C_{t+1}}\right\} \qquad \ldots\ldots\ldots\ldots (9)$$

Equation (9) is the stochastic discount factor.

From equations (1) and (5)

$$\frac{\theta}{(1-\tau^{c})P_tC_t} = \beta\lambda_{t+1}E_t\left[R^k{}_t + (1-\delta_t)\right]$$

$$\Rightarrow \frac{\theta}{(1-\tau^{c})P_tC_t} = \frac{\beta\theta E_t\left[R^k{}_t + (1-\delta_t)\right]}{(1-\tau^{c})P_{t+1}C_{t+1}}$$

$$\Rightarrow \theta(1-\tau^{c})P_{t+1}C_{t+1} = (1-\tau^{c})\beta\theta E_t\left[R^k{}_t + (1-\delta_t)\right]P_tC_t$$

$$\Rightarrow P_{t+1}C_{t+1} = \beta E_t\left[R^k{}_t + (1-\delta_t)\right]P_tC_t$$

$$\Rightarrow C_t^{-1} = \frac{P_t}{P_{t+1}}\beta E_tC_{t+1}^{-1}\left[R^k{}_t + (1-\delta_t)\right] \qquad \ldots\ldots\ldots\ldots (10)$$

Equation (10) is the Euler equation linking consumption and investment in adjacent periods.

Domestic Firms

The optimization problem of the firms' output in time t is

$$\prod_{D,t} = \mathrm{P_t Y_t} - \left(\mathrm{W_t N_t} + \mathrm{R_t^k K_t} + P_t^{e,D}\mathrm{EN_t}\right)$$

$$\mathrm{Y_t} = \mathrm{A_t K_t^{\alpha} N_t^{\vartheta} EN_t^{(1-\alpha-\vartheta)}}$$

$$\Rightarrow \prod_{D,t} = \mathrm{P_t}\left[\mathrm{A_t K_t^{\alpha} N_t^{\vartheta} EN_t^{(1-\alpha-\vartheta)}}\right] - \left(\mathrm{W_t N_t} + \mathrm{R_t^k K_t} + P_t^{e,D}\mathrm{EN_t}\right)$$

$$\frac{\partial \Pi_{D,t}}{\partial \mathrm{K_t}} = \mathrm{P_t}\alpha\mathrm{A_t K_t^{\alpha-1} N_t^{\vartheta} EN_t^{(1-\alpha-\vartheta)}} - \mathrm{R_t^k} = 0$$

$$\Rightarrow \mathrm{R_t^k} = \alpha\mathrm{P_t A_t K_t^{\alpha-1} N_t^{\vartheta} EN_t^{(1-\alpha-\vartheta)}}$$

$$\Rightarrow \frac{\mathrm{R_t^k}}{\mathrm{P_t}} = \frac{\alpha\mathrm{A_t K_t^{\alpha} N_t^{\vartheta} EN_t^{(1-\alpha-\vartheta)}}}{\mathrm{K_t}}$$

$$\Rightarrow \frac{\mathrm{R_t^k}}{\mathrm{P_t}} = \frac{\alpha\mathrm{Y_t}}{\mathrm{K_t}} \qquad \text{..................(11)}$$

$$\frac{\partial \Pi_{D,t}}{\partial \mathrm{N_t}} = \mathrm{P_t}\vartheta\mathrm{A_t K_t^{\alpha} N_t^{\vartheta-1} EN_t^{(1-\alpha-\vartheta)}} - \mathrm{W_t} = 0$$

$$\Rightarrow \mathrm{W_t} = \vartheta\mathrm{P_t A_t K_t^{\alpha} N_t^{\vartheta-1} EN_t^{(1-\alpha-\vartheta)}}$$

$$\Rightarrow \frac{\mathrm{W_t}}{\mathrm{P_t}} = \frac{\vartheta\mathrm{A_t K_t^{\alpha} N_t^{\vartheta} EN_t^{(1-\alpha-\vartheta)}}}{\mathrm{N_t}}$$

$$\Rightarrow \frac{\mathrm{W_t}}{\mathrm{P_t}} = \frac{\vartheta\mathrm{Y_t}}{\mathrm{N_t}} \qquad \text{..................(12)}$$

$$\frac{\partial \Pi_{D,t}}{\partial \mathrm{EN_t}} = \mathrm{P_t}(1-\alpha-\vartheta)\mathrm{A_t K_t^{\alpha} N_t^{\vartheta} EN_t^{(-\alpha-\vartheta)}} - P_t^{e,D} = 0$$

$$\Rightarrow P_t^{e,D} = \mathrm{P_t}(1-\alpha-\vartheta)\mathrm{A_t K_t^{\alpha} N_t^{\vartheta} EN_t^{(-\alpha-\vartheta)}}$$

$$\Rightarrow \frac{P_t^{e,D}}{\mathrm{P_t}} = (1-\alpha-\vartheta)\mathrm{A_t K_t^{\alpha} N_t^{\vartheta} EN_t^{(-\alpha-\vartheta)}}$$

Multiplying through by EN_t

$$\Rightarrow EN_t\frac{P_t^{e,D}}{\mathrm{P_t}} = (1-\alpha-\vartheta)\mathrm{A_t K_t^{\alpha} N_t^{\vartheta} EN_t^{(-\alpha-\vartheta)}}EN_t$$

$$\Rightarrow EN_t\frac{P_t^{e,D}}{\mathrm{P_t}} = (1-\alpha-\vartheta)\mathrm{A_t K_t^{\alpha} N_t^{\vartheta} EN_t^{(1-\alpha-\vartheta)}}$$

$$\Rightarrow \frac{P_t^{e,D}}{\mathrm{P_t}} = (1-\alpha-\vartheta)\frac{\mathrm{Y_t}}{EN_t} \qquad \text{..................(13)}$$

$$\Rightarrow \frac{P_t^{e,D}}{\mathrm{P_t}}EN_t = (1-\alpha-\vartheta)\mathrm{Y_t}$$

$$\Rightarrow P_t^{e,D}EN_t = P_t^D(1-\alpha-\vartheta)\mathrm{Y_t}$$

$$\Rightarrow EN_t = \frac{P_t^D}{P_t^{e,D}}(1-\alpha-\vartheta)\mathrm{Y_t}$$

From equation (13)

$$\frac{P_t^{e,D}}{\mathrm{R}_t^k} = \frac{(1-\alpha-\vartheta)}{\alpha}\frac{\mathrm{K}_t}{EN_t}$$

$$\frac{\mathrm{K}_t}{EN_t} = \left(\frac{P_t^{e,D}}{\mathrm{K}_t}\right)\frac{\alpha}{1-\alpha-\vartheta}$$

$$\mathrm{Y}_t = \mathrm{A}_t\mathrm{K}_t^{\alpha}\mathrm{N}_t^{\vartheta}\mathrm{EN}_t^{(1-\alpha-\vartheta)}$$

$$\mathrm{W}_t = \vartheta\mathrm{A}_t\mathrm{K}_t^{\alpha}\mathrm{N}_t^{\vartheta-1}\mathrm{EN}_t^{(1-\alpha-\vartheta)}$$

$$\mathrm{R}_t^k = \alpha\mathrm{A}_t\mathrm{K}_t^{\alpha-1}\mathrm{N}_t^{\vartheta}\mathrm{EN}_t^{(1-\alpha-\vartheta)}$$

$$P_t^{e,D} = (1-\alpha-\vartheta)\mathrm{A}_t\mathrm{K}_t^{\alpha}\mathrm{N}_t^{\vartheta}\mathrm{EN}_t^{(-\alpha-\vartheta)}$$

From equation (12)

$$\mathrm{R}_t^k = \alpha\mathrm{A}_t\left(\frac{\mathrm{K}_t}{EN_t}\right)^{\alpha-1}\mathrm{N}_t^{\vartheta}\mathrm{EN}_t^{-\vartheta}$$

$$\frac{\mathrm{K}_t}{EN_t} = \left[\frac{\mathrm{R}_t^k}{\alpha\mathrm{A}_t}\left(\frac{EN_t}{\mathrm{N}_t}\right)^{\vartheta}\right]^{\frac{1}{\alpha-1}}$$

$$\frac{\mathrm{K}_t}{EN_t} = \left[\frac{\alpha\mathrm{A}_t}{\mathrm{R}_t^k}\left(\frac{\mathrm{N}_t}{EN_t}\right)^{\vartheta}\right]^{\frac{1}{1-\alpha}}$$

$$P_t^{e,D} = (1-\alpha-\vartheta)\mathrm{A}_t\mathrm{K}_t^{\alpha}\left(\frac{\mathrm{N}_t}{EN_t}\right)^{\vartheta} EN_t^{-\alpha}$$

$$P_t^{e,D} = (1-\alpha-\vartheta)\mathrm{A}_t\left(\frac{\mathrm{K}_t}{EN_t}\right)^{\alpha}\left(\frac{\mathrm{N}_t}{EN_t}\right)^{\vartheta}$$

$$\frac{\mathrm{N}_t}{EN_t} = \left[\frac{P_t^{e,D}}{(1-\alpha-\vartheta)\mathrm{A}_t}\left(\frac{\mathrm{K}_t}{EN_t}\right)^{-\alpha}\right]^{\frac{1}{\vartheta}} = \left[\frac{(1-\alpha-\vartheta)}{P_t^{e,D}}\left(\frac{\mathrm{K}_t}{EN_t}\right)^{\alpha}\right]^{-\frac{1}{\vartheta}}$$

$$\mathrm{W}_t = \vartheta\mathrm{A}_t\left(\frac{\mathrm{K}_t}{EN_t}\right)^{\alpha}\left(\frac{\mathrm{N}_t}{EN_t}\right)^{\vartheta-1}$$

$$\mathrm{W}_t = \vartheta\mathrm{A}_t\left(\frac{\mathrm{K}_t}{EN_t}\right)^{\alpha}\left\{\left[\frac{(1-\alpha-\vartheta)\mathrm{A}_t}{P_t^{e,D}}\left(\frac{\mathrm{K}_t}{EN_t}\right)^{\alpha}\right]^{-\frac{1}{\vartheta}}\right\}^{\vartheta-1}$$

$$\mathrm{W}_t = \vartheta\mathrm{A}_t\left(\frac{\mathrm{K}_t}{EN_t}\right)^{\alpha}\left(\frac{\mathrm{K}_t}{EN_t}\right)^{\alpha\left(\frac{1-\vartheta}{\vartheta}\right)}\left[\frac{(1-\alpha-\vartheta)\mathrm{A}_t}{P_t^{e,D}}\right]^{\vartheta-1}$$

$$\mathrm{W}_t = \vartheta\mathrm{A}_t\left[\frac{(1-\alpha-\vartheta)\mathrm{A}_t}{P_t^{e,D}}\right]^{\vartheta-1}\left(\frac{\mathrm{K}_t}{EN_t}\right)^{\frac{\alpha}{\vartheta}}$$

$$\mathrm{W}_t = \vartheta\mathrm{A}_t^{\vartheta}(1-\alpha-\vartheta)^{\vartheta-1}P_t^{e,D\,(1-\vartheta)}\left[\left(\frac{P_t^{e,D}}{\mathrm{K}_t}\right)\frac{\alpha}{1-\alpha-\vartheta}\right]^{\frac{\alpha}{\vartheta}}$$

$$\mathrm{Y}_t = \mathrm{A}_t\mathrm{K}_t^{\alpha}\mathrm{N}_t^{\vartheta}\mathrm{EN}_t^{(1-\alpha-\vartheta)}$$

$$\frac{\mathrm{W}_t}{\mathrm{R}_t^k} = \frac{\vartheta\mathrm{Y}_t}{N_t}\Big/\frac{\alpha\mathrm{Y}_t}{\mathrm{K}_t} = \frac{\vartheta\mathrm{Y}_t}{N_t}.\frac{\mathrm{K}_t}{\alpha\mathrm{Y}_t} = \frac{\vartheta}{\alpha}.\frac{\mathrm{K}_t}{N_t}$$

$$N_t = \frac{\vartheta}{\alpha}\left(\frac{R_t^k}{W_t}\right)K_t$$

$$EN_t = \frac{(1-\alpha-\vartheta)}{\alpha}\frac{R_t^k}{P_t^{e,D}}K_t$$

$$Y_t = A_t K_t^{\alpha} N_t^{\vartheta} EN_t^{(1-\alpha-\vartheta)}$$

$$Y_t = A_t K_t^{\alpha}\left[\frac{\vartheta}{\alpha}\left(\frac{R_t^k}{W_t}\right)K_t\right]^{\vartheta}\left[\frac{(1-\alpha-\vartheta)}{\alpha}\frac{R_t^k}{P_t^{e,D}}K_t\right]^{(1-\alpha-\vartheta)}$$

$$= A_t\left(\frac{\vartheta}{\alpha}\right)^{\vartheta}\left[\left(\frac{(1-\alpha-\vartheta)}{\alpha}\right)^{(1-\alpha-\vartheta)} K_t^{\alpha}K_t^{\vartheta}K_t^{(1-\alpha-\vartheta)}R_t^{k\,(1-\alpha)}W_t^{-\vartheta}P_t^{e,D\,(\alpha+\vartheta-1)}\right]$$

$$Y_t = A_t\delta R_t^{k\,(1-\alpha)}W_t^{-\vartheta}P_t^{e,D\,(\alpha+\vartheta-1)}K_t$$

$$K_t = \frac{Y_t}{A_t\delta}R_t^{k\,(\alpha-1)}W_t^{\vartheta}P_t^{e,D\,(\alpha+\vartheta-1)}$$

$$\delta = \left(\frac{\theta}{\alpha}\right)^{\theta}\left(\frac{(1-\alpha-\vartheta)}{\alpha}\right)^{(1-\alpha-\theta)}$$

$$N_t = \frac{\vartheta}{\alpha}\frac{R_t^k}{W_t}K_t$$

$$N_t = \frac{\vartheta}{\alpha}\frac{R_t^k}{W_t}\left[\frac{Y_t}{A_t\delta}R_t^{k\,(\alpha-1)}W_t^{\vartheta}P_t^{e,D\,(1-\alpha-\vartheta)}\right]$$

$$N_t = \frac{\vartheta}{\alpha\delta}\frac{Y_t}{A_t}R_t^{k\,\alpha}W_t^{\vartheta-1}P_t^{e,D\,(1-\alpha-\vartheta)}$$

$$N_t = \left(\frac{\vartheta}{\alpha}\right)^{1-\vartheta}(1-\alpha-\vartheta)^{\alpha+\vartheta-1}\frac{Y_t}{A_t}R_t^{k\,\alpha}W_t^{\vartheta-1}P_t^{e,D\,(1-\alpha-\vartheta)}$$

$$EN_t = \frac{(1-\alpha-\vartheta)}{\alpha}\frac{R_t^k}{P_t^{e,D}}K_t$$

$$EN_t = \frac{(1-\alpha-\vartheta)}{\alpha}\frac{R_t^k}{P_t^{e,D}}\left[\frac{Y_t}{A_t\delta}R_t^{k\,\alpha-1}W_t^{\vartheta}P_t^{e,D\,(1-\alpha-\vartheta)}\right]$$

$$EN_t = \frac{1-\alpha-\vartheta}{\alpha\delta}\frac{Y_t}{A_t}R_t^{k\,\alpha}W_t^{\vartheta}P_t^{e,D\,(-\alpha-\vartheta)}$$

$$EN_t = \left(\frac{\vartheta}{\alpha}\right)^{-\vartheta}\left(\frac{(1-\alpha-\vartheta)}{\alpha}\right)^{\alpha+\vartheta}\frac{Y_t}{A_t}R_t^{k\,\alpha}W_t^{\vartheta}P_t^{e,D\,(-\alpha-\vartheta)}$$

$$TC_t = W_tN_t + R_t^kK_t + P_t^{e,D}EN_t$$

$$= \{W_t\left[\left(\frac{\vartheta}{\alpha}\right)^{1-\vartheta}(1-\alpha-\vartheta)^{\alpha+\vartheta-1}\frac{Y_t}{A_t}R_t^{k\,\alpha}W_t^{(\vartheta-1)}P_t^{e,D\,(1-\alpha-\vartheta)}\right] +$$

$$R_t^k\left[\left(\frac{\vartheta}{\alpha}\right)^{-\vartheta}(1-\alpha-\vartheta)^{\alpha+\vartheta-1}\frac{Y_t}{A_t}R_t^{k\,(\alpha-1)}W_t^{\vartheta}P_t^{e,D\,(1-\alpha-\vartheta)}\right] +$$

$$P_t^{e,D}\left[\left(\frac{\vartheta}{\alpha}\right)^{-\vartheta}\left(\frac{(1-\alpha-\vartheta)}{\alpha}\right)^{\alpha+\vartheta}\frac{Y_t}{A_t}R_t^{k\,\alpha}W_t^{\vartheta}P_t^{e,D\,(-\alpha-\vartheta)}\right]\}$$

$$TC_t = \left(\frac{\vartheta}{\alpha}\right)(1-\alpha-\vartheta)^{\alpha+\vartheta}\frac{1}{A_t}[\left(\frac{\vartheta}{\alpha(1-\alpha-\vartheta)}R_t^{k^{\alpha}}W_t^{\vartheta}P_t^{e,D(1-\alpha-\vartheta)}\right)+$$
$$\left(\frac{\alpha}{(1-\alpha-\vartheta)}\right)R_t^{k^{\alpha}}W_t^{\vartheta}P_t^{e,D(1-\alpha-\vartheta)}+\left(R_t^{k^{\alpha}}W_t^{\vartheta}P_t^{e,D(1-\alpha-\vartheta)}\right)]$$

$$MC_t = \frac{\phi}{A_t}R_t^{k^{\alpha}}W_t^{\vartheta}P_t^{e,D(1-\alpha-\vartheta)}\left[\frac{\vartheta}{\alpha(1-\alpha-\vartheta)}+\frac{\alpha}{(1-\alpha-\vartheta)}+1\right]$$

$$MC(i) = \left(\frac{P_H(i)}{P_H}\right)^{\varepsilon H} MC_t$$

$$MC(\gamma) = \frac{\phi}{A_t}R_t^{k^{\alpha}}W_t^{\vartheta}P_t^{e,D(1-\alpha-\vartheta)}[\gamma]$$

where $\gamma = \frac{\vartheta}{\alpha(1-\alpha-\vartheta)} + \frac{\alpha}{(1-\alpha-\vartheta)} + 1 = \frac{\vartheta+\alpha^2+\alpha(1-\alpha-\vartheta)}{\alpha(1-\alpha-\vartheta)}$

$$MC(\gamma) = \gamma\frac{\phi}{A_t}R_t^{k^{\alpha}}W_t^{\vartheta}P_t^{e,D(1-\alpha-\vartheta)}$$

$$MC(i) = \left(\frac{P_H(i)}{P_H}\right)^{\varepsilon H}.\gamma\frac{\phi}{A_t}R_t^{k^{\alpha}}W_t^{\vartheta}P_t^{e,D(1-\alpha-\vartheta)}$$

$$Max\left\{\sum^{\infty}\vartheta^k E\left[\Lambda_k\left(\frac{P_H'}{P_H}\left(\frac{P_H'}{P_H}\right)^{-\varepsilon_H}\right)Y_H - \frac{mc}{P_H}\left(\frac{P_H'}{P_H}\right)^{-\varepsilon_H}Y_H\right]\right\}$$

Dividing through by P_H and differentiating gives

$$\sum\vartheta^k\Lambda_k[(1-\varepsilon)(P_H'^{-\varepsilon}P_H^{\varepsilon-1}Y_H + \varepsilon P_H'^{-\varepsilon-1}P_H^{\varepsilon-1}mc_H)] = 0$$

$$E_t\sum\vartheta^k\Lambda_k(\varepsilon-1)P_H'^{-\varepsilon}P_H^{\varepsilon-1}Y_H = E_t\sum\vartheta^k\Lambda_k\left(\varepsilon P_H'^{-1-\varepsilon_H}\widehat{mc}P_H^{\varepsilon-1}Y_H\right)$$

$$(\varepsilon-1)P_H'^{-\varepsilon}E_t\sum^{\infty}\vartheta^k\Lambda_k(P_H^{\varepsilon-1}Y_H) = \varepsilon P_H'^{-\varepsilon-1}E_t\sum^{\infty}\vartheta^k\Lambda_k(\widehat{mc}P_H^{\varepsilon-1}Y_H)$$

$$\frac{P_H'^{-\varepsilon}}{P_H'^{-\varepsilon-1}} = P_H' = \frac{\varepsilon}{\varepsilon-1}\frac{E_t\sum\vartheta^k\Lambda_k(mc_H P_H^{\varepsilon-1}Y_H)}{E_t\sum\vartheta^k\Lambda_k(P_H^{\varepsilon-1}Y_H)} = P_H^{\#}$$

NB.$P_H' = P_H(j)$

$$mc_H = mc(j)$$
$$[P_{t+s} = P_{H,t}]$$
$$Y_H(i)$$

$$= \left(\frac{P_H(i)}{P_H}\right)^{-\varepsilon}Y_H \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$mc(i) = \left(\frac{P_H(i)}{P_H}\right)^{-\varepsilon}mc_H$$

$$P^H = \frac{\varepsilon}{\varepsilon-1}\frac{A}{B}$$

where $A = E_t\sum_{k=o}^{\infty}(\phi\beta)^k\Lambda_{t,t+k}(mc_{t+k}P_{t+1}^{\varepsilon-1}Y_{t+k})$, and

$$B = E_t\sum^{\infty}(\phi\beta)^k\Lambda_{t,t+1}(P_{t+k}^{\varepsilon-1}Y_{t+k})$$

$A = \varphi_t P_t^{\varepsilon-1}y_t + \phi\beta\Lambda_{t,t+1}E_tA_{t+1}$, $B = P_t^{\varepsilon-1}y_t + \phi\beta\Lambda_{t,t+k}E_tB_{t+1}$

But $P_t = \left[\int_0^1 P_t(j)^{1-\varepsilon}dj\right]^{\frac{1}{1-\varepsilon_H}}$

$$P_t = \left[\int_0^1 \left((1-\phi)P_t^{\#1-\varepsilon} + \phi P_{t-1}^{1-\varepsilon}\right) dj\right]^{\frac{1}{1-\varepsilon}}$$

$$= \left[\int_0^{1-\phi} P_t^{\#1-\varepsilon}\, dj + \int_0^{\phi} P_t^{1-\varepsilon}\, dj\right]$$

$$= [(1-\phi)P_t^{\#1-\varepsilon} + \phi P_{t-1}^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}$$

$$\frac{A}{P_{t-1}} = \frac{1}{P_{t-1}}\left(\varphi_t P_t^{\varepsilon-1} y_t + \phi\beta\Lambda_{t,t+1}E_t A_{t+1}\right)$$

$$= \frac{\varphi_t P_t^{\varepsilon-1}}{P_{t-1}} y_t + \frac{\phi\beta\Lambda_{t,t+1}E_t A_{t+1}}{P_{t-1}}$$

$$\frac{\varphi}{P_t} = mc\gamma = \frac{mc}{P_t}$$

$$\frac{A_t}{P_{t-1}} = mc\frac{P_t}{P_{t-1}} P_t^{\varepsilon-1} y_t + \frac{\phi\beta\Lambda_{t,t+1}E_t A_{t+1}}{P_{t-1}}$$

$$= mc_t\left(\frac{P_t}{P_{t-1}}\right)$$

$$= mc_t\left(\frac{P_t}{P_{t-1}}\right) P_t^{\varepsilon-1} y_t + \phi\beta\Lambda_{t,t+1}\frac{P_t}{P_{t-1}}\frac{E_t A_{t+1}}{P_t}$$

$$\widehat{A_t} = \frac{A_t}{P_{t-1}} = (1+\pi_t)\left(mc_t P_t^{\varepsilon-1} y_t + \phi\beta\Lambda_{t,t+1}\hat{A}_{t+1}\right)$$

where $\frac{A_t}{P_{t-1}} = \hat{A}_t$

$$\frac{P_t^H}{P_{t-1}} = \frac{\varepsilon}{\varepsilon-1}\frac{\widehat{A_t}}{\widehat{B_t}} \Rightarrow \frac{P_t^H}{P_{t-1}} = \frac{\varepsilon}{\varepsilon-1}\frac{\widehat{a_t}}{\widehat{b_t}}$$

Let $\widehat{a_t} = \frac{\widehat{A_t}}{P_t^{\varepsilon-1}}$ and $\widehat{b_t} = \frac{B_t}{P_t^{\varepsilon-1}}$

$$\widehat{a_t} = \frac{\widehat{A_t}}{P_t^{\varepsilon-1}} = (1+\pi_t)\left(mc_t y_t + E_t\phi\beta\Lambda_{t,t+1}\frac{\widehat{A_{t+1}}}{P_t^{\varepsilon-1}}\right)$$

$$= (1+\pi_t)\left(mc_t y_t + E_t\phi\beta\Lambda_{t,t+1}\left(\frac{P_{t+1}}{P_t}\right)^{\varepsilon-1}\frac{\widehat{A_{t+1}}}{P_{t+1}^{\varepsilon-1}}\right)$$

$$\widehat{a_t} = (1+\pi_t)\left(mc_t y_t + E_t\phi\beta\Lambda_{t,t+1}(1+\pi_{t+1})^{\varepsilon-1}\widehat{a_{t+1}}\right)$$

$$\widehat{b_t} = \frac{B}{P_t^{\varepsilon-1}} = \frac{1}{P_t^{\varepsilon-1}}\left(P_t^{\varepsilon-1} y_t + E_t\phi\beta\Lambda_{t,t+1}B_{t+1}\right)$$

$$\widehat{b_t} = y_t + E_t\phi\beta\Lambda_{t,t+1}\frac{B_{t+1}}{P_t^{\varepsilon-1}}$$

$$\widehat{b_t} = y_t + E_t\phi\beta\Lambda_{t,t+1}\left(\frac{P_{t+1}}{P_t}\right)^{\varepsilon-1}\frac{B_{t+1}}{P_{t+1}^{\varepsilon-1}}$$

$$\widehat{b_t} = y_t + E_t\phi\beta\Lambda_{t,t+1}(1+\pi_{t+1})^{\varepsilon-1}\widehat{b_{t+1}}$$

$$1+\pi_t = \left[(1-\phi)\left(\frac{P_t^{\#}}{P_{t-1}}\right)^{1-\varepsilon} + \phi\right]^{\frac{1}{1-\varepsilon}}$$

$$\frac{P_t^{\#}}{P_{t-1}} = \frac{\varepsilon}{\varepsilon-1}\frac{\hat{a}_t}{\hat{b}_t}$$

Let $1+\pi_t = [(1-\phi)(1+\pi_t^{\#})^{1-\varepsilon} + \phi]^{\frac{1}{1-\varepsilon}}$

$$1+\pi_t^{\#} = \frac{\varepsilon}{\varepsilon-1}\frac{\hat{a}_t}{\hat{b}_t}$$

$$\hat{a}_t = (1+\pi_t)\left(mc_t y_t + E_t\phi\beta\Lambda_{t,t+1}(1+\pi_{t+1})^{\varepsilon-1}\widehat{a_{t+1}}\right)$$

$$\hat{b}_t = y_t + E_t\phi\beta\Lambda_{t,t+1}(1+\pi_{t+1})^{\varepsilon-1}\widehat{b_{t+1}}$$

But $Q_{t,t+1} = \left(\frac{c_{t+1}}{c_t}\right)^{-\sigma}$ $\Lambda_t = \beta\, E_t\left\{\frac{P_t C_t}{P_{t+1}C_{t+1}}\right\}$

$$1+\pi_t = \left[(1-\phi)\left(\frac{\varepsilon}{\varepsilon-1}\frac{\hat{a}}{\hat{b}}\right)^{1-\varepsilon} + \phi\right]^{\frac{1}{1-\varepsilon}}$$

$$1+\pi_t = [(1-\phi)(1+\pi_t^{\#})^{1-\varepsilon} + \phi]^{\frac{1}{1-\varepsilon}}$$

$$ln(1+\pi_t) = \frac{1}{1-\varepsilon} ln[(1-\phi)(1+\pi_t^{\#})^{1-\varepsilon} + \phi]$$

Taylor Expression

$$ln(1+0) + \frac{d\pi_t}{1+0} = \frac{1}{1-\varepsilon} ln(1) + \frac{1}{1-\varepsilon} ln[(1-\varepsilon)(1-\phi)^{1-\varepsilon}(1+0)d\pi_t^{\#}]$$

$$d\pi_t = (1-\phi)d\pi_t^{\#}$$

$$d\pi_t = \widehat{\pi}_t, d\pi_t^{\#} = \widehat{\pi_t^{\#}}$$

$$\hat{\pi}_t = (1-\phi)\hat{\pi}_t^{\#}$$

TE is about zero inflation

$$1+\pi_t = \frac{\varepsilon}{\varepsilon-1}\frac{\hat{a}_t}{\hat{b}_t}$$

$$ln(1+\pi_t^{\#}) = ln\varepsilon - ln(\varepsilon-1) + ln\hat{a}_t - ln\hat{b}$$

$$ln(1+0) + d\pi_t^{\#} = ln\varepsilon - ln(\varepsilon-1) + ln\hat{a}^{\star} - ln\hat{b}^{\star} + \frac{d\hat{a}}{\hat{a}^{\star}} - \frac{d\hat{b}}{\hat{b}^{\star}}$$

$$\widehat{\pi_t}^{\star} = d\pi_t^{\#} = ln\varepsilon - ln(\varepsilon-1) + ln\left(\frac{\hat{a}^{\star}}{\hat{b}^{\star}}\right) + \hat{\hat{a}} - \hat{\hat{b}}$$

$$\hat{\hat{a}} = \frac{d\hat{a}}{\hat{a}^{\star}}$$

$$\hat{a} = (1+\pi_t)\left(mc_t y_t + E_t\phi\beta\Lambda_{t,t+1}(1+\pi_{t+1})^{\varepsilon-1}\widehat{a_{t+1}}\right)$$

$$\hat{a}^{\star} = mc^{\star}y^{\star} + \phi\beta\hat{a}^{\star}$$

$$\hat{a}^{\star} = \frac{mc^{\star}y^{\star}}{1-\phi\beta}$$

$$\hat{b} = y + E\phi\beta\Lambda(1+\pi_{t+1})^{\varepsilon-1}\widehat{b_{t+1}}$$

$$\hat{b}^{\star} = \frac{y^{\star}}{1-\phi\beta}$$

$\pi_t = \frac{P_t}{P_{t-1}} = 0$ at the steady state

$$\frac{\hat{a}^{\star}}{\hat{b}^{\star}} = \hat{a}^{\star} = \frac{mc^{\star}y^{\star}}{1-\phi\beta}.\frac{1-\phi\beta}{y^{\star}} = mc^{\star} = \frac{\varepsilon-1}{\varepsilon}$$

$$ln\left(\frac{\hat{a}^{\star}}{\hat{b}^{\star}}\right) = ln(\varepsilon-1) - ln\varepsilon$$

$$\widehat{\pi_t}^{\star} = ln\varepsilon - ln(\varepsilon-1) + ln\left(\frac{\hat{a}^{\star}}{\hat{b}^{\star}}\right) + \hat{\hat{a}} - \hat{\hat{b}}$$

$$= \hat{\hat{a}}_t - \hat{\hat{b}}_t$$

$$\hat{a}_t = (1+\pi_t)(mcy_t + E\phi\beta\Lambda(1+\pi_{t+1})^{\varepsilon-1}\widehat{a_{t+1}})$$

$$ln\hat{a}_t = ln(1+\pi_t) + ln(mcy + E\phi\beta\Lambda(1+\pi_{t+1})^{\varepsilon-1}\widehat{a_{t+1}})$$

TE (a) steady state

$$mc^{\star}y^{\star} + E\phi\beta\hat{a}^{\star} = \hat{a}^{\star}$$

$$ln\hat{a}^{\star} + \frac{d\hat{a}}{\hat{a}^{\star}} = ln(1+0) + d\pi_t + d\hat{a}^{\star} + \frac{dmcy^{\star}}{\hat{a}^{\star}} + \frac{dymc^{\star}}{\hat{a}^{\star}} + \frac{\phi\beta d\Lambda\hat{a}^{\star}}{\hat{a}^{\star}} - \frac{(1-\varepsilon)\phi\beta\pi_t\hat{a}^{\star}}{\hat{a}^{\star}} + \frac{\phi\beta d\widehat{a_{t+1}}}{\hat{a}^{\star}}$$

$$= d\pi_t + \frac{dmcy^{\star}}{\hat{a}^{\star}} + \frac{dymc^{\star}}{\hat{a}^{\star}} + \phi d\Lambda - (1-\varepsilon)\phi\beta d\pi_{t+1} + \phi\beta d\widehat{a_{t+1}}$$

$$ln\hat{b} = ln\left(y + E\phi\beta\Lambda(1+\pi_{t+1})^{\varepsilon-1}\widehat{b_{t+1}}\right)$$

$$\hat{b}^{\star} = y^{\star} + E\phi\beta\hat{b}^{\star}$$

$$\hat{\hat{b}} = d\pi_t + \frac{dy_t}{\hat{b}^{\star}} + \phi d\Lambda - (1-\varepsilon)\phi\beta d\pi_{t+1} + \phi\beta d\widehat{\widehat{b_{t+1}}}$$

$$\hat{\hat{a}} = d\pi_t + \frac{ydmc}{\hat{a}^{\star}} + \frac{mc^{\star}}{\hat{a}^{\star}}dy + \phi d\Lambda - (1-\varepsilon)\phi\beta d\pi_{t+1} + \phi\beta d\widehat{\widehat{a_{t+1}}}$$

$$\hat{\hat{b}} = d\pi_t + \frac{dy}{\hat{b}^{\star}} + \phi d\Lambda - (1-\varepsilon)\phi\beta d\pi_{t+1} + \phi\beta d\widehat{\widehat{b_{t+1}}}$$

$$\hat{\hat{a}} - \hat{\hat{b}} = dt + \frac{y^{\star}}{\hat{a}^{\star}}dmc + \frac{mc^{\star}}{\hat{a}^{\star}}dy_t - \frac{dy}{\hat{b}^{\star}} + \phi\beta\left(\widehat{\widehat{a_{t+1}}} - \widehat{\widehat{b_{t+1}}}\right)$$

$$\frac{y^{\star}}{\hat{a}^{\star}} = \frac{(1-\phi\beta)}{mc^{\star}}$$

$$\frac{mc^{\star}}{\hat{a}^{\star}} = \frac{1}{\hat{b}^{\star}}$$

$$\hat{\hat{a}}_t - \hat{\hat{b}}_t = \widehat{\pi_t} + (1-\phi\beta)\widehat{mc}_t + \phi\beta\left(\hat{\hat{a}}_{t+1} - \hat{\hat{b}}_{t+1}\right)$$

$$\hat{\pi}_t = (1-\phi)\left(\hat{\hat{a}}_t - \hat{\hat{b}}_t\right)$$

$$\left(\widehat{\widehat{a_{t+1}}} - \widehat{\widehat{b_{t+1}}}\right) = E_t\frac{\hat{\pi}_{t+1}}{1-\phi}$$

Hence

$$\hat{\pi}_t = (1-\phi)\hat{\pi}_t + (1-\phi)(1-\phi\beta)\widehat{mc} + \alpha\beta E_t\hat{\pi}_{t+1}$$

$$\phi\hat{\pi}_t = (1-\phi)(1-\phi\beta)\widehat{mc} + \alpha\beta E_t\hat{\pi}_{t+1}$$

$$\hat{\pi}_t = \frac{(1-\phi)(1-\phi\beta)}{\phi}\widehat{mc}_t + \alpha\beta E_t\hat{\pi}_{t+1}$$

Appendix 1: Symmetric Equilibrium of the Model

$$C_t = \left[(1-\sigma)^{\frac{1}{\eta}} C_t^{D\frac{\eta-1}{\eta}} + \sigma^{\frac{1}{\eta}} C_t^{f\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$$

$$C_t^D = (1-\sigma)\left(\frac{P_t^D}{P_t}\right)^{-\eta} C_t$$

$$C_t^f = \sigma\left(\frac{P_t^f}{P_t}\right)^{-\eta} C_t$$

$$P_t = \left[(1-\sigma)(P_t^D)^{1-\eta} + \sigma\left(P_t^f\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}$$

$$P_t C_t = P_t^f C_t^f + P_t^D C_t^D$$

$$\mathrm{Q_t} = (\tau^{CO_2} - 1)CO_{2t} + \mathrm{Q}_{t-1}$$

$$\mathrm{K_t} = (1-\delta)\mathrm{K_{t-1}} + \mathrm{I_t}$$

$$P_t^{e,D} = (1+\tau^{IM})RER_t$$

$$RER_t = e_{n_t}\frac{P_t^D}{P_t^f}$$

$$\frac{\mathrm{C_t}}{\mathrm{Q_t}} = \frac{\theta \mathrm{P}_t^e}{\gamma \mathrm{P_t}}$$

$$\mathrm{C}_t^{-1} = \frac{\mathrm{P_t}}{\mathrm{P_{t+1}}}\beta \mathrm{E_t}\mathrm{C}_{t+1}^{-1}(1+\mathrm{r_t})$$

$$\mathrm{C}_t^{-1} = \frac{\mathrm{P_t}}{\mathrm{P_{t+1}}}\beta \mathrm{E_t}\mathrm{C}_{t+1}^{-1}\left[\mathrm{R^k}_t + (1-\delta)\right]$$

Firms

$$Y_t = A_t K_t^{\alpha} N_t^{\vartheta} EN_t^{(1-\alpha-\vartheta)}$$

$$\frac{R_t^k}{P_t} = \frac{\alpha Y_t}{K_t}$$

$$\frac{W_t}{P_t} = \frac{\vartheta Y_t}{N_t}$$

$$\frac{P_t^{e,D}}{P_t} = (1-\alpha-\vartheta)\frac{Y_t}{EN_t}$$

$$MC = rhov.\frac{\phi}{A_t} R_t^{k\,\alpha} W_t^{\,\vartheta} P_t^{e,D\,(1-\alpha-\vartheta)}$$

$$CO_{2t} = (1 - \tau^{CO_2} - V_t)EN_t$$

$$Y_t = C_t + I_t + G_t + XM_t$$

Government

$$G_t + (1+\mathrm{r_{t-1}})\mathrm{B_{t-1}} = \tau^{CO_2}CO_{2t} + \tau^{IM}C_t^f + \mathrm{B_t}$$

Monetary Policy

$$r_t = \phi_\pi(\pi_t) + \phi_y(y_t) + er_t$$

Shocks

$$\mathrm{In}(A_t) = \rho_A \ln A_{t-1} + \mu_t^{A_t},\ \rho_{A^D} \in (0,1), \mu_t^A \sim N(0,\sigma_A^2)$$

$$\mathrm{In}(V_t) = \rho_v \ln V_{t-1} + \mu_t^{V},\ \rho_V \in (0,1), \mu_t^V \sim N(0,\sigma_V^2)$$

$$\ln(er_t) = \rho_{er}\ln er_{t-1} + \mu_t^{er}, \rho_{er_t} \in (0,1), \mu_t^{er} \sim N(0,\sigma_{er}^2)$$