An econometric study of public policy applied to renewable energy, economic growth and taxation

by

Jehu A. Mette

B.Sc., Kansas State University, 2017

M.A., Kansas State University, 2019

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the
requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Economics
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2021

Abstract

This dissertation consists of three essays on public policy related to renewable energy, economic growth and tax policy. Each chapter is implemented with a different econometric method to investigate the policy question of interest. The first chapter studies the effect of renewable energy utilization on many food price categories in relation to the Energy Policy Act of 2005. The second chapter investigates the link between public education expenditures and long term economic growth in the context of countries' institutional quality, while the third chapter focuses on the impact of the 2012 Kansas tax reform on state employment across industries.

The first essay, co-authored with Dr. Bebonchu Atems, examines the link between renewable energy consumption and consumer food prices in recent years. The Energy Policy Act of 2005 increased the amount of biofuel that must be mixed with commercial gasoline sold in the U.S. to 7.5 billion gallons by 2012. The Energy Independence and Security Act of 2007 further increased this requirement to 36 billion gallons by 2022. This increase in the production and consumption of biofuels, in particular, and renewable energy sources, in general, may compel farmers to divert significant quantities of cropland away from food and feed crops, which, in turn may lead to a rise in crop prices, feed prices, meat and poultry prices, and hence, overall food prices. Employing structural vector autoregression (SVAR) models and monthly U.S. data for the period 1974:01 to 2019:12, this paper examines, empirically, the impact of renewable energy consumption on food prices. We find, in general, that renewable energy shocks have no significant impact on food prices. For the period since the passage of the Energy Policy Act, however, shocks to biomass and wind energy consumption raise food prices significantly and persistently.

In the second econometric essay, co-authored with Dr. William Blankenau, we utilize panel and cross sectional data to explore the link between education spending and long

run growth among countries with different institutional quality. The economics literature suggests that education spending and strong institutions both positively affect economic growth. However, their combined effect has received considerably less attention. To explore this, we derive a growth regression from an endogenous growth model constructed to map the link between education spending, institutional quality and growth outcomes. It would be natural to expect that the marginal effect of education spending increases with strong institutions. Our results suggest that education spending and strong institutions instead operate as substitutes in generating growth, especially in rich and developing countries. The explanation could be that growth can arise from better skills due to higher education spending or from enhanced economic activity due to stronger institutions. This relationship could suggest a certain redundancy especially when countries with high institutional quality also invest substantially in education spending. We emphasize that the implication is not that one is less important or has a negative effect on growth.

In the third essay, which is co-authored with Dr. Ross Milton, we revisit the impact of one of the largest state tax reforms in history. In 2012, the state of Kansas eliminated taxation for business income and lowered marginal tax rates on other personal income sources. Contrary to predictions of the new legislation's proponents, prior work has established that the tax reform had no significant impact on the aggregate state employment or real economic activity. In this study, we ask whether the effect was the same for high pass-through industries and other sub-samples of interest to policymakers. Overall, we find no aggregate employment increase but rather job losses in a few industry groups. We find that even after excluding the aircraft manufacturing, the oil and energy industries as well as the agricultural sector, the aggregate state employment did not increase. We further test whether industries with a high concentration of pass-through employment experienced more job gains. We find that while a positive link exists between high pass-through concentration and job gains, the link is never significant regardless of time horizons or specifications while income re-characterization cannot be ruled out.

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Approved by:

Major Professor
William Blankenau

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Acknowledgments

At the end of this season of my life, I would like to express my deepest gratitude to all the people who have influenced me. Professor William Blankenau comes first to my mind as a tireless mentor, supervisor and role model. He exemplified and encouraged the work habits necessary to long term research productivity. He helped me become a better student and researcher. I also want to thank Dr. Ross Milton for his patient support and belief in me as I explored the technical foundations of empirical work. Your availability, example and encouragement have inspired me to develop life-long learning habits for empirical research. I am extremely grateful to Dr. Cassou, Dr. Hageman and Dr. Xia for being excellent teachers and researchers who provided invaluable comments and ideas throughout this process. Dr. Philip Gayle and Dr. Lei Lei Shen influenced my decision to begin this journey despite my wavering self-confidence. Four years later, I could not be more glad to have benefited from their advice. Their excellence and support was a reminder of what is possible as I was going through my training. Dr. Mohaned Al-Hamdi and Dr. Daniel Kuester originally motivated me to pursue teaching through their professionalism and care for students. Their achievements have encouraged me to always put students first as I improve myself. To every member of the economics department faculty and staff especially, Dr. Chang for combining excellence and cheerfulness, Dr. Amanda Gaulke for sparking my interest in empirical research, Dr. Lance Bachmeier for the several seen and unseen efforts to help graduate students succeed and all the other members, thank you.

There must be a special and deep thankfulness extended to Dr. Bebonchu Atems. Upon losing my mother to leukemia during the Ph.D. program, all emotional and mental circumstances concurred to my abandonment of the doctoral process. Dr. Atems became a mentor, and saw what I could not see, encouraged me to attempt what I would have never contemplated on my own. More than a temporary help to surmount tragedy, he has become a friend and a life-long comfort zone challenger.

If coaches and trainers get you ready to perform well during the race, many unseen heroes give you a chance to compete at all. Among those are Eric and Thelma Carley, who have welcomed and housed me during my first semester in the United States. Words cannot express my eternal gratitude. Paulin Kadunyi and Jacques Faye were irreplaceable friends in time of dire needs. I cannot thank you enough. Dean Alison Wheatley went the extra miles when I was in the process of translating my French original degree. If it was not for your heart of kindness and patience to listen and understand my educational background, none of this would have been possible. Paul and Élise Metté, my parents, have made sacrifices I shall never fully understand. I will reach as high as I can, be mindful of others and always improve to honor you.

I have an immense gratitude toward my colleagues and friends who kept my social life going during the doctoral program. Frank Evans, Jorge Caceres, Ryan Ostenberg, Hannah Shear, Preety Bhogal, Tian Liu, Modhi and Meznah Albaqami you were such good friends and dedicated study partners during our time together. Thank you Atika Benaddi, Manzamasso Hojdo, and Tennecia Dacass for your advices and practical help for exam preparation and software questions. Throughout this journey, a robust community of friends in Called to Greatness and Reformed University Fellowship have kept me grounded and encouraged. Thank you for your love and encouragements especially Jon Hupp, Rob Zima and Jon Dunning.

To my wonderful spouse Jessica, you make me a better person. I extend to you my deepest gratitude and love for your exceptional support. A lifetime with you is not enough.

Dedication

To my parents, Paul & ÉliseAmetté, for their sacrifices, prayers and patient love for me.

Chapter 1

The impact of renewable energy consumption on food prices: the role of the Energy Policy Act of 2005

1.1 Introduction

Between 1974 and 2005, U.S. real retail food prices experienced a persistent decline. In contrast, real retail food prices paid by American consumers have generally trended upward since 2006. Figure (1.1) plots these trends in U.S. consumer prices from January 1974 to June 2020. The graph shows aggregate U.S. food prices, as well as eight subcategories of food consumed by U.S. households. The figure shows that overall food prices fell by more 16% between January 1974 and December 2005. Over the same period, the prices of meat and poultry, dairy products, alcoholic beverages, and overall food at home displayed even larger declines, decreasing by as much as 41%, 32%, 25%, and 20%, respectively. Consumer prices of the remaining food items fell at a slower pace, with fruits and vegetable prices falling by 12%, nonalcoholic beverages by 6%, cereals and baked goods by 5%, and overall food consumed away from home by 4%. Since 2006, however, U.S. consumer prices have risen by over 5% in the aggregate, driven primarily by the increase in meat and poultry prices, prices of food consumed away from home, and cereals and baked goods, which respectively rose by 14%, 13%, and 4%. Other food prices have continued to trend downward since 2006, but at a much slower rate than during the 1974 to 2005 period. Overall, then, U.S. real retail food prices have behaved quite differently before and after 2006.

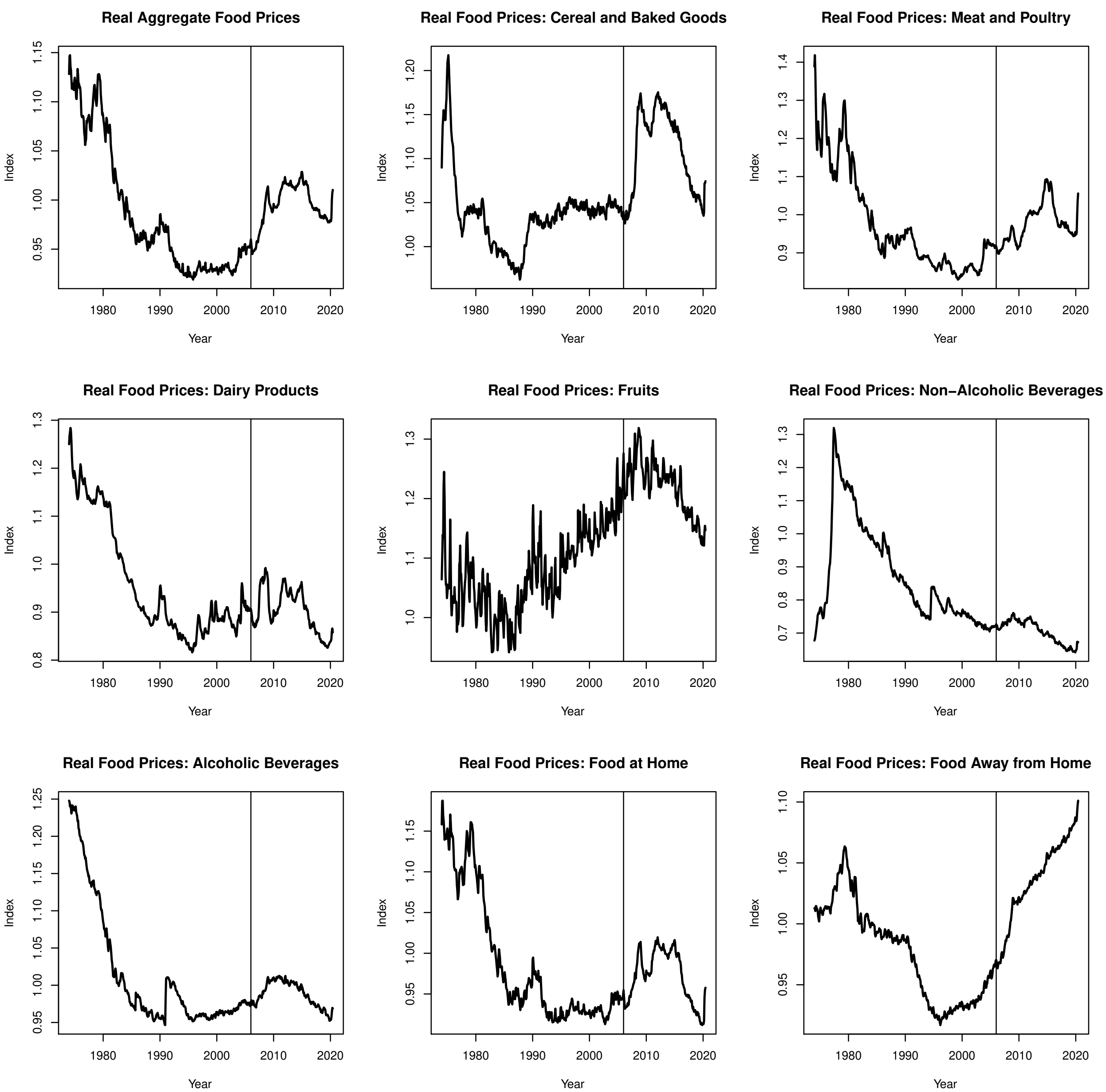
This rise in U.S. retail food prices has been attributed to a multitude of factors, including the depreciation of the U.S. dollar in the late 2000s and early 2010s, trade policy, oil and other commodity price shocks, financial speculation, and U.S. monetary policy. Abbott et al. (2011), for example, point out that a depreciating U.S. dollar relative to the currencies of its trading partners increases imported food prices, making U.S. retail food prices more expensive[1]. Giordani et al. (2016), Anderson and Martin (2011) and Bouet et al. (2012) argue that trade policy aimed at protecting the domestic market from, say, positive price shocks emanating from the global food market may have a multiplier effect in that these actions may further disrupt international food markets. Foreign governments, in turn, may respond to these food market disruptions by implementing protective trade measures, which further escalates food prices. Using structural VAR models, Anzuini et al. (2013), and Hammoudeh et al. (2015) provide evidence that a U.S. contractionary monetary policy shock leads to positive and persistent increases in food prices, but a fall in beverage prices. A causal link from oil prices to food prices is expected as higher oil prices may increase food production, processing, packaging, and distribution costs (Baumeister and Kilian (2014)[2]).

While the factors discussed above may have contributed to the recent rise in food prices, many observers have also argued that the recent rise in biofuels production and consumption, in particular, and renewable energy sources, in general, may in part be responsible for escalating food prices. Figure (1.2) provides the rationale for this view. The percent of total renewable energy as a share of total U.S. primary energy was smaller in 2006 than in 1974. Since 2006, however, total U.S. renewable energy production and consumption has soared from about 6% of total primary energy to almost 12% in 2020. This rise has been primarily

[1]For example, in January 2002, a Euro cost \$0.88. At its weakest point in April 2008, a Euro cost about \$1.60. While the dollar has, in general, appreciated since its low in mid-2008, it still remains weak relative to the Euro, with one Euro costing \$1.12 at the time of this writing.

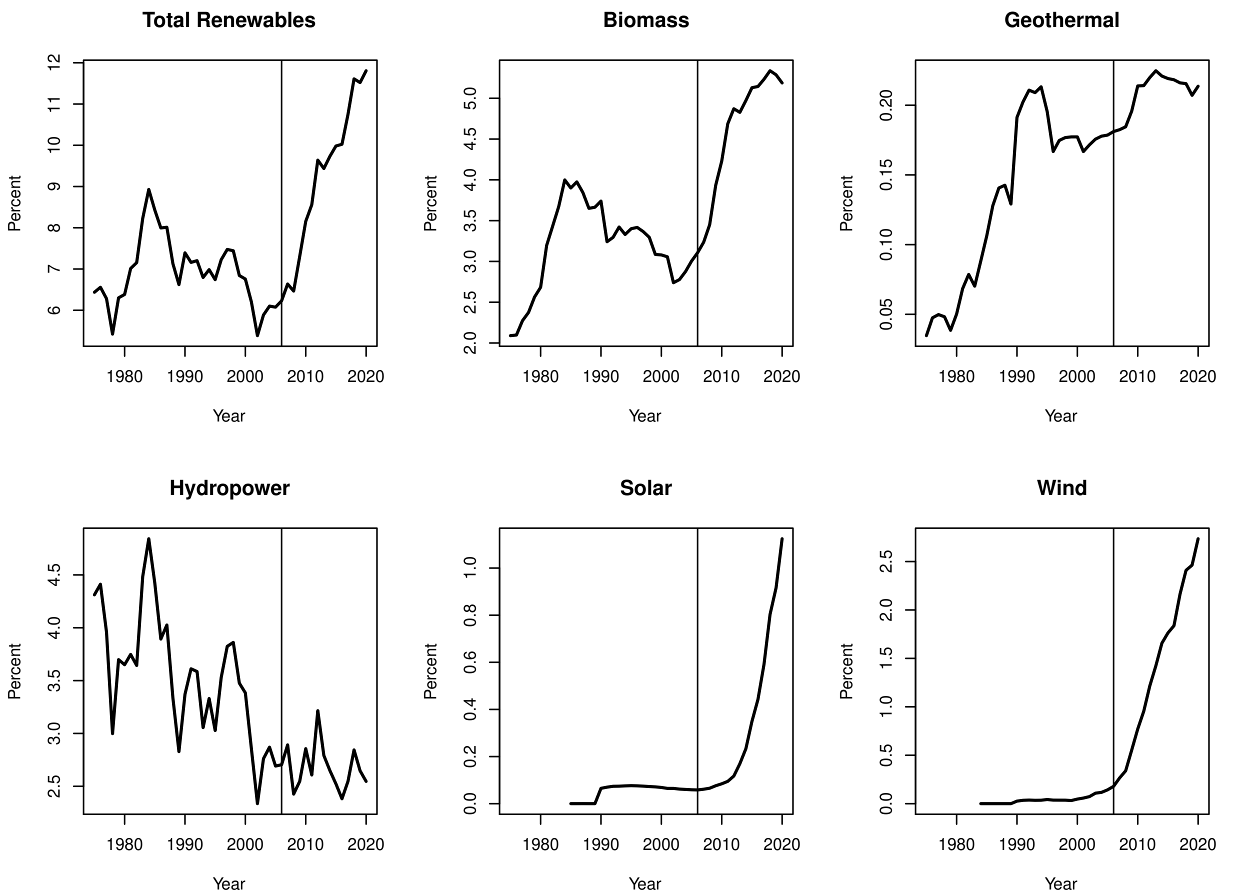
[2]Specifically, transportation costs, as well as costs associated with plastic and foam packaging can lead to substantial increases in food prices.

Figure 1.1: U.S. real retail food prices: 1974:01-2019:12



Notes: Real food prices are the U.S. consumer price index (CPI) for the respective food item, deflated by U.S. core CPI. The vertical line identifies January 2006.

Figure 1.2: Percent of total primary energy production by energy sources: 1974:01-2019:12



Notes: Data collected from the Energy Information Administration (EIA). The vertical line identifies January 2006.

driven by the rise in the production and consumption of biomass, wind, and solar energy sources. Biomass rose from almost 3% in 2006 to about 6% in 2020, wind from 0.25% to about 3% over the same time period, while solar production and consumption rose twenty-fold, from 0.06% to 1.4%. Equally important, Figures (1.1) and (1.2) illustrate that while there in no apparent link between food prices and renewable energy sources before 2006, a clear positive correlation is evident for the period from January 2006 to June 2020.

This paper is motivated by the trends shown in Figures (1.1) and (1.2). We seek to investigate whether the correlation (or lack thereof, depending on the sample period under consideration) between renewable energy consumption and production, and food prices represents a causal link. There are compelling reasons to believe that changes in production and consumption of some renewable energy sources may have causal impacts on food prices. Consider the case of biofuels. First, corn, sugar cane, soybeans, and other oil seeds are used both as food and as inputs to produce ethanol, biodiesel, or other biofuels. The diversion of food crops to biofuels leads to a clear "food versus fuel" trade-off (Gilbert (2010)), resulting in a leftward shift of the food supply curve, and raising food prices. Second, corn, soybeans, sorghum, oats, and barley are the primary ingredients used in commercially prepared feed. This shift from feed-related crops to biofuels raises the cost of producing meat, poultry, and dairy products, and consequently an increase in their prices. Third, competition between agricultural commodities and the raw materials used for biofuels (corn, soybean, and other oil seeds) for land, water, fertilizers, and other scarce resources, puts further upward pressure on food prices. In addition, the extent to which diesel and other biofuels are used to power farm machinery and equipment will impact food prices.

Biofuels are but one example of a renewable energy source that may directly impact food prices. There are also reasons to believe that an expansion of other renewable energy sources may raise food prices. Like biofuels, competition between wind farms and agricultural land may lead to a diversion of land from the latter to the former. To the extent that this happens, food prices are expected to rise. Furthermore, while farmers do not operate windmills, they lease or sell the land required for their installation, receiving compensation that typically surpasses agricultural land lease and sale prices (Myrna et al. (2019)). Given the ample evidence that land parcels and prices tend to be spatially correlated ((Kostov (2009), Wasson et al. (2013)), the value of agricultural lands adjoining wind farms is expected to rise, leading to an increase in agricultural prices. A similar argument can be made with respect to geothermal, hydropower, and solar energy sources, although in these cases, the link to food prices is less clear, and ultimately an empirical question.

This paper is not the first to examine the link between renewable energy consumption and food prices. Serra and Zilberman (2013) summarizes the broader literature and key findings of the research of the impact of biofuels on food prices. Other papers that examine this research question applying time-series approaches, include Peidong et al. (2009), Zhang et al. (2010), Serra et al. ((2011a), (2011b)) and Janda et al. (2011). One concern with these papers is that they rely on atheoretical time series models, making it difficult to attribute a causal interpretation to the (generally) positive correlations documented. These atheoretical models, for example, may not address potential simultaneity bias, since changes in the consumption of biofuels and other renewable energy sources may impact food prices, but changes in food prices are also expected to impact renewable energy consumption. There may be further endogeneity problems that arise from external factors that simultaneously determine movements in food prices and renewable energy consumption. For example, a global economic expansion is likely to lead to an increase in both renewable energy consumption and food prices, making it misleading to invoke the ceteris paribus assumption when examining the "effect" of renewable energy consumption on food prices. Therefore, the increases in food prices cannot be attributed to increases in renewable energy consumption only. Put differently, food prices would have responded quite differently if, say, federal, state, and local government policies had been responsible for an increase in renewable energy consumption of the same magnitude as the increase resulting from the economic expansion.

Cognizant of the above-mentioned complications, this paper attempts to estimate the impact of shocks to U.S. renewable energy consumption on retail food prices paid by U.S. consumers. Our econometric approach relies on structural vector autoregressions (SVAR), a methodology typically employed in modern empirical macroeconomics to estimate dynamic causal effects (see e.g. Cristiano et al. (1999), Kilian and Park (2009), Atems et al. (2015)). Applying this methodology to U.S. monthly data for the period 1974:01 to 2020:12, we find no significant evidence to support the hypothesis that shocks to renewable energy consumption increase food prices. In contrast, for the period since the passage of the Energy Policy Act, specifically, from 2006:01 to 2020:06, we find evidence that shocks to biomass and wind energy consumption lead to significant, and persistent increases in aggregate food prices, as well as other important retail food prices. We find no evidence that shocks to geothermal, hydropower, and solar energy consumption impact food prices before, or since the passage of the Energy Policy Act. However, our results show that shocks to the various renewable energy sources considered explain a larger proportion of the fluctuations in food prices in the period since the Energy Policy Act than before.

This paper is related to the broader literature that employs structural dynamic econometric models to investigate the relationship between energy and food prices. Baumeister and Kilian (2014) apply an SVAR model to examine the impact of oil price shocks on food prices, concluding that “there is no evidence that oil price shocks have been associated with more than a negligible increase in U.S. retail food prices in recent years” (page 691). Hausman et al. (2012) apply an SVAR model to analyze the response of U.S. crop prices to shocks in acreage supply, reporting that a negative shock in own acreage raises soybean and corn prices. Other papers that apply SVAR models to the “food versus fuel” debate include among others, Carter et al. (2016), Qui et al. (2012), and Anzuini et al. (2013).

The rest of the paper proceeds as follows. Section 1.2 provides a brief review of the literature on the effect of biofuels in particular, and renewable energy in general, on food prices. Section 1.3 provides some background on the Energy Policy Act and how it possibly changed the relationship between renewable energy consumption and food prices. In Section 1.4, we present the data and discuss some stylized facts about renewable energy and food prices. In the next section, we conduct tests for unit roots and structural breaks in the data. In Section 1.6, we discuss theoretical mechanisms through which changes in renewable energy consumption may impact food prices. The empirical methodology and main results of the analysis are presented in Section 1.7 and 1.8. Section 1.11 presents concluding remarks.

1.2 Related literature

The topic of renewable energy has gained growing attention both from the public and economic researchers in recent years. The concern for fossil fuels sustainability has led many large economies to orient their energy policy toward more clean and renewable alternatives. Biofuels stand out both for their current importance and future possibilities in this debate. The literature addressing the impact of renewables energies on food prices has produced several papers with mixed results.

Ajanovic (2011) focuses on biofuels’ production originating from the first generation of feedstock such as corn, wheat, and sugar cane, asking whether the then moderate increase in biofuels production had any significant effect on agricultural commodity prices. The study focuses on biofuels' production, land use, yields, and feedstock as well as crude oil prices. Two main approaches are used throughout. First, the basic relationship between quantities of crops output, costs of production and expected market prices is used. Second, the paper provides a review of the most relevant literature around the "food versus fuel" debate. The paper suggests that despite the modest but constant increase in bio-energy reliant fuels, feedstock production has increased as well and kept up. Altogether, the author concludes that biofuels and food commodities can cohabitate but emphasizes that a complete shift to biofuels would be impossible because of land limitations. Janda et al. (2012) contrasts this view by providing an overview of the motivating forces behind the increased use of biofuels and reports that they are primarily policy driven and the first generation of biofuels is economically viable. The study highlights the existence of heavy government subsidies enabling this orientation (except for Brazil, with its developed sugar cane based ethanol). The study further emphasizes that the environmental implication of these policies are for the most part ambiguous. They also undertake a review of the methods used in the literature. They report that more theory-based studies evaluating the impact of biofuels rely on partial equilibrium or computable general equilibrium models (CGE) with among others Rajagopal and Zilberman (2007) who provide a substantial overview of biofuels related models. Reduced form models linking prices in agricultural market and energy, as does Serra and Zilberman (2012). Carter et al. (2017) estimates that corn prices were about 30% higher between 2006 and 2014 compared to the expected levels if the Energy Independence and Security Act of 2007 did not create a surge in demand. Their method involves a partially identified structural vector autoregressive model.

Mueller et al. (2008) also find that the increase in food prices and biofuels production could not be interpreted as causal. Then, their findings show that the contribution of the biofuels' production is at best modest but mostly non-existent for food prices. Tangermann (2008) makes the argument that based on competing land requirements for biofuels production and food commodities there was a serious risk to the global food supply based on this emerging trade-off. Taking the examples of India and China, the paper supports that speculators were not the culprit in the food prices surge observed, but that it was rather the biofuels' production which was a significant element in the price increase. Likewise, Rathmann et al. (2010) provides further evidence that a competitiveness exists in land uses with regard to biofuel crops and traditional food commodities. The paper also reports short run increases in food prices as a result of increased biofuel production.

More recently, Mitchell (2010) supports this view and also concludes that the most important factor in the observed increase emanated from the U.S. and European Union policy shift with respect to biofuels. Berndes et al. (2003) in a review of 17 studies not only finds also mixed results but argues as well that the explanation lies in the uncertainty and diverging opinions in regard to land yields and energy crops production. Serra et al. (2013) provides another substantial survey of the biofuels and time series related literature with an exposition of the main methods used. Some theoretical modelling papers as Ciaian (2011) and Wright (2011) emphasize that these advances have not led to a consensus for modelling food prices volatility. These studies conclude that long run agricultural price levels are driven by energy prices, and that instability in the latter is transferable to food markets.

Serra et al. (2011) use a non-linear approach to address a similar question. With a smooth transition vector error correction model, the paper investigates price relationships within the U.S. ethanol industry. They study daily prices between mid 2005 and 2007. Their results suggest that ethanol, corn and oil prices have equilibria and that only ethanol prices adjust in a non-linear way to long-run parity deviations. Furthermore, they find that ethanol prices respond to shocks to either oil or corn prices reaching a peak after 10 days which fades approximately after a month. Other studies have found that to keep up with the world population growth and its demand in food supply, crop production must at least double by 2050. Yet, Ray and Mueller (2013) find that these expectations could not be met with the recorded yield levels worldwide. They further make the case that this difference between the reality and policymakers' expectations could make the trade-off a major concern much earlier than 2050 when considering the increasing production of biofuels.

Another question in the literature is the extent to which the consumption of U.S. biofuels reflects it domestic production. Ireland (2018) reports that the U.S. is the world's largest exporter of wood pellets (categorized under biofuels) and that the largest share of its international trade occurs with European countries. However, the volume is largely influenced by the European Union (EU) climate change regulations.

Biofuels production is not the only point in this debate and the role of the other sources of renewable energy has also been extensively discussed in the literature. Zhang et al. (2010) presents an overview of the status of renewable energy development in China, and the targets for 2050. The country is arguably one of fastest growing economies of the past century but also the second-largest emitter of carbon dioxide in the world according to the authors. Highlights of the paper include the China's "Renewable Energy Law" passed by congress in February 2005 with renewable energy covering already 23.4% of total installed power capacity. Qiu et al. (2012) deals with similar questions. Sayigh and Milborrow (2019) provides a thorough analysis of the cost of wind energy and its prevalence in recent years. The paper reports that wind energy is one of the cheapest in the renewable category. Lantz et al. (2016) shows that this alternative was not only cheaper, but supplied already up to 4.7% of the total U.S. electricity generation, a noteworthy growth considering that this number was essentially zero two decades earlier.

1.3 U.S. energy policy and background

Historically, U.S. food prices had been decreasing since the 1970s but experienced a surge midway through the first decade of the new millennium. A multitude of factors can explain this reversal, but many papers in the literature re-emphasize (see Carter et al. (2017), Janda et al. (2012)) that the shift in energy policy is a major factor. Two outstanding policy acts involving renewable energy consumption and production happened around that time and in this section we will explore each in more details.

1.3.1 The Energy Policy Act of 2005

In response to an increase in volatility of oil prices, U.S. dependence on foreign energy, and the environmental consequences of carbon emissions and climate change, among other factors, the Energy Policy Act of 2005 was passed by the United States Congress in July 2005 and signed into law by President George W. Bush in August of the same year[3]. The purpose of the policy, therefore, was to enhance U.S. energy security, while ameliorating the environmental and sustainability concerns related to climate change. Most provisions of the bill were to be enacted between 2005 and 2009. Among these are provisions[4] pertaining to but not limited to:

- Renewable Fuels Standard (RFS): This provision required that gasoline sold in the United States had to contain an increasing amount of renewables starting in 2006 (for example biodiesel or ethanol). Motor fuels had to contain at least 4 billion gallons of the renewables in 2006 with a target of 7.5 billion by 2012 under a yearly increment of 700 million gallons.

- Domestic energy: The act encourages production of energy on federal lands through reduced royalty and increased access for drilling activity and other energy projects.

- Tax reduction: A target of a $14.5 billion decrease over 11 years to encourage domestic energy production.

- Electricity: Several standing acts were repealed and the Federal Energy Regulatory Commission (FERC) was authorized to certify a national Electric Reliability Organization (ERO) to enforce reliability standards.

The Energy Act of 2005 was the first omnibus[5] bill signed in the U.S. in more than a decade. Due to their size and the scope of key topics they cover, these bills have faced

[3] According to the Congressional Research Service, the 2005 Energy Act came during a period of all-time high crude oil prices which hit $63 per barrel and gasoline reaching $2.4 per gallon. At the time, the U.S. imported 58% of its oil. The U.S. energy Information Administration predicted that imports would grow to 68% of the domestic demand by 2025. https://www.everycrsreport.com/reports/RL33302.html/.

[4] congress.gov/bill/109th-congress/house-bill/6/.

[5] Omnibus bills are laws proposal that covers many often unrelated topics. They are single documents accepted in a single vote by a legislature but packages together several subjects.

criticism in the past (see Massicotte (2013)). Nevertheless, the Energy Act provided financial incentives for homeowners to make changes to their energy consumption. Another element was the tax credit offered to drivers of hybrid vehicles and the increased competition among car manufacturers for fuel efficient vehicles to meet the demand. In retrospective, these provisions reduced the reliance on fossil fuels both in the short and long run.

1.3.2 The Energy Independence and Security Act (EISA) of 2007

This following act was signed on December 19, 2007 by President Bush to further address the goals of the 2005 act. Among others, it was aiming to provide the U.S. with a greater energy independence and security, enhance the production of clean energy resources and protect consumers[6]. The EISA aimed to solidify the original target and bring more aggressive requirements through three main provisions summarised here[7]:

- Corporate Average Fuel Economy (CAFE): The setting of 35 miles per gallon as target for the combined fleet of cars and light trucks by model year 2020.
- Renewable Fuels Standards (RFS): The 2005 RFS was modified, now requiring U.S. motor fuels to contain at least 9.0 billion gallons of renewables in 2008 and rising to 36 billion gallons by 2022.
- Energy Efficiency Equipment Standards: The law includes various new standards for lighting and for residential and commercial appliance equipment. The equipment includes residential refrigerators, freezers, refrigerator-freezers, metal halide lamps, and commercial walk-in coolers and freezers.

A notable decision was also the repealing of two tax subsidies in order to offset the estimated cost to implement the CAFE provision.

[6]https://www.epa.gov/laws-regulations/summary-energy-independence-and-security-act/.
[7]https://www.everycrsreport.com/reports/RL34294.html/.

1.4 Data

1.4.1 Data on renewable energy consumption

The data on renewable energy production and consumption come from the U.S. Department of Energy's Energy Information Administration (EIA). The agency provides a number of measures of energy production and consumption at different frequencies and geographic level. For our purposes, we utilized the data on total renewable energy and various disaggregate measures, namely biomass, wind power, geothermal, hydroelectric power, and solar power. All data are available in British Thermal Unit (BTU) for comparability across sources. The data are monthly, and cover the period from January 1974 to June 2020, except for wind and solar that start respectively in January 1983 and January 1984. All the measures of renewable energy are expressed as a share of total primary energy consumption, and further expressed in per capita terms by dividing by monthly U.S. population, collected from the Federal Reserve Economic Data (FRED). Expressing the data in this format is common in the literature (see Sadorsky (2009), Mishra et al. (2009), Kumar (2020), Liu et al. (2020)).

Figure 1.2 displays the trends in U.S. renewable energy consumption as a percent of total primary energy consumption from January 1974 to June 2020. Except for hydropower, which displays a downward trend, consumption of most renewable energy sources in the U.S. has risen since 1974, but this rise is most apparent after 2005. In the figure, we include a vertical line in January 2006 to make this difference in the consumption of various renewable energy sources even clearer. In fact, since January 2006, the total U.S. renewable energy consumption as a share of total U.S. primary energy consumption doubled from about 6% to 12%. This doubling in total renewable energy consumption has been fueled by the consumption of biomass, which includes biodiesel, biogas, wood, wood waste, ethanol, municipal solid waste and landfill gas. While the consumption of geothermal energy has more than quadrupled since 1974, it still comprises a negligible proportion of total primary energy consumption. On the other hand, consumption of solar and wind energy, which each stood at around 0% in 2006, now reach approximately 1.2% and 3% of the primary energy consumption, respectively.

The literature has suggested a number of reasons for this expansion of renewable energy consumption. Rentschler (2013) suggests that the increased volatility and prices of oil and other non-renewable energy sources has played a significant role. Bowden and Payne (2010) attribute it to the U.S. dependence on non-renewable energy sources finding a bidirectional Granger-causality between commercial and residential non-renewable energy consumption and real GDP. Zweibel et al. (2008) argue that the environmental consequences of carbon emissions and climate change have, in part, been responsible for the shift away from fossil fuels to alternative energy sources. These factors have led to U.S. government policies and programs that provide incentives in the form of subsidies, tax credits, and rebates for choosing to produce renewable energy contributing to the pattern. Chief among these policies have been the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007.

1.4.2 Data on food prices

The data on food prices are also monthly, from January 1974 to June 2020. We use the Consumer Price Index (CPI) of the food item as the measure of food prices for that item. All the food prices are collected from FRED, and are expressed in real terms by deflating using the U.S. CPI excluding both food and energy (core CPI). To measure aggregate food prices, we use the U.S. city average food and beverages CPI for all urban consumers. In addition to aggregate food prices, we consider eight important food prices, namely cereals and bakery products; meats, poultry, fish, and eggs (meat and poultry, henceforth); dairy and related products; fruits and vegetables (fruits, henceforth); alcoholic beverages; non-alcoholic beverages; food at home; and food away from home. These food prices have been considered by Baumeister and Kilian (2014) in their study of the impact of oil shocks on food prices.

As shown in Figure 1.1, aggregate U.S. retail food prices displayed a downward trend until the mid 2000s, after which they started rising, peaking in January 2015. While real food prices in the aggregate began to fall in 2015, they still exceed their January 2006 levels.

Prices of cereals and baked products, meat and poultry, and food away from home generally mimic aggregate food prices. However, not all food prices have trended similarly. Prices of fruits and vegetables have declined persistently since 2009, while prices of dairy products, alcoholic beverages, and non-alcoholic beverages are below their 2006 levels.

1.4.3 Additional control variables

In the robustness section, we include measures of global crude oil production, global real economic activity (REA), and crude oil prices into our baseline econometric model. The data on crude oil production is collected from the EIA. The REA index is constructed by Lutz Kilian and is available publicly[8]. To measure crude oil prices, we use the refiner acquisition cost of imported crude oil as in Kilian (2009). We express crude oil prices in real terms by dividing by core CPI. In addition, we gather data on ethanol producer price index (PPI) that we later use as a proxy for renewable energy prices.

1.5 Time series properties

In this section, we examine the time series properties of our data by conducting a series of tests for unit root and structural breaks.

1.5.1 Unit root and stationarity testing

There are many tests for stationarity but for this analysis, we will use the Augmented Dickey Fuller (ADF) test and the Phillips-Perron Test. The first takes the general form:

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \delta_1 \Delta y_{t-1} + ... + \delta_{p-1} \Delta y_{t-p+1} + \epsilon_t \tag{1.1}$$

where α is a constant, β is the coefficient on the time trend, γ is the coefficient on the one period lagged value, δ_1 is the coefficient on the one period lagged first difference, p is the lag length, δ_{p-1} is the coefficinet on the $p-1$ period of the first difference lag at the same

[8] https://drive.google.com/file/d/169Nj256wQ27xOnuVEllfj_jbb7JNGrlQ/view/.

period, y_t is the value of the series of interest at time t, Δy_t is the first different of y_t and ϵ_t is a normally distributed error term. The null hypothesis of this test is that a unit root exists in the time series. The alternative is different depending on the version of the ADF test, that is whether we consider a constant, a linear trend, or both. We usually decide between stationarity and trend stationarity. The ADF statistic is a negative number and the more negative it is, the stronger the null can be rejected. When both α and β in Equation (1.1) are zero, we are running an ADF without a drift or trend. When β alone is zero in Equation (1.1), we are running an ADF test with drift but no linear trend. The idea is that if the series actually has a unit root then the lagged y_{t-1} will provide no relevant information to predict the change in y_t beyond the one coming from Δy_{t-p+1} where $p-1$ is the lag length chosen by the information criteria. So essentially, the test checks whether γ is statistically different from zero:

$$DF = \frac{\gamma}{SE(\gamma)}$$

where DF is the Dickey-Fuller test statistic and SE denotes the standard error. The value of the test statistic is then compared to the critical values from the Dickey Fuller t-distribution. On the other hand, the Phillips-Perron (PP) test (Phillips and Perron (1988)) differs from the ADF test mainly in how it deals with serial correlation and heteroskedasticity in the errors. The PP test proceeds by estimating the model:

$$y_t = \alpha + \beta t + \Pi y_{t-1} + \epsilon_t \tag{1.2}$$

where y_t is the value of the series at time t, y_{t-1} its value in the previous period, t is the time trend, α is a constant, β is the coefficient on the time trend and ϵ_t is a normally distributed error term. The Phillips-Perron test fits Equation (1.2) and the results are used to calculate the test statistic. The test statistic can be thought of as an autocorrelation-robust Dickey-Fuller statistic. Davidson and Mackinnon (2004) report that the ADF test preforms better than the PP test in finite samples. As emphasized by Bierens (2001), regressions estimated with data that contain unit roots are likely to be spurious. In addition, there may exist

Table 1.1: Unit root tests

	Augmented Dickey-Fuler			Phillips - Perron Test	
	Ho : Non-Stationarity			Ho : Non-Stationarity	
	None	Drift	Drift and Trend	z-alpha	z-tau
Renewable Energy	-0.574(-1.95)	-4.46(-2.87)	-5.03(-3.42)	0.23(0.93)	-2.86(-3.765)
Biomass	-0.51(-1.95)	-3.70(-2.87)	-4.51(-3.42)	-19.17(3.07)	-3.52(-2.86)
Geothermal	-0.78(-1.95)	-5.96(-2.87)	-6.32(-3.42)	-87.5(6.83)	-3.52(-2.86)
Food Price Index	-0.058(-1.95)	-1.98(-2.87)	-2.72(-3.42)	-5.51(1.64)	-3.52(-2.86)
Hydropower	-1.71(-1.95)	-6.35(-2.87)	-10.04(-3.42)	-28.16(3.54)	-3.52(-2.86)
Wind power	-0.55(-1.95)	-1.36(-2.87)	-4.28(-3.42)	0.77(0.96)	-3.52(-2.86)
Solar power	-2.90(-1.95)	-3.90(-2.87)	-5.45(-3.42)	0.23(0.93)	-3.52(-2.86)
Cereals and baked goods	0.34(-1.95)	-1.14(-2.87)	0.20(-3.42)	-4.47(1.63)	-3.52(-2.86)
Meat and poultry	0.03(-1.95)	-1.06(-2.87)	-1.65(-3.42)	-4.21(1.44)	-3.52(-2.86)
Dairy products	-0.38(-1.95)	-2.56(-2.87)	-2.51(-3.42)	-12.18(2.34)	-3.52(-2.86)
Fruits	0.08(-1.95)	-2.48(-2.87)	-2.83(-3.42)	-6.65(2.1)	-3.52(-2.86)
Non-alcoholic beverages	-1.84(-1.95)	-1.73(-2.87)	-3.05(-3.42)	-3.92(1.46)	-3.52(2.86)
Alcoholic beverages	-0.05(-1.95)	-1.98(-2.87)	-1.66(-3.42)	-7.31(1.91)	-3.52(-2.86)
Food at home	-0.55(-1.95)	-1.06(-2.87)	-0.82(-3.42)	-5.00(1.45)	-3.53(-2.86)
Food away from home	2.77(-1.95)	2.39(-2.87)	-3.54(-3.42)	1.30(-1.16)	-3.52(-2.86)

linear combinations of two or more nonstationary series which are stationary, meaning that these linear combinations may be interpreted as long-run relationships. For these reasons, we conduct both tests discussed above on all series and report the results in Table 1.1. Our tests for stationarity show that all energy measures are stationary. The aggregate and disaggregated measures of food prices are shown to be non-stationnary in levels. To avoid the sort of spurious regressions problems documented by Granger and Newbold (1974) when using a mixture of I(0) and I(1) variables, we follow Atems et al. (2015) and use first log difference of our food prices measures. We proceed with a first log difference of both categories and obtain stationary series.

1.5.2 Testing for structural breaks

Looking at Figures 1.1 and 1.2 it is apparent that renewable energy production and food prices behaved very differently before and after the mid 2000s. In particular, U.S. retail food prices decreased persistently until the mid 2000s, after which they experienced a significant rise. Similarly, U.S. consumption of renewable energy was generally low before the mid 2000s, but have more than doubled since then. This raises the question of whether there has been a structural break in these series, and whether this potential break may impact the relationship between renewable energy consumption and food prices. Baumeister and Kilian (2014) emphasize that there is no consensus as to a clear date when the relationship between energy and food prices may have changed.

The Energy Policy Act was signed into law by President Bush in August 2005, making that date a plausible candidate. Using the Narayan and Popp (2010) test, Mishra and Smyth (2014) estimate a structural break in U.S. natural gas consumption in December 2005, and attribute this break to the Energy Policy Act of 2005. Carter et al. (2013) states that informed market participants would have known by late 2006 of a coming surge in ethanol production, suggesting a structural break in late 2006. Avalos tests for, and finds, a structural break in U.S. food prices in May 2006. What is evident from this discussion is that many papers agree that the underlying structure of U.S. renewable energy and food prices dynamics changed some time between August 2005 and 2006, but there is no consensus as to the exact date.

In this paper, we select January 2006 as a candidate break data, and use the Chow test to confirm this date. Table A.7 presents the results of the Chow test. For five of the six renewable energy consumption measures considered, the test rejects the null hypothesis of no structural break confirming the conjecture of a break in January 2006. Similarly, at the 5% level, the test supports our conjecture of a break in January 2006 for aggregate food prices, fruits and vegetables, non-alcoholic beverages, alcoholic beverages, and food away from home. The test also rejects the null hypothesis of no structural break in 2006 for meat and poultry prices at the 10% level. However, for cereal and baked goods, dairy products, and food at home, the hypothesis of a break in January 2006 is rejected.

1.6 The link between renewable energy and food prices

An overwhelming proportion of the findings and opinions in the literature point to a growing competition for land use allocation between biofuels and traditional crops used for food. Rathmann, Szklo and Schaeffer (2010) analyze the literature and find evidences that the emergence of biofuels had altered the dynamics of land use but only in the short run. More recently, Muscat et al. (2020) review 75 studies dealing with the question of competition. The review suggests that the allocative dilemma is supported by evidence and requires a holistic analysis. Rather than a Hecksher-Ohlinian decision at trading geographical units, it appears that it is individual farmers regardless of their crops or regional specialization who have progressively moved towards the production of renewable energy type sources. The food versus fuel debate is often considered the main channel of transmission between the two markets. In the case of ethanol, for example, as it becomes more profitable for farmers to produce corn suitable for biomass production, we could expect the supply of nutritious corn to decrease leading to higher food prices especially in categories that use corn as inputs.

The involvement in this energy harvest has greatly varied among farmers plausibly for two reasons. First, renewable energy harvesting has a high upfront opportunity cost. Taking the example of solar energy, there is a very large requirement of land for relatively small energy output. It takes 3,500 acres of land to produce about 392 megawatts. In perspective, if the U.S. were to rely on solar energy alone, it would require an area of 22,000 acres or the size of the Mojave Desert[9]. Secondly, besides the case of biomass (generated from a particular strand of corn), getting started in the renewable energy field could mean abandoning traditional crops for which farmers already have both physical and human capital. Once the Energy Policy Act of 2005 was introduced, the ethanol composition of commercial gas became a monitored requirement and the demand for suitable biofuels increased. This sudden increase in the demand for such crops most likely caused a short run surge in the biofuel market price with its short term inelastic supply. Over time, in reaction to these prices, the producers of these biofuel crops have had an opportunity to expand their operations and newcomers to enter this now lucrative market.

We believe that these dynamics have strongly affected the supply of food crops and in turn the food items for which they are inputs. Taking the case of wind then, the perception of farms growing crops and also benefiting from sporadic installation of windmills is not

[9]The National Renewable Energy Laboratory state that 3.4 acres of panels are needed to produce one gigawatt hour over a year. The estimated need for the U.S. is about 4 pettawatts of electrity for a year. https://www.cia.gov/library/publications/the-world-factbook/rankorder/2233rank.html/.

accurate. In practice, the installation of a windmill operation requires multiple GPS trackers and the creation of new roads to properly install the machines. In other words, the loss in land is not only the columns seen from afar. The Illinois Agricultural Aviation Association (IAAA) states "Farmers with wind generators may lose the option of aerial application of farm protection products, seeds, fertilizers, etc. on their farm ground. The fact is, it is dangerous to fly within the confines of a wind generator farm[10]." Nevertheless, even after accounting for these losses, the share of land that is lost to windmill operations is arguably small. Another theory that can explain the impact of wind energy production on food prices is the income effect for farmers. Given that wind energy revenue is a more stable source of income for farmers, it could disincentivize or limit farmers' production of feed crops if they are able to achieve comparable income with the new revenue. This would mean a lower supply of crops and higher food prices.

The reliability of wind turbines has also been making improvement in recent years, but they still constitute a danger for farmers who potentially work around them on a daily basis. This hazard makes this trade-off between crops production and wind energy highly pressing as more and more rural localities have their revenue funded by wind electricity production. An extreme example is Sheldon, New York which fully eliminated local taxes because revenue from wind energy sufficed for the local budget[11]. This double-edged reliance could lead the farmers to shift toward full time wind production and decrease or abandon altogether food inputs production as a source of income.

1.7 Empirical methodology

This section provides the details of the econometric methodology used in this paper. Specifically, we present a VAR model to evaluate the impact of renewable energy shocks on food prices. We incorporate the various measures of renewable energy and food prices into the VAR model one at a time, since it is not feasible to include all of them in one model.

[10] https://agaviation.com/wind-farms/.

[11] https://cleanpower.org/blog/wind-power-creates-town-no-taxes/.

For each measure of renewable energy consumption and food prices, we estimate the bivariate reduced-form VAR model:

$$\begin{bmatrix} R_t \\ F_t \end{bmatrix} = \begin{bmatrix} A_{11}(L) & A_{12}(L) \\ A_{21}(L) & A_{22}(L) \end{bmatrix} \begin{bmatrix} R_t \\ F_t \end{bmatrix} + \begin{bmatrix} \epsilon_{R,t} \\ \epsilon_{F,t} \end{bmatrix} \tag{1.3}$$

where R_t is the percentage change in the measure of renewable energy consumption, F_t represents the percentage change in the measure of food prices[12]. In Equation (1.3), L is the lag operator, $A(\cdot)$ is a polynomial in L, $\epsilon_{R,t}$ and $\epsilon_{F,t}$ are the reduced form residuals for each equation. The lag order, L, is chosen by minimizing the Akaike Information Criteria (AIC).

Hirotugu Akaike (1974) proposed this estimator of prediction error and quality of modeling. Provided with different models for a set of data, the AIC criterion estimate the quality of each model by relying on a trade-off between the goodness of fit and the simplicity of the model. It is formulated as:

$$AIC = 2k - 2\ln(L)$$

where k is the number of estimated parameters and L the maximum value of the likelihood function for the model. Given a number of models with varying lags, the preferred model is the one with the minimum AIC value.

Then, let $u_{R,t}$ and $u_{F,t}$ respectively denote the structural shocks to renewable energy consumption and food prices. We assume that the reduced-form residuals and the structural shocks have the following relationship:

$$\begin{bmatrix} \epsilon_{R,t} \\ \epsilon_{F,t} \end{bmatrix} = B_0^{-1} \begin{bmatrix} u_{R,t} \\ u_{F,t} \end{bmatrix}, \tag{1.4}$$

where B_0 is a non-singular matrix that describes the contemporaneous relationship between the two variables:

[12]Expressing the variables in percentage change is supported by many unit root tests. Those tests results are available upon request.

$$B_0 = \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix}. \tag{1.5}$$

Further restrictions must be imposed on B_0 in order to identify the structural shocks $u_{R,t}$ and $u_{F,t}$. In this paper, we impose the assumption that shocks to renewable energy consumption impact food prices contemporaneously, whereas it takes at least a month for shocks to food prices to affect renewable energy consumption. This assumption implies that $B_{12} = 0$ in Equation (1.5), yielding:

$$B_0 = \begin{bmatrix} B_{11} & 0 \\ B_{21} & B_{22} \end{bmatrix}. \tag{1.6}$$

Premultiplying Equation (1.3) by B_0 in Equation (1.6) results in the SVAR model:

$$\begin{bmatrix} B_{11} & 0 \\ B_{21} & B_{22} \end{bmatrix} \begin{bmatrix} R_t \\ F_t \end{bmatrix} = \begin{bmatrix} B_{11} & 0 \\ B_{21} & B_{22} \end{bmatrix} \begin{bmatrix} A_{11}(L) & A_{12}(L) \\ A_{21}(L) & A_{22}(L) \end{bmatrix} \begin{bmatrix} R_t \\ F_t \end{bmatrix} + \begin{bmatrix} u_{R,t} \\ u_{F,t} \end{bmatrix}. \tag{1.7}$$

We use this identified VAR model to construct impulse response functions and perform forecast error variance decomposition analyses.

1.8 Empirical results

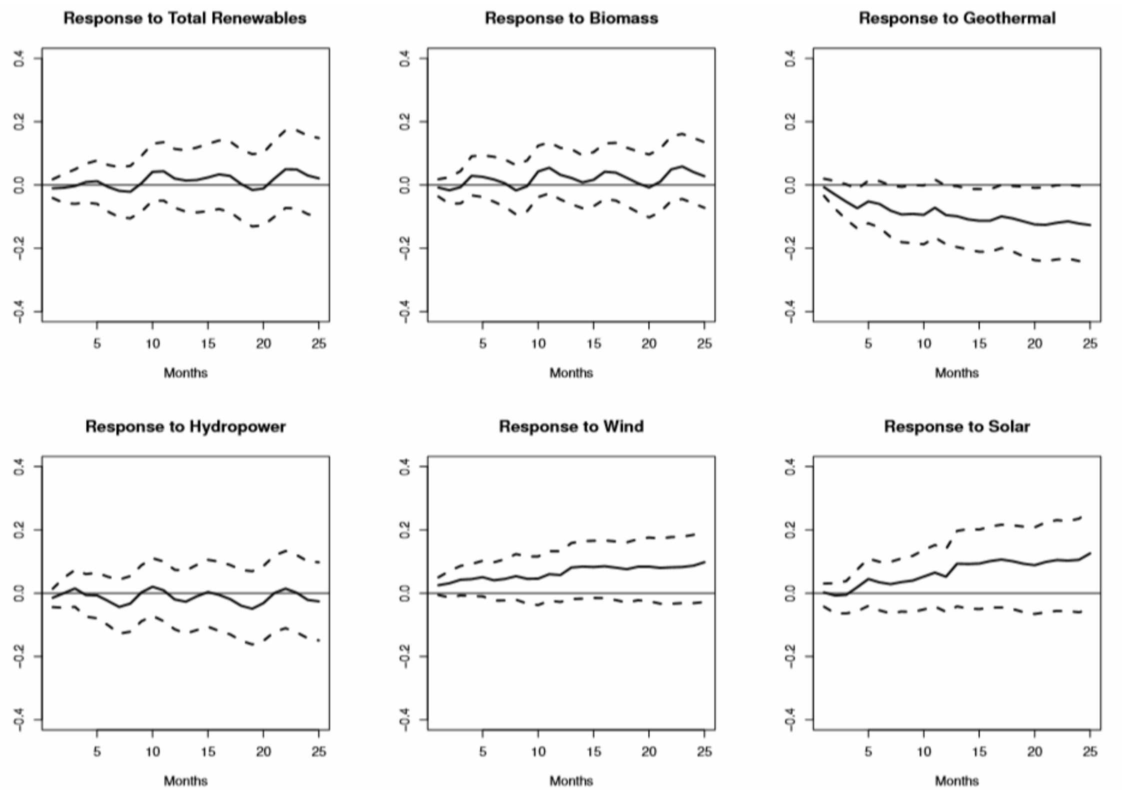
In this section, we present the responses of aggregate and disaggregate measures of food prices to a 1% shock in energy consumption. Energy consumption is either the total renewable consumption or the disaggregate measures, namely biomass, geothermal, hydropower, solar, and wind. We report these responses for the entire sample period (1974:1-2019:12), as well as two subsample periods, namely 1974:1-2005:12, and 2006:2-2019:12. This sample split is supported by a Chow test for structural breaks. The latter period is intended to capture the effects, if any, that shocks to renewable energy consumption have on food prices, following the energy policy shift after 2005. The solid lines in the impulse response functions represent the cumulative impulse response estimates, with the dotted lines depicting the 90% confidence bands obtained through a wild bootstrap procedure (Goncalves and Kilian (2004)) with 1000 repetitions. We also report forecast error variance decomposition to assess the quantitative importance of the various renewable energy shocks for movements in food prices.

1.8.1 Impulse responses and variance decomposition for aggregate food prices

The response of aggregate food prices to a shock to each of the various renewable energy consumption measures for the entire sample period (1974:1-2019:12) is shown in Figure 1.3. It is apparent from the figure that none of the renewable energy shocks exert an impact on aggregate real food prices that is significantly different from zero at any time horizon. To evaluate the quantitative importance of the various renewable energy consumption shocks for the overall variance of aggregate real retail food prices, Table 1.2 provides results of decomposition of variance analyses.

The table reveals that shocks to renewable energy consumption have minimal explanatory power for the short and long run movements in U.S. real retail food prices over the period 1974:1-2019:12. Shocks to biomass and hydropower consumption, which display the largest explanatory power, still explain only about 5% of variance of aggregate U.S. real retail food prices after three years. The other renewable energy shocks each explain less than 4% at any forecast horizon.

Figure 1.3: The impact of renewable energy consumption on aggregate food prices



Notes: Solid lines are the cumulative impulse response functions, while dashed lines are the 90% confidence bands based on the Wild bootstrap with 1000 replications. The sample period is 1974:01-2019:12.

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The finding that renewables in general, but biomass in particular, have no significant impacts on food prices while also contributing little to overall fluctuations in food prices is rather surprising, given the multitude of papers (see e.g. Serra and Zilberman (2013), Peidong et al. (2009), Zhang et al. (2010), Serra et al. (2011a), Janda et al. (2011)) that report a positive correlation between biofuels and food prices.

As mentioned before, however, one concern with previous studies that apply time series methods is their empirical reliance on atheoretical models, making it difficult to attribute a causal interpretation of their findings.

Table 1.2: Percent contribution of shocks to renewable energy consumption to the variability of aggregate food prices: Sample period, 1974:1-2019:12

Horizon	Total Renewables	Biomass	Geothermal	Hydropower	Wind	Solar
1	0.003	1.123	0.145	0.157	0.002	0.034
3	0.242	1.457	0.354	0.181	0.026	0.051
6	0.641	3.129	0.526	0.301	0.065	0.704
12	2.508	3.627	1.765	2.863	1.126	2.422
18	2.843	4.865	2.348	2.998	1.256	2.591
24	3.532	5.075	2.790	4.413	1.828	3.227
36	4.222	5.657	3.090	5.354	2.111	3.430

Notes: Forecast error variance decomposition based on structural VAR model.

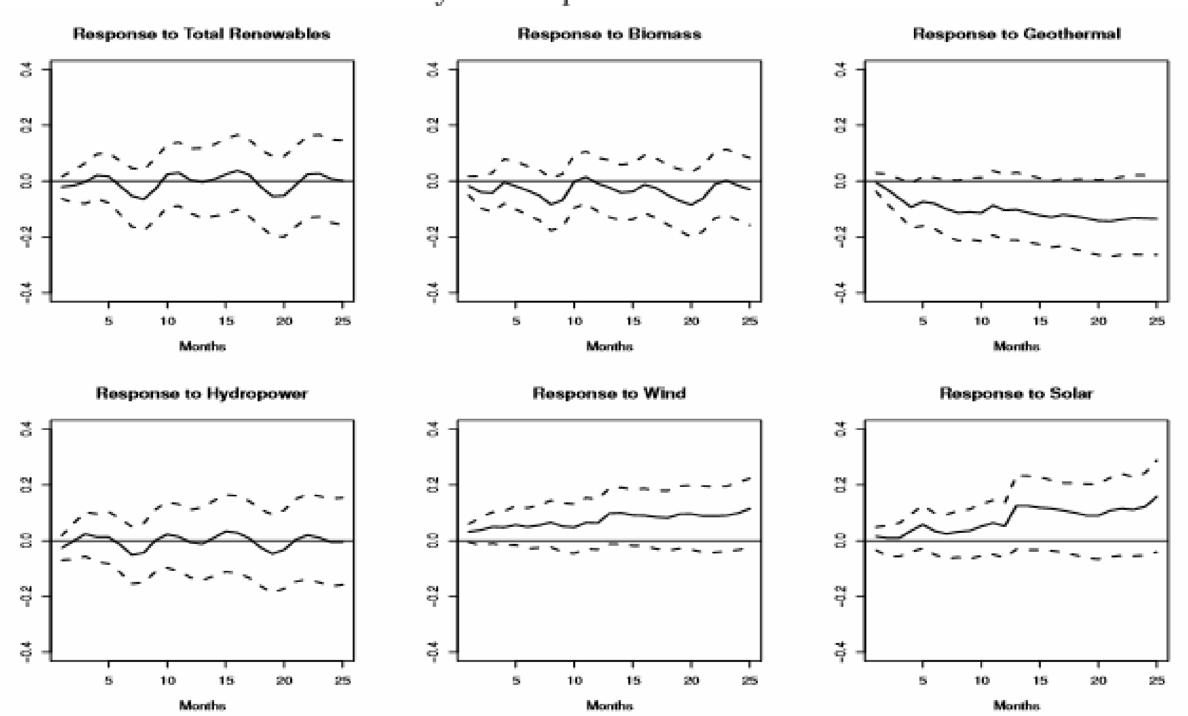
In particular, atheoretical models may not address potential simultaneity bias, since changes in the consumption of biofuels and other renewable energy sources may impact food prices, but changes in food prices are also expected to impact renewable energy consumption.

Subsample analyses

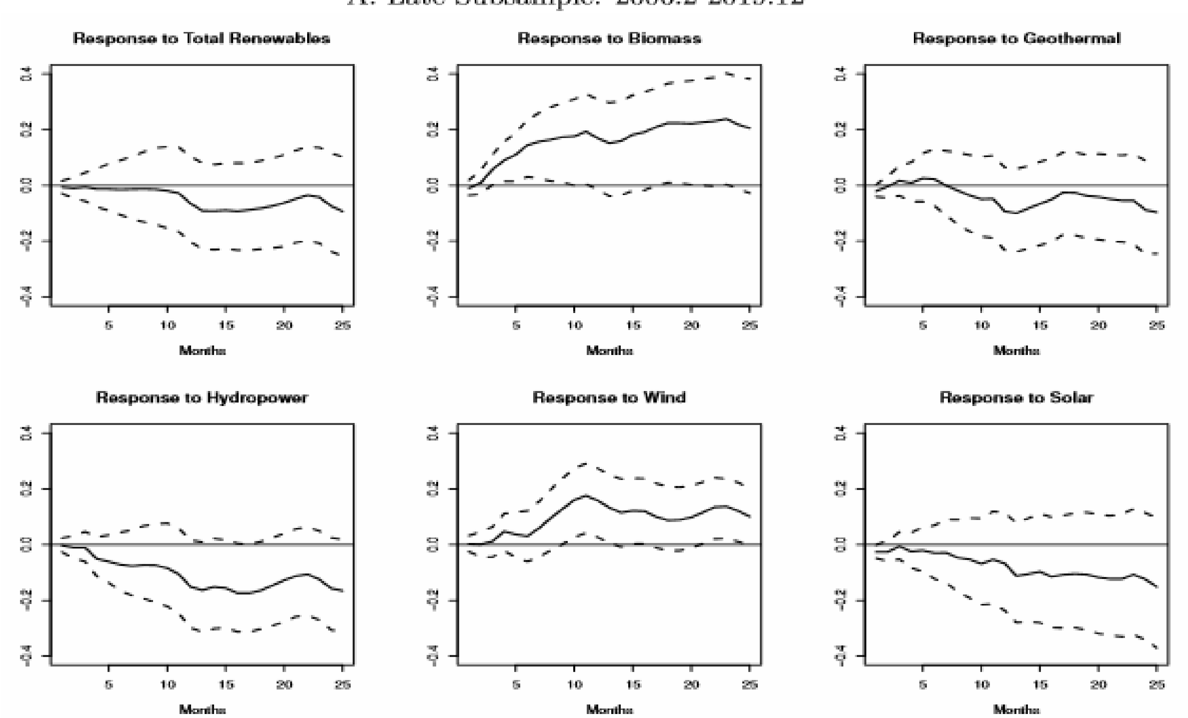
Figure 1.4 shows the results for the early subsample (1974:1-2005:12) while Figure 1.5 shows the food price responses for the late subsample (2006:2-2019:12). The impulse responses for the 1974:01-2005:12 period mimic those of the entire sample: that is, the response of food prices is not different from zero statistically at any horizon. After 2005, however, an increase in biomass consumption is followed by a rise in aggregate food prices for the first 24 months. This increase is significantly different from zero between months 3 to 10 and around month 20. The largest aggregate food price response occurs after twenty-two months with a cumulative impact of approximately 0.22% suggesting that a 1% transitory shock to biomass energy consumption leads to a cumulative aggregate food price increase of about 0.2% after eight months. This result is consistent with recent findings linking biofuels and food prices, including Mitchell (2008), Chen and Önal (2016), and Hochman et al. (2014).

Figure 1.4: The impact of renewable energy consumption on aggregate food prices: Subsample analysis

A. Early Subsample: 1974:1-2005:12



A. Late Subsample: 2006:2-2019:12



Notes: Solid lines are the cumulative impulse response functions, while dashed lines are the 90% confidence bands based on the Wild bootstrap with 1000 replications.

This finding that an increase in biomass consumption increases food prices is not surprising because producers, in order to increase supply to meet the increase in demand for biomass, must divert large quantities of cropland away from food and feed crops to biomass production. This diversion, all else equal, decreases the supply of food crops and animal feed, leading to a rise in crop prices, feed prices, and hence, meat prices. Figure 1.8 further shows that for the period since 2006, a shock to wind energy consumption raises aggregate food prices by as much as 0.21% after eleven months, and 0.18% after twenty two months.

Myrna et al. (2019), using data for Germany from 2007 to 2016, report that a higher cumulative capacity of wind turbines in communities leads to higher farmland transaction prices, with farmland prices per hectare rising by 0.4% following a doubling of the average cumulative capacity of wind turbines per community. In addition, they find that farmlands that are directly affected by a wind turbine experience stronger price increases. These increases in farmland prices raise food prices, as they raise the cost of production for farmers.

Table 1.3: Percent contribution of shocks to renewable energy consumption to the variability of aggregate food prices: Subsample analysis

Horizon	Total Renewables	Biomass	Geothermal	Hydropower	Wind	Solar
A: 1974:1-2005:12						
1	0.017	1.962	0.084	0.496	0.014	0.000
3	0.503	2.432	0.314	0.541	0.072	0.076
6	1.512	4.817	0.394	0.622	0.167	0.893
12	4.891	5.918	1.836	4.399	1.120	2.568
18	5.688	7.470	2.447	4.756	1.279	3.010
24	6.688	7.715	2.825	6.652	1.740	3.439
36	7.604	8.398	3.099	7.995	1.968	3.753
B: 2006:2-2019:12						
1	0.345	0.000	0.613	0.300	0.246	0.832
3	1.553	2.321	0.985	0.653	3.421	2.809
6	2.845	4.314	3.785	2.800	5.367	3.382
12	3.663	6.758	6.683	6.344	7.301	4.144
18	4.790	7.398	8.828	7.766	7.401	5.413
24	5.033	8.077	10.503	9.350	8.199	5.327
36	5.714	9.020	12.761	10.889	8.459	5.713

Notes: Forecast error variance decompositions based on structural VAR model.

Table 1.3 shows the percent of the forecast error variance of aggregate food prices explained by the various renewable energy sources based on the SVAR model described in

Section (1.4). Panel A shows that each of the shocks to the various renewable energy sources does not have much explanatory power for the variability of food prices during the early sample period. As in Table 1.2, we see that biomass and hydropower have the largest explanatory power during this period, respectively explaining 8.4% and 8%. The decomposition of variance analysis for the later sample period shown in Panel B reveals that the explanatory power of renewable energy consumption for unpredictable movements in food prices has increased considerably, with shocks to biomass, geothermal, hydropower, and wind energy consumption respectively explaining roughly 9%, 12.8%, 10.9%, and 8.5% of the overall variability of food prices.

Based on the results discussed so far, the rest of the analysis will focus on the food price responses to shocks to renewable energy consumption for the period 2006:2-2019:12. Results for the early subsample generally mimic the corresponding responses to a total renewable energy shock (see Table A.1 to A.6). That is, impulse response functions are generally statistically indistinguishable from zero, while decomposition of variance analyses suggest that the shocks explain very small proportions of the variance of various food prices considered. These detailed results are available upon request.

1.8.2 Impulse responses for disaggregate food prices

To understand the finding above that a shock to biomass and wind energy increase food prices for the period since February 2006, this section examines the responses of disaggregate food price indexes to the two shocks. In addition, while shocks to geothermal, hydropower, and solar energy consumption may not impact aggregate food prices (as shown above), they may have effects on the prices of specific food products. We focus on eight food products whose prices are likely to be impacted by shocks to renewable energy consumption (especially biomass and wind), namely cereals and baked goods, meat and poultry, dairy, fruits, alcoholic and non-alcoholic beverages, food at home and food away from home. These food price measures are the same ones examined by Baumeister and Kilian (2014) in their study of the impact of oil price shocks on food prices. As with the aggregate food price measure, all disaggregate food prices are deflated by the core CPI to express them in real terms. Recall that the analysis here focuses on the period 2006:2-2019:12. For each disaggregate food price index and each renewable energy source, we estimate a series of bivariate VAR models containing the renewable energy source and the food price measure of interest. We maintain the assumption that a shock to renewable energy consumption impacts food prices contemporaneously, whereas food prices impact renewables with a lag of at least a month. As before, the solid lines depict the cumulative impulse response estimates, while the dashed lines are the 90% confidence bands obtained via the Wild bootstrap with 1000 repetitions.

Figure 1.5 presents the impulse responses of each of the eight disaggregate food price measures to a shock of 1% to biomass consumption. The figure shows that a biomass shock raises food prices, with the increase being statistically different from zero for meat and poultry, fruits, alcoholic and non-alcoholic beverages, and food away from home. This rise in food prices following a biomass shock over the January 2006 to December 2019 period is exactly what one would expect. To face growing domestic demand for biofuels, U.S. biomass production has increased tremendously in recent years. A large share of the biomass is converted to ethanol and biodiesel for transportation purposes. In 2001, the U.S. produced only 3 billion bushels of soybean, with only a small proportion going to biodiesel production. By 2018, the production had risen to 4.5 billion bushels, with over a quarter used for biofuels according to the United Soybean Board[13]. Between 2010 and 2018, the share of total soybean oil consumed as biodiesel doubled from 15% to 30%[14]. A 2019 Energy Information Administration (EIA) report, in fact, revealed that soybean oil now comprises the largest share of U.S. biodiesel production[15]. Similarly, the U.S. Department of Agriculture's National Agriculture Statistics Services reported in its annual crop production summary of 2019 that corn production rose from 9.5 to 14.42 billions bushels between 2001 and 2018 (a 52% increase), while the share going to bio-fuels production increased from 7% to almost 40%[16]. These developments in biomass production are crucial especially when considering that corn and

[13] https://www.nass.usda.gov/Newsroom/archive/2019/02-08-2019.php: :text=Soybean%20production%20for/.

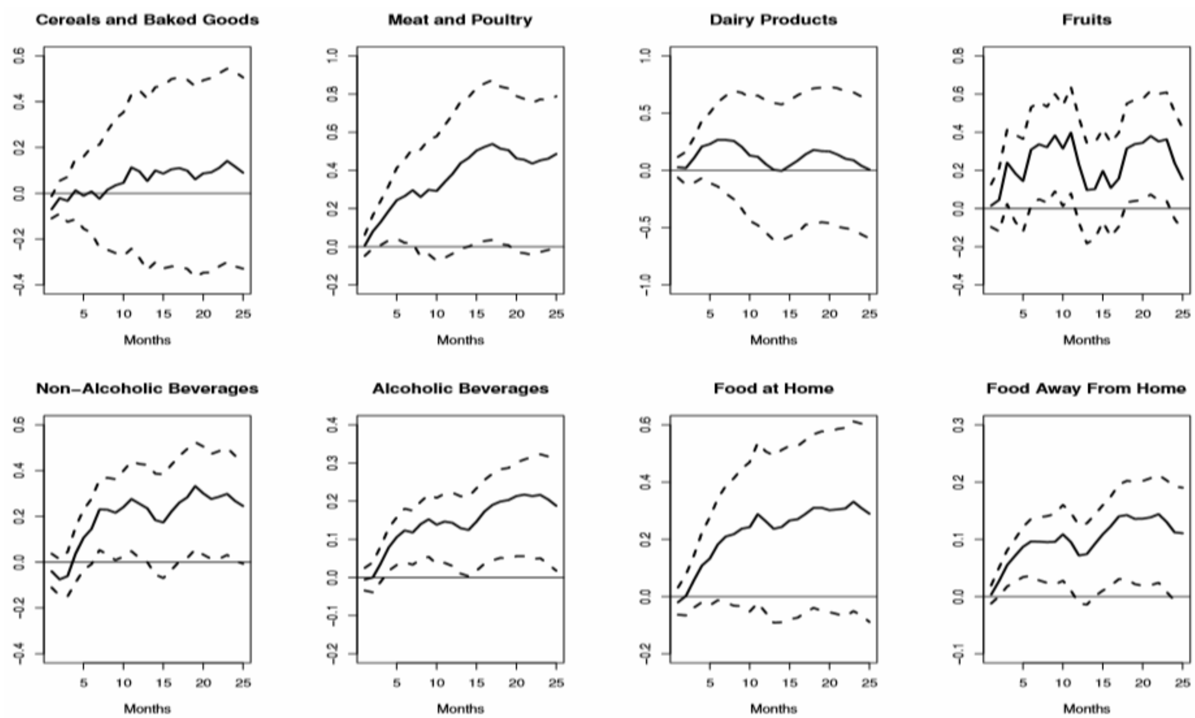
[14] The Energy Information Administration reported in May 2019 that the share of soybean oil in biodiesel went from 15% to 30% (https://www.eia.gov/todayinenergy/detail.php?id=39372).

[15] https://www.eia.gov/todayinenergy/detail.php?id=39372.

[16] https://www.nass.usda.gov/Publications/Todays$_{R}$*eports/reports/cropan*20*.pdf*.

soybean also represent the largest cost share of animal feed. This unprecedented increase in the demand for biofuels has decreased the portion of land dedicated to growing food and feed-related crops, thereby raising crop, animal and poultry feed, meat, and poultry prices, and hence, overall all food prices. This finding is also consistent with recent findings linking biofuels and food prices, including Mitchell (2008), Chen and Önal (2016), and Hochman et al. (2014).

Figure 1.5: The impact of a shock to biomass consumption on disaggregate food prices



Notes: Solid lines are the cumulative impulse response functions, while dashed lines are the 90% confidence bands based on the Wild bootstrap with 1000 replications.

Figures 1.6, 1.7, 1.8, and 1.9 display the disaggregate food price responses to shocks to geothermal, hydropower, wind, and solar energy consumption, respectively. The impulse responses of Figures 1.6 and 1.8 reveal that shocks to geothermal and wind energy consumption raise prices of alcoholic and non-alcoholic beverages, as well as prices of food away from home. On the other hand, hydropower (Figure 1.7) and solar energy (Figure 1.9) elicit responses which are not statistically different from zero at any horizon.

Table 1.4: Percent contribution of shocks to renewable energy consumption to the variability of disaggregate food prices

A. Biomass

Horizon	Cereals & Baked Goods	Meat & Poultry	Dairy	Fruits	Nonalcoholic Beverages	Alcoholic Beverages	Food at Home	Food Away from Home
1	1.647	0.014	0.166	0.025	1.009	0.736	0.037	3.462
6	6.076	7.371	3.180	1.264	2.951	3.202	3.654	4.375
12	7.570	6.386	6.256	3.003	8.887	6.574	5.373	7.886
24	9.052	7.078	7.005	3.884	11.882	7.839	6.540	11.115
36	9.976	7.599	7.689	4.316	12.687	8.194	7.283	13.147

B. Geothermal

Horizon	Cereals & Baked Goods	Meat & Poultry	Dairy	Fruits	Nonalcoholic Beverages	Alcoholic Beverages	Food at Home	Food Away from Home
1	1.192	0.014	0.094	2.494	1.036	1.092	0.796	0.024
6	11.725	1.021	1.573	4.639	6.668	3.293	3.978	2.291
12	15.782	1.895	4.968	6.683	7.795	4.092	5.340	8.267
24	21.189	2.118	6.345	8.060	9.289	4.500	7.797	12.208
36	24.553	2.222	6.693	8.247	9.699	4.682	8.910	14.150

C. Hydropower

Horizon	Cereals & Baked Goods	Meat & Poultry	Dairy	Fruits	Nonalcoholic Beverages	Alcoholic Beverages	Food at Home	Food Away from Home
1	1.385	0.298	0.245	0.111	0.560	1.119	0.206	0.265
6	3.548	2.553	5.187	2.923	9.715	4.420	1.705	6.039
12	12.938	3.609	6.724	5.605	10.165	13.825	3.804	10.993
24	14.062	3.648	6.958	7.899	13.287	15.842	5.398	13.888
36	14.751	3.777	7.009	8.928	14.608	16.451	6.113	15.123

D. Wind

Horizon	Cereals & Baked Goods	Meat & Poultry	Dairy	Fruits	Nonalcoholic Beverages	Alcoholic Beverages	Food at Home	Food Away from Home
1	2.988	1.936	1.194	1.238	1.164	0.174	0.001	1.228
6	8.139	3.592	3.212	2.208	12.850	4.618	5.507	5.746
12	11.284	4.441	3.014	5.196	15.875	7.051	6.451	9.476
24	11.809	4.235	2.889	6.254	18.599	8.237	6.725	12.834
36	12.069	4.126	2.789	6.335	20.057	8.659	6.670	14.162

E. Solar

Horizon	Cereals & Baked Goods	Meat & Poultry	Dairy	Fruits	Nonalcoholic Beverages	Alcoholic Beverages	Food at Home	Food Away from Home
1	2.713	3.071	0.256	0.030	0.800	2.457	0.109	1.127
6	6.321	5.806	1.055	3.851	4.629	3.927	2.690	2.294
12	8.948	9.739	1.523	4.938	4.395	4.014	3.111	3.409
24	10.384	10.198	1.735	5.722	5.778	4.786	4.419	4.832
36	10.331	10.297	1.861	5.935	6.332	5.086	5.059	5.321

Notes: Forecast error variance decompositions based on structural VAR model.

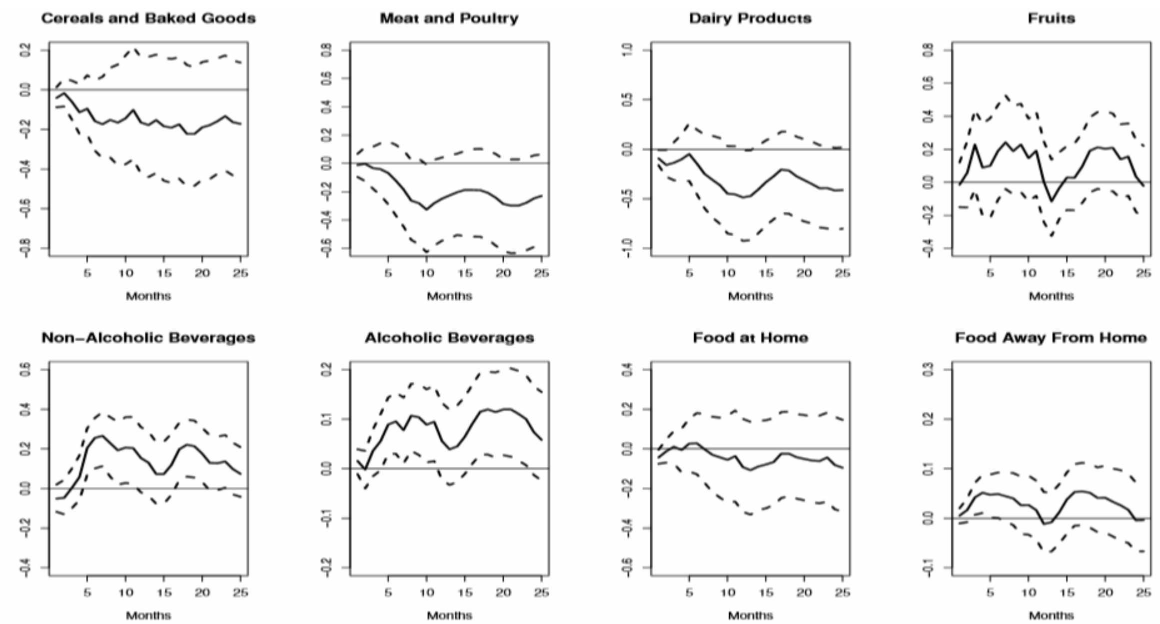
We conjecture that the finding that increased geothermal and wind energy consumption raise certain food prices because like biomass, competition between wind farms and agricultural land may lead to a diversion of land from the latter to the former. To the extent that this happens, food prices are expected to rise.

Furthermore, while farmers do not operate windmills and geothermal power plants, they lease or sell the land required for their installation, receiving compensation that typically surpasses agricultural land lease and sale prices (Myrna et al. (2019). Given the good deal of empirical evidence that land parcels and prices tend to be spatially correlated (Kostov (2009), Wasson et al. (2013)), the value of agricultural lands adjoining wind farms is expected to rise, leading to an increase in agricultural prices.

To quantify the average importance of the various renewable energy shocks for movements in the distinct food price measures, Table 1.4 displays the forecast error variance decompositions. It is immediately apparent that for all the food prices considered, there is an increase in the explanatory power of renewable energy consumption shocks overtime, but this increase varies considerably for the various food price measures. After three years, a shock to wind energy consumption explains 20% and 14% of the variation in prices of non-alcoholic beverages and food away from home, respectively. The contribution of biomass to fluctuations in the same food prices is approximately 13% each, while solar and geothermal have much less contribution.

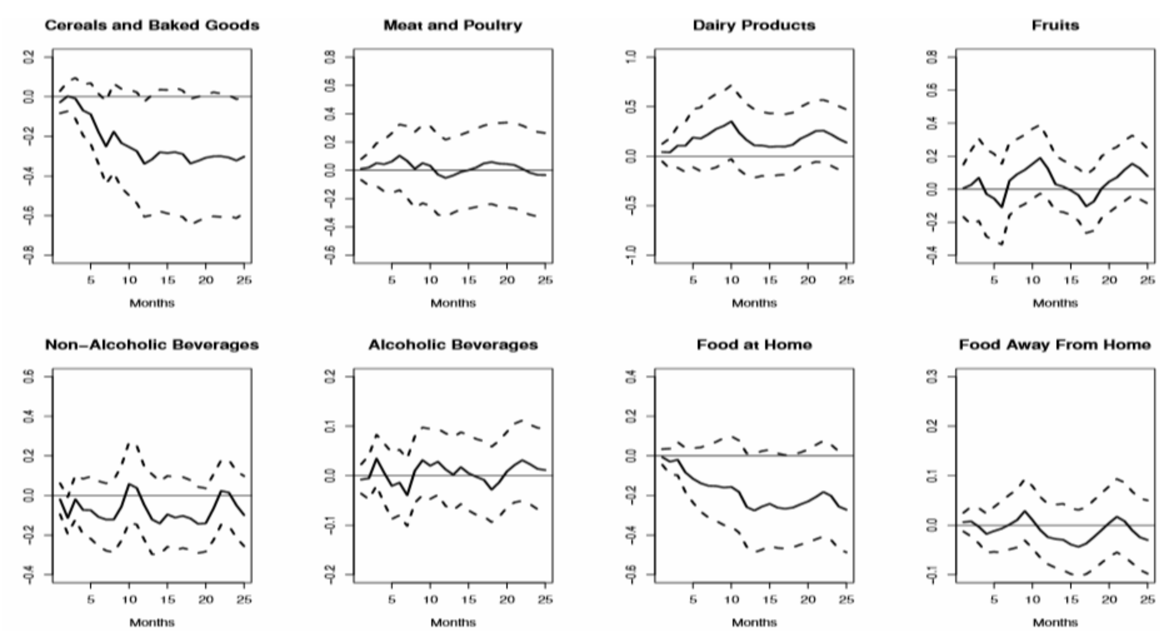
Geothermal consumption, however, is shown to have the largest explanatory power for variations in prices of cereals and baked goods, explaining as much as 25% of its variability. This exercise demonstrates that renewable energy consumption shocks can have considerable explanatory power for the unpredictable movements in aggregate and disaggregate measures of U.S. real retail food prices.

Figure 1.6: The impact of a shock to geothermal consumption on disaggregate food prices



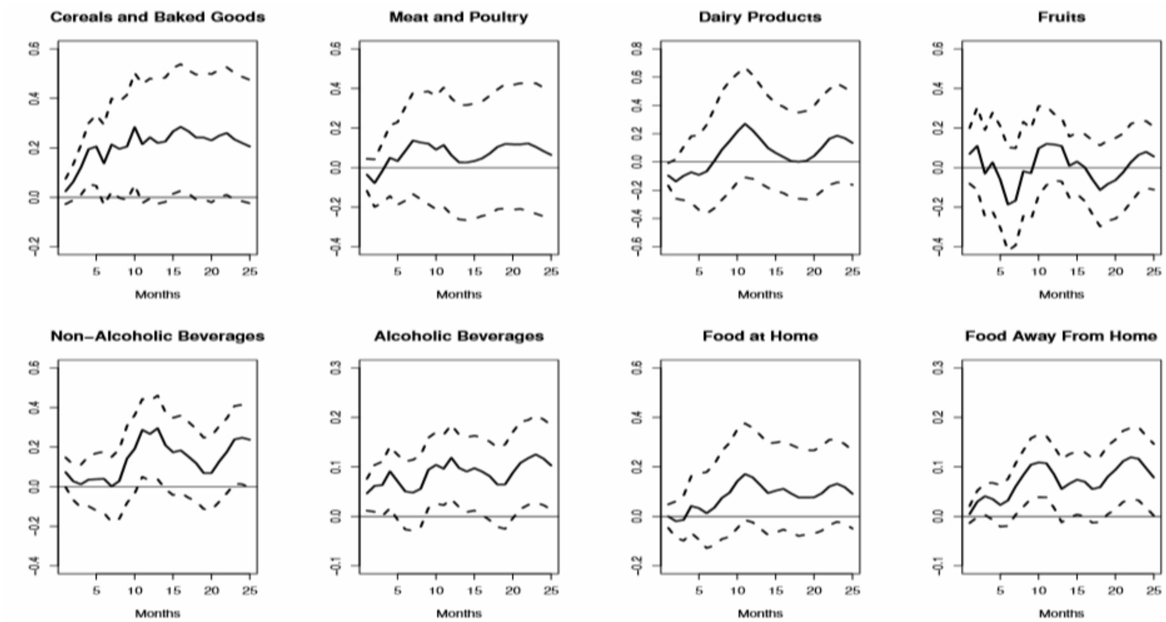
Notes: Solid lines are the cumulative impulse response functions, while dashed lines are the 90% confidence bands based on the Wild bootstrap with 1000 replications. The sample period is 2006:2-2019:12.

Figure 1.7: The impact of a shock to hydropower consumption on disaggregate food prices



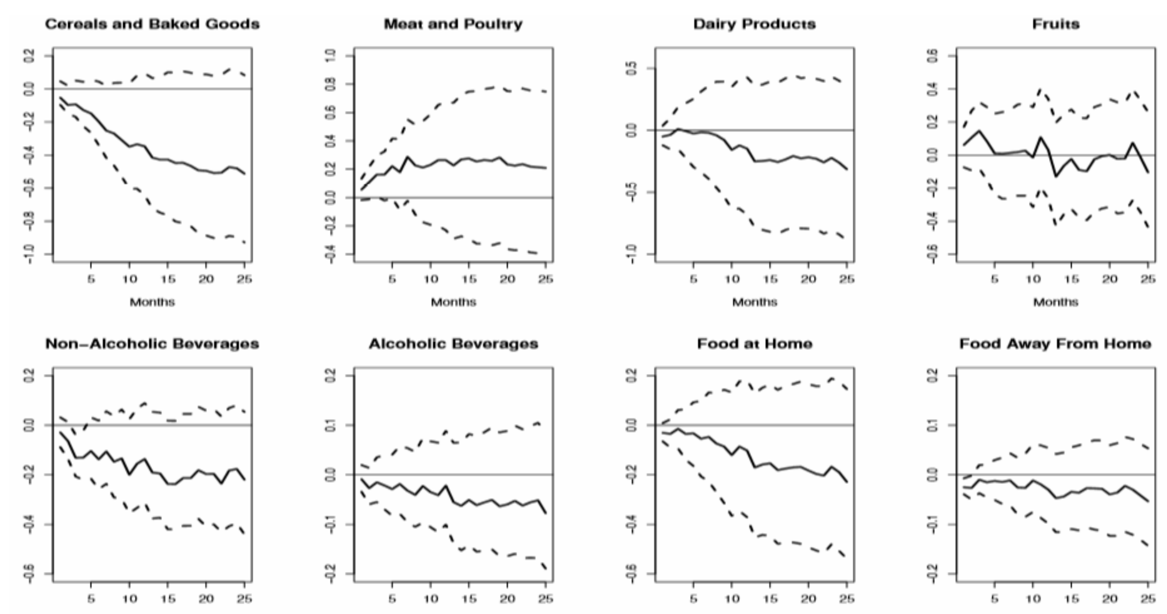
Notes: Solid lines are the cumulative impulse response functions, while dashed lines are the 90% confidence bands based on the Wild bootstrap with 1000 replications. The sample period is 2006:2-2019:12.

Figure 1.8: The impact of a shock to wind consumption on disaggregate food prices



Notes: Solid lines are the cumulative impulse response functions, while dashed lines are the 90% confidence bands based on the Wild bootstrap with 1000 replications. The sample period is 2006:2-2019:12.

Figure 1.9: The impact of a shock to solar consumption on disaggregate food prices

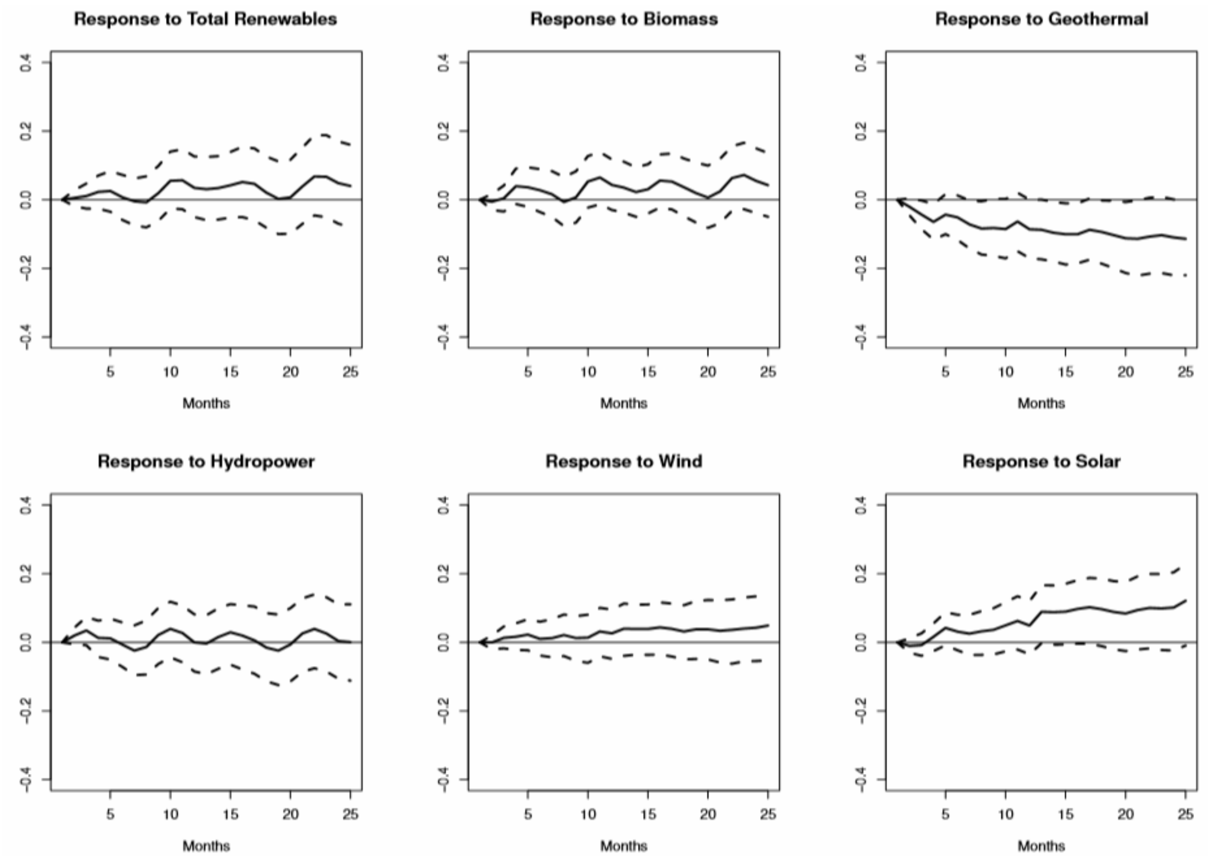


Notes: Solid lines are the cumulative impulse response functions, while dashed lines are the 90% confidence bands based on the Wild bootstrap with 1000 replications. The sample period is 2006:2-2019:12.

1.9 Robustness checks

1.9.1 Are the results driven by an unreasonable identification restriction?

Figure 1.10: The impact of renewable energy consumption on aggregate food prices: Reverse ordering of variables.



Notes: Solid lines are the cumulative impulse response functions, while dashed lines are the 90% confidence bands based on the Wild bootstrap with 1000 replications. The sample period is 1974:01-2019:12.

There is a concern that our results may be driven by the specific identification restriction of the VAR model. Our identification strategy, which relies on the Choleski decomposition, attempts to side step this problem by imposing the identification restriction that shocks to renewable energy consumption affect food prices on impact, but that shocks to food prices impact renewable energy consumption with a delay of at least a month. This assumption, however, may be subject to some debate.

As a result, Figure 1.10 plots impulse response functions resulting from an estimated SVAR model in which identification is achieved by assuming that changes in food prices affect renewable energy consumption contemporaneously, but that shocks to renewable energy consumption impact food prices with a lag (i.e. the reverse ordering). Figure 1.10 confirms the findings reported in Figure 1.3, suggesting that the statistical insignificance of the responses of food prices to the various renewable energy consumption shocks is not the result of an unreasonable identification restriction. Variance decompositions (not reported) continue to show that the contribution of shocks to renewable energy consumption to fluctuations in food prices is minimal.

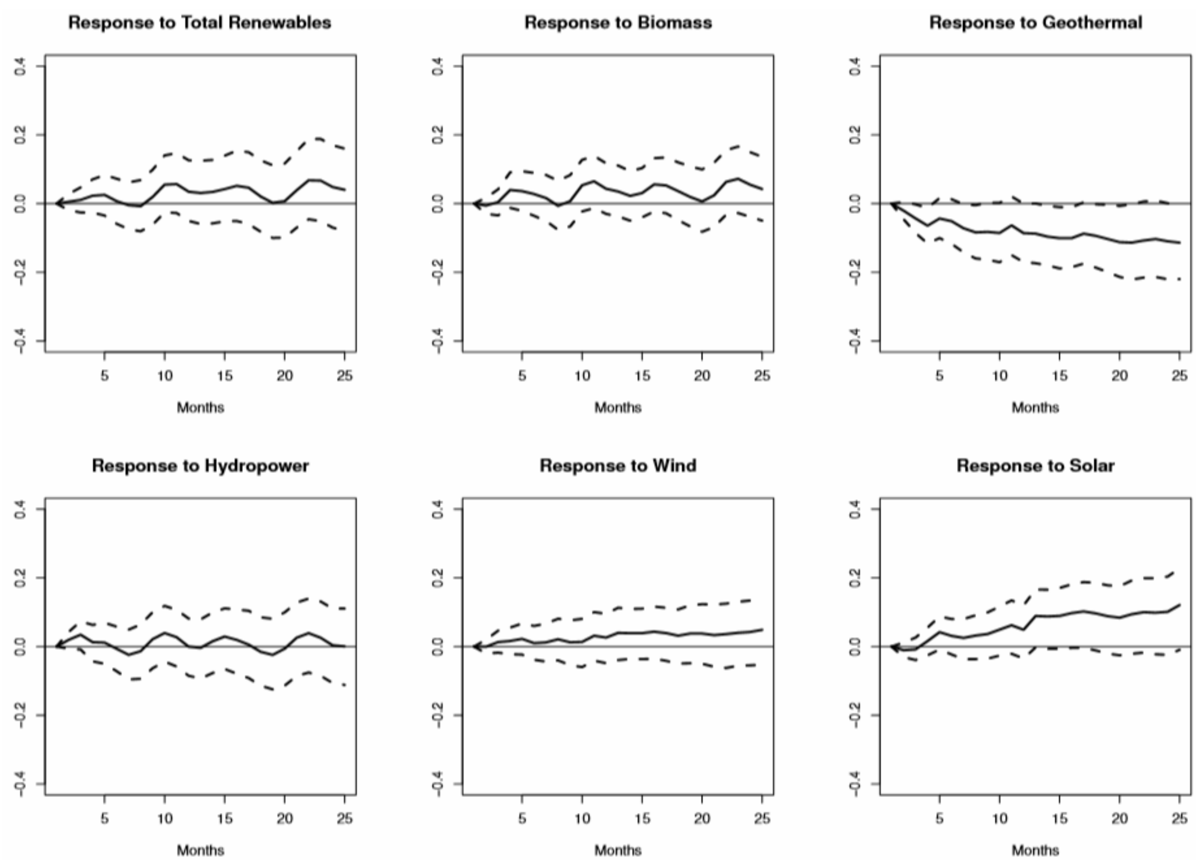
1.9.2 Are the results driven by omitted variable bias?

Another concern with our findings in Figure 1.3 is that the impulse response functions result from a bivariate VAR model. Our main reason for relying on a bivariate VAR model is that below we split our data into two subsamples following results from a structural break test. The resulting smaller samples, together with the long lag order selected by the AIC (in all cases 12 lags) raises degrees of freedom concerns since the VAR parameters increase as the square of the number of variables is higher (Stock and Watson (2001)).

Nevertheless, it is possible that the insignificance of the responses in Figure 1.3 are in part due to endogeneity problems arising from the omission of factors that simultaneously determine movements in food prices and renewable energy consumption. For example, changes in global economic conditions are likely to lead to changes in both renewable energy consumption and food prices: a global economic boom is likely to lead to higher demand for renewables and higher food prices. Similarly, changes in oil prices, which are often associated with changes in agricultural and commodity prices, are also likely to impact the consumption of renewables.

To address this concern, we add global crude oil production, global real economic activity, and crude oil prices to the baseline bivariate VAR model. The ordering of these variables follows Kilian (2009). In addition, we order these variables before U.S. renewable energy consumption and food prices because changes in U.S. variables are unlikely to impact the global economy instantaneously whereas changes in the global oil market and global economic activity are likely to have an immediate impact domestically. Figure 1.11 shows that controlling for these variables has little effect qualitatively and quantitatively on the estimated impulse responses. Consequently, the impulse response functions shown hereafter are based on the multivariate VAR model with the maintained assumption that food prices respond to shocks to renewable energy consumption with a delay of at least a month, whereas renewable energy consumption shocks have a contemporaneous effect on food prices.

Figure 1.11: The impact of renewable energy consumption on aggregate food prices: Additional controls.



Notes: Solid lines are the cumulative impulse response functions, while dashed lines are the 90% confidence bands based on the Wild bootstrap with 1000 replications. The sample period is 1974:01-2019:12. The VAR model controls for global crude oil production, global real economic activity, and real oil prices.

1.9.3 The role of renewable energy prices: The case of the ethanol production price index

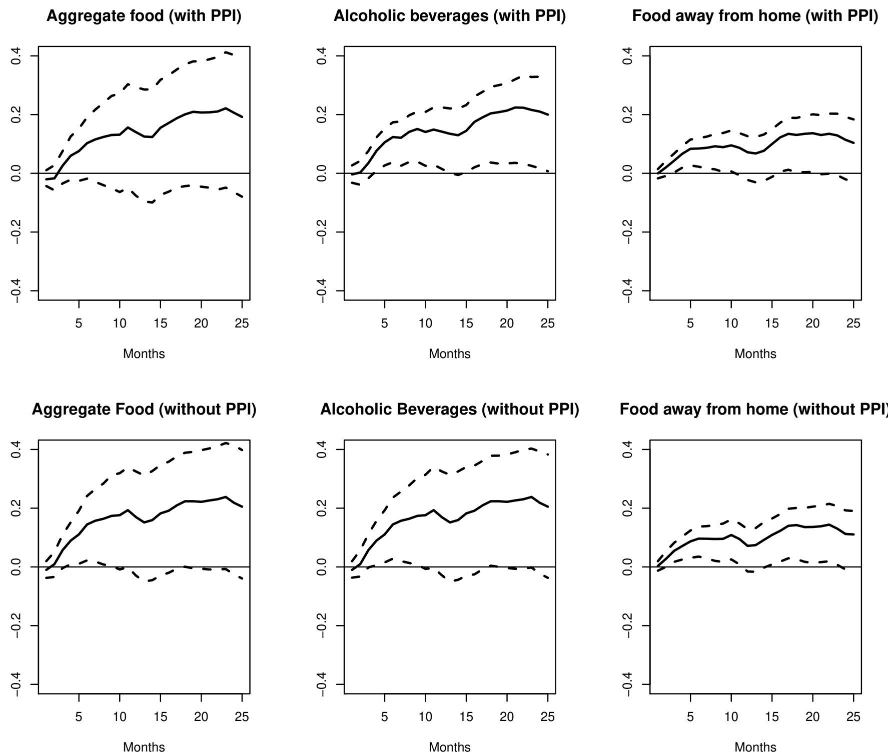
An additional consideration is the role of energy prices in the link between renewable energy consumption changes and the impact on food price categories. We address this concern in the case of biomass consumption by bringing into the analysis the Ethanol Production Price Index (PPI). Nonetheless, as renewable energy consumption has had a relatively short history, data on prices are less readily available. The measure obtained is only recorded from the first month of 2006 until the present. Our VAR now takes the form:

$$B_0 \begin{bmatrix} P_t \\ R_t \\ F_t \end{bmatrix} = B_0 \begin{bmatrix} A_{11}(L) & A_{12}(L) & A_{13}(L) \\ A_{21}(L) & A_{22}(L) & A_{23}(L) \\ A_{31}(L) & A_{32}(L) & A_{33}(L) \end{bmatrix} \begin{bmatrix} P_t \\ R_t \\ F_t \end{bmatrix} + B_0 \begin{bmatrix} \epsilon_{P,t} \\ \epsilon_{R,t} \\ \epsilon_{F,t} \end{bmatrix} \tag{1.8}$$

where P_t represents the real ethanol producer price index[17], R_t is the biomass share of primary energy consumption and F_t is the measure of real food prices. B_0 is our lower-triangular coefficient matrix conveying our identification restriction. We assume that real ethanol PPI can impact itself and other variables contemporaneously. Figure 1.12 presents the food price response of aggregate food prices, alcoholic beverages and food away from home. Earlier, the three categories showed significant increases a few months after a shock to biomass consumption (see Figure 1.4 and Figure 1.5). In the upper panel we show the results including the ethanol PPI and those without in the lower panel. After including ethanol PPI, the shock to biomass no longer displays a significant positive effect on aggregate food prices. However, alcoholic beverages prices still record the same spikes 8 months and 17 months after. Furthermore, the confidence interval is smaller after the inclusion. Finally, in the case of food away from home, the results is similar. A shock to renewable energy consumption in the biomass category causes a positive significant increase in prices 6 months and 17 months after a shock.

[17] We deflate the Ethanol PPI by the aggregate producer price index to obtain real values.

Figure 1.12: The impact of biomass consumption on food prices: Inclusion of ethanol price index.



Notes: Solid lines are the cumulative impulse response functions, while dashed lines are the 90% confidence bands based on the Wild bootstrap with 1000 replications. The sample period is 1974:01-2019:12. The VAR model controls for global crude oil production, global real economic activity, and real oil prices.

1.10 Policy implications

Our results broadly support that increased U.S. consumption of renewable energy has impacted food prices especially in recent years. This renewable consumption surge is largely policy driven (Janda et al. (2012)) with heavy government subsidies and production goals that have modified the incentive structure faced by farmers. We have explicitly shown that this occurs after the 2005 Energy Act even after taking into consideration the global crude oil production, the global real activity as well as the crude oil prices. This policy change has affected the supply of food crops through a variety of mechanisms depending on the energy source considered.

Domestically, it is important to recognize that the passing of the second Energy Act of 2007 shows a long term commitment of the American government to move toward more renewable energy production in particular bio-fuels. These energy acts have already contributed to higher U.S. food prices which raise concerns about poverty, and food security. This energy orientation will likely persist and continue to increase domestic food prices if government subsidies continue to encourage energy crops.

Another crucial consideration is the extent of these effects on foreign food prices. As the food price increases have been recorded in the U.S., they nevertheless represent a comparatively small share of the per-capita income of the average American household. This is not so for developing countries. The United States is the world's largest exporter of corn totaling about 38% of the global exports in 2019 with Argentina in second place with less then half this share (about 12.8%)[18]. The same year, about 40% of U.S. corn production went to ethanol[19]. In other words, any change in the U.S. food markets is likely going to affect the global food markets. Hundred of millions of consumers in these developing countries rely on U.S. corn[20] for food security and have felt the food prices pressure emerging from larger ethanol production.

This research suggests that the substantial increase in renewable energy production and consumption in the U.S. has lead to higher food prices through croplands substitution effects accentuated by large federal subsidies. If the effect is measurable but modest for domestic consumers, there are reasons to suspect that lower income foreign consumers could have been more impacted by this trade-off.

[18] http://www.worldstopexports.com/corn-exports-country/.

[19] https://afdc.energy.gov/data/10339.

[20] https://grains.org/buying-selling/corn/.

1.11 Conclusion

Since the passage of the Energy Policy Act of 2005, there has been a substantial increase in total U.S. renewable energy production and consumption, particularly biomass, solar, and wind. This period has also coincided with significant increases in food prices paid by U.S. consumers. This positive correlation has raised the question of the increase in U.S. renewable energy production and consumption has causal impacts on food prices. There are a number of theoretical reasons to believe that an increase in the production and consumption of certain renewable energy sources may increase food prices. Consider the case of biofuels. Corn, sugar cane, soybeans, and other oil seeds are used both as food and as inputs to produce ethanol, biodiesel, or other biofuels. From a supply point of view, therefore, a diversion of food crops to biofuels results in a leftward shift of the food supply curve, leading to a rise in food prices. Second, corn, soybeans, sorghum, oats, and barley are the primary ingredients used in commercially prepared feed. This shift from feed-related crops to biofuels raises the cost of producing meat, poultry, and dairy products, ultimately leading to an increase in their prices. Third, competition between agricultural commodities and the raw materials used for biofuels for land, water, fertilizers, and other scarce resources puts further upward pressure on food prices. In addition, the extent to which diesel and other biofuels are used to power farm machinery and equipment will impact food prices.

There are also reasons to believe that an expansion of other renewable energy sources may raise food prices. Like biofuels, competition between wind farms and agricultural land may divert land from the latter to the former. To the extent that this happens, food prices are expected to rise. Furthermore, while farmers do not operate windmills, they lease and sell the land required for their installation, receiving compensation that typically surpass agricultural land lease and sale prices. If land parcels and prices are spatially correlated, the value of agricultural lands adjoining wind farms is expected to rise, leading to an increase in agricultural prices. A similar argument can be made with respect to geothermal, hydropower, and solar energy sources, although in these cases, the link to food prices is less clear.

Using an SVAR model and monthly U.S. data for the period 1974:01-2019:12, this paper examines the impact of shocks to renewable energy consumption on food prices. The identification of structural shocks relies on the assumption that shocks to renewable energy consumption impact food prices contemporaneously, whereas it takes at least a month for shocks to food prices to affect renewable energy consumption. Our results provide no significant evidence to support the hypothesis that shocks to renewable energy consumption increase food prices for the entire sample period. However, for the period since the passage of the Energy Policy Act, specifically, from 2006:2 to 2019:12, we find evidence that shocks to biomass and wind energy consumption lead to significant increases in food prices in the aggregate, as well as other important retail food prices. Hydropower and solar energy consumption have no impact on food prices before, or since the passage of the Energy Policy Act. We do, nevertheless, find that shocks to the various renewable energy sources considered explain a larger proportion of the fluctuations in food prices in the period since the Energy Policy Act than before.

The results of this paper raise important policy considerations. In response to the increased volatility of oil and other non-renewable energy prices, the U.S. dependence on foreign energy, the environmental consequences of carbon emissions and climate change, U.S. federal, state, and local government officials have enacted policies that provide subsidies, rebates, and tax credits for renewable energy production, the installation of renewable energy systems, renewable energy portfolio standards, and the creation of markets for renewable certificates. A rise in biomass and wind energy production and consumption increases food prices and could be a concern about poverty, hunger, and food security, which must be taken into consideration when promoting biofuels, wind, and other renewable energy programs.

Chapter 2

Education spending and growth: The role of institutional quality

2.1 Introduction

Many variables influence the differences between countries' economic growth. Among these, education spending and economic institutions have consistently occupied important ranks in the attempts to better understand the patterns of growth over time and between different countries. Different governments dedicate different shares of their Gross Domestic Product (GDP) to develop their human capital through education. Moreover, they have built a wide variety of institutions. For poorer countries, education spending has historically been lower than for the rest of the world (Blankenau, Simpson and Tomljanovich (2005)). While many explanations populate the economics literature, policymakers and researchers still strive to better understand the role of education spending and institutions in generating growth.

Economic theory provides much motivation to this inquiry. On the one hand, the link between government education expenditures, human capital and long term economic growth has been thoroughly formalized in the endogenous growth literature[1]. On the other hand, in their seminal paper on "The Colonial Origins of Comparative Development: An Empirical

[1] Examples include Cassou and Lansing (1998) and Glomm and Ravikumar (1997).

Investigation", Acemoglu and Robinson (2001) emphasize the critical role that good institutions play for economic development through property rights and argue that the current global development disparities can be largely attributed to the colonial influence and its inherited government structures. While the role of education spending has been shown to be important by many authors (Blankenau and Simpson (2004)), the majority of economic models ignore the institutional context in which these expenditures are made. We believe that this approach is incomplete and that a realistic picture of the impact of education spending on growth can be better captured in light of the existing institutional quality.

Our results show that both education spending and institutions positively contribute to long run growth especially in rich and developing countries. However, the positive effect of education spending seems to vary greatly depending on the existing institutional quality. In particular, the marginal benefit of increased education spending decreases with better institutional quality. This suggests a possible substitute relationship between the two in terms of economic growth. In other words, as education spending and institutions both have a positive and significant impact on growth, their combined change seems to create a somewhat redundant effect.

The rest of the paper is organized as follows. Section 2.2, provides a brief background of the related literature on growth. Section 2.3 introduces the concept of institutions, their creation and why they persist. Section 2.4 develops a simple endogenous growth model, Section 2.5 presents a detailed exposition of the data used, while Section 2.6 describes the resulting empirical specifications. Section 2.7 presents the results, and Section 2.8 conducts a sensitivity analysis. We conclude in Section 2.9.

2.2 Related literature

2.2.1 Institutions and growth

Acemoglu, Johnson and Robinson (2004) develop an empirical and theoretical framework arguing that economic institutions are a fundamental engine of long run growth. The study relies on two historical quasi-experiments with the division of Korea into two parts with different institutions and the 15th century European colonization of many areas of the world. The paper makes the case that economic institutions determine the incentives experienced by economic actors. Further, economic institutions encouraging economic growth can only emerge when political institutions allocate power to groups with interest in property rights enforcement. Institutions must create constraints on power holders and there must be few rents to be captured. This paper shows the importance and status of institutional quality in a new light. Institutions are central to growth, but they can change when the right set of conditions exist.

Similarly, Aisen and Veiga (2013), using a GMM estimator in a panel of 169 countries between 1960 and 2004 find that higher degrees of political instability are associated with lower growth rates of GDP per capita. Regarding the channels of transmission, they find that political instability adversely affects growth by lowering productivity and, to a smaller degree, physical and human capital accumulation. Finally, they find that economic freedom and ethnic homogeneity are beneficial to growth, while democracy may have a small negative effect. By and large, the recent economics literature has endorsed the idea that national institutions are indeed important to understand development patterns. With more investment in human and physical capital and less distortionary policies, nations get to use their resources more efficiently and achieve a greater level of income and growth.

Payen and Ronde (2020) present a detailed treatment of institutions and their definition in recent years as well as several alternatives for their measurements. Institutions as measured by property rights can determine growth because of the incentives they generate (North (1981)). Calderon and Chong (2020) use a causal analysis method and show the link between institutions and economic growth. The study uses a yearly panel of 44 developing countries between 1965 and 1995 with a reduced form approach controlling for simultaneity and reverse causality. They also show how the impact of institutional change takes time to be visible. In other words, the more time is given, the stronger the effect of institutional changes on economic growth can be.

In the literature, there are different perspectives on institutions and their nature, for example, political as opposed to economic institutions. Some studies have focused only on the direct relationship between political institutions alone and economic growth. For the most part, they find that political regimes which promote participation may be expected to have positive and long-term economic growth. Rodrik (2000) is a landmark study with this perspective. The author emphasizes the importance of private initiative and incentives in the context of strong institution building. Henisz (2000) extends this paper and shows that the relationship is not linear.

Despite the general orientation of the literature to confirm this institution to growth relationship, it is necessary to note that a number of authors question the finding. A well known study by Glaeser, La Porta, Lopez-De-Silanes and Shleifer (2000) contradicts the previous studies. They suggest that the measure of institutions in use are unable to provide the perspective that researchers need. Instead, their results support growth theories which emphasize the spillover effect of human capital as opposed to institutional quality. Their findings suggest that a country will emerge from poverty through the accumulation of physical and human capital allowed by the government (be it a dictatorship or a democracy) which in turn leads to change in institutions allowing the achievement of even further growth in a virtuous cycle. In many regards, the Glaeser et al. (2000) study presents a perspective of institutions which is far more fluid than Acemoglu and Robinson (2001) where institutions have a tendency to persist over decades and even centuries. Another theory provided by Auer (2013) suggests that geography has influenced colonization policies and in turn institutional outcomes more than is usually shown in the literature. The study argues that Acemoglu et al. (2001) overestimates the importance of institutions for economic growth by 28% and that La Porta et al. (2009) underestimates the importance of colonization imposed institutions by 63% because Britain tended to colonize countries away from Europe.

We see that the literature on growth and institutions is not unanimous. Nevertheless, researchers have attempted to unify the different views by introducing other variables. Lee and Kim (2009) show that the effect of institution and human capital on growth varies depending on the initial level of development. They show that developed countries must promote higher education and technological innovations while emerging economies should focus on primary education and the development of stronger institutions.

Overall, we take from this brief analysis of the literature that the positive impact of institutions on growth is robust but can be influenced by several additional variables including the country's original level of development, geography and political stability.

2.2.2 Education spending and growth

Human capital has long been recognized as a critical determinant of economic growth. Education spending allows countries to build this capital but great disparities still exist in education spending between rich and developing countries.

The hypothesis that more education spending promotes growth has been supported by theoretical and empirical studies alike even in some developing countries (Pradhan (2009), Tamang (2011)). For example, Owusu-Nantwi (2015), uses data on education spending and growth from Ghana from 1970 to 2012 and shows that this positive relationship exists also in this emerging economy. Hong Sang and Thorbecke (2003) simulate a computable general equilibrium model in Tanzania and Zambia showing not only that education spending can improve growth but also that an optimally targeted spending level can also reduce poverty. Hussin et al. (2012) use a vector autoregression model (VAR) for the Malaysian economy between 1970 and 2012 and find that GDP growth is positively cointegrated with fixed capital formation, education expenditures and labor force participation. Nevertheless, studies on this question have not produced consistent results in all part of the world and at all growth stages.

Pradhan (2009) investigates the same link in India between 1951 and 2001. The author's findings suggests a unidirectional causality from economic growth to education expenditures. The econometric model was an Vector Error Correction Model (VECM). Other studies have found a negative or even no such relationship such as Devarajan, Swaroop, and Zou (1996) and Blis and Klenov (2000). Devarajan et al. (1996) studies a sample of 43 countries over 20 years and finds a negative influence of education expenditures on growth. Blis and Klenov (2000) argues that the link was too weak to support significance. Their study involves 52 countries between 1960 and 1990.

Many other studies have explored this relationship between education spending and economic growth with mixed results even in more developed countries. Fisher (1997) provides a review of the literature and concludes that the link between education spending and economic growth is relatively weak. The review features 19 studies done between 1985 and 1995 investigating this link also at the U.S. state level. Some studies used spending on either K-12 or higher education or in some cases both. Among the studies, only 6 showed a positive and significant impact on growth. We note that most of these studies do not control for general equilibrium changes and do not control for state or local government budget constraints.

Blankenau and Simpson (2004) provide a theoretical framework explaining that the mixed empirical results observed in the literature could be attributed to general equilibrium effects. Practically, this means that productive education spending can nonetheless lower growth due to the negative growth effect of taxation. If the decrease in real economic activity due to higher taxes is larger than the increase due to more education spending, a negative relationship will be observed. Deskins, Hill and Ullrich (2010) study this link using a U.S. state panel approach from 1992 to 2002 and separately analyze higher and K-12 education spending. They also account for possible spillover effects due to increased neighbors' states spending. They conclude that increased spending on higher education consistently exhibits a large negative effect on private sector employment and state growth when financed through own resource revenue. They do not identify a significant relationship between K-12 education spending and growth. The results also rules out cross-state spillover effects.

Blankenau, Simpson and Tomljanovich (2005) address this gap by considering the same link and developing a theoretical model leading to a growth equation. After estimation in a panel of rich countries, they find that a positive link exists between public education expenditures on growth for developed countries once the national budget constraint is imposed. They argue that the lack of consensus in the literature emanates from a failure to consistently account for the source of financing of increased education spending.

Given that a purpose of education spending is to improve a country's human capital, other studies have focused on the human capital link to long run growth. Hanushek and Woesman (2012) develop a new metric of educational achievement distribution across countries to better track cognitive skills. Their cross-country regressions show a close relationship between cognitive skills and GDP growth which is robust to several sensitivity checks of time period, country samples and specifications. Another study by Angelopoulos, Malley and Philippopoulos (2008) calibrates a dynamic general equilibrium model where human capital fuels long run endogenous growth. Their results suggest that while more education spending raises growth, welfare does not necessarily increase. The relation between public expenditures and long run growth as well as the lifetime utility has an inverted-U shape. As public expenditures crowd out private consumption, increased public spending enhances welfare only if there is a change in the government tax-spending schedule.

Furthermore, other research has shown that changes in education spending take time to be affect economic growth. Atems and Blankenau (2020) shows that output can have a delayed response to public education spending because it takes time for impacted students to enter the labor force. The paper uses a stochastic overlapping generation model to track the dynamics of the economy when it is responding to higher education spending. The study is done at the U.S. state level between (1963-2016) with a panel structural VAR methodology. The identification assumption is that shocks to output affect education spending with a lag. Furthermore, their results align with their model prediction and show that output responds to education spending with peaks occurring between 3 and 13 years after the spending shock. Another finding is that shocks to education spending explain a relatively large share of the long run variation in output.

2.2.3 The interaction of education spending and institutions

The current literature on education spending and growth finds a positive link[2] especially among developed countries (Blankenau et al. (2005)) and a consistent positive impact of institutions has also been documented (Rodrik (2008)). This abundance of related studies contrasts greatly with the limited attention given to the combined effects of these two

[2] Bose, Haque and Osborn (2007).

important forces in achieving long term economic growth. Most studies have explored the impacts of education spending on growth as if they were detached from the countries' institutional environment. Conversely, other studies of growth have focused on institutions without accounting for the role of the education spending lever. A gap exists in their combined consideration.

Keefer and Knack (2008) investigate the role of public expenditures for growth and shows an inverse relationship to productivity due to government quality. In other words, limited public investment could be more productive given a lower quality of government. Weak governments with high spending face the risk of inefficiency and waste. A limitation of these results in our context, is that the study investigates public spending in general without focusing on the education share. Nevertheless, these findings are consistent with previous results showing that the method of financing matters because of spending reallocation (Deskins, Hill and Ullrich (2010)). A weaker government plausibly runs the risk of more inefficiencies and waste. Butkiewicz and Yanikkaya (2008) expand on this question by exploring different categories of government expenditures between developing and developed countries. Although education spending is not separately investigated, the study shows that public consumption spending has a negative effect on growth in developing nations and no effect in developed ones. The mixed results show that the growth impact of government spending can suffer from failure to account for government quality.

Our hypothesis is that a similar attention to institutions is necessary to properly estimate the impacts of education spending on growth especially when general equilibrium effects are not accounted for. We explore this question by using education expenditures and several indexes of countries' institutional quality via panel and cross-sectional approaches. Given previous specifications in the literature, we study separate samples for rich, middle income and developing countries as well as all countries collectively.

2.3 The creation of institutions and their persistence

Acemoglu and Robinson (2001) argues that institutions are inherited from early historical events and persist for long periods of time. The study focuses on the climate and disease shocks experienced by the European colonists when accessing different territories. The idea is that the environment essentially molded the kind of institutions Europeans established. For example, malaria and yellow fever contributed to more than 80% of European deaths in colonies, while gastrointestinal diseases (such as diarrhea, dysentery and others) only accounted for 15% of the deceased (Curtin (1989)). Colonies which did not have these diseases, such as New Zealand, were actually healthier than Europe since tuberculosis, pneumonia and small pox, among others, were quite rare in the new territories even if they still existed in Europe (Curtin (1989)).

Both malaria and yellow fever are transmitted by mosquito vectors[3]. In West Africa, individuals can get many hundred bites per year and this from an early age[4]. To a person without developed immunity, malaria is often lethal. European settlers were in this situation and many died in Africa, India and the Caribbean. In these colonies, Europeans created institutions geared toward extracting resources instead of promoting free market operations through property rights. In contrast, historians (Cain (1993)) have documented the development of "settler colonies". In such colonies, Europeans settled in large numbers and modeled life after the home country customs. These settlers demanded institutions which allowed them to acquire what they wanted through freedom and private ownership. An example is Australia. Most of the early settlers in Australia were ex-convicts and the lands were mostly owned by ex-jailers and there was no protection against arbitrary landowners' decisions. In 1788, Australia started as a penal colony. Great Britain sent its convicts to be imprisoned and to provide free labor. Later, they received freedom when Australia was established. However, in the earlier phase, due to residual powers, the ex-jailors now assumed the role of landowners requiring rents and taxes as well as other arbitrary demands from the newly freed population. Despite early resistance from Great Britain, the settlers argued

[3]Anopheles gambiae and funestus and Aedes aegypti.

[4]https://www.vectorbase.org/organisms/anopheles-gambiae.

that they were British as well and deserved jury trials, freedom from arbitrary arrests and electoral representation, which they obtained eventually (Hughes (1987)).

This depiction is in sharp contrast with the experience of other colonies. For instance, in Latin America during the seventeenth and eighteenth century, the main objective of the Spanish and Portuguese colonists was to obtain gold and other valuable resources. Therefore, they organized a complex mercantilist system of monopolies and trade customs aiming to extract resources from the Latin American colonies (Lang (1975)). In Africa, the logic behind the slave trade was similar. Before the mid-nineteenth century, the colonists were on the coasts and focused on the slave trade, gold and other commodities including ivory. This explains the naming of some territories as "Gold Coast" now Ghana or "The Ivory Coast" with the latter having kept the suggestive name. One of the most extreme cases of extraction was Belgium with King Leopold who forbade the market economy in Congo and instead set up a compulsory system of cultivation of crops to be sold and distributed by the state at controlled prices. Peemmans (1975) estimates that the tax rate on Africans in the Congo climbed as high as 60 percent of their income between 1920 and 1930.

Acemoglu and Robinson (2001) argue that these conditions explain why certain institutions were created during the colonial era and have persisted even to this day. An example of this persistence is the monetary structure in many old French colonies in West Africa. After the independence in the 1960's, many French-speaking African nations kept their currency tied to the French central bank, limiting their monetary policy tools. Another example of inherited procedures was Zaire, now Congo. Mobutu Sese Seko then the president reinstated forced labor long after the European colonists had left.

Acemoglu and Robinson (2001) emphasize that the extractive institutions can persist due to two main mechanisms: First, creating new institutions which place restrictions on government, require accountability, legal equity and enforcement of property right is expensive and time demanding. In contrast, the marginal benefit of the status quo is likely higher than the costs for the new elite of the newly independent countries. The inherited system is already in favor of the ruling class. They can avoid these "transformation" costs by simply carrying on with the inherited extractive institutions and processes. Second, if agents have already made investments that are complementary to the old extractive institutions, it will not be in their favor to switch to the other kind.

2.4 Model

Our investigation of the literature generally supports that both education spending and institutional quality exert a positive effect on economic growth. We also find that their combined effect is essentially unexplored. Our next objective is therefore to develop an economic model that ties them together in the growth generating process.

We use an overlapping generation model of growth which shares features with Blankenau, Simpson and Tomljanovich (2005) to investigate the relationship between education spending and growth in the context of institutional quality. Our model economy consists of three-period-lived homogeneous agents, a representative firm producing a single good, a government and a technology for producing human capital. The model is set up to produce a closed-form solution leading to a growth equation which we later estimate. The main distinction of our model is the interaction of national institutions with education expenditures within this technology.

2.4.1 The agents' problem

A continuum of agents, normalized to 1, is born in each period. The initial old are endowed with K_o units of physical capital. The period t learners (agents in their first period of life) receive an endowment of public education inputs given by E_t. The initial old are endowed with K_0 units of physical capital and the original earners has h_0 units of human capital. Public inputs, E_t, combine with the human capital of the previous generation's, h_t, in order to create period $t+1$ human capital according to:

$$h_{t+1} = \xi E_t^{\mu} h_t^{1-\mu} \tag{2.1}$$

where μ is between 0 and 1 and $\xi > 0$. We will later set $\xi \equiv \xi(q, e)$ where q and e represent institutional quality and a measure of education expenditures. For ease of notation, we currently express this as ξ. The parameter μ governs the relative importance of public education expenditures and human capital in the formation of future human capital and ξ acts as a scaling effect.

Agents inelastically supply their one unit of human capital endowment to the representative firm and receive after tax lifetime income in proportion to their human capital level. In particular, agents receives $w_{t+1}h_{t+1}(1-\tau_t)$ where w_{t+1} is the period $t+1$ wage, h_{t+1} is the human capital in period $t+1$ and τ_t is the income tax rate. Earners either consume their net wage income or save for the third period through capital accumulation. The capital holding for the period t learner at the end of period $t+1$ is $K_{t,t+2}$ emphasizing that this capital is productive in period $t+2$. A unit of capital purchased in period t returns $r_{t+1}(1-\tau_t)$ in period $t+1$. $C_{t,t+1}$ and $C_{t,t+2}$ respectively denote the consumption by agents born in time t in period $t+1$ and subsequently in period $t+2$. Preferences are logarithmic in both consumption levels with discount rate $0 \leq \beta < 1$. The representative agent's problem is:

$$\max_{C_{t,t+1},C_{t,t+2},K_{t,t+2}} \ln C_{t,t+1} + \beta \ln C_{t,t+2} \tag{2.2}$$

subject to

$$C_{t,t+1} + K_{t+2} \leq w_{t+1}h_{t+1}(1-\tau_t)$$

$$C_{t,t+2} \leq r_{t+2}K_{t+2}(1-\tau_t)$$

$$C_{t,t+j} \geq 0, j = 1, 2.$$

Rewriting the constraints with equality yields:

$$C_{t,t+1} + \frac{C_{t,t+2}}{r_{t+2}(1-\tau_t)} = w_{t+1}h_{t+1}(1-\tau_t)$$

or

$$C_{t,t+2} = \left[w_{t+1}h_{t+1}(1-\tau_t) - C_{t,t+1}\right] r_{t+2}(1-\tau_t).$$

Substituting this expression of $C_{t,t+2}$ into Equation (2.2) and taking first order condition with respect to $C_{t,t+1}$ gives:

$$\frac{1}{C_{t,t+1}} = \frac{\beta}{w_{t+1}h_{t+1}(1-\tau_t) - C_{t,t+1}r_{t+2}(1-\tau_t)}$$

or

$$C_{t,t+1} = \frac{w_{t+1}h_{t+1}(1-\tau_t)}{1+\beta}.$$

Knowing that

$$K_{t+2} = \frac{C_{t+2}}{r_{t+2}(1-\tau_t)}$$

then

$$K_{t+2} = \frac{\left[w_{t+1}h_{t+1} - \frac{(w_{t+1}h_{t+1})(1-\tau_t)}{1+\beta}\right] r_{t+2}(1-\tau_t)}{r_{t+2}(1-\tau_t)}.$$

Solving the agent's problem for optimal saving yields

$$K_{t+2} = \frac{\beta}{\beta+1}\left[w_{t+1}h_{t+1}(1-\tau_t)\right]. \tag{2.3}$$

2.4.2 Firms

A representative firm combines human capital and physical capital to generate a single final good. As is common in the growth literature, we assume that output is a Cobb-Douglas combination of physical and human capital. The parameter A denotes the effectiveness of labor with $A > 0$. The share parameter α is between 0 and 1. We define Y_t as the total output and H_t the total human capital hired by the firm. We also define k_t and y_t respectively as the capital per unit of labor and the output per unit of labor. We then have:

$$Y_t = AK_t^{\alpha}H_t^{1-\alpha} \tag{2.4}$$

or:

$$y_t = \frac{Y_t}{L_t} = Ak_t^{\alpha}.$$

The market for inputs and output are competitive. Thus, the firm takes prices as given and hires additional inputs until:

$$r_t = A\alpha k_t^{\alpha-1} \tag{2.5}$$

$$w_t = A(1-\alpha)k_t^{\alpha}. \tag{2.6}$$

where r_t is the rental rate of capital and w_t is the wage of workers both in period t.

2.4.3 Government

Government spends a share e of output on public education expenditures and we define $\tilde{e} \equiv exp(e)$. Expenditures are related to educational inputs by

$$E_t = \tilde{e}Y_t. \tag{2.7}$$

An additional share of output, g_t, is spent by the government on items other than education and which have no impact on productivity. All expenditures are financed through taxes on labor and capital income and the tax rate is given by τ_t. Revenues and expenditures must balance in each period. Government policy then is the set $\{\tau_t, e_t, g_t\}$ such that:

$$\tau_t(w_t h_t + r_t K_t) = (e_t + g_t)Y_t. \tag{2.8}$$

2.4.4 Equilibrium and balanced growth path

Definition 1: *A competitive equilibrium in this environment is a sequence of consumption levels and portfolio holdings* $\{C_{t,t+1}, C_{t,t+2}, K_{t,t+2}\}_{t=0}^{t=\infty}$ *chosen by the representative agents of each generation, a sequence of outputs and inputs chosen by the representative firm in each period* $\{Y_t, K_t, L_t\}_{t=0}^{t=\infty}$*, a sequence of government policies* $\{\tau_t, e_t, g_t\}_{t=0}^{t=\infty}$ *, a sequence of prices*

$\{w_t, r_t\}_{t=0}^{t=\infty}$, *and a set of initial conditions* $\{K_0, h_0\}$ *such that:*

1. period t learners chooses $C_{t,t+1}, C_{t,t+2}$ and $K_{t,t+2}$ to solve their agents problem taking prices and government policy as given,

2. the firm chooses Y_t, K_t and L_t in period t to maximize profits taking prices, government policy and the production possibilities (Equation (2.4)) as given,

3. the government chooses $\{\tau_t, e_t, g_t\}_{t=0}^{t=\infty}$ subject to a balanced budget constraint,

4. the stock of human capital evolves according to Equations (2.1) and (2.7),

5. the goods market clears: $Y_t = (e_t + g_t)Y_t + C_{t-1,t} + C_{t-2,t} + K_{(t-1,t+1)}$,

6. the capital market clears, and

7. the labor market clears: $L_t = h_t$.

Definition 2: *A balanced growth path satisfies Definition 1 and has the following additional properties:*

1. Government policy is time invariant, $\{\tau_t, e_t, g_t\}_{t=0}^{t=\infty} = \{\tau, e, g\}$,

2. The stock of human capital, the stock of physical capital, consumption by earners, consumption by the old, and output all grow at the same and constant rate, γ_t. That is, $1 + \gamma_t = 1 + \gamma = \frac{h_{t+1}}{h_t} = \frac{K_{t+1}}{K_t} = \frac{C_{t,t+1}}{C_{t-1,t}} = \frac{C_{t,t+2}}{C_{t-1,t+1}} = \frac{Y_{t+1}}{Y_t}$.

An implication of Definition 2 is that k_t, y_t, w_t and r_t are constant. Let us solve for the balanced growth path. When subscripts are dropped, Equations (2.1) and (2.7) reduce to

$$1 + \gamma = \xi(\tilde{e}Ak^{\alpha})^{\mu}. \tag{2.9}$$

We solve for k as a function of policy instruments and the parameters of the model. Substituting Equations (2.1), (2.5) and (2.6) into Equation (2.3) yields:

$$K_{t+2} = \frac{\beta}{1+\beta}(A(1-\alpha)k_{t+1}^{\alpha}\xi(\tilde{e}y_t)^{\mu}h_t^{1-\mu}L_t^{\mu}(1-\tau)).$$

Labor market clearing requires $L_t = h_t$ giving:

$$k_{t+2} = \frac{\beta}{1+\beta}(A(1-\alpha)k_{t+1}^{\alpha}\xi(\tilde{e}y_t)^{\mu}(1-\tau)).$$

Dropping time subscripts and solving for k gives:

$$k = \left[\frac{\beta}{1+\beta}(A^{1-\mu}(1-\alpha)\xi\tilde{e}^{\mu}(1-\tau)\right]^{\frac{1}{1-\alpha-\alpha\mu}}.$$

Putting this expression in Equation (2.9) and rearranging terms yields:

$$1+\gamma = A^{\mu}\left[\frac{\beta}{1+\beta}A^{1-\mu}(1-\alpha)\right]^{\frac{\alpha\mu}{1-\alpha(1+\mu)}}\xi^{\frac{1-\alpha}{1-\alpha(1+\mu)}}\tilde{e}^{\frac{\mu(1-\alpha)}{1-\alpha(1+\mu)}}(1-\tau)^{\frac{\alpha\mu}{1-\alpha(1+\mu)}}. \tag{2.10}$$

Recall $\xi \equiv \xi(q,e)$, where q is the quality of institutions. This is a central innovation to our study. The fundamental intuition of our specification is that the human capital stock grows in Equation (2.1) in proportion to education spending but also due to the scaling effect of ξ. Here we present this scalar ξ as an interaction term of education spending and institutional quality.

This is not the only way of modeling this relationship so we also provide an alternative specification in Section B.2.1 for more intuition while we focus on the current form. We also introduce χ_1 and χ_2 which respectively represent the importance of institutional quality and its interaction with education spending to the scaling effect. Both parameters can be any real number. In particular:

$$\xi \equiv \exp(q)^{\chi_1}\exp(qe)^{\chi_2}$$

so Equation (2.10) becomes

$$1+\gamma = A^{\mu}\left[\frac{\beta}{1+\beta}A^{1-\mu}(1-\alpha)\right]^{\frac{\alpha\mu}{1-\alpha(1+\mu)}}\left[\exp(q)^{\chi_1}\exp(qe)^{\chi_2}\right]^{\frac{1-\alpha}{1-\alpha(1+\mu)}}\tilde{e}^{\frac{\mu(1-\alpha)}{1-\alpha(1+\mu)}}(1-\tau)^{\frac{\alpha\mu}{1-\alpha(1+\mu)}}.$$

To arrive at a simpler expression for growth, we perform a monotonic transformation through the natural logarithm of each side and use the approximation $\ln(1+\gamma) \approx \gamma$ to arrive at:

$$\gamma \approx \lambda_0 + \lambda_1 e + \lambda_2 q + \lambda_3 qe \tag{2.11}$$

as $\lambda_0 = \ln[A^{\mu}[A^{1-\mu}\frac{\beta}{1+\beta}(1-\alpha)]^{\frac{\alpha\mu}{1-\alpha(1+\mu)}}] - \frac{\alpha\mu}{1-\alpha(1+\mu)}\tau$, $\lambda_1 = \frac{\mu(1-\alpha)}{1-\alpha(1+\mu)}$, $\lambda_2 = \frac{\chi_1(1-\alpha)}{1-\alpha(1+\mu)}$, and $\lambda_3 = \frac{\chi_2(1-\alpha)}{1-\alpha(1+\mu)}$.

This is the baseline specification of our growth equation including education spending and the interaction term with institutional quality. In addition, we present a second specification including the government budget constraint to find the relationship between e and τ. Equation (2.8) implies:

$$\tau(w_t h_t + r_t K_t) = (e_t + g_t)Y_t$$

which can be rewritten as:

$$\tau Y_t = (e_t + g_t)Y_t.$$

This implies:

$$\tau = e + g.$$

Recall that

$$\lambda_0 = \ln[A^{\mu}[A^{1-\mu}\frac{\beta}{1+\beta}(1-\alpha)]^{\frac{\alpha\mu}{1-\alpha(1+\mu)}}] - \frac{\alpha\mu}{1-\alpha(1+\mu)}\tau.$$

So we define

$$\lambda_0 = \phi_0 + \lambda_4\tau$$

where

$$\phi_0 = \ln[A^{\mu}[A^{1-\mu}\frac{\beta}{1+\beta}(1-\alpha)]^{\frac{\alpha\mu}{1-\alpha(1+\mu)}}]$$

and

$$\lambda_4 = -\frac{\alpha\mu}{1-\alpha(1+\mu)}\tau.$$

Therefore, the growth equation including the budget constraint is:

$$\gamma \approx \phi_0 + \lambda_1 e + \lambda_2 q + \lambda_3 qe + \lambda_4 [e + g]$$

or

$$\gamma \approx \phi_0 + (\lambda_1 + \lambda_4)e + \lambda_2 q + \lambda_3 qe + \lambda_4 g. \tag{2.12}$$

This growth equation including e, q and qe conveys the fundamental intuition of the model. The effect of education spending on economic growth is different depending on the level of institutional quality. If we focus on Equation (2.12), the marginal effect of education spending varies with the institutional quality:

$$\frac{\partial \gamma}{\partial e} = \lambda_1 + \lambda_4 + \lambda_3 q.$$

Conceptually, λ_1 represents the direct positive effect of education spending on growth. The parameter λ_4 represents the indirect negative effect due to education spending financed through taxation[5]. In previous research, if the effect from λ_1 dominates the taxation effect from λ_4 education spending positively impacts growth. Otherwise, the overall impact is negative. In this paper, we extend the theory by including the effect coming from λ_3 which is the institutional quality effect. Three cases are possible with respect to institutional quality.

First, if no complement or substitute relationship exists between education spending and the latter, λ_3 is zero and institutional quality has no bearing on the relationship between education expenditures and growth. If λ_3 is positive then both variables have a complementary effect in achieving economic growth. The third case is when λ_3 is negative. This would mean that there is a substitute relationship between education spending and institutional quality. In other words, ceterus paribus, the better the existing institutions, the lower the marginal impact of education expenditures on growth is. The marginal effect of education spending would decrease in institutional quality. We emphasize that this does not mean that

[5] Blankenau et al. (2005) show that this effect is negative.

institutional quality or education spending are detrimental to growth, but rather that when high levels of one exist, the marginal benefit of the other diminishes.

In Section (2.5) we present the data used to empirically estimate this parameter λ_3 and test our model in a panel of countries.

2.4.5 Institutional quality and optimal growth spending

Our model of growth also offers the opportunity to derive the optimal level of education spending within the boundaries of our framework. We use Equation (2.10):

$$1+\gamma = A^{\mu}\left[\frac{\beta}{1+\beta}A^{1-\mu}(1-\alpha)\right]^{\frac{\alpha\mu}{1-\alpha(1+\mu)}}\left[\exp(q)^{\chi_1}\exp(qe)^{\chi_2}\right]^{\frac{1-\alpha}{1-\alpha(1+\mu)}}\tilde{e}^{\frac{\mu(1-\alpha)}{1-\alpha(1+\mu)}}(1-\tau)^{\frac{\alpha\mu}{1-\alpha(1+\mu)}}.$$

Our objective is to derive the level of education spending that maximizes growth γ in this expression. Taking the first order condition with respect to e after a logarithmic monotonic transformation, we obtain:

$$e^{*} = 1 - g - \frac{\alpha\mu}{(\chi_2+\mu)(1-\alpha)}. \tag{2.13}$$

Conceptually, as education expenditures are productive, countries below this threshold of spending would still be experiencing a positive effect on growth. Conversely, spending beyond this threshold would yields negative marginal benefits.

2.5 Data

In the previous section, we have modeled the joint impact of education spending and institutional quality in an overlapping generations model of growth. In this section, we provide a detailed presentation of the core variables used to estimate this relationship in the rest of the chapter. They include q, our measure of institutional quality, e, the measure of education spending and γ, the measure of economic growth which is based on GDP data and additional control variables for robustness checks. We present some information about their origin, their construction and their meaning in context. We show how countries are grouped based on income levels and finally provide summary statistics to describe the data.

2.5.1 The measures of institutional quality

The main measure of institutional quality is the index of protection against expropriation. Political Risk Services produces the data, but they are not free to access. Our data originate from the Acemoglu and Robinson (2001). This measure of institutional quality was first used in the literature by Knack and Keefer (2001). The index reports a value between 0 and 10 for each country and year where 10 represents the highest protection against expropriation. For example, both Netherlands and the United States have a ranking of 10. Our measure is the average of the index between 1985 and 1995. We note that there are many missing values before that time.

One limitation of this measure is that it does not vary with time. However, because national institutional quality is persistent through time, we do not believe this to be a major challenge. We supplement our analysis with additional measures of institutional quality for sensitivity analysis. Alternatively, we use property rights and government integrity. The two indexes originate from the Economic Freedom database of the Heritage Foundation and are available every year between 1995 and 2019 for several countries. We expect that high measures of the three indexes will reflect the notion of strong institutional quality. According to our hypothesis, this would be countries with a tradition of rule of law, enforcement of property rights as well as legal rights.

2.5.2 The measure of public education expenditures

The World Bank database reports total education expenditures for all levels of government as a percentage of GDP. This measure also includes expenditures funded by transfers from international sources to government. The data is originally provided by the United Nations Educational, Scientific and Cultural Organization (UNESCO). This measure is useful to compare education spending relative to the size of an economy over time. It is important to note that in many cases the data refers to education spending organized by the ministry of education only and does not capture other ministries' involvement. The estimate is based on data collected from official responses to annual education surveys. As the school year spans two years in most countries (for example September 2014 to June 2015) the referenced year will be 2015 in our database. Unlike Devarajan et al. (1996), we measure education spending as a share of total output rather than government expenditure. We follow Blankenau, Simpson and Tomljanovich (2005) since we are interested in the role of education expenditures and not the bulk of government spending. Furthermore, the measure of education spending includes not only the central government but also all other levels including local and state government. In most countries, a majority of public education expenditures comes from local and state governments rather than the central government alone[6].

2.5.3 The Penn World Table and our measure of growth

If comparing income levels within a given country can be challenging because of price level differences as well as living standards disparities, the task is even more complicated at the international level across time. One widely used source of such data is the Penn World Tables (PWT) maintained by researchers at the University of California Davis and the University of Groningen. In this section, we present a brief overview of its data collection rules and computations to understand the strength and limitations of the main source of growth data.

The Penn World Tables were built from the International Comparison Program (ICP) in 1968 at the University of Pennsylvania[7]. The ICP benchmark comparisons were themselves based on 150 expenditure headings for which price analysis was made for 3 to 6 items per basic category. At first, the benchmark comparisons were for 10 countries in 1970 and then 34 countries in 1975. This number rose to 150 countries by 2005. At first, expansion to more countries was a problem, but Summers and Ahmad (1974) elaborated a new method and published estimates for 101 countries. Their new method applied the relationship between

[6] https://educationdata.org/public-education-spending-statistics.

[7] This is the origin of the name Penn World Tables.

per capita income and prices for benchmark countries to estimate the purchasing power parity (PPP) of non-benchmark countries. Several challenges came with this approach and the modern versions of the database have attempted to address them. Successive updates throughout the past four decades have added more countries (183 in the PWT10) and more years (1950-2019) with measures of capital, productivity, employment, population, exchange rates, total factor productivity and GDP from several perspectives. In comparison with other databases such as the World Bank Development Indicators (WDI), the PWT offers a larger time coverage and also more data to compare productivity across countries.

The common practice in the literature had been to compare GDP across countries using the exchange rate. The approach is problematic because it rests on the assumption that relative prices (which are based on traded products) are representative of all prices across countries. In other words, this approach assumed that these relative prices reflect well the PPP of each currency. The PWT, in contrast, uses detailed prices within each country for a vector of expenditures categories, including both traded and non-traded goods (i.e. clothing as opposed to lawn mowing care). Then, these prices are aggregated in an overall relative price level which is referred to as the country's PPP. These detailed prices emanate from data originating from the World Bank and mainly the ICP[8].

Feenstra, Inklaar and Timmer (2015) document what is commonly known as the "Penn Effect". They find that real GDP is substantially underestimated when using the real exchange rate instead of the PPP in comparing GDP across countries. This is traditionally attributed to the Balassa-Samuelson effect (see Asea (1994), Samuelson (1994) and Balassa (1964)). Asea (1994) presents a dynamic two sector growth model with two countries and an open economy with imperfectly competitive non-traded goods along with supporting empirical results. Essentially, the idea is that as countries grow richer, productivity increases mostly in the manufacturing sector and other trade related activities. This increases wages and prices of other non-traded goods and services eventually raising the overall price level in the economy. The result is that many rapidly growing countries like China are shown to be much richer using PPP based real GDP compared to the exchange rate real GDP.

[8] Feenstra et al. (2013).

The PWT is also a more detailed alternative because it includes data on consumption, investment, government and more. Estimates are provided with the benchmark year 2011 either in current or constant chained prices. The database is extensively used in economic research. We note that the OECD also provides PPP estimates that are more reliable for their member countries. The measure is more reliable within the OECD because the countries have more comparable goods harmonized by the PPP. In contrast, the PWT attempts to provide a comparable benchmark for countries that have vastly varying levels of economic development. For example, one unit of housing in the U.S. is likely different from one unit of housing in the Congo, a poorer economy, on average. The main advantage of the PWT is the number of countries and years covered. In contrast, the World Bank also provides PPP estimates each year in their World Development Report[9], but they are not formatted as time series. The PWT also provides quality grades depending on the number of benchmark comparison in which a country has taken part and how consistent are the estimates in previous issues of the database.

One of the main concepts in the PWT is the measurement of real GDP in the international context. For an accurate comparison of real GDP, merely evaluating GDP at constant prices (as with a numeraire traded good) across countries is not enough. To address this problem, the PWT holds all prices for goods and services constant across countries. Knowing there are several ways to approach this problem as well as different measures of interests, the measures of real GDP vary depending on the measurment objective of the researchers. For example, some measures are better suited to assess difference across time within a country while other measures are more advised for cross-country comparison. A basic distinction in the database is drawn between GDP measured from the expenditure side and the production or output side. Earlier issues of the PWT only reported expenditure side measures, but beginning in 2015, output side measures were added.

The output side measure of GDP was difficult to measure because its calculation involved relative prices of consumption and investments as well as data on exported and imported goods and services. The researchers thus started with the unit values of imported and

[9]http://pubdocs.worldbank.org/en/332341517441011666/PPP-brochure-2017-webformat-rev.pdf

exported goods. Feenstra and Romalsi (2014) obtain quality adjusted prices across countries which are much more reliable. After dividing exports by these adjusted prices, they obtain quality adjusted quantities which are treated as output. Likewise, after dividing imports by the adjusted prices, they obtain measures which are treated as inputs. This measure of real GDP from the output side is particularly fit for analyzing the disparities in productivity across countries in a given year. This measure will vary from the expenditure side to the extent that countries have heterogenous terms of trade (Feenstra et al. (2009)).

The other important concept in measurement with the PWT is whether the prices of goods are held constant across countries (variables prefixed with "C") or across countries as well as across time (variables prefixed with "R"). It follows from this distinction that the previously mentioned values of GDP from the output side (suffixed with "o") and expenditure side (suffixed with "e") come in current or real forms. In the database, real GDP based on constant prices across countries but only in the current year are $CGDP^e$ and $CGDP^o$. On the other hand, real GDP using prices constancy across countries as well as over time are labeled $RGDP^e$ and $RGDP^o$. The first concept which uses the current year (changing from year to year) is often referred to in the international comparison literature as "current-prices" real GDP. As such, it is relatively straightforward to correct these measures for inflation in a particular country, but it is not real in the common sense of the term.

Note that the set of prices at which the GDP is evaluated changes from year to year. As such, this measure of real GDP is especially suited for comparison of GDP across countries in a particular year. The measures starting with "R" hold prices constant across countries and over time. It is closer in spirit to what is commonly referred to as "real". We refer to it as "constant prices" real GDP. These variables work well for comparisons across countries over time. For example, they could be used to compare the productive capacity of an African country now to the U.S. economy at a point in the past. Because of the way they are constructed, the data of current and constant prices real GDP overlap in year the 2001 ($CGDP^e$=$RGDP^e$ and $CGDP^o$=$RGDP^o$).

However, the main measure of real GDP in our study is the $RGDP^{NA}$ or real GDP at constant national prices obtained from national accounts data for each country. This measure is advised by Feenstra et al. (2015) when focusing on growth of GDP over time in each country. Furthermore, they recommend using $RGDP^{NA}$ over $RGDP^{e}$ for pure time-series comparisons of growth rates but they also mention that the national prices present a certain degree of limitation compared to other measures. Using nighttime lights data and comparisons with the World Development Indicators (WDI), Pinkovskiy and Sala-i-Martin (2016) provide several evidences that $RGDP^{NA}$ has better cross-sectional performances than $RGDP^{e}$ (which measure output form the expenditure side)[10].

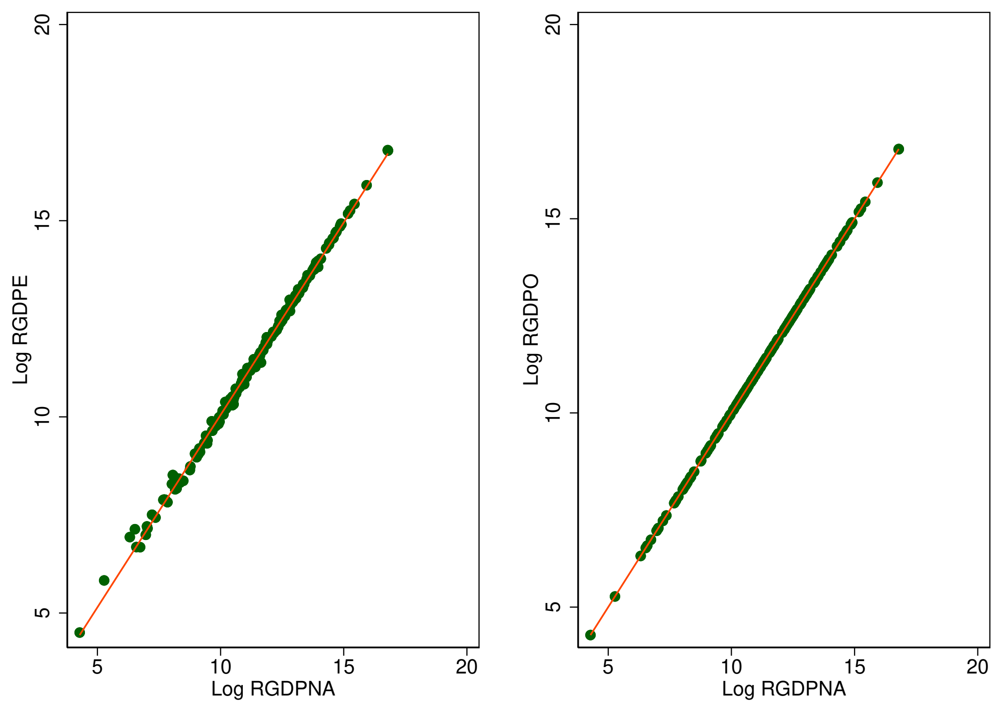


Figure 2.1: Link between different measures of GDP in 2017

Figure 2.1 shows the relationship between the three measures of GDP. We see that $RGDP^{NA}$ is highly correlated with both $RGDP^{e}$ and $RGDP^{o}$. Note that this close proximity need not imply equality because of the added balance of trade in the case of $RGDP^{NA}$.

The Penn World Tables have long been a preferential source of estimates for data overtime and across countries. We have attempted in this section to present a brief introduction to its

[10] Pinkovskiy and Sala-i-Martin (2016) use these data because they are a measure of economic activity unlikely to suffer the measurement problem of other databases. The study investigates several releases of the PWT to provide insights on its evalution and performance over the years.

content and construction to better understand the data colllection process and the choices which have determined the use of certain variables over others and the meaning that is attached to their respective construction. In summary, and for the data most important to this study of economic growth, education spending and institutional quality, we retain that GDP^e and GDP^o measure the relative level across countries and come either at current prices "C" or real prices "R." The first variable is best for comparative well-being or living standards while the output version is best suited for productive capacity analysis. However, we favor the national account measure of GDP in the rest of our study because it is more fit to analyse growth rates across countries and time. We also note that there is a non-negligible margin of error when comparing countries with largely different patterns and income levels (see Section B.3.1). Finally, the national account data can also be different between the PWT releases due to constant revisions and updates.

2.5.4 Additional control variables

We supplement our baseline regression with several control variables. We add measures of human capital, government expenditures net of education, average hours worked per year, capital stock per capita, depreciation rate of capital stock, GDP per capita in 1970 and the latitude of the country's capital to account for geographical differences. In this section, we present them in more details but focus on the measure of human capital because of the relative complexity of its construction. Furthermore, several analogous variables populate the literature, so we provide a brief comparison of the PWT strengths.

Evidence supports the inclusion of government spending in the growth regression as an additional regressor. Landau (1986) and Easterly and Rebelo (1993) find that real government consumption net of education and defense has a significant negative effect on growth. In comparison, Bleaney, Gemmell and Kneller (2001) show that non-education expenditures can increase growth. In our study, we include it in many sensitivity analysis specifications. We emphasize that our measure of government spending is net of education spending. It represents the share of public spending allocated to compensation of employees, defense and security but exclude government military spending. We obtain the data from the WDI.

There is also a large literature which suggests that educational attainment and cognitive skills are crucial determinants of growth. This is especially important for our model relying on education spending and growth. In a cross-section approach, one of the most comprehensive datasets on cognitive skills is provided by Hanushek and Woesmann (2012). The study shows a positive significant link between these cognitive skills and long run growth. Another study, Neycheva (2010), investigates a related question in a panel of 20 Europeans countries with a number of post-communist economies. One result is that the positive effect of education expenditures emanates from its impact on labor productivity. R&D spending is also strongly linked to growth. The positive relationship is only positive and statistically significant for the developed countries and appears either statistically insignificant or unstable for post-communist countries.

However, we use the human capital measure of the Penn World Table as a proxy for education attainment. Comparing average human capital, high institution countries have a measure 73% higher than their lower insitution counterparts (Table 2.2). The human capital index of the PWT is based on the average years of education found in Barro and Lee (2013) and the internationally estimated Mincerian returns to education of Psacharapoulos (1994). Barro and Lee (2013) contains data of 146 countries between 1950 and 2010. Their data provided information on gender and age at 5 year intervals and are based on census data which also provides estimates of mortality rates and completion rates by education level and age. These estimates are regarded as reasonable proxies for countries' human capital and have been used in many studies aside from the PWT.

An earlier alternative measure is provided in Cohen and Soto (2007) for the period between 1960 and 2000. This dataset is also based on surveys. The surveys were made by the UNESCO and merged with educational attainments provided by the Organisation for Economic Co-operation and Development (OECD) databases. At the time, the dataset was regarded as an improvement in quality fit to be a direct substitute for the Barro and Lee (henceforth, BL) dataset. On the other hand, Psacharapoulos (1994) has been influential in the development literature since its release because it provides a comprehensive exposition of the profitability of investment in education at the international scale. The study reports that primary education is the main investment target for developing countries, that the returns decline by the level of schooling and per capita income, that women's education was in general more profitable to men's, that returns for those working in the private sector is higher than their public sector counterpart and that the public financing of advanced education is regressive. Another notable finding is that investment in schooling continued to be a very attractive opportunity both from the private and public perspectives.

The computation of human capital has generally been controversial because of the difficulty to assess average years of schooling while keeping a consistent use of the data source. The BL dataset has faced related criticism because of such problems. De La Fuente and Domenech (2006) construct their own estimates of educational attainment for 21 OECD countries and include previously unused data remedying the sharp break in previous datasets. This new dataset was then used in replication studies along with the BL data. The authors find a clear positive correlation between their richer data quality and the size and significance of human capital coefficients in growth regression across various specifications. Figure 2.2 presents a comparison of the average years of schooling in Germany (1950-2000) across the different databases[11]. We note that although the reported levels are relatively close, the BL estimate are essentially stagnant up to 1990 while the other database show a gradual increase.

Essentially, the challenge in the computation of years of schooling is twofold. On the one hand, it requires to combine information from decadal (each 10 years) population censuses with information on school enrollment which are annual. On the other hand, this ought to be done in the context of inconsistencies in classification systems between sources or censuses. After the July 2013 release of the PWT 8.0, Cohen and Leker (2014) produced another dataset which they judged superior to the BL dataset. Feenstra et al. (2015) does not take a stand as to which dataset is accurate but uses the Cohen, Soto and Lecker (2014)[12] as an opportunity for comparison to the BL data. Furthermore, they use this comparison to make

[11]Source: PWT 9.0 documentation.
[12]Henceforth referred to as the CSL dataset.

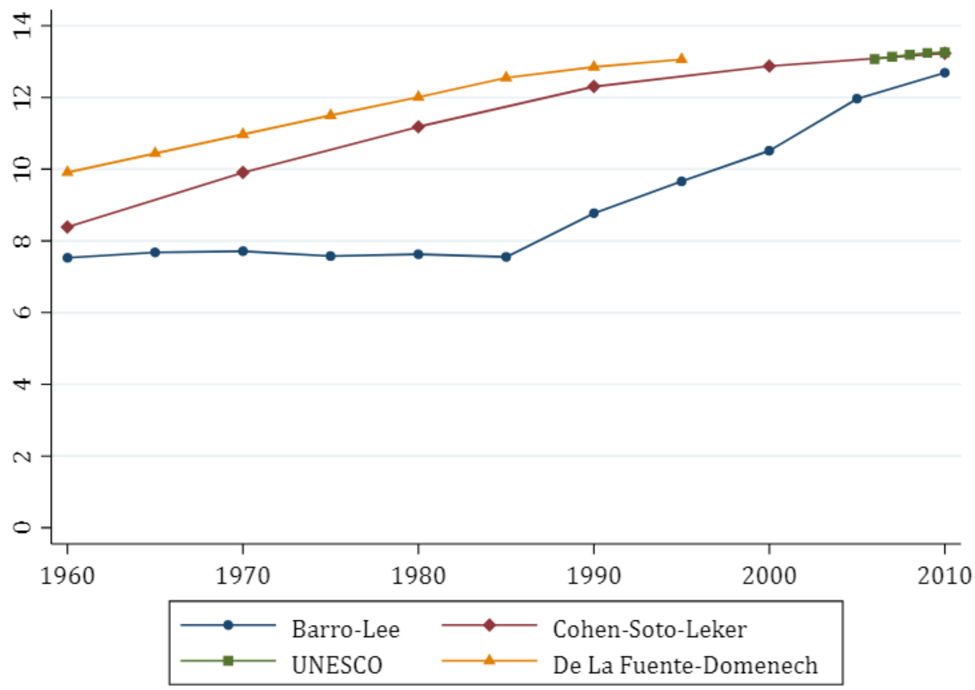


Figure 2.2: Average years of schooling in Germany (1950-2010)

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a case that there are grounds for combining data from both sources as they construct the PWT measure of human capital.

The PWT also provide additional control variables. We use data on the capital stock available per capita. The estimate is available in 2017 U.S. dollars. We also utilize the depreciation rates of capital in our sensitivity analysis. Finally, we obtain data on the latitude of each country's capital to account for geographical differences. Except for latitude, all other data are annual and available at the country level.

Another important point in the growth literature is the role of original income in growth. Historically, rich countries tend to grow at a slower rate than their poorer counterparts. Among our specifications of the empirical equation, we include the logarithm of the per-capita GDP in 1970 for each country. Our goal is to assess whether the convergence phenomenon plays a role in the effect of education spending and institutions on growth. In Table B.1 (Appendix), we see a clear difference in the 1995 logarithm of GDP per capita between countries with high versus low institutional quality.

2.5.5 Countries' classification

The PWT provides us with data on 115 countries between 1979 and 2019. This sample represents our main dataset from which we later produce sub-samples for a variety of regressions and sensitivity analyses. According to growth theory, different countries are at different levels of development and researchers ought to take this into account. In this section we will present how we organize these 115 countries when performing the empirical estimation.

First, an important consideration is the role of relatively small countries with unusually large GDP per capita. Often, this can be the result of exceptional growth episodes due to new natural resources but it can also stem from other fiancial activities. In a report issued in 2000 by the OECD, a number of jurisdictions had been identified as tax havens according to certain criterias[13].

Table 2.1: 2000 OECD report tax havens compared to the U.S.

Countries	GDP per cap (2019 U.S. dollars)	Population in 2019 (in millions)
Anguilla	14,999	0.014
Bahrain	46,442	1.641
Bahamas	32,696	0.389
Bermuda	52,075	0.062
Cayman Islands	70,783	0.064
U.S.	62,490	329,064

Notes: The Gini coefficient for the so-called "tax-haven" countries was not reported by the WDI, the OECD, or the United Nations report. The data on GDP and population originate from the PWT 10.

Among the countries listed, 38 made commitments to increase transparency and more information sharing. Table 2.1 shows a subset of these countries along with the U.S. for comparison. Column (1) shows that in 2019, they recorded a relatively high GDP per capita combined with a remarkably low population as seen in Column (2). For example, the Cayman

[13] https://www.oecd.org/countries/andorra/list-of-unco-operative-tax-havens.htm/.

Islands had a GDP per capita 13% larger than the U.S. with a population of only 64,000 inhabitants. For the majority of these countries, data on inequality are hardly available. These observations advise for a careful treatment of their GDP per capita fluctuations as they could be related to factors beyond real economic activity.

Many of these countries are part of our original sample and although it may not be necessary to eliminate them altogether from the analysis, we attempt to be mindful of this issue. To address this uncertainty, we also present regressions estimated in a more restricted sub-set of countries. In a study of economic convergence, Barro (2012) uses a sample of 77 countries (see Table B.2) which are also within the PWT. We run regressions in this smaller sample (henceforth, Barro sample). An exhaustive list of the selected 77 countries is available in Section B.1 in the appendix. We also present results based on the larger sample including all the countries available[14]. Furthermore, the dynamics between education spending and growth in the context of institutional quality likely varies for countries depending on the country's current development level. We present different subsamples of countries based on their average GDP per capita in 1970. We use data for the 77 countries of the Barro sample with varying sample sizes depending on specifications and data availability. We present both cross sectional (see Table B.3 and B.4) and panel specifications. GDP per capita based on output is from the Penn World Table 10 (Feenstra et al. (2015)) as explained before. This measure is better suited to comparison of levels than the real GDP based on national account data. We define rich countries as those with more than $11,000 in real per capita GDP in 1970 (in 2017 dollars), middle income countries had between $2,700 and $11,000 in real GDP, and developing countries had under $2,700 in per capita term.

Overall this sample has 29 rich countries, 21 middle income countries and 27 developing countries. For example, in the case of rich countries the Barro sample excludes Bahamas, Bahrain, Kuwait, Quatar and Saudia Arabia among others. Two of these countries figured on the 2000 OECD report as tax havens and the other three have had exceptional changes brought in large part due to relatively recent oil extraction. We provide an exhaustive list

[14]For the remainder of our analysis we will use this sample except when we clearly mention the Barro sample.

of the member countries of each income categories in Appendix B. For the cross sectional specification, we start with annual data which we convert into a 30 years average of growth by country between 1989-2019. This construction is common in the literature (Hanushek and Woessman (2012)).

2.5.6 Descriptive statistics

Depending on the specification, the explained variable is either the 30 years average growth rate or the non-overlapping 10 years average growth rate in GDP per capita (1979-2019) for each country. The fastest growing countries are the poorest with a growth rate of 2.02% compared to 1.78% for the whole sample. Table 2.2 shows that richer countries have a growth of 1.67% on average. Rich countries spend the largest share of their GDP on education spending while the poorest countries have the smallest share (see Table B.1).

The next three rows show the measures of institutional quality. Unsurprisingly, our main measure of protection against expropriation is highest in rich countries along with property rights and government integrity. Rich countries also have the largest share of government spending net of education. We also report an estimate of hours worked per year. Here developing countries lead with an average of 2260 hours worked per year against only 1720 hours in developed countries. The capital stock per person available in richer countries is about 12 times what developing countries have. Developing countries, however, have a higher rate of depreciation of capital. We also note that richer countries appear to have higher latitude than poorer nations.

Figure 2.3 helps visualize the data availability as well as some patterns of growth, education spending and institutions in our dataset. First, most variables are available in all continents including Africa. The fastest growing countries are in Asia and other regions of the world. This figure shows a noteworthy pattern. In most countries, high growth is not accompanied by simultaneously strong institutions and high education spending. For example Canada, Norway, France and the U.S. have relatively high education spending as well as high institutions but only a modest 20 years average GDP growth rate.

Table 2.2: Descriptive statistics

Variables	All	Rich	Developing	Middle Income
Average 10 year growth rate	1.78	1.67	2.02	1.67
per-capita real GDP (γ), %	(2.81)	(2.74)	(3.05)	(2.66)
Education expenditures (% GDP)	3.80	4.43	3.22	3.80
	(1.69)	(1.46)	(1.80)	(1.61)
Institutional quality	7.15	8.95	6.07	6.82
(Protection from expropriation out of 10)	(1.76)	(1.08)	(1.34)	(1.49)
Property rights	5.27	6.54	3.97	5.12
Index of Economic Freedom (IEF)	(2.20)	(2.36)	(1.51)	(1.87)
Government integrity (IEF)	4.27	5.83	2.85	3.96
	(2.25)	(2.58)	(1.11)	(1.67)
Government spending	11.86	14.11	9.74	11.39
net of education (%GDP)	(4.58)	(4.05)	(3.78)	(4.70)
Average hours worked per year (1000h)	1.93	1.72	2.26	2.02
	(0.03)	(0.02)	(0.02)	(0.02)
Human capital	2.28	2.97	1.70	2.25
	(0.74)	(0.54)	(0.51)	(0.57)
Capital stock per capita	80.68	177.77	15.46	62.39
in 2017 U.S. dollars (1,000)	(103.4)	(128.2)	(231.2)	(65.2)
Depreciation rate (of capital stock), %	4.32	3.87	4.71	4.33
	(1.29)	(0.97)	(1.43)	(1.27)
Initial GDP per capita in 1970 ($1000)	4.77	10.11	1.49	5.11
	(1.14)	(0.81)	(0.39)	(0.40)
Latitude of capital (divided by 90[15])	0.29	0.48	0.18	0.22
	(0.19)	(0.14)	(0.11)	(0.15)
Countries	115	29	21	27

Notes: The table reports means between 1970 and 2019 and the standard deviations in parenthesis.

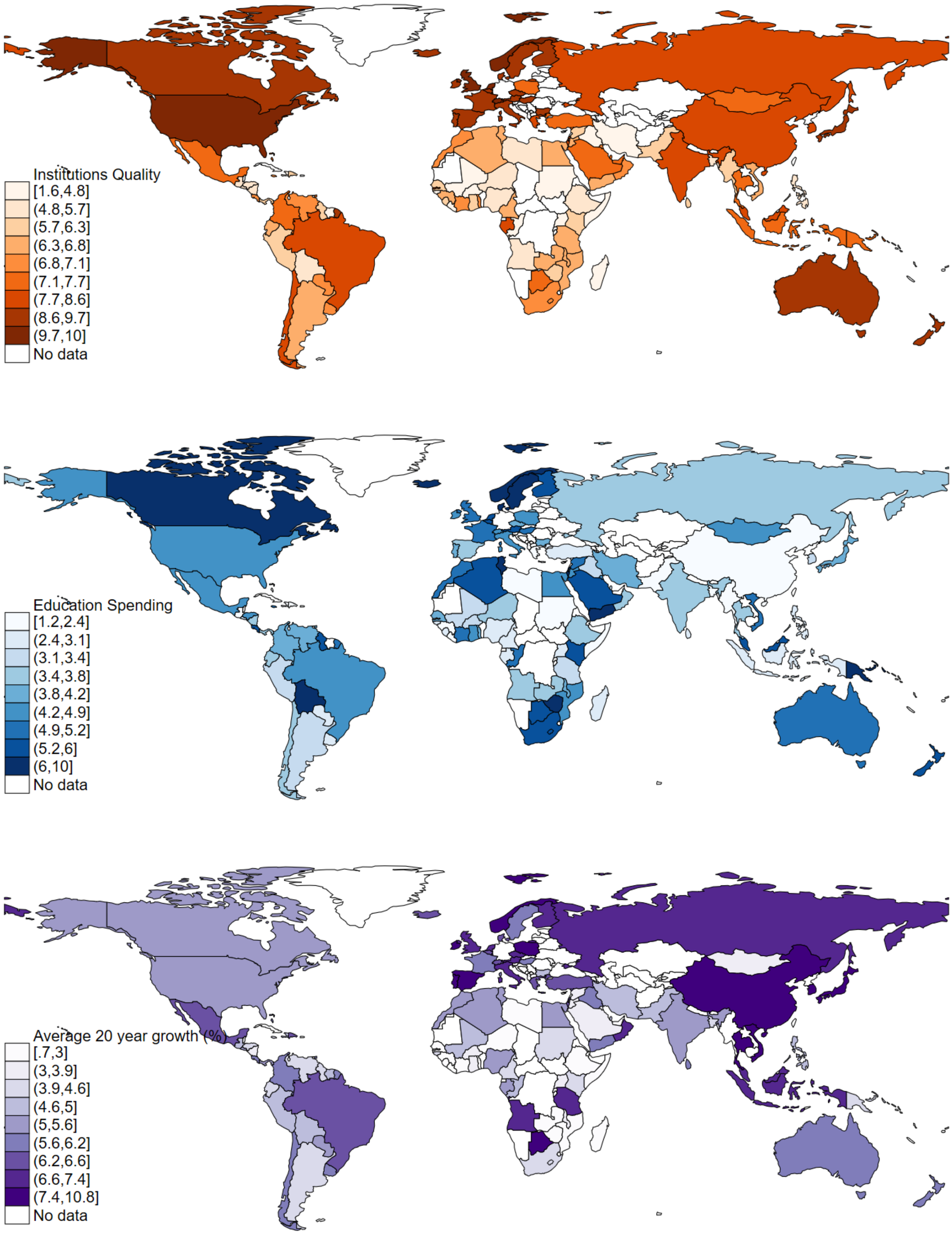

Figure 2.3: Institutional quality, education spending and growth

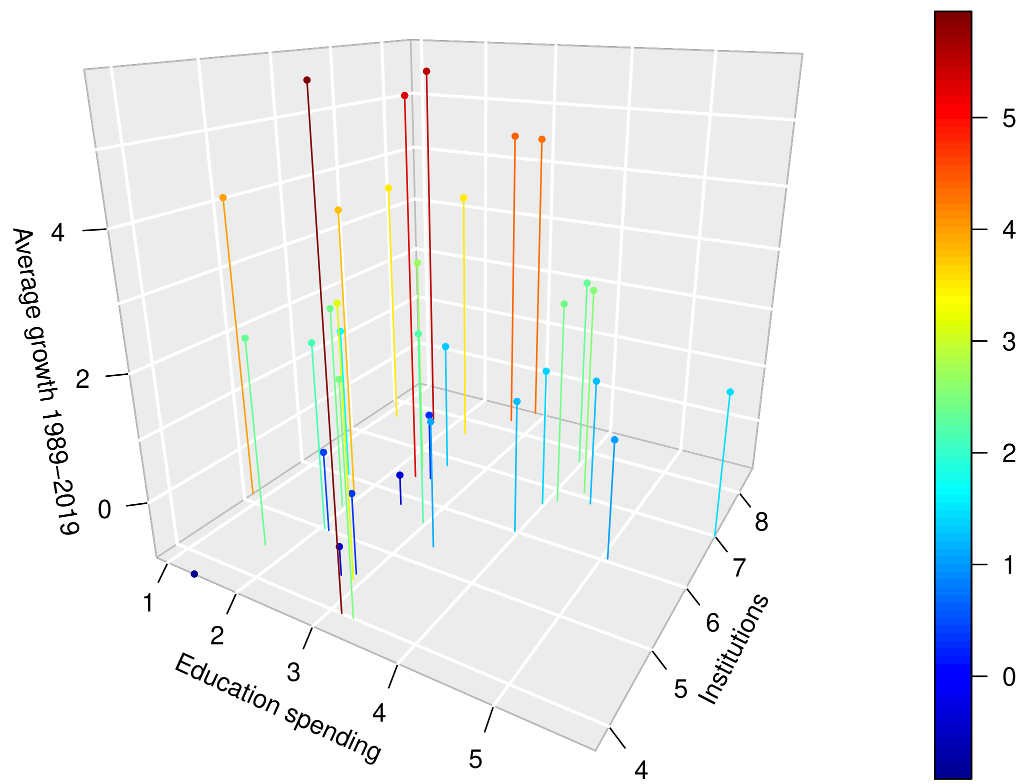

Figure 2.4: Institutional quality, education spending and growth among developing countries.

In contrast, other countries like the Russian Federation, China, Portugal, Spain and even Tanzania have average or good institutions with modest education spending but still record relatively high growth. This pattern will be the subject of our analysis.

Finally, we note that a concern in our analysis is the potential multicollinearity between education expenditures and institutional quality. In Section B.2.2, we explore the question and do not find evidence of this issue. On the other hand, rich countries have commonly higher level of institutional quality as we have seen. However, the estimation of our model requires a level of variation among institutions. In Section B.2.3, we show that variation exist in the distribution of institutional quality even between developed countries (see also

Figure B.3).

Figure 2.4 focuses on the developing countries of our dataset. The challenge to the theory of greater marginal effect of high education spending in the context of strong institutional quality is clearer. In particular, few developing countries with simultaneously high education spending in a context of relatively strong economic institutions show large growth over the 30 year period. Among these countries are Côte d'Ivoire, Zambia, Egypt, and Togo. In contrast, some countries with lower education spending and good institutions managed faster growth rates.

Among these countries are Ethiopia, Thailand, Vietnam and Bangladesh. In addition, based on log GDP 1970, China and Indonesia also belong to this group. Both countries are in the bottom 20% of education spending among developing countries but had institutions in the top 20% and recorded among the highest average growth rate with respectively 5.5% and 3.5% between 1979 and 2019.

2.6 Empirical methodology

In this section, we show how our growth relationship obtained from the overlapping generation model maps to the empirical specification of our regression. Recall Equation (2.11) as:

$$\gamma \approx \lambda_0 + \lambda_1 e + \lambda_2 q + \lambda_3 qe.$$

The most elemental version of our empirical equation mirrors Equation (2.11) and provides estimates of the coefficients λ_0, λ_1, λ_2 and λ_3 with:

$$\gamma_{n,t} = \bar{\beta}_0 + \beta_1 e_{n,t-1} + \beta_2 q_n + \beta_3 q_n e_{t-1} + \delta_t + u_{n,t}. \tag{2.14}$$

This is the baseline specification of our model. Countries are indexed by n and time periods by t. Here, $\gamma_{n,t}$ represents the non-overlapping decadal growth rate of each country, $e_{n,t-1}$ is the average education spending of each country in the previous decade and q_n is the measure of each country's institutional quality. The equation presents the basic explanatory variables of growth in this paper, their interaction and a time fixed effect component δ_t. We account for the stochastic nature of the growth process by including an independent and identically distributed error term $u_{n,t}$. Our error term is clustered at the country level. The coefficient of interest is β_3 and can provide insight into whether the effect of education spending varies with different levels of institutional quality.

2.7 Empirical results

We now estimate the relationship between education spending, institutional quality, their interaction and GDP growth. We present different specifications and samples (see Table B.4 and B.5 for cross sections). We only add fixed effects over time unless running specifications that exclude the measure of institutional quality. In those specifications, we allow for two-ways fixed effects across time (δ_t) and countries (η_t). Recall that our estimation periods are not overlapping.

Our growth model theorizes that education spending and institutional quality affect growth interactively. Therefore, we run different regressions with either variable and advance with specifications which progressively include both variables as well as an interaction term. In essence, the different specifications are cases of restrictions of different coefficients in Equation (2.16). Later, we supplement the regressions with a range of control variables including human capital (as measured in the PWT10) and log per capita GDP in 1970.

We present an exhaustive list of the regressions used. We begin by estimating the relationship between education expenditures and the average ten years growth without any controls. This basic form does not account for any original GDP level nor other controls. We run a similar regression with only the measure of institutional quality. We respectively refer to these regressions as Regression 1 and Regression 2. The next two regressions feature the two variables at the same time. In Regression 3, we use education spending and institutional quality as regressors without an interaction term. Regression 4 adds the interaction term of the two variables. This specification is the most basic form of our theoretical model but does not yet include original GDP levels. Regressions 5, 6, 7, 8 are specifed in the same way as the previous four. The only difference is that we estimate the relationship in the Barro (2012) sample of countries[16]. The addition of initial GDP per capita in future specifications will allow us to study the effect of education spending and institutions while controlling for potential β-convergence predicted by exogenous growth models. A negative coefficient would imply that developing countries grow at a faster rate than initially rich countries when other variables are kept constant.

2.7.1 Panel approach

In many specifications, we find that the effect of education spending is either insignificant or significantly negative even after controlling for institutional quality. However, once we introduce the interaction term of the two variables, education spending is often positive and significant and the interaction term has a negative sign. This points to a differing effect of education expenditures depending on the level of institutional quality but also suggests a certain substitutability between the two variables in achieving long run growth. We present cross sectional results in Appendix B.

Rich countries

Panel A in Table 2.3 presents the estimation results for the developed countries separately. Regression 1 shows that when no other variable is accounted for, public education spending has a positive significant effect on growth. The same is valid for institutional quality as seen in Regression 2. Regression 3 introduces both regressors and the positive effect of education spending is no longer significant while institutional quality is still significantly linked to growth. Regression 4 adds the interaction term of the two variables. When the interaction effects are taken into account, we now find that both education spending and institutional quality positively affect growth with significance.

[16] Recall that this sample is restricted to the 77 countries used in Barro (2012) to which we later add all the additional countries on which we have data available.

Table 2.3: Panel baseline results (1979-2019)

Variables	(1)	(2)	(3)	(4)	(5) Barro	(6) Barro	(7) Barro	(8) Barro
Panel A: Rich countries								
Education spending	0.66**		0.18	2.94***	0.12		0.03	3.95*
	(0.32)		(0.11)	(0.79)	(0.12)		(0.08)	(2.04)
Institutional quality		0.90***	0.66***	1.97***		0.28*	0.26	1.52**
		(0.18)	(0.17)	(0.54)		(0.15)	(0.19)	(0.65)
Inst*Ed				-0.31***				-0.41*
				(0.08)				(0.21)
Observations	121	112	107	107	84	84	84	84
R-squared	0.39	0.27	0.24	0.28	0.25	0.16	0.17	0.22
Panel B: Developing countries								
Education spending	-0.40		-0.51***	1.09	-1.00***		-0.49**	1.48
	(0.26)		(0.14)	(0.88)	(0.35)		(0.18)	(1.13)
Institutional quality		0.62**	0.80***	1.45***		0.70**	0.80**	1.60***
		(0.25)	(0.25)	(0.39)		(0.33)	(0.35)	(0.48)
Inst*Ed				-0.24*				-0.30
				(0.13)				(0.18)
Observations	183	152	135	135	103	104	103	103
R-squared	0.48	0.24	0.29	0.31	0.58	0.21	0.25	0.27
Panel C: Middle Income countries								
Education spending	-0.10**		-0.09**	-0.31	0.06		-0.14	-0.92
	(0.04)		(0.04)	(0.77)	(0.23)		(0.21)	(1.48)
Institutional quality		0.45***	0.36***	0.21		0.43*	0.32	-0.05
		(0.11)	(0.12)	(0.52)		(0.22)	(0.24)	(0.79)
Inst*Ed				0.04				0.11
				(0.13)				(0.22)
Observations	241	184	170	170	114	120	114	114
R-squared	0.42	0.16	0.14	0.14	0.59	0.13	0.13	0.13
Panel D: All countries								
Education spending	-0.09		-0.15**	0.26	-0.29		-0.29**	0.31
	(0.05)		(0.06)	(0.29)	(0.21)		(0.12)	(0.48)
Institutional quality		0.21***	0.21***	0.47**		0.17*	0.25**	0.53*
		(0.07)	(0.07)	(0.24)		(0.10)	(0.11)	(0.30)
Inst*Ed				-0.06				-0.08
				(0.05)				(0.06)
Observations	545	448	412	412	301	308	301	301
R-squared	0.42	0.09	0.09	0.10	0.48	0.05	0.07	0.08

Notes: The dependent variable in column (1)-(8) is the average 10 years growth rate of log GDP per capita. Institutional quality is measured on a scale of 0 to 10 with higher scores indicating stronger institutional quality. The measure originates from Political Risk Services and is averaged between 1985 and 1995. Education spending is obtained from the World Bank World Development Indicators and is expressed as a percentage of GDP. Barro refers to the sample of countries used in Barro(2012). The sample is more restricted as the study was an investigation of β-convergence. Asterisks between 1 and 3 respectively indicate significance at the 10%, 5% and 1% level. See Section 2.5 for a more detailed variable definitions and sources.

The presence of this significant interaction term suggests that the effect of education spending on growth varies given different levels of institutional quality as pointed out by the large difference in coefficient magnitudes. More precisely, given an institutional level of zero, a 1% increase in education spending results in a 2.95% increase in per capita decadal growth rate, a large effect. Conversely, given perfect institutional quality, a 1% increase in education spending would be associated with a -0.16% change or $(2.94 - 0.31 * (1 * 10))$ in GDP per capita, a negative effect. In addition, the negative significance of the interaction between public education spending and institutions points to a substitute relationship in achieving long term growth.

Regressions 5, 6, 7, 8 in the more restrictive Barro sample reflects the previous results especially in term of magnitude. We note that this sample is more restrictive and we lose a substantial number of observations in each regression. Regressions 5 and 6 show that both education spending and institutional quality positively affect growth but only the latter remains significant. Regression 7 which introduces both shows that significance is lost. However, results in Regression 8 vary greatly from the previous three. Once more, when we introduce the interaction term, all regressors regain significance although the magnitudes are different from Regression 4. The effect of education spending on growth is shown to vary according to the level of institutional quality. Here, given institutional quality of zero, a 1% increase in education spending is associated with a 3.95 % increase in gdp per capita growth. For a country with perfect institutions, a one percent increase in education spending would be associated with a -0.15% or $(3.95 - 0.41 * (1 * 10))$ change in GDP per capita. An effect which is almost identical in sign and magnitude to Regression 4. We remark that the relationship is relatively stable between the two samples although the Barro group of rich countries excludes about 10 countries from the estimation. The effect reported is essentially the same. In addition, the evidence for plausible substitutability is still observed.

Developing countries

We run the same regressions for the developing countries. Regression 1 now shows that education spending is associated with slower growth, although insignificantly. Regression 2 shows a positive link for institutional quality that is also significant. Regression 3 results, however, are different from the findings in rich countries. While institutional quality remains positively significant, the effect of education spending is now significantly negative. In Regression 4 as we add the interaction term, we find that education spending has again a positive effect although it is not significant, both institutional quality and the interaction term are significantly associated with growth as before.

The last four regressions are run in the Barro sample of countries as before. Here again the effect of education spending is reported to be negative but significant in Regression 5. The next regression also shows a positive link between institutional quality and average decadal growth. Regression 7 shows that both regressors have a significance effect on growth. Education spending has a negative effect but the magnitude is only half compared to the previous Regression 5. Institutional quality shows a positive association to growth with a magnitude close to the previous estimation. The results of Regression 8 only shows significance for institutional quality, but the signs are conserved. In Regressions 4 and 8 the coefficient on education spending is not significant although the interaction term is.

Middle income countries

Among middle income countries, Regression 1 shows that education spending has a negative effect as with developing countries although the coefficient is now significant. Institutional quality is again positively linked to growth. When both regressors are introduced in Regression 3, their significance and signs are conserved and there is little change in magnitude. When we add the interaction term in Regression 4, we find a markedly different pattern. The interaction term is positive and the effect of education spending remains negative but no regressor displays signficance. The results in Regressions 5, 6, 7, 8 follow the same pattern (see also Table B.3).

All countries

Lastly, we investigate the relationship for all countries available. We use the same specifications and report similar signs to Panel A and B although significance is not reached except for institutional quality. We find that the interaction of the two variables is still negative but not significant. Nonetheless the magnitudes are much smaller. This could be driven by the rich and developing countries of the sample as middle income countries show mitigated results as shown above.

2.8 Robustness checks

2.8.1 Additional controls

When we augment our regression with additional controls, we rely on Equation (2.14) and in particular the $\bar{\beta}_0$ term. We define this parameter $\bar{\beta}_0$ as a function of a sequence of additional control variables. We assume there are m items that can be used to approximate $\bar{\beta}_0$. That is:

$$\bar{\beta}_0 \approx \beta_0 + \sum_{j=1}^{m} \beta_{j+2} x_{j,n,t-1} \tag{2.15}$$

where $x_{j,n,t-1}$ is the measure of item x_j of country n in period $t-1$. We control for the effect of the average human capital in previous decade by adding $h_{n,t-1}$. We also allow for the possibility of convergence by controlling for the level of income in country n at the origin denoted $y_{n,1970}$. We also include the government's budget constraint. Furthermore, when possible, we control for heterogeneity over time and across countries by adding two-ways fixed effects denoted by δ_t and η_n in the sensitivity analysis. Substituting Equation (2.15) into Equation (2.14) and displaying some of the control variables gives our new growth regression the form:

$$\gamma_{n,t} = \beta_0 + \beta_1 e_{n,t-1} + \beta_2 q_n + \beta_3 q_n e_{t-1} + \beta_4 [e_{n,t-1} + g_{n,t-1}] + \beta_5 y_{n,1970} + \beta_6 h_{n,t-1} + \sum_{j=1}^{m-4} \beta_{j+2} x_{j,n,t} + \delta_t + \eta_n + u_{n,t}. \tag{2.16}$$

We emphasize that we consider the growth effects of the lagged education spending with the implied restriction that government expenditures take time to affect growth. This assumption finds support in the growth literature. Atems and Blankenau (2020) find that education expenditures can take between 3 to 13 years to impact output level due to the timing of impacted students to join the labor force. The other important element is the time invariability of the institution measure. We use our measure of institution quality in this way based on the assumption of persistence through time (Acemoglu and Robinson (2001)). Later, we relax this assumption in our sensitivity analysis and use multiple proxies for institutional quality. In particular, we use property rights, government integrity and business freedom.

Table 2.5 presents our panel results with additional controls (see Table B.7 for middle income countries and all countries). The regressions are the same as Table 2.3 within the same time period. As before, we regress the 10 years average growth rate of real per capita GDP on institutional quality and education expenditures in the previous decade. Original per capita income and human capital are the average in the previous decade. We focus on results for rich and developing countries but report middle income countries and all countries results in Appendix B. For all specifications, we add a list of additional control variables. We include the depreciation rate of capital, an estimate of capital available per person, latitude and government expenditures net of education to be consistent with other research in the literature. All control variables are the averages from the previous decade to the decadal growth rate we aim to explain.

Among rich countries, Regression 1 presents our baseline regression for comparison as we progressively add controls. Regression 2 introduces the per capita level of income in 1970. As expected, the coefficient is significantly negative. Education spending and institutional quality keep their previous signs, significance and the magnitudes are also close to earlier findings. For the remaining specifications, we keep the original GDP measure. Regression 3 introduces the share of total government spending net of educations spending. The coefficient is not significant and the three baseline coefficients do not change greatly[17]. We note that the coefficient on education spending is still positive, but the magnitude is lower. This finding is consistent with the prediction of our growth model when including the government budget constraint. Regression 4, shows the effect of including human capital in the equation. Although the coefficient is not significant itself, the magnitude of the baseline coefficient changes. In particular, the effect of education spending is remarkably larger. In Regression 5, we include the depreciation rate of capital in the economy. The effect is not significant.

[17]The significance level goes from the 1% level to the 5% level.

Table 2.4: Panel regressions with additional controls (1979-2019)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Rich countries								
Education spending	2.94***	2.95***	2.78**	3.26***	3.01***	2.97***	2.91***	3.47*
	(0.79)	(0.84)	(1.30)	(1.01)	(0.85)	(0.96)	(0.86)	(1.74)
Institutional quality	1.97***	1.77***	1.96**	1.75***	1.74***	1.99***	1.78***	2.04**
	(0.54)	(0.54)	(0.79)	(0.58)	(0.51)	(0.62)	(0.54)	(0.76)
Inst*Ed	-0.31***	-0.31***	-0.30**	-0.35***	-0.32***	-0.32***	-0.30***	-0.38*
	(0.08)	(0.09)	(0.14)	(0.11)	(0.09)	(0.10)	(0.09)	(0.19)
y_{1970}		-0.65*	-0.38	-0.57	-0.49	-0.47	-0.64*	-0.09
		(0.33)	(0.39)	(0.34)	(0.45)	(0.45)	(0.32)	(0.47)
Government Exp.			0.04					0.07
			(0.04)					(0.05)
Human capital				0.78				0.74
				(0.55)				(0.57)
Depreciation					-0.19			-0.27
					(0.28)			(0.32)
Capital per person						-0.47		0.59
						(0.39)		(0.45)
Latitude							-0.35	0.70
							(0.98)	(1.55)
Observations	107	107	101	103	107	107	107	97
R-squared	0.28	0.31	0.38	0.33	0.32	0.32	0.31	0.44
Panel B: Developing countries								
Education spending	1.09	1.53**	1.26*	1.50*	1.29*	1.54**	2.55***	2.27***
	(0.88)	(0.73)	(0.68)	(0.77)	(0.67)	(0.74)	(0.71)	(0.74)
Institutional quality	1.45***	1.69***	1.55***	1.54***	1.56***	1.69***	1.93***	1.71***
	(0.39)	(0.39)	(0.39)	(0.41)	(0.39)	(0.38)	(0.35)	(0.33)
Inst*Ed	-0.24*	-0.30***	-0.25**	-0.29**	-0.26**	-0.30***	-0.45***	-0.40***
	(0.13)	(0.11)	(0.10)	(0.11)	(0.10)	(0.11)	(0.10)	(0.11)
y_{1970}		-2.22***	-2.27***	-2.37***	-2.11***	-2.23***	-2.22***	-2.04**
		(0.62)	(0.75)	(0.61)	(0.56)	(0.65)	(0.58)	(0.83)
Government Exp.			-0.07					-0.08
			(0.07)					(0.08)
Human capital				0.80*				0.47
				(0.43)				(0.71)
Depreciation					0.16			-0.04
					(0.15)			(0.22)
Capital per person						0.01		-0.24
						(0.33)		(0.47)
Latitude							6.41***	6.72***
							(1.60)	(1.97)
Observations	135	135	120	130	135	135	135	116
R-squared	0.31	0.40	0.37	0.41	0.41	0.40	0.46	0.43

Notes: The dependent variable in column (1)-(8) is the average 10 year growth rate of log GDP per capita. Institutions are measured on a scale of 0 to 10 with higher scores indicating better protection against expropriation. The measure originates from Political Risk Services and is averaged between 1985 and 1995. Education spending is obtained from the World Bank World Development Indicators and is expressed as a percentage of GDP. Standard errors are in parenthesis. Barro refers to the sample of countries used the Barro(2012) study of economic convergence. Barro+ includes all countries. Asterisks between 1 and 3 respectively indicate significance at the 10%, 5% and 1% level. See Section (2.5) for more detailed variable definitions and sources.

Next, we add the amount of capital per capita and the latitude of the countries' capitals in

Regression 6 and 7. Neither is significant and both signs are negative. The baseline results are the same. In Regression 7, the original GDP is now significant at the 10% level. In Regression 8, we apply all the control variables at once. The baseline signs and significance are conserved although the significance level decreases. The effect of education spending and institutional quality are both larger. We interpret that a 1% increase in education expenditures is associated with a -0.10% change in the decadal growth rate.

Among developing countries, the baseline results of Regression 1 are similar in sign to the findings of Regression 2. Nonetheless, adding the original GDP in the latter leads all the baseline coefficients to become significant. The negative coefficient on original GDP suggests that the poorest countries in the sample tend to growth faster than their richer counterparts. The magnitude is large. In Regression 3, the addition of government expenditures net of education does not change the results significantly. However, the magnitude of the effect of education spending is lower. As for rich countries, when we add the human capital measure, the baseline coefficients are significant and larger. In contrast, however, the positive effect of human capital is significant. The addition of both the depreciation rate and the amount of capital per person in Regression 5 and 6 keep the coefficients' significance. We also add in Regression 7 the latitude of the countries capital as before. The findings differ starkly from the sample of rich countries.

Among developing countries, geography as measured by latitude appears to be a significant positive driver of long term growth. Finally, in Regression 8 we add all the regressors at once and find highly significant coefficients for the baseline equation. Among developing countries, we interpret that given institutional quality of 0, a 1% increase in education spending is associated with a 2.27% higher growth rate. In comparison, for a poorer economy with perfect institutions, a similar change in education spending would actually be associated with a slower growth by -1.73%. This finding suggest a certain robustness to the hypothesis of varying impact of education spending with respect to institutional quality in rich and developing countries alike.

2.8.2 Are the results driven by the measure of institutional quality?

In this section, we investigate the sensitivity of the results to alternative measures of institutional quality. Our assumption about the measure of institutions is that little variation occurs in short periods of time following Acemoglu et al. (2001). We choose two proxies for institutional quality originating from the Index of Economic Freedom (IEF) database[18]. Property rights and government integrity measures are available between 1995 and 2019 at a yearly frequency. We compute the average of each index based on their measure in the year 1999, 2009 and 2019. This provides one observation per country.

These values show a relatively high level of correlation with the original measure of institutional quality of above 70% in both cases. All regressions are performed in the complete dataset without use of the restricted Barro (2012) sample. Regression 1 to 4 present the results for rich, developing, middle income countries and all countries sequentially. The original GDP is added. Regression 5 to 8 uses the same sequence but includes more control variables. The cross sectional results are reported in Table B.6.

Panel A presents the results based on the use of property rights while Panel B uses government integrity as a proxy for institutional quality. Regression 1 in both panels shows consistent results with our previous findings for rich countries. In both specifications, the interaction term is significantly negative as expected. Regression 5 in both panel also display the same pattern for signs although only the measure of property rights is significant. Regressions 2 and 6 in both panels show the results for developing countries. Although the sign are conserved, only in the case of government integrity as a proxy for institutional quality do we record similar coefficients to the baseline regressions. Regression 3, 4, 7 and 8 show comparable results to previous findings for middle income countries and all the countries. Notably in Regression 8 using government integrity all coefficients are significant even if the magnitude as considerably lower. As before, the measure of latitude is a strong predictor for

[18]This is a publication of the Heritage Foundation. Several additional variables are available estimating tax burden, business freedom, financial freedom and more.

growth among developing countries.

Table 2.5: Panel regressions with alternative measures of institutions (1979-2019)

Variables	(1) Rich	(2) Developing	(3) Middle Income	(4) All	(5) Rich	(6) Developing	(7) Middle Income	(8) All
Panel A: Institutional quality proxied by property rights								
Education spending	1.30*	0.18	-0.02	0.07	1.57**	0.63	-0.04	0.10
	(0.72)	(0.49)	(0.07)	(0.09)	(0.74)	(0.43)	(0.07)	(0.06)
Property rights	1.13**	1.04**	0.49***	0.62***	1.01**	1.37***	0.66***	0.68***
	(0.50)	(0.49)	(0.15)	(0.13)	(0.47)	(0.43)	(0.16)	(0.15)
Pr*Ed	-0.16*	-0.10	-0.01	-0.03*	-0.20**	-0.21**	-0.02	-0.05***
	(0.09)	(0.11)	(0.03)	(0.02)	(0.10)	(0.10)	(0.03)	(0.02)
y_{1970}	-0.72***	-1.22*	-0.81	-0.92***	-0.35	-1.39	-0.59	-0.86***
	(0.24)	(0.67)	(0.51)	(0.12)	(0.50)	(0.96)	(0.52)	(0.16)
Human capital_t-1					0.53	0.69	0.42	0.47
					(0.55)	(0.82)	(0.39)	(0.30)
Depreciation					-0.22	0.11	0.04	0.16*
					(0.29)	(0.17)	(0.12)	(0.09)
Capital per person					-0.18	-0.29	-0.56**	-0.21
					(0.47)	(0.47)	(0.27)	(0.17)
Latitude					1.37	6.01***	0.31	1.30
					(1.41)	(2.08)	(1.02)	(0.82)
Observations	113	155	197	465	110	134	150	394
R-squared	0.30	0.20	0.18	0.17	0.30	0.39	0.37	0.26
Panel B: Institutional quality proxied by government integrity								
Education spending	1.10**	0.34	-0.07	0.08	0.87	1.45***	-0.08	0.12*
	(0.52)	(0.57)	(0.10)	(0.09)	(0.57)	(0.45)	(0.10)	(0.07)
Government integrity	0.82**	1.65*	0.42***	0.59***	0.69**	3.02***	0.59***	0.65***
	(0.33)	(0.83)	(0.14)	(0.13)	(0.26)	(0.64)	(0.18)	(0.14)
Gvi*Ed	-0.13*	-0.19	0.00	-0.04*	-0.10	-0.55***	-0.02	-0.07***
	(0.07)	(0.18)	(0.04)	(0.02)	(0.07)	(0.15)	(0.04)	(0.02)
y_{1970}	-1.09***	-1.26*	-0.76	-0.92***	-0.05	-1.37	-0.92	-0.97***
	(0.12)	(0.74)	(0.53)	(0.14)	(0.37)	(0.97)	(0.58)	(0.18)
Human capital_t-1					-0.99**	0.76	0.81**	0.81***
					(0.39)	(0.69)	(0.38)	(0.25)
Depreciation					-0.08	0.08	0.03	0.17*
					(0.23)	(0.18)	(0.10)	(0.09)
Capital per person					-0.13	-0.40	-0.45*	-0.20
					(0.27)	(0.45)	(0.24)	(0.17)
Latitude					-1.08	5.51***	0.67	1.27
					(0.81)	(1.62)	(1.18)	(0.81)
Observations	113	155	197	465	84	134	150	394
R-squared	0.29	0.20	0.16	0.15	0.22	0.42	0.36	0.24

Notes: The dependent variable in column (1)-(8) is the average 10 year growth rate of log GDP per capita. Institutions proxied by property rights and government integrity averaged between 1999, 2009 and 2019. A large score indicates strong institutions, property rights or government integrity. Education spending is obtained from the World Bank World Development Indicators and is expressed as a percentage of GDP. Standard errors are in parenthesis. Asterisks between 1 and 3 respectively indicate significance at the 10%, 5% and 1% level. See Section 2.5 for a more detailed variable definitions and sources.

2.8.3 Institutional quality and the role of settlers' mortality

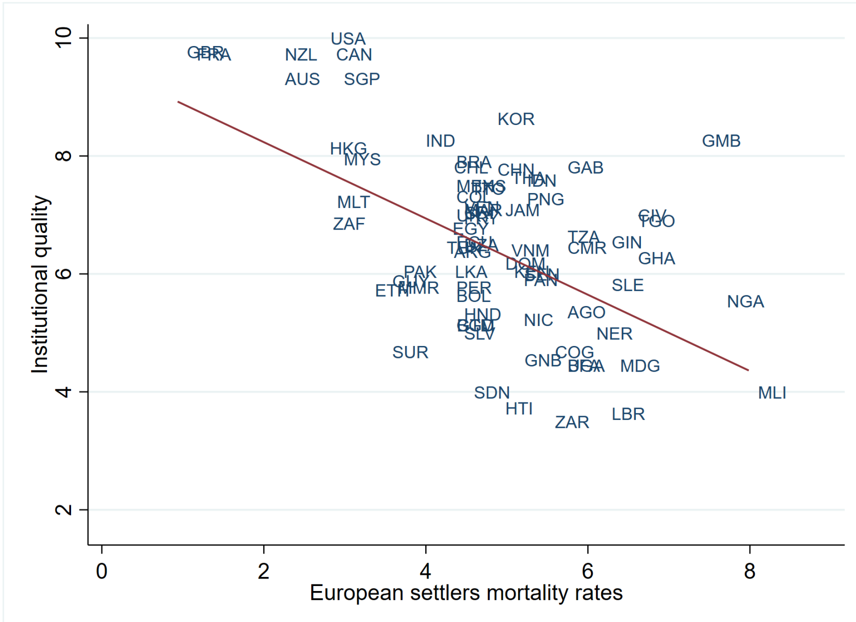

Figure 2.5: OLS relationship between settlers' mortality and institutional quality.

In this section, we link institutional quality and economic growth in a causal manner based on the approach of Acemoglu et al. (2001). Following their method, we instrument institutional quality with the logarithm of European settlers' mortality rates. The assumption of this method is based on the time distance between the two events and their plausible independence except through institutional heritage. According to Acemoglu et al. (2001) the local environment in terms of diseases and other adverse conditions for Europeans settlers can be reflected in the number of deaths recorded in earlier colonial times. The idea is that the decision for settlement organization (extractive institutions vs. institutions with property rights and establishment of the rule of law for market economy) depended greatly on the mortality risks for Europeans.

Table 2.6: Instrumental variable approach (1989-2019)

Variables	(1) Barro	(2) Barro	(3) Barro	(4) All	(5) Barro	(6) Barro	(7) Bottom half	(8) Top half
Education spending		1.12	1.12	0.21	0.46	0.34	0.38	3.25
		(2.93)	(2.93)	(1.66)	(2.97)	(1.94)	(4.69)	(3.76)
Institutional quality	0.26	1.27	1.27	0.58	0.50	1.76	1.55	3.40
	(0.28)	(2.25)	(2.25)	(1.28)	(2.20)	(1.66)	(2.39)	(2.76)
Inst*Ed		-0.23	-0.23	-0.08	-0.10	-0.07	-0.07	-0.43
		(0.48)	(0.48)	(0.26)	(0.44)	(0.29)	(0.74)	(0.49)
Government Exp.				-0.06	-0.09	-0.06	-0.15**	-0.07
				(0.05)	(0.08)	(0.09)	(0.07)	(0.17)
Y_{1970}						-2.22***	-2.94***	-3.07**
						(0.83)	(0.68)	(1.19)
Observations	72	69	69	62	50	62	30	32

Notes: The explained variable is the 30 years average growth rate. Only a subset of countries have settlers mortality because no Europeans settlers died in the recent past during colonial activity. For example Great Britain does not appear in these regressions while most African countries, New Zealand and Australia do. Education spending and government spending are the average per country in the 1979-1989 decade. Bottom half are the countries under the 50th percentile and top half is the complementary set. Institutional quality is instrumented by the measure of European settlers of Acemoglu et al. (2001).

Figure 2.5 shows that there is a quasi-linear negative relationship between the levels of Europeans settlers' mortality and the modern institutional quality. The data on mortality rates are originally from the work of Philip Curtin (1989). The first data starts around 1815 with organized military medical records and by 1870 most European countries published medical reports on soldiers deaths. Curtin (1989) presents a detailed review of the construction of the estimates. The measure of European settlers' mortality is the number of deaths per thousand per annum.

In the spirit of Acemoglu and Robinson (2001) the regressions in Table 2.7 are under cross-section specification. Only a few countries experienced a colonial influence in the relatively close past so only those are included. For example, although Britain experienced colonial influence from the Romans in the distant past, this event does not directly appear in this analysis because no data on Roman soldiers death is available to our knowledge. So we run the regressions on a sample of 72 countries which possess these data. As with previous cross sectional approach, the explained variable is the average 30 years growth rate of per capita GDP between 1989 and 2019. Our exclusion restriction is that settlers' mortality can affect current GDP growth rates only through the medium of inherited institutional quality.

Regression 1 shows that institutional quality has a positive but insignificant causal impact on growth. Across the other samples and specification, we consistently report a negative sign on the interaction term and a positive sign for both education spending and the instrumented institutional quality. The lack of significance could stem from low observations.

2.9 Conclusion

This study investigates the link between economic growth and education spending in the context of institutional quality. We begin by developing a theoretical model that yields a growth regression later estimated under various specifications in different samples. We report two main findings.

First, between 1979 and 2019, we find that economic growth was positively affected by both public education expenditures and institutional quality especially in rich countries. However, this relationship is sensitive to the addition of the cumulative effect of the two. This positive relationship between education spending and growth finds precedent in the economic literature. Blankenau, Simpson, Tomljanovich(2005) show this relationship by demonstrating that the mixed empirical results seen in the literature were due to unaccounted general equilibrium effects. Specifically, they find that any positive effect of education expenditures on growth requires the imposition of the government budget constraint and that no significant growth effects of public education expenditures can be detected unless crowding-out effects are properly taken into consideration. One contribution of this paper is to show that failure to account for institutional quality could be another explanation of the mixed results in the empirical literature linking education spending and economic growth.

The second main finding is that in most specifications, the interaction effect of education spending and institutional quality is significantly negative especially for rich and in some cases for developing countries. We interpret this result as suggesting a substitution effect between education spending and high-quality institutions. In other words, it is plausible that growth could alternatively stem from skill enhancement due to education spending or market conducive institutional quality. For countries to invest in both at the same time appears to be somewhat redundant in achieving growth.

For middle income countries, we find mixed results at best. The interaction of education spending and institutions does not yield a consistent sign or significance. Although most specifications show a negative interaction term, it is safe to say that middle income countries exhibit a pattern that requires further investigation. We leave it to future research.

As all research is limited to particular contexts and sets of variables, policy implications can be difficult to bring forth. However, our study suggests that because economic institutions tend to persist through time, optimizing education spending is a more potent tool for policymakers especially when the institutional context is properly taken into account.

Chapter 3

The Kansas Tax Experiment: Did industries benefit?

In 2012, Kansas began treating business income preferentially relative to wage income even when both appear on individual income tax returns. This so called "pass-through" income is more common in some industries compared to others. For example, more than half of the real estate workers in Kansas were employed by pass-through businesses. Others sectors, such as hospitals and telecommunications, have fewer pass-through entities and most of their workers are employed by corporations, the local or the state government. A limited number of states have implemented similar income tax reductions, and there are, relatively few conclusive empirical investigations of their causal effects on industries with low pass-through employment. This lack of evidence is the more unfortunate given the ongoing consideration of similar tax reforms by other states and the Federal government. For example, to boost business investment and jobs creation, The Federal Tax Cuts and Jobs Act of 2017 was enacted based on a similar approach to taxation.

This paper revisits the debate on pass-through tax reduction and employment growth among dis-aggregated industries. Despite the abundant research which finds no consistent relationship between the two[1], current tax policies continue to consider tax reductions as

[1] Debacker et al. (2019) and Turner and Blagg (2018).

a viable option to spur job creation and long run growth. Among proponents of income tax reductions, a common rebuttal to earlier research on the Kansas tax reform is that unforeseen events and special industries' outcomes drove the statewide inconclusive results[2]. The out-of-state relocation of Boeing, an historical employer in the state, is an often cited attenuating circumstance. To our knowledge, our paper is one of the first to reconsider this link across Kansas' dis-aggregated industries, attempting to account for these special cases and re-assess whether the impacts of the Kansas Tax reduction of 2012 are different especially among industries which had fewer pass-through businesses.

Considering the traditional perception of pass-through businesses as an engine of the economy, Kansas lawmakers created the reform expecting several benefits for the real economic activity and jobs creation. The rationale behind this policy is often attributed to similar tax reductions belonging to the "supply-side" economics school of thought. King and Peters (2013) present a more detailed exposition of the idea and how it has created national attention.

Proponents of the reform subscribed to two main arguments (Norquist (2003) and Peters and Mark (2013)). The first is that tax reductions create more jobs by leaving more capital in entrepreneurs' hands, spurring the expansion of existing operations, and creating new businesses. Eventually, this is expected to indirectly create more revenue for the state. The second channel is via incentives to relocate businesses in Kansas from higher tax states. Indeed, a large share of the Kansas population is located in border counties so this appeared as another appeal to the theory. On the other hand, detractors of the policy strongly disagreed and predicted catastrophic harm to the state's revenue and economic activity (Johnson and Mazerov (2012)). The state and national debate surrounding this income tax reform calls for further investigation of the mechanisms and outcomes of this policy change and its ability to be a stimulus for economic prosperity.

While high expectations existed, relatively few studies had previously analyzed how effective these tax reductions could be. In this regard, the 2012 Kansas Senate Bill Substitute HB

[2]Alvord (2019) argues that the political articulation of fiscal challenges depends largely on the state's ability to run deficits. Given the greater capacity of the Federal government to run fiscal deficits, the structural reckoning is delayed.

2117[3] was an experiment. In addition to the possible real economic changes that the reform could promote, it also had the potential to cause businesses to reorganize their finances while creating no real economic benefit. One of the main challenge associated with the reform was the opportunity for tax avoidance through income re-characterization. Take the example of an insurance brokerage firm paying an employee based on a salary. In response to the tax reform, he or she could change how the salary is received. Former wages would become payment to a sole proprietor and thus income taxes would not be paid. In this example, the state would lose tax revenue, gain a sole proprietor, and lose a wage employee while no real employment change occurred. Debacker, Heim, Ramnath and Ross (2019) find a slight increase (0.5%) in the probability of reporting sole proprietorship income in Kansas. They use U.S. federal income tax data and conclude that this observation could be the result of a shift in compensation from wage to self-employment income. Another important finding of the paper is that sole-proprietors who previously reported both wage income and pass-through income before 2012, were the most responsive to the reform. They suggest that these filers would be the most susceptible to re-characterise their income.

Several papers have analysed the effects of the Kansas Experiment. These papers provide concordant results about the lack of positive effect of the reform at the state level. To our knowledge, five other papers have analysed this tax policy change. They investigate its effects on state revenue, real business activity, gross domestic product, creation of new establishments and employment. Turner and Blagg (2018) measure the short-term effect of the reform on aggregate measures of employment and proprietorship. The paper estimates these two outcomes in three different fashions (log, per capita and growth rate). Among other conclusions, they find that starting in 2012, the estimated impacts for both outcomes are negative but are not statistically significant. The impact on the employment growth, however, is positive but not statistically significant. For proprietors, estimates are all negative and not statistically significant. McCloskey (2018) considers the impact on employment, real gross state product (RGSP) per capita and on the increase in business establishments. The author finds that none of them is positively affected by the tax reform in a consistent

[3] The legal name of the bill signed in May 2012 by Governor Sam Brownback.

way with the findings of the previous studies. In Hayes (2017), the author relates not only a drop in personal income tax revenue but also no statistically significant increase in either GDP or the number of hours worked after the policy implementation.

Nevertheless, this body of research has left several questions unanswered. The Kansas aircraft manufacturing industry suffered the loss of many employees due to Boeing's departure from the state. Between 2012 and 2017, Kansan farmers also faced historically low commodity and energy prices which could have negatively affected the agricultural and energy sector (Berck, Leibtag, Solis, and Villas-Boas (2009)). Furthermore, despite the focus of the reform on pass-through businesses, earlier research has given limited attention to high pass-through sectors leaving the possibility that job gains or losses have occurred in these industries even if aggregate results are insignificant.

The goal of this study is to build on the existing research and investigate the effects of the tax reform on dis-aggregated industries and different pass-through business sectors. We report three main results. First, industries with more pass-through businesses seem to have incurred less job losses compared to industries with less pass-through businesses although the relationship is not statistically significant regardless of specifications or time horizons. If anything, industries with fewer pass-through businesses may have incurred more job losses after the reform. Second, after removing the aircraft manufacturing as well as the oil and energy industries, the impact on Kansas employment is still insignificant. Over the 14 quarters post-reform, we estimate an insignificant aggregate loss of 0.15% jobs against 0.33% when including aircraft manufacturing and energy sectors. Third, employment excluding the agricultural sector has very similar insignificant results to previous aggregate findings. These results could be evidence against the claim that the tumult in the energy markets and the departure of Boeing from Kansas were coincidences that largely explain the null impact of the reform. In addition, these results rule out the hypothesis that sectors with many pass-through businesses significantly benefited from the tax reform but instead suggests lost jobs in sectors with fewer pass-through businesses.

The rest of the paper is organized as follows. The next section provides a brief background on the 2012 tax reform and the pass-through businesses categories. The third section provides a review of the literature on income tax and the Kansas experiment in particular. The fourth section introduces and describes our data and their sources. The next section presents our empirical methodology before the empirical results in section sixth. We end by presenting a placebo analysis and a conclusion.

3.1 The background of the 2012 Kansas Tax Reform

Businesses choose different legal structures to organize their activity depending on several factors. This decision has broad effects on how tax policy applies to them. One major difference is whether they will pay corporate income taxes or be taxed as "pass-through" businesses[4]. Income generated by sole proprietorships, partnerships and sub-chapter S-corporations "passes through" to firm owners and is taxed as personal income. This individual tax level approach means that the owners directly report their business income on Form 1040 of their tax return. In contrast, sub-chapter C-corporations pay "entity-level" taxes through the corporate income tax system. S and C-corporations also differ because of restrictions on the number of shareholders, and how shares and dividends work.

Historically, pass-through businesses have remained an important and celebrated form of business in the United States. While no formal definition exists as to what is a small business, the literature often classifies them under the umbrella of pass-through businesses. For decades, they have represented an important segment of the American economy. Cooper et al. (2015) reports that prior to 2012 they made up 20 to 50% of all business income in the country. This proportion is remarkable when considering that, in general, pass-through businesses are small businesses or self-employment[5]. Debacker et al. (2019) report that two

[4]There are three forms of pass-through businesses. Sole proprietorships, partnerships and S-corporations. A sole proprietor is an individual entrepreneur who owns and runs a business where no legal distinction exists between him or her and the business entity. A partnership will have the business income distributed among each partner based on partnerships agreements. Taxes are filed at the entity level. A partnership can be owned by individuals, non-profits and limited liability companies (LLC) can choose taxation as partnerships. Finally, S-corporations file corporate tax returns although the income is passed-through pro-rata to shareholders. They differ from partnerships as the number of shareholders is limited and shareholders must generally be U.S. citizens.

[5]Krupkin and Looney (2017) relate that sole proprietorships are the most common form of pass-through businesses. They represent 43% of all pass-throughs and 41% of all businesses.

years after the tax changes as much as 30% of all Kansas taxpayers reported one form or another of such self-employment income. This points to either a strong positive effect or a potential re-characterization of income to take advantage of the tax break without new output creation. The size and revenue generated by these pass-through businesses have made them central in the debate around economic growth both at the state and national level even before 2012. This perception of pass-through businesses explains, in part, why they were the main target of the Kansas reform.

Even if this case has been profusely debated by the public and economic researchers, it is far from being the only reform of its kind in recent years. In 2014, the state of Nebraska eliminated capital gains taxes for companies that created a program for employee stock options and Oklahoma signed its own income tax reduction law in 2014 which took effect in 2016. The notable signing of the Federal Tax Cuts and Jobs Act of 2017 by the U.S. president shows that this perspective on tax policy is still current[6].

It was in May of 2012, that the governor of Kansas signed the reform into tax law which was to be enacted in July of the same year. At the time, it was one of the largest income tax cuts in the state's history. Then, it was presaged to become "a shot of adrenaline into the heart of the Kansas economy[7]." The reform was expected to create more than 23,000 jobs by the year 2020. The cuts had been part of the agenda as early as January 2011 and the tax provisions were to come in effect in 2013. The reform brought the taxation of pass-through businesses to zero which narrowed the tax base. The marginal taxation rate of individual income were also reduced from three to two brackets along with higher deductions for heads of households. However, in order to offset ensuing early revenue losses, sales taxes did not decrease despite previous plans to do so.

Unlike some U.S. states which have personal income tax reciprocity, Kansas requires its residents to pay taxes on all their income (in and out-of-state generated). For non-residents, only the Kansas portion was taxable. Practically, this meant that for a business owner to

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https://www.brookings.edu/research/9-facts-about-pass-through-businesses/.

[6]We note that income tax cuts have historically been based in the economic approach colloquially referred to as "supply-side" economics.

[7]This metaphor was used by the former Kansas governor when talking about the expected effects of the tax policy change. https://www.kansas.com/opinion/opn-columns-blogs/article1096336.html/.

fully benefit from the tax break, he or she must have been a resident of Kansas. In the newly formed top and low brackets of individual taxation, rates fell respectively from 6.45% to 4.9% and 3.5% to 3%. The exclusion involved income originating from businesses, partnerships, rental real estate, royalties, S-corporations, farm income and trust. This bill lead to large differences between Kansas and other states' tax rates. There were few significant tax reform targeting pass-through businesses at the time of the policy other than Nebraska and Oklahoma's tax reductions.

The Kansas tax experiment did not noticeably affect corporate income taxation; at least not directly. McCloskey (2018) mentions that we should expect direct labor demand effects to be limited to mostly non-corporate businesses. Between 2010 and 2012 this group formed about 38% of the total Kansas employment. At the signing of the bill, proponents were confident that it would be followed by a positive economic outcome for Kansas while others predicted unrivaled business and budget crisis. The governor argued that the cuts would pay for themselves through the increased revenue due to the expected real economic activity boost. Since 2012, however, Kansas has faced multiple fiscal crises with public schools funding sustaining major hits. Many schools lost accreditations and staff. Among several categories including job creations, unemployment and average income per person, Kansas was lagging behind surrounding states (Ritholtz (2017)).

Some political observers have argued that the ambivalent comments on the policy effects should be considered in light of the environment surrounding the reform. Moore (2014) emphasizes that the effects were in part due to the steep decline in the price of oil and gas[8] and the hit on farmers from historically low commodity prices. Boeing, a major aircraft manufacturer and historical large employer also left Wichita around the same period. Michael Mazerov (2015) responds by saying that the aircraft and energy industry represented less than 1% of the total state employment and so could not be explaining the greater part of what was witnessed. He further admonishes that while farm earning fell by 9.6 % in Kansas

[8]Kansas is an energy producing state. In 2020, The state's three petroleum refineries accounted for 2% of U.S. refining capacity and can process a combined 401,000 barrels of crude oil per calendar day. Kansas is also one of the 10 largest ethanol-producing states, and its 13 ethanol plants have a combined production capacity of about 609 million gallons a year. *https://www.eia.gov/state/?sid=KS*.

between 2012 ans 2016, all of Kansas' neighbors except Nebraska sustained even larger losses along with the U.S. as a whole. In contrast to their more adverse situations, the Kansas employment growth was still lagging behind them all.

3.2 Related literature

There is a sizeable economic literature exploring the impact of state income taxes on real economic activity and employment. The results are mixed at best. This is in part because many outcomes could be affected by income tax policy in the context of business activity. For example, Gale, Krupkin and Rueben (2015) revisit the effect of state tax policy on real growth, entrepreneurship and employment. Previous studies had found a significant, negative and robust effect of taxes on growth. Through extension of the sample beyond the earlier time window observed by these studies, they find no such stable negative relationship. The paper suggests, besides other findings, that timing is important to properly address this question. In contrast, Cullen and Gordon (2007) present a theoretical model analysing how tax laws can influence individuals' entrepreneurial risk taking. In addition, they use U.S. tax return data to show that tax laws have sizeable impacts on agents' behavior, and thus affect the level of entrepreneurial risk taking. The study focuses on the different incentives created by taxes on business income vs. wage income as well as the tax treatment of losses compared to profits.

Tax changes could directly affect business employment, but also business creation depending on the tax medium, rate and length of time. Borchers, Deskins and Ross (2016) review several papers dealing with tax policy effects on a number of business related indicators. The paper focuses on studies done within the state-panel framework. They find that large businesses activity does not seem to be influenced by state tax policies but that higher state tax rates and corporation income tax rates are associated with slower small businesses growth. Another more recent survey of the literature by Rickman and Wang (2020) concludes that a better understanding of tax policy has been achieved but universal tax policy guidance is still beyond the ability of policymakers and researchers. They suggest instead a more specific state and local policies approach to income taxation policy. As previously mentioned, a plausible argument in favor of this suggestion is the several outcomes under consideration. Tax cuts can potentially affect employment, business creation, real growth, innovation and even inequality[9]. Although uniform impacts are possible, traditional trade-offs are more likely to exist.

When considering the impact of tax cuts on employment, a sizeable number of studies exist with mostly uniform conclusions. Zidar (2019) studies how different income groups are affected by tax changes and finds a differing effect. Positive relationships between tax cuts and employment are largely driven by tax cuts for low-income groups while the effect for the top 10 percent earners is small. Although tax cuts were not allocated on the basis of income group, the self-employed recipients could be more representative of higher earners. Leachman and Mai (2014) show that the Kansas cuts led to higher inequality and taxes on the lowest income families without showing signs of increased job growth.

Other studies have investigated the impact of tax cuts on real economic growth with mitigated results. A landmark study by Grueber and Saez (2002) investigates how elastic taxable income is to tax changes and concludes that a flat or even declining marginal rate structure for middle and high income earners could be desirable due to their higher elasticity. Atanassov and Liu (2020) hypothesize that higher corporate income taxes negatively influence the firms' incentive to innovate. Using a Difference-in-Differences (DiD) approach, they show that 2 years or more after a tax reduction corporate innovation increases. Other studies have instead found no impact on real growth or in certain cases a negative effect. Gurley-Calvez and Bruce (2007) use a 12 year panel of tax return to examine the effect of tax rates on entrepreneurial entry. They find that lower tax rates for entrepreneurs increase the likelihood of entry. Ben-Michael, Feller and Rothstein (2021) use the augmented synthetic control approach and find a significant negative effect on Kansas' real economic growth.

Slemrod (1995) echoes the cautionary stance by investigating whether tax reductions

[9] Nallaredy, Rouen, Serrato and Suarez (2019) study the effect of corporate taxes on inequality and find that tax reduction lead to higher income for both top and bottom earners. However, they report that the link is positive in part because higher earners can shift compensation to reduce taxes and gain a comparatively larger benefit from such reforms.

stimulate income creation or income shifting instead. The paper focuses on the effects of the Tax Reform Act of 1986 and presents two important insights. The first is that behavioral responses to taxation changes are far from negligible. In the 1980's substantial taxpayers' responses occurred. The second insight is that the responsiveness of variables like employment was not high enough to justify the marginal social costs of taxation. Long (1982) provides evidence among male workers of such income shifting. The empirical analysis concludes that rising income taxes induced labor to shift from wages and salaries toward self-employment. Rohlin, Rosenthal and Ross (2014) also demonstrates new businesses' tendency to favor one side of a state border over another based on tax policy. The study uses a cross-border tax variation approach and shows that states with higher tax rate recorded more business creation when the reciprocity agreements did not exist[10]. More recently Debacker, Heim, Ramnath and Ross (2019) utilizes tax return data between 2010 and 2014 to investigate the impact of the reform on the Kansas economy. They find that the probability of reporting sole proprietorship income had increased but that this appeared to have come about as a result of income shifting.

3.3 Empirical methodology: The synthetic control method

The synthetic control method is a relatively recent alternative to DiD estimators. It allows the effect of unobserved confounders on the outcome measure to vary over time by assigning a weight to the control group units. This feature allows the relaxation of the parallel trend assumption which is sometimes difficult to verify for DiD estimates.

The method was introduced in Abadie and Gardeazabal (2003) and applied in Abadie, Diamond and Hainmueller (2010, 2015) in the context of comparative studies. In this section, we will briefly present the basic requirements and procedures of this method and how it is applied in our context. We also present a more detailed exposition of the algorithm used in Section C.4 of the appendix.

[10]Reciprocity agreements allow entrepreneurs or workers to pay taxes to the state of residence instead of the state where the business is located. In 2021, 17 states including Arizona, Illinois and Iowa did not require non-residents workers to pay state taxes.

3.3.1 The synthetic control method: The case of many industries

Let us consider one industry (see Section C.4.1 for an example involving the crop production sub-sector). Let us assume for simplicity that there are $J+1$ similar industries across all other U.S. states in the sample[11]. We index these industries by j and define $j = 1$ to denote our tax treated state or the Kansas' industry. The units are observed for time $t = 1, 2, 3, ..., T$. We note that it is necessary to have as large a pre-treatment period as possible to train the algorithm. We denote the treatment period as T_0. Then, the algorithm constructs the synthetic sector based on a weighted average of the other control states $j = 2, 3, .., J + 1$ industries based on the pre-treatment period. We refer to this remaining group as the donor pool. The weighting vector is $W = (w_2, ..., w_{j+1})$ with all weights between 0 and 1. The sum of all weights is equal to 1. The choice of W is based on minimizing the squared difference between the full quarter employment in the Kansas' industry and the synthetic control over the pre-treatment period[12]. Our selected predictors include lagged values of full quarter employment, quarter employment[13] and payroll data. Once this is done in the one Kansas industry, we repeat the same procedure for every 3 digit North American Industry Classification System (NAICS) code in Kansas in the same way and obtain industry specific effects.

Most studies using the SCM, only investigate a handful of outcome variables. In fact, most analysis related to the impact of the Kansas tax reform have studied either employment changes, GDP per capita, the creation of new businesses, state revenue or a combination of them. In this paper, we focus exclusively on full quarter employment alone at the more dis-aggregated level of industries within Kansas. This approach presents both advantages and challenges considering the 99 industries and more than 40 states involved. Firstly, it is important to emphasizes that the control groups and their weights do not remain constant

[11] In theory, there would be 50 of such industries (including Kansas) given the 50 U.S. states which potentially have the same industry.

[12] The SCM does not allow for extrapolation, so we have a convexity constraint. In other words, no weights of the W matrix is negative.

[13] Total employment for a quarter records all employees working during the quarter. The challenge with this measure, is that it cannot deal with short spells of employment and employees who left a job and gain another one during a particular quarter would be counted twice.

throughout the mutiples SCM procedures. In this paper, we are dealing with several control groups depending on the industry at hand. What this means in practice is that the states which would be selected from the donor pool when studying the aircraft industry in Kansas, would likely be different from those chosen when studying the food manufacturing industry for instance. Furthermore, this means that when studying even the food manufacturing industry as opposed to the beverage manufacturing industry, though very close, the states and the weight each one would take could be much different. In Table C.2, we present a more detailed list of the donor pool.

As emphasized by McCloskey (2017), there are two elements worth noting about the SCM. First, unlike the DiD method, it does not require the parallel trend assumption. Second, if a Kansas industry happened to be strictly larger or smaller than all donor states, values in the same industry, the Kansas values would not be a reproducible convex combination of the donor pool values. Fortunately, this case did not happen in our study because for all considered sectors, Kansas does not have the smallest nor the largest industry in term of full quarter employment.

Finally, to assess the quality of the pre-period match we rely on the root mean square prediction error (RMSPE) in the pre-intervention period for goodness of fit. The RMSPE is given by:

$$RMSPE = \sqrt{\frac{1}{T_0}\sum_{t=1}^{T_0}\left(Y_{1t} - \sum_{s=2}^{S+1} w_s Y_{st}\right)^2}$$

where Y_{1t} is the outcome in Kansas at time t, T_0 is the time of intervention, w_s is the weight on state s of donor pool and Y_{st} is the outcome in state s at the same time.

3.3.2 Donor pool and predictors variables

The donor pool includes all the potential control units that will be used for estimation. Unlike DiD estimators, we include as many units as possible in the donor pool to allow the algorithm to select which ones should continue to be used. The donor pool consists of the

47 U.S. states other than Kansas and with the exception of Massachusetts and Michigan for recurrent missing data issues. We often exclude all states which do not have corporate income taxes (South Dakota, Wyoming, Nevada, Ohio, Texas, and Washington). Occasionally, other states also do not appear because the relevant industry did not exist (see Table C.1). This is only true for particular cases meaning that the state could re-appear in other SCM procedures for different industries. For example, Maryland is excluded from the analysis of the Oil and Gas Extraction sub-sector because no data is available. However, in theory, it appears in all other sub-sector estimations. Furthermore, the SCM relies on a strongly balanced panel dataset and missing data for any quarter also resulted in the removal of the state. Every valid donor state had a minimum of 41 quarters of data available including the third quarter of 2012 which is the treament date. In Appendix C, we provide a sample of the states and their participation in the donor pool.

Furthermore, the SCM requires predictor variables to compare outcome of the treated state against the control states. We also refer to them as matching variables. We use three variables in this study. First, we have the quarter employment, then the lagged values of the full quarter employment, which is the outcome variable, and finally workers payroll per quarter[14].

3.3.3 Inference

The SCM relies on a mode of inference that differs from usual comparative methods. Abadie and Gardeazabal (2003) use placebo or permutation methods (Abadie et al. (2010)). We run placebo tests for every state in the donor pool. Each state has its own synthetic control built and we end up with a distribution of placebo. There is a placebo for all other states (the policy shift did not happen there). The obtained distribution gives an idea of how likely the observed effect could be the product of chance. Because this can be done for many time periods after the intervention, the researcher can calculate a "p-value" for every quarter afterwards.

[14]One difficulty inherent to our approach at the dis-aggregated level, is the difficulty to find a proper quarterly recorded variable that varies at the industry level within each state.

These values indicate the likelihood of estimating an effect as large as the real treated Kansas. In cases when placebo estimates do not fit well in the pre-tax reform period, it is expected that they would not fit better after the intervention. To account for this we can introduce thresholds based on pre-intervention quality of fit. An alternative to avoiding the cut-off option is to look at the ratio of the pre-period to the post period RMSP following Abadie, Diamond and Hainmueller (2015). This allows to calculate the following ratio of post to pre-$RMSPE$ to see what share of placebo effects are larger than Kansas. The ratio is given by:

$$Ratio_{si} = \frac{RMSPE_{Post,si}}{RMSPE_{Pre,si}} = \frac{\sqrt{\frac{1}{T-(T_0+1)} \sum_{t=T_0+1}^{T} \left(Y_{si,t} - \sum_{s \neq si}^{S+1} w_s^* Y_{st}\right)^2}}{\sqrt{\frac{1}{T_0} \sum_{t=1}^{T_0} \left(Y_{si,t} - \sum_{s \neq si}^{S+1} w_s^* Y_{st}\right)^2}}$$

where w_s is the SCM generated weight on state s. A challenge peculiar to the synthetic control method is the lack of traditional inference statistics. Instead, placebo methods are used to ensure that the results are reliable. We perform placebo tests for every state in the donor pool. In practice, this entails building a synthetic control state for each state. Because the tax cuts only occurred in Kansas, all these constructed controls are labeled as "placebo." For this reason, these states should not, in theory, show large estimated treatment effects. The distribution of these placebo effects is then used to compute empirical p-values for average effects based on the quarter of observations. In other words, we observe one p-value for every quarter post policy enactment.

The empirical p-values inform us as to the likelihood of the observed effect in each Kansas industry for each post period of resulting from chance alone. The algorithm is documented in details in Quirstoff and Galiani (2017) and follows Abadie, Diamond and Hainsmueller (2010).

It is often the case that the placebo estimates display a poor fit in the pre-period phase and thus the difference between observations and placebo could be very large adding no meaningful information to a subsequent incorporation in the p-values group. To address this, two options apply. First, Abadie, Diamond and Hainsmueller (2010) advise the use of thresholds based on the pre-intervention period for restriction. Three distinct cutt-offs with either more than 20 times the treated state $RMSPE$, more than 5 times the treated state $RMSPE$, and finally more than twice the treated state $RMSPE$ (see Section C.1). In our case this entails an approach case-by-case depending on the industry of interest. Another approach expanded in Quirstoff and Galiani (2017) is to divide all effects by the corresponding pre-treatment match quality to get "pseudo t-statistic" measures.

Still the placebo tests cannot rule out the possibility that other causes lie behind the observed effects. The SCM method offers a more data driven procedure to select the control units. Nonetheless, the selection of elements including donor pool members and even the predictors variables specifications must be noted as independent of the algorithm decision.

3.4 Data

The industry-state data are from the Quarterly Workforce Indicators (QWI) which is published by the U.S. Census Bureau. This nationally representative dataset originates from a variety of sources including administrative records on employment collected by the states, social security data and other survey data. It covers the 50 U.S. states and the District of Columbia. The observations are available between 2001 and the present[15] at a quarterly frequency. In its original form, the QWI dataset contains 32 economic indicators including job gains, workers' demographics and firms characteristics (NAICS code[16], geography, industry and more).

The industry codes are listed at the 3 digits levels for a total of 99 subsectors. The dataset also provides county-level data. At this fine level of observation, certain states occasionally lack sufficient information for different reasons. The relatively new creation of an industry, its non-existence in a particular state or issues of confidentiality are a few explanations (see Section C.3). Notably, Michigan and Massachusetts systematically missed some industry

[15]The data are released with a 9 months lag.

[16]NAICS stands for North American Industry Classification System. The system was developed in 1997 for use by Federal Statistical Agencies for data collection and analysis related to the U.S. economy.

measures and do not appear in the final analysis. We do not believe this to be a significant loss. However, most industries are present in all other states for all periods.

The QWI is a superior database for its ability to track both workers and firms and link them throughout time. These features also allow researchers to do analysis on workers' characteristics and comparing desired outcomes across geographic units at the national, state, local and even metropolitan level. The NAICS codes are available up to the fourth digits at all the above cited geographic scales. The QWI is released quarterly and the available data are always three quarters behind the time of release. For instance, the QWI released in the fourth quarter or 2021 will have information up to the first quarter of that same year. If data submission or quality problems arise, the QWI release for a state may be skipped for one or more quarters, until the problem is solved. This explains the rare but recurrent absence of some observations for particular units.

The QWI has noteworthy strengths and weaknesses for our particular analysis. On the one hand, its link between employers and workers is one advantage along with the ability to show a difference between real employment opportunity versus sporadic employment growth in an area. Because a large part of employment opportunities do not emerge from new job creation as much as workers' turnover, the database offers a valuable distinction in this regard by providing several measures of employment. Being released quarterly, the QWI is a relatively high frequency database considering the scope of the data available while most of the studies of the Kansas Tax reform have only used yearly data. It is also compatible with the QCEW (Quarterly Census of Employment and Wages) released by the BLS (U.S. Bureau of Labors Statistics). In addition, one of the greatest strengths of the QWI, is the type of workers counted. Unlike other databases providing bulk measures at the state level, the QWI does not report self-employed workers and independent contractors[17]. In other words, the full quarter employment measure for each industry only involves the employees on payroll. This peculiarity implies that our measure of employment is well suited to analyse industry differences in terms of their employment creation or losses of payroll workers with minimum noise from income re-characterization processes. Weaknesses include the fact that

[17] https://lehd.ces.census.gov/doc/Metadata4_QWI.htm/.

the QWI reports the industry at the 4th rather than the 6th digits levels, a setback which is mostly inconsequential unless endeavoring fine data mining exercises. This is not our aim. Furthermore, like most databases of its kind, the QWI has many non-disclosed values due to confidentiality concerns. Finally, we cannot differentiate between voluntary and forced loss of employment. In other words, we are unable to know if workers left their job or got terminated.

Our other source database is the County Business Patterns (CBP). This annual database provides state economic data by industry. We get detailed information on the number of establishments and their type as well as the number of employees on payroll. We use it as the main source to calculate the percentage of employees working for a pass-through entity within a given industry. The construction of buildings, repair and maintenance as well as the real estate industry have the highest concentration of pass-through workers with over 70% of their workforce in that category. Hospitals, utilities and telecommunications are among the lowest pass-through industries with less than 5% of their workforce in a sole-proprietorship, partnerships or S-corporations. Although government sub-sectors are included in the database, they do not have pass-through entities. They thus have zero pass-through employment share.

3.4.1 The outcome variable: the full quarter employment

We investigate one outcome of interest which is the employment during the full quarter. This is a measure of stable jobs or jobs that were held both at the beginning and at the end of the considered quarter. In particular, a worker is fully quarter employed with a firm if the worker has positive earnings in the earlier, current and next time period. We believe this measure minimizes the noise in the analysis and most importantly helps answer whether or not a certain industry experienced steady job gains or losses after 2012. To match the Kansas' trend in this outcome, the SCM scales each state's full quarter employment so that it is 1 in the last pre-treatment quarter.

3.4.2 Predictors or matching variables

To perform the algorithmic minimization procedure and the selection of controls, the SCM relies on different predictor variables. There is little consensus in the literature as to which variables are "the best predictors" and researchers often use historically good variables on a case-by-base basis. For example, Hayes (2017) studying a similar question uses GDP per capita, percentage job in agriculture and percentage jobs in construction. The author also uses demographic predictors including state population, percentage of residents over 64 years of age and finally political predictors (for example an indicator for a divided state government, or an index of citizens' ideology). For the purpose of our current study we use lagged values of full quarter employment per sector, employment at anytime during the quarter[18] and the amount of the payroll to workers for each industry between the second quarter of 2007 and the fourth quarter of 2011.

3.4.3 Summary statistics

Given the large number of industries, and the many workforce attributes, we offer in this section a subsample of the available information. For each industry, we have information on several workforce characteristics and show them in contrast to neighbor states. We also present information of the four border states, that are, Nebraska, Colorado, Missouri and Oklahoma. We present descriptive statistics before the reform and after alongside the difference between high pass-through and low pass-through industries.

[18]This measure has certain limitations. Double counting can occur if a worker left a job and gets another one mid quarter. The other drawback, is that this measure also includes very short spells of work. Consider a person working for a week and resigning.

Table 3.1: Descriptive statistics of Kansas and border states' workforce

Workers features (%)	2011	2014	2016	Kansas(2016) High pass-trough	Kansas(2016) Low pass-trough	Border states (2016) High pass-trough	Border states (2016) Low pass-trough	Border states (2016) All sectors
Female	49.76	49.17	49.33	41.91	56.52	46.94	52.39	49.51
Bachelor or more	24.11	23.00	22.46	18.27	27.25	21.00	24.35	22.46
High School	24.68	24.88	24.99	24.82	24.30	22.00	19.49	20.81
Less than HS	9.15	10.07	10.68	12.39	8.75	17.50	16.52	16.95
White	88.41	87.39	86.79	84.62	87.68	42.09	35.79	39.77
Black	6.33	6.93	7.22	8.16	6.96	13.53	9.73	11.74
14-18	2.47	2.62	2.87	4.96	1.46	9.55	9.31	9.26
35-44	20.62	20.68	20.82	20.31	21.41	15.38	16.56	15.79
55-64	16.31	17.07	17.54	13.64	20.35	13.01	14.41	13.63

Notes: High pass-through industries have above 51.2% of workers (above 75th percentile) employed by sole proprietorships, partnerships or S-corporations. Low pass-through industries have less than 24.10% of workers (under 25th percentile) in the same categories. Border states include Nebraska, Missouri, Oklahoma and Colorado.

A lower percentage of the workforce are women compared to men both in Kansas and the neighbor states. However, women's employment seems higher in industries with less pass-through businesses. An increasing share of the Kansas workforce appears to have a bachelor degree or more although the change is not very large. In addition, a lower percentage of workers in high pass-through sectors have a bachelor compared to low-pass through sectors. There is more uniformity in term of high school diploma both across time and between sector types. We note that a higher percentage of workers in high pass-through sectors report having less than a high school diploma both in Kansas and in the border states. A large share of the Kansas workforce is white (above 86%). The employment of teenagers (between 14 and 18 years of age) has been increasing since 2001 although the change is very small. A larger share of the workforce in neighbor states are teenage workers. We also note that in high pass-through Kansas' industries, the employment of teenage workers is more than double than that in the low pass-through sectors. This is not the case in border states as the shares are essentially equal there. When considering the share of the workforce between 55 and 64 years of age, Kansas appears to have a relatively older workforce compared to neighbor states.

3.5 Empirical results

In this section, we present the different results that we obtain by investigating the industries in the QWI. The majority of studies related to the Kansas tax reform investigate bulk employment outcomes. Here, we look at sub-sectors of interest. For example, an unexplored hypothesis is the role of Boeing's departure in the loss of Kansas employment. We are able to remove that industry and verify whether the outcome differs. We also investigate the policy's impact on low pass-through versus high pass-through industries as well as other sub groups. Because of the volume of results inherent to our approach, we only present a handful of outcomes and interpret them. We present the exhaustive results in Appendix C. For each outcome we present the path of the Kansas variable versus its corresponding synthetic control as well as the estimated difference between the two.

3.5.1 The impact of the tax reform on the aggregate Kansas employment

We begin by revisiting the effect of the 2012 tax reform on the aggregate Kansas employment using quarterly data. The pre-treatment match is better 12 quarters before the policy intervention and the vertical line indicates the time of the tax reform. The left side of Figure 3.1 shows the difference between Kansas and it's synthetic control. The second panel of Figure 3.1 shows that at the time of intervention, the number of employees in the Kansas workforce was close to 1.28 million. In line with earlier related studies, we do not find a significant gain of employment (see Figure C.6 with p-values consistently beyond 0.1). The path of the actual Kansas is very similar to it's synthetic control. The SCM effect on full quarter employment of the aggregate Kansas employment is an -0.5% loss in the 14 quarters after the tax reform. This change is not significant as shown by Figure C.6 as no p-values is ever lower than 0.1.

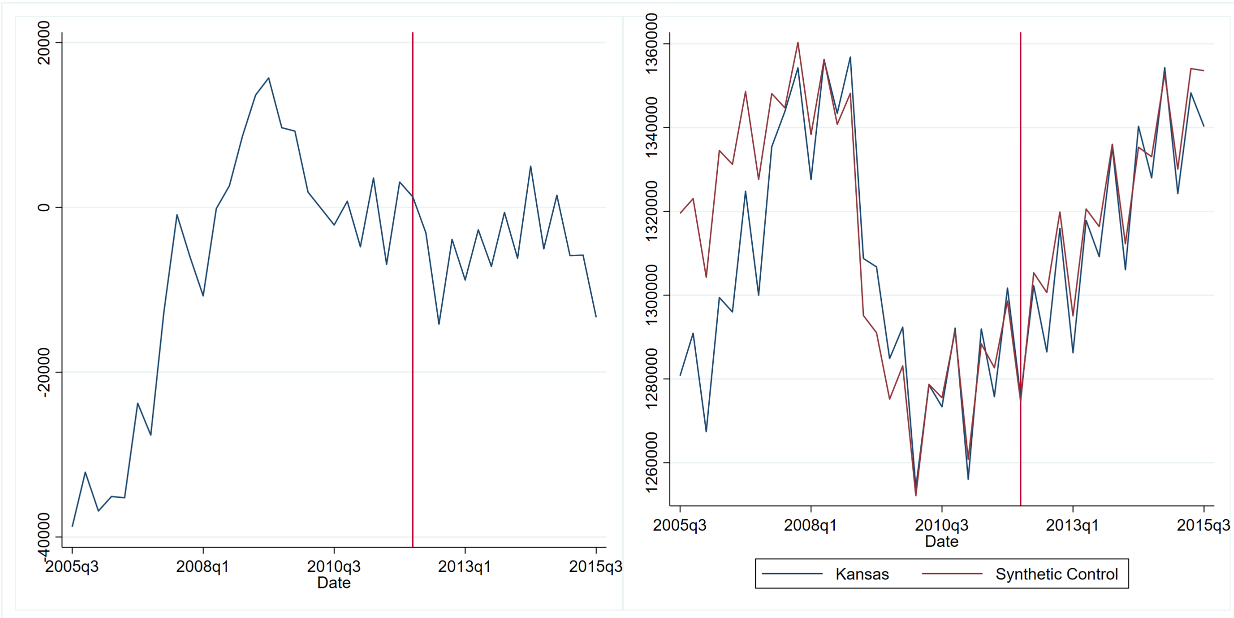

Figure 3.1: Trends in full quarter employment: Kansas vs. synthetic control

3.5.2 Did industries with more pass-through businesses benefit?

In this section, we focus on industries and regroup them based on the percentage of workers employed by either form of pass-through business. Our measure of pass-through employment emanates from the Country Business Patterns (CBP). We obtain detailed data on the forms of establishments in each sector and compute the percentage of workers employed by a form of pass-through entity as opposed to large corporations, the government or others. We choose to rely on the year 2011, as it is close enough to the reform date without plausibly suffering any effect from the tax reform one year later. Our assumption is that the measure reflects the tendency of businesses organization in each sector.

We define industries where less than 24.10% of the workforce is employed by a pass-through business as "low pass-through" sectors. This number represents the 25% percentile. Conversely, we also define industries where more than 51.2% of workers are employed by pass-through businesses as "high pass-through" sectors. This number represents the share above the 75% percentile. Based on this measure, we regroup the workforce of low pass-through sectors and rerun the SCM in a similar fashion as before.

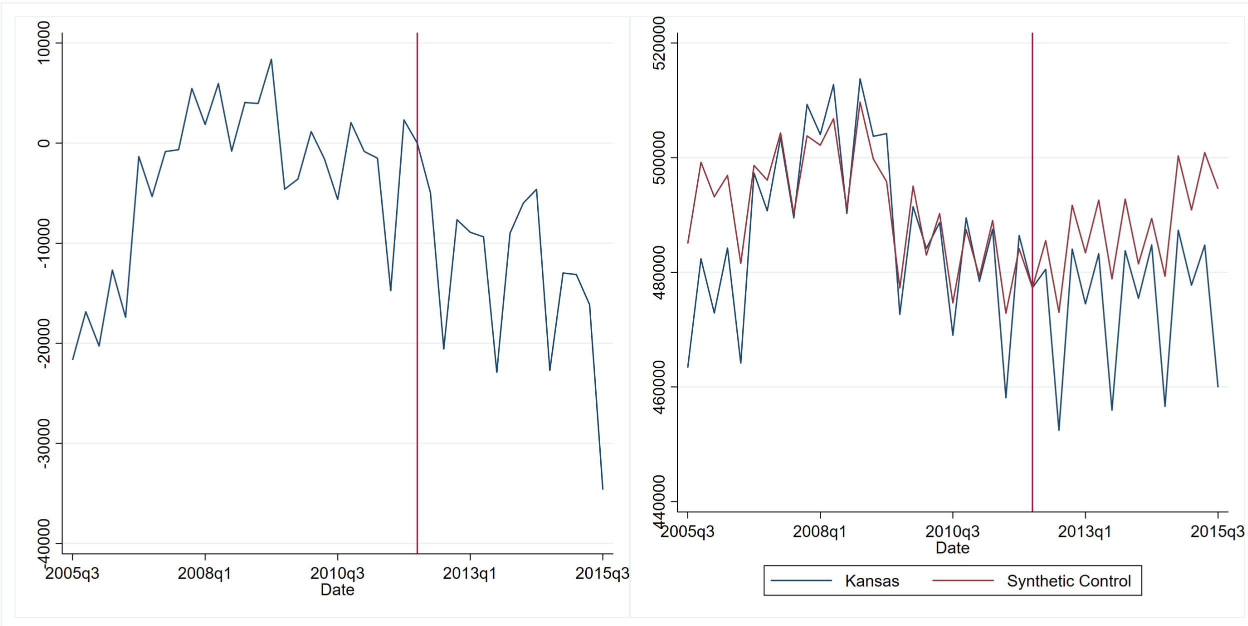

Figure 3.2: Trends in full quarter employment for low pass-through industries: Kansas vs. synthetic control

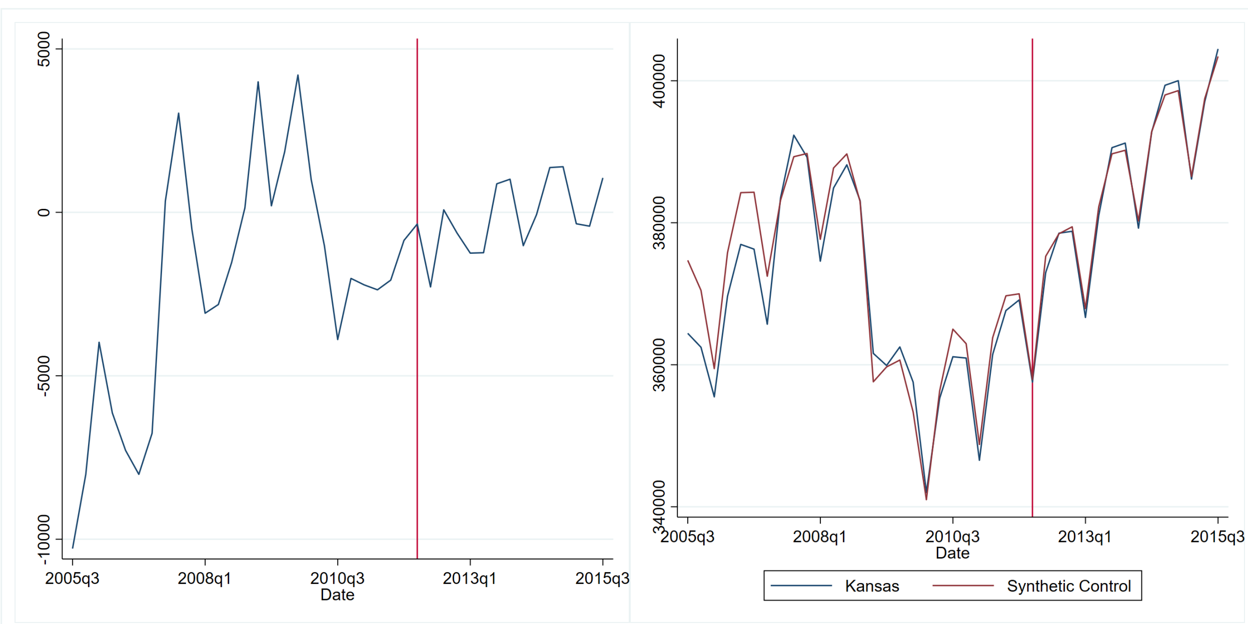

Figure 3.3: Trends in full quarter employment for high pass-through industries: Kansas vs. synthetic control

As before, Figure 3.3 shows that the pre-period match between Kansas and its synthetic control is better after the recession of 2008. For so-called low pass-through industries we record an insignificant 1.47% decrease in full quarter employment (see Figure 3.5). In contrast, we record an also insignificant -0.4% change for high pass-through industries employment as seen in Figure 3.4. In Figure 3.4, we also see that two years after the policy change, the effect across high pass-through industries is normally distributed across zero with few positive and negative outliers.

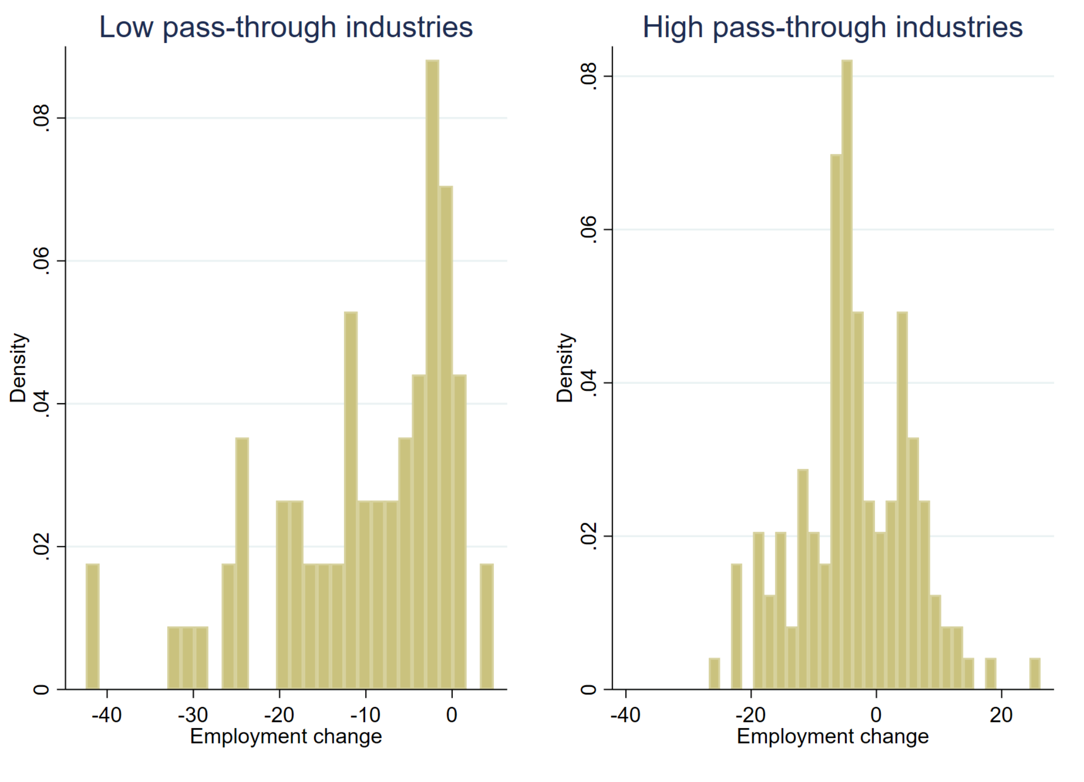

Figure 3.4: Distribution of effects 2 years after the tax reform.

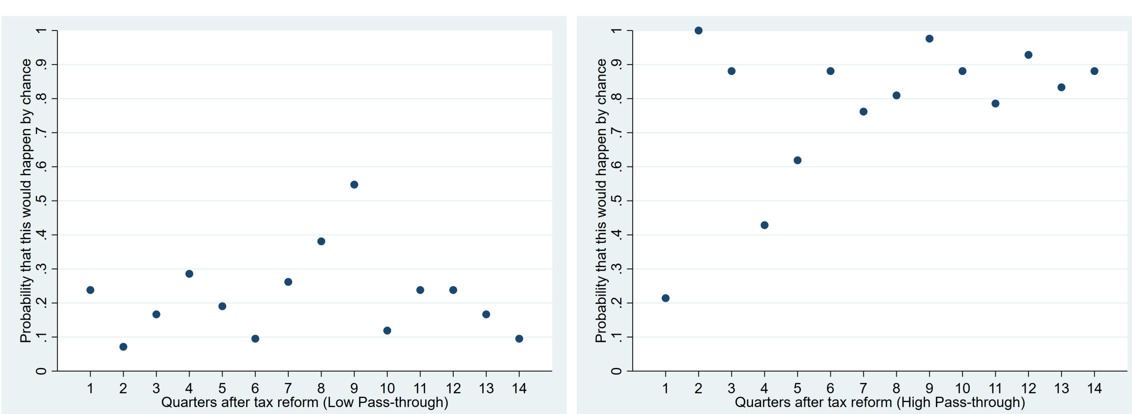

Figure 3.5: Low (left) vs. High (right) pass-through full quarter employment p-values.

Figure 3.6: 2015 First quarter effect on industry employment versus pass-through level.

Figure 3.4 shows the distribution of effects 2 years after the tax reform enactment for low versus high pass-through industries. Low pass-through industries appear to have lost jobs more significantly than high pass-through industries. Among high pass-through the effect is distributed around zero. The significance of the finding for low pass-through businesses can be seen by considering Figure 3.5. The p-values are lower in the 14 quarters post enactment. This suggests that it is unlikely that the full quarter employment was lower by chance. To provide more insights into the results, we present in Figure 3.6 the relationship between the job growth in several sectors and the percentage of pass-through employees. We focus on industries with better pre-period fit and the size of the dots represents the size of the workforce of each industry.

Figure 3.6 shows that while most industries were negatively affected by the tax reform, the negative effect on high-pass-through sectors is less pronounced. This reveals another important observation that we can observe at the industry level. Although the fitted line has a positive slope, most sectors record negative job creation in the first quarter of 2015.

In addition, in Table 3.2, we regress the recorded employment effects across all industries and quarters on the 2011 pass-through classification measure while including quarter fixed effects. Column (1) shows that the full quarter employment growth in Kansas has a positive but non-significant relationship to the percentage of the workforce employed in pass-through businesses. Similarly, regardless of other specifications and time horizons, the higher pass-through levels never appear to be correlated with statistically significant growth in full quarter employment.

Table 3.2: Industries' job gains and pass-through employment in 2011

	(1) All	(2) 2012	(3) 2013	(4) 2014	(5) 2015	(6) 2016	(7) All(better fit)	(8) Better fit 2015	(9) Better fit 2016
2011 Pass-through %	0.074	0.020	0.032	0.074	0.113	0.133	0.032	0.078	0.086
	(0.047)	(0.039)	(0.041)	(0.049)	(0.077)	(0.081)	(0.035)	(0.053)	(0.065)
Quarter FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,328	166	332	332	332	166	704	176	88
R-squared	0.015	0.006	0.012	0.018	0.020	0.033	0.010	0.041	0.031

Notes: The explained variable is the percentage change in jobs for Kansas. Clustering is done at the industry level. We refer to indutries with pre-treatment RMSPE under the 25th percentile as better fit. Alternative cutoffs are shown in Appendix. Government sectors are included with an imputed passthrough percentage of zero.

One explanation for the observed job losses in the low pass-through sectors could be an indirect effect of the well documented state revenue loss in Kansas[19]. It could be that jobs were lost in response to budget cuts or government contract cancellations with large or mid-sizes corporations due to the lack of revenue. For example, most public schools in Kansas had to cut their staff and expenses to accommodate the large loss in revenue. Other non pass-through companies also lost jobs. For example, Affinis Corp, a C-corporation, faced some of the negative effect of the state revenue losses. They specialize in small government projects such as levies and dams. In response to project cancellations they have had to let employees go[20].

[19]Hayes (2017) finds that there is an almost 50% difference between Kansas and its synthetic control personal income tax revenue. Studies have shown that individual income tax revenue is a large contributor to state and local governments' revenue (Malm and Kant (2013)).

[20]https://www.theatlantic.com/video/index/558143/kansas-tax-cuts/.

3.5.3 Were the Kansas employment outcomes driven by the aircraft manufacturing and oil industry shocks?

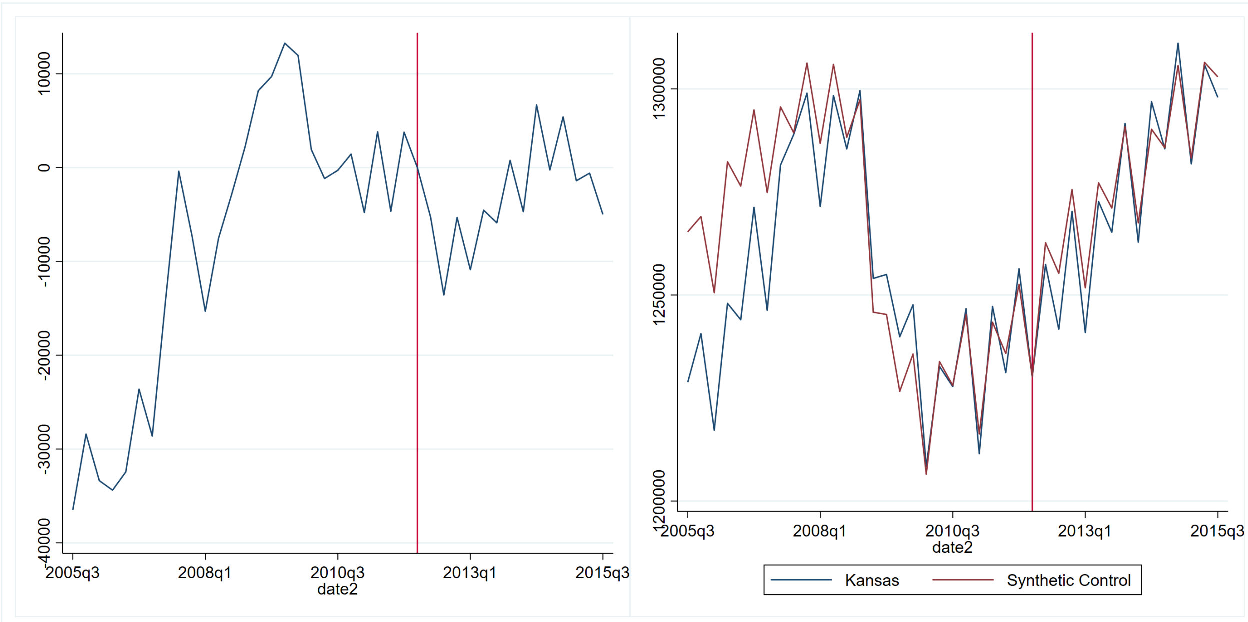

Figure 3.7: Trends in employment excluding aircraft manufacturing, oil and gas extraction Kansas vs. synthetic control

After the Kansas Tax cuts were implemented and the effects witnessed, supporters and critics of this policy were still debating what lessons could be learned. A major contention point raised by several policymakers is that the state of Kansas in 2012 was not actually a level business field to draw the sort of final inference critics of the cuts were making. In particular, around the time of enactment there were steep declines in oil and gas prices and Kansas is an energy producing state. Perhaps this could have been a large burden on farmers. Another point of the debate is the aircraft manufacturer Boeing who left Wichita (KS) with more than 2000 direct job losses at the time and with no accurate estimate of the potential support activities job losses.

In a piece published by Center on Budget and Policy Priorities, Michael Mazerov (2018) supports that none of these events can actually account for nearly enough to explain the outcomes observed. He points out that the energy price drops did not affect Kansas alone but also the neighboring states, even harder in fact, while the earning in this sector for

Kansas was behind all of them but Nebraska. On the other hand he argues that the segment of employees lost in Wichita to Boeing's move is definitely too small to be a valid explanation. To our knowledge, there has currently been no economic study which has investigated the question from this angle. An industry disaggregated approach could provide an adequate setting to study the issue to provide further elements of answers. To address the question we compare the aggregate outcomes (sum of all industry outcomes) to a state of Kansas without the industries of aircraft manufacturing and the energy sector in order to find out if the results vary substantially.

Figure 3.7 shows the impact on the full quarter employment in Kansas when the aircraft manufacturing and the energy industry are removed. The effects are almost identical. This provides evidence against the possibility that events in these industries largely explain the aggregate outcomes in Kansas. Figure C.7 also shows that the effect is not statistically significant regardless of the quarter considered.

3.5.4 Removing the Wichita Metropolitan Statistical Area (MSA) to account for Boeing's departure

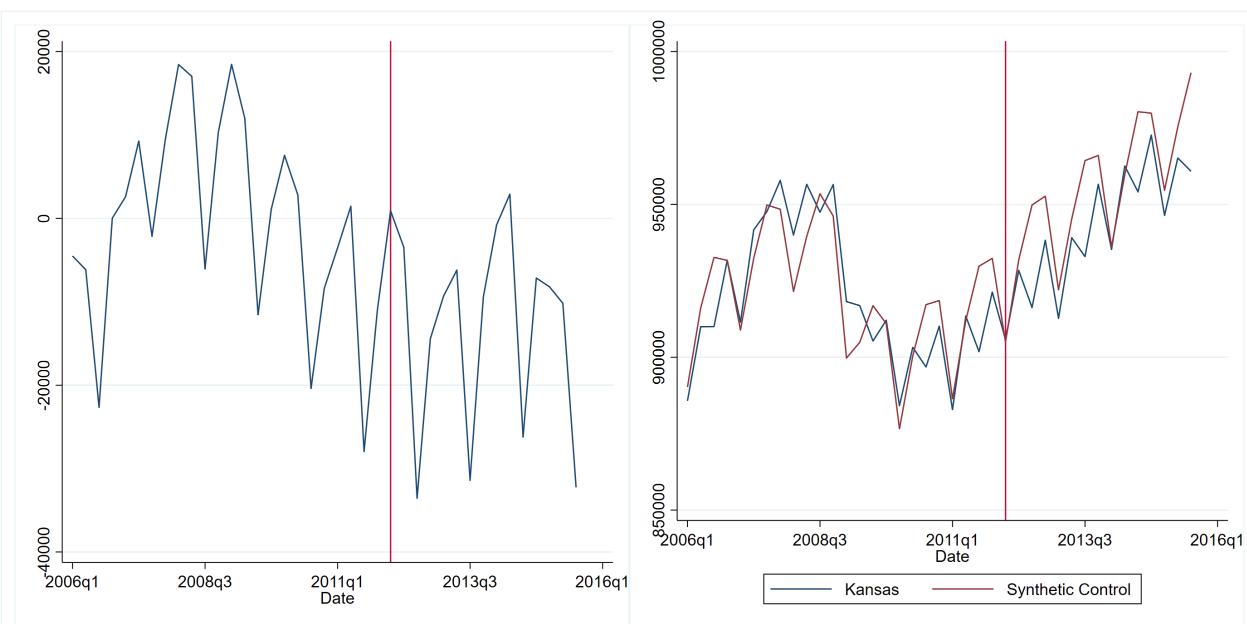

Figure 3.8: The effect of removing the Wichita counties.

To further explore the potential effect of Boeing's departure from Kansas, we remove the 4 counties (Sedgwick, Butler, Harvey, Kingman) forming the Wichita metropolitan statistical area. Wichita is the largest city in the state of Kansas[21] with an estimated 644,000 in the 4 above cited counties alone. Starting in the 1920s, several aircraft companies including Cessna and Steerman Aircrafts started manufacturing operations in the area. More companies joined eventually with Airbus, Spirit AeroSystems and Textron Aviation. Wichita has been called over the years the "Air capital of the world[22]."

Thus, the role of Boeing's departure from the state could be a relevant question for employment fluctuation in Kansas. In this section, we address the question by removing Wichita from Kansas and re-run the SCM method. Figure 3.8 and Figure C.8 show that we do not find evidence of significant loss or job gains when this is done. Essentially, the results are very similar to the previous one including Wichita. This offers evidence against the hypothesis that Boeing's departure from Kansas is an important explanation for why the tax reform did not deliver the expected results.

[21] https://www.census.gov/programs-surveys/decennial-census.html/.
[22] https://www.aircapitaloftheworld.com/.

3.5.5 What effects when excluding the agricultural sector?

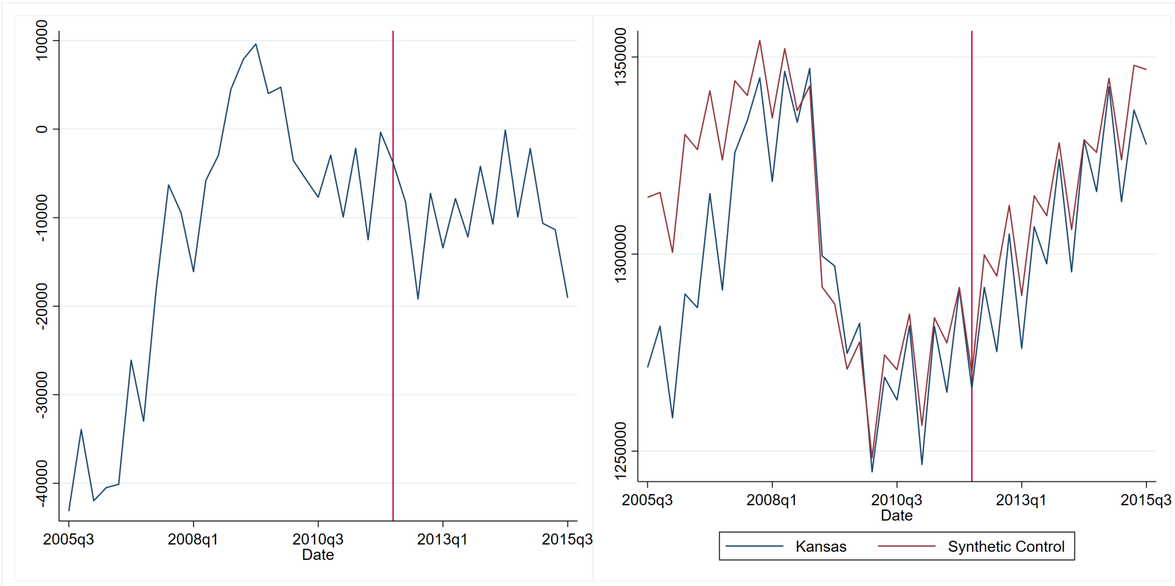

Figure 3.9: Trends in employment excluding agricultural sector: Kansas vs. synthetic control

Another concern with the outcome of the tax reform is the effect of the agricultural sector downturn. Combined earnings of farm proprietors and employees was reduced by 15.8% in Kansas between 2012 and 2016 (Mazerov (2016)). We explore the effect of the reform excluding the agricultural sector in Kansas. Once more, Figure 3.9 results look close to the aggregate ones. Figure C.9 shows that the p-values do not report significance.

3.6 Placebo studies

We focus on the full quarter employment in the low pass-through industries. Previously we have shown that a negative significant effect was recorded in these industries. We use placebo studies to show what significance means in this case. In essence, we run similar SCM procedures for non-treated states with the assumption that the effect should be close to zero. We then compare the distribution of these effects to Kansas which should be larger if the reform had an effect.

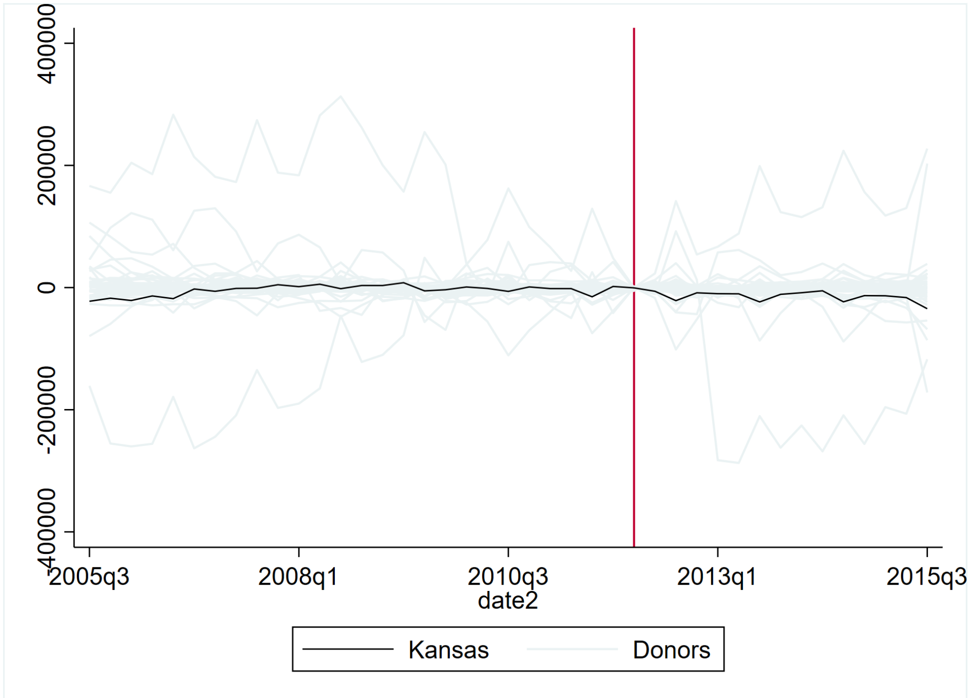

Figure 3.10: Full quarter employment in Kansas low pass-through industries and placebo gaps in all 43 control states.

Figure 3.10 displays the results for this test. The light gray lines represent the gap between placebos and actual state outcomes for the 43 other states of the donor pool. In other words, they show the difference between each states' full quarter employment in low pass-through industries and its corresponding synthetic control. The dark line represents the outcome for Kansas. The graph shows that although the gap post 2012 is modest, it is lower than most U.S. states. Figure 3.11 excludes states with pre-$RMSPE$ 1.5 times higher than Kansas'. This removes only two states. The graph shows more clearly that the Kansas outcome is consistently lower than the remaining states.

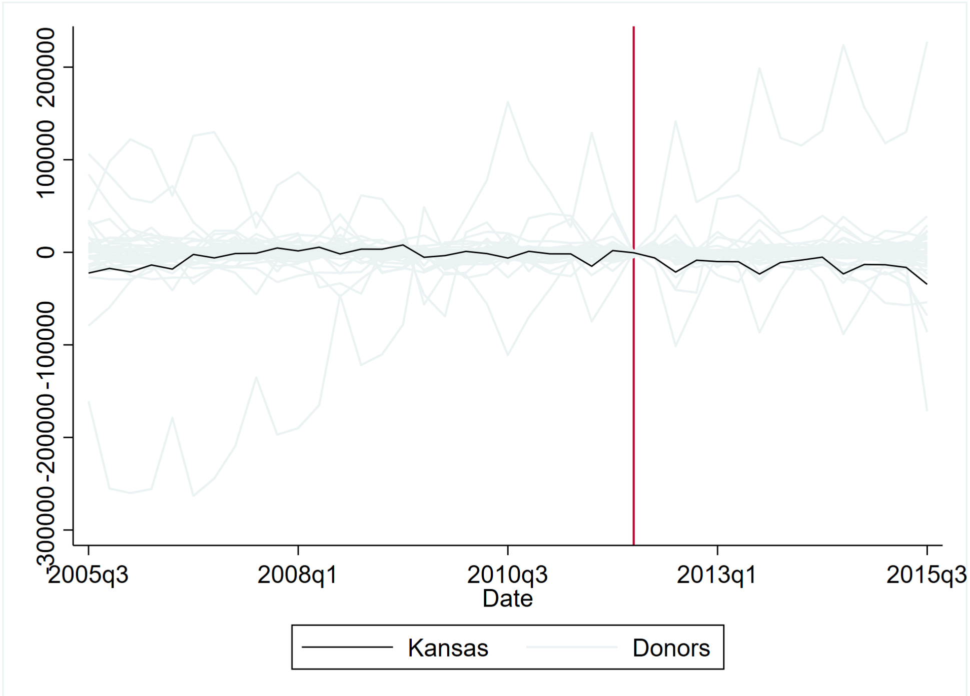

Figure 3.11: Full quarter employment in Kansas low pass-through industries and placebo gaps in 41 control states.

3.7 Conclusion

The 2012 Kansas tax reform will remain an important historical event for many reasons. To date, it is the largest income tax reduction policy to ever occur in the state and very mixed interpretations still surround many consistent findings. While the objective of the tax cuts was to achieve economic growth through incentive geared toward pass-through businesses, the results have been different from the expectations of the proponents. Still, other states and federal governments continue to express interest in similar tax reduction policies. Thus, understanding the effects and mechanisms involved in this reform at a deeper level than the aggregate results motivated our study.

In line with previous research, we find that no significant aggregate employment effect can be detected in Kansas. However, we also find that a few sectors suffered sizeable employment losses possibly due to state revenue reductions. First, industries with more pass-through businesses seem to have incurred less job losses compared to industries with less pass-through businesses although the relationship is not statistically significant regardless of specifications or time horizons. If anything, industries with fewer pass-through businesses may have incurred more job losses after the reform. Second, after removing the aircraft manufacturing as well as the oil and energy industries, the impact on Kansas employment is still insignificant. Over the 14 quarters post-reform, we estimate an insignificant aggregate loss of 0.15% jobs against 0.33% when including aircraft manufacturing and energy sectors. Third, employment excluding the agricultural sector has very similar insignificant results to previous aggregate findings. Nevertheless, we are unable to rule out that the non-significant job creation observed for high pass-through sectors is but income re-characterization.

Our lack of a significant positive impact on employment is consistent with the related literature on the Kansas reform. To our knowledge, our study is the first presenting an analysis of high pass-through sectors' employment and finding negative effects in several categories.

A number of caveats of our study are necessary to acknowledge. First, the 3 digits level NAICS code offered relatively few reliable covariates besides payrolls and alternative employment measures as explanatory variables. Although additional variables would improve the SCM fit, we believe it is unlikely that largely different results would emerge. Second, the large number of industries (99 industries) increases the likelihood of false positives. However, we refrain from using particular outlier industries as evidence for or against our original hypothesis and try the present findings in the context of other estimated effects.

Our results do not unambiguously show that the 2012 Kansas tax reform failed to increase employment but present cases that were object of debate. This includes the departure of Boeing and the energy crisis happening at the time as attenuating circumstances. The negative impact on government sectors' employment excluding the executive branch is in line with previous estimates of state budget loss of 8% and future estimates as high as 16% in the five years post 2012 (Leachman and Mai (2016)). In light of our results, policymakers and researchers considering similar reforms should be aware of the negative impacts on several sectors even while aggregate employment could appears stable. This stability could still possibly be the effect of mere income re-characterization (Debacker et al. (2019)) for preferential tax treatments.

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Appendix A

Chapter 1

We present a list of forecast error decompositions of shocks to renewable energy to food prices.

Table A.1: Percent contribution of shocks to renewable energy consumption to the variability of aggregate food prices

Horizon	Total Renewables	Biomass	Wind	Hydropower	Geothermal	Solar
Panel A : 2005-2019						
0	0.000	0.000	0.000	0.000	0.000	0.000
5	1.223	1.430	4.339	1.759	2.208	3.181
10	2.989	3.664	7.010	5.773	5.639	4.621
15	2.657	5.036	7.42	6.448	7.546	5.533
20	3.591	6.447	7.942	8.138	9.461	5.514
25	3.655	6.681	8.106	9.158	10.119	5.452
30	4.0191	7.198	8.015	9.886	11.044	5.685
35	4.313	7..765	8.406	10.775	12.359	5.913
Panel B: 1978-2019						
0	0.000	0.000	0.000	0.000	0.000	0.000
5	0.614	2.697	0.167	0.269	0.696	0.196
10	1.099	3.603	0.967	1.012	0.923	1.410
15	1.033	3.674	1.303	1.611	1.861	2.445
20	1.523	4.675	1.471	1.970	2.195	2.618
25	1.582	4.831	1.854	2.558	2.481	3.213
30	1.709	5.265	1.954	2.544	2.629	3.234
35	1.950	5.307	2.112	2.983	2.634	3.334
Panel B:1978-2005						
0	0.000	0.000	0.000	0.000	0.000	0.000
5	1.204	3.836	0.223	0.000	0.679	0.306
10	2.006	5.345	1.111	0.505	0.951	1.484
15	2.185	5.393	1.414	1.363	1.953	2.868
20	2.927	6.532	1.597	2.462	2.344	3.068
25	3.075	6.695	1.890	2.916	2.594	3.510
30	3.237	7.095	2.011	3.733	2.735	3.698
35	3.563	7.130	2.096	3.718	2.746	3.785

Table A.2: Contribution of biomass and wind to variability of cereals and baked goods prices

	Biomass			Wind		
Horizon(Months)	1978-2019	1978-2006	2006-2019	1978-2019	1978-2006	2006-2019
1	0.000	0.000	0.000	0.000	0.000	0.000
5	2.071	3.754	9.776	1.412	3.653	3.333
10	2.727	4.232	12.04	3.348	5.694	10.79
15	2.844	4.454	10.54	3.835	6.225	10.24
20	3.668	5.251	11.29	4.441	6.747	10.94
25	3.802	5.416	11.58	4.654	7.060	10.95
30	4.209	5.816	11.62	4.786	7.163	10.81
35	4.265	5.841	12.16	4.932	7.323	11.41

Table A.3: Contribution of biomass and wind to variability of alcoholic beverage prices

	Biomass			Wind		
Horizon(Months)	1978-2019	1978-2006	2006-2019	1978-2019	1978-2006	2006-2019
1	0.000	0.000	0.000	0.000	0.000	0.000
5	3.760	4.094	4.615	0.049	0.052	3.904
10	4.540	4.871	8.009	0.050	0.052	6.579
15	4.280	4.794	8.797	0.503	0.052	6.226
20	5.401	5.769	9.695	0.503	0.052	7.018
25	5.372	5.779	9.398	0.503	0.052	7.250
30	5.847	6.189	9.341	0.503	0.052	7.262
35	5.822	6.185	9.903	0.503	0.052	7.955

Table A.4: Contribution of biomass and wind to variability of non-alcoholic beverage prices

	Biomass			Wind		
Horizon	1978-2019	1978-2006	2006-2019	1978-2019	1978-2006	2006-2019
1	0.000	0.000	0.000	0.000	0.000	0.000
5	1.717	2.195	1.433	1.051	1.085	8.623
10	4.083	5.106	4.783	5.608	6.743	14.389
15	4.070	5.416	8.137	6.417	7.829	15.131
20	4.393	5.815	8.892	7.334	8.371	17.377
25	4.947	6.360	10.234	7.639	8.518	18.399
30	5.085	6.476	10.191	7.675	8.548	18.919
35	5.303	6.654	10.425	7.767	8.560	20.001

Table A.5: Contribution of biomass and wind to variability of meat and poultry prices

	Biomass			Wind		
Horizon(Months)	1978-2019	1978-2006	2006-2019	1978-2019	1978-2006	2006-2019
1	0.000	0.000	0.000	0.000	0.000	0.000
5	0.467	1.093	1.031	0.535	1.218	2.583
10	1.169	1.949	6.618	0.543	1.259	3.571
15	1.207	2.069	5.733	0.543	1.259	3.438
20	1.347	2.240	6.805	0.543	1.259	3.419
25	1.551	2.509	6.336	0.543	1.259	3.393
30	1.612	2.582	6.734	0.543	1.259	3.289
35	1.731	2.698	7.024	0.543	1.259	3.329

Table A.6: Contribution of biomass and wind to variability of fruits prices

	Biomass			Wind		
Horizon(Months)	1978-2019	1978-2006	2006-2019	1978-2019	1978-2006	2006-2019
1	0.000	0.000	0.000	0.000	0.000	0.000
5	1.022	1.484	1.554	0.509	0.594	1.997
10	2.224	2.907	3.094	0.942	0.654	5.823
15	3.352	4.461	2.977	0.977	0.661	6.799
20	3.335	4.468	2.983	0.979	0.661	6.885
25	3.192	4.330	2.993	0.979	0.661	6.690
30	3.155	4.292	2.995	0.979	0.661	6.534
35	3.129	4.264	3.205	0.979	0.661	6.570

Table A.7: Results of the Chow structural break test

Variable	Test statistic	p-value
Renewable Energy Sources		
Total Renewable Energy	2053.555	0.000
Biomass	1073.078	0.000
Geothermal	1080.172	0.000
Wind power	1104.287	0.000
Hydropower	459.016	0.000
Solar power	836.530	0.000
Food Prices		
Food Price Index	3578.088	0.000
Cereals & baked goods	696.544	0.000
Meat and poultry	3104.131	0.000
Dairy products	1853.996	0.000
Fruits	457.943	0.000
Non-alcoholic beverages	659.438	0.000
Alcoholic beverages	1751.569	0.000
Food at home	2457.098	0.000
Food away from home	5600.123	0.000

Appendix B

Chapter 2

B.1 List of countries by group

B.1.1 Developed countries (21)

Australia, Austria, Belgium, Canada, Switzerland, Denmark, Spain, Finland, France, United Kingdom, Greece, Iceland, Italy, Japan, Luxembourg, Netherlands, Norway, New Zealand, Sweden, Trinidad and Tobago, United States.

B.1.2 Middle income countries (29)

Algeria, Argentina, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Gabon, Ghana, Gambia, Guatemala, Ireland, Jamaica, Jordan, Sri Lanka, Malaysia, Mexico, Nicaragua, Panama, Peru, Paraguay,Portugal, Singapore, Tunisia, Turkey, Taiwan, Uruguay, Venezuela, South Africa.

B.1.3 Developing countries (27)

Bangladesh, Bolivia, Botswana, China, Cameroon, Cote d'Ivoire, Egypt, Honduras, Haiti, Indonesia, India, Kenya, Republic of Korea, Morocco, Mali, Malawi, Niger, Pakistan, Philippines, Senegal, Sierra Leone, El Salvador, Togo, Thailand, Uganda, Zambia.

B.2 Additional summary statistics

Table B.1: Descriptive statistics

	All	Rich	By quartiles of protection from expropriation (1)	(2)	(3)	(4)
Average GDP growth 1970-2017	2.20%	2.69%	1.35%	1.82%	2.88%	2.76%
	(1.50)	(1.43)	(1.31)	(1.44)	(1.65)	(1.15)
GDP per capita in 1995	8.47	9.49	7.32	7.72	8.72	9.91
	(1.19)	(0.53)	(0.74)	(0.82)	(0.71)	(0.21)
Education spending	4.04	4.44	3.19	3.93	3.98	5.03
	(1.30)	(1.32)	(0.88)	(1.23)	(1.26)	(1.15)
European settlers mortality	4.56	3.69	5.28	4.81	4.41	2.47
	(1.40)	(1.31)	(1.25)	(1.00)	(1.06)	(1.20)
Overall freedom	62.61	68.21	56.48	55.45	63.10	74.00
	(10.88)	(11.37)	(6.72)	(5.74)	(11.87)	(2.33)
Trade freedom	76.79	81.57	70.38	70.86	78.56	86.64
	(9.91)	(8.94)	(10.51)	(6.91)	(8.27)	(2.33)
Government integrity	46.64	60.46	28.95	33.93	44.20	76.78
	(21.44)	(21.35)	(6.94)	(7.16)	(14.00)	(11.52)
Investment freedom	63.14	70.65	52.75	52.95	61.36	82.17
	(20.35)	(21.31)	(19.22)	(14.28)	(22.21)	(7.80)
Number of countries	91	46	19	22	22	23

Notes: The GDP per capita and European settlers' mortality rates are reported in logarithmic forms. Education spending is expressed as a share of total output. Overall Freedom, trade Freedom, government intergrity and investment freedom originate from the Heritage Foundation database of economic freedom indicators. The index is averaged or each country between 1999, 2009 and 2019.

Table B.2: Countries inside the Barro (2012) sample

Countries	Years of education data	Countries	Years of education data
Argentina	1979-2019	Jordan	1979-2019
Australia	1979-2019	Japan	1979-2019
Austria	1979-2019	Kenya	1979-2019
Belgium	1979-2019	South Korea	1979-2019
Bangladesh	1979-2019	Sri Lanka	1979-2019
Bolivia	1979-2019	Luxembourg	1979-2019
Brazil	1979-2019	Morocco	1979-2019
Botswana	1979-2019	Mexico	1979-2019
Canada	1979-2019	Mali	1979-2019
Switzerland	1979-2019	Malawi	1979-2019
Chile	1979-2019	Malaysia	1979-2019
China	1979-2019	Niger	1979-2019
Cote d'Ivoire	1979-2019	Nicaragua	1979-2019
Cameroon	1979-2019	Netherlands	1979-2019
Congo, Republic	No data	Norway	1979-2019
Colombia	1979-2019	New Zealand	1979-2019
Costa Rica	1979-2019	Pakistan	1979-2019
Denmark	1979-2019	Peru	1979-2019
Dominica Republic	1979-2019	Philippines	1979-2019
Algeria	1979-2019	Panama	1979-2019
Ecuador	1979-2019	Portugal	1979-2019
Egypt	1979-2019	Paraguay	1979-2019
Spain	1979-2019	Senegal	1979-2019
Finland	1979-2019	Singapore	1979-2019
France	1979-2019	Sierra Leone	1979-2019
Gabon	1979-2019	El Salvador	1979-2019
United Kingdom	1979-2019	Sweden	1979-2019
Ghana	1979-2019	Togo	1979-2019
Gambia	1979-2019	Thailand	1979-2019
Greece	1979-2019	Trinidad	1979-2019
Guatemala	1979-2019	Tunisia	1979-2019
Honduras	1979-2019	Turkey	1979-2019
Haiti	1989-2019	Taiwan	No data
Indonesia	1979-2019	Uganda	1979-2019
India	1979-2019	Uruguay	1979-2019
Ireland	1979-2019	United States	1979-2019
Iceland	1979-2019	Venezuela	1979-2019
Italy	1979-2019	South Africa	1979-2019
Jamaica	1979-2019	Zambia	1979-2019

B.2.1 Alternative specification of the scaling effect

The scaling effect in the human capital accumulation process, ξ, can be defined alternatively to help conceptualize the substitutability between education spending and institutional quality. To see this more clearly, let us consider an alternative definition of ξ given by the CES form:

$$\xi \equiv [ae^{\rho} + (1-a)q^{\rho}]^{\frac{\nu}{\rho}} \tag{B.1}$$

where a (between zero and one) is the share parameter of inputs, ρ is the substitution parameter, and ν denotes the level of homogeneity of the production process where $\nu < 1$ gauges the extend of decreasing return to scale (DRS). The elasticity of substitution $\sigma = \frac{1}{1-\rho}$. In this case, it is straightforward to show that:

$$\frac{\partial^2 \xi}{\partial e \partial q} = ae^{\rho-1}(\mu-\rho)(1-a)q^{\rho-1}\left[ae^{\rho} + (1-a)q^{\rho}\right]^{\frac{\mu-2\rho}{\rho}}.$$

These cross derivatives are negative if the elasticity of substitution is less than $\frac{1}{1-\nu}$. In other words, education spending and institutional quality are sufficiently substitutable.

B.2.2 Is there multicollinearity between education spending and institutional quality?

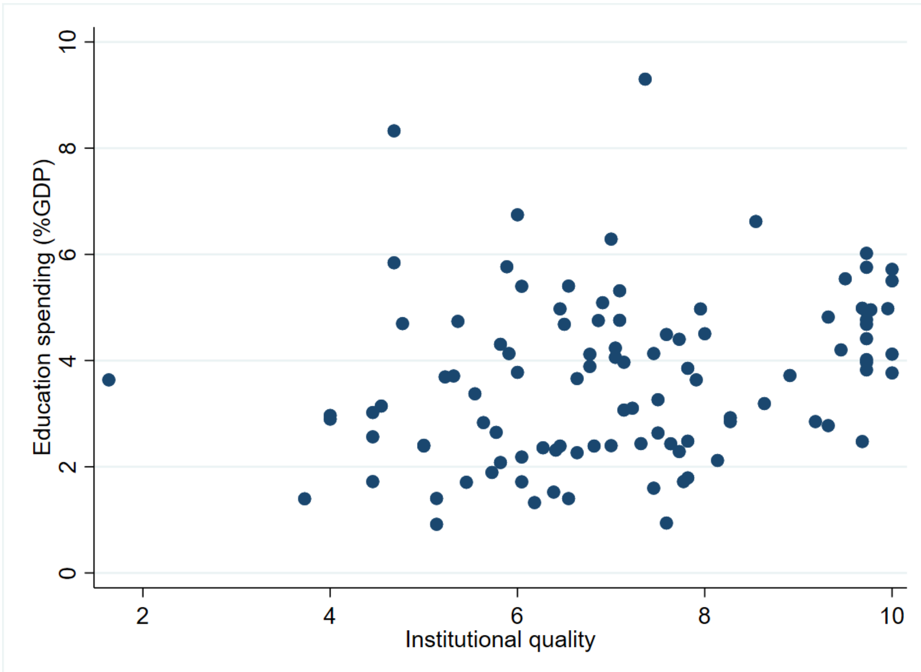


Figure B.1: Average education spending (1979-2009) and institutional quality

In our baseline model, education spending and institutional quality are the main explanatory variables for economic growth. However, if the level of education spending is strongly correlated to existing institutions, there is an endogeneity problem that must be addressed. Figure B.1 presents the relationship between the two variables. We see that no strong positive nor negative relationship emerges. The correlation coefficient is also low around 26.14%.

B.2.3 Does institutional quality vary among rich countries?

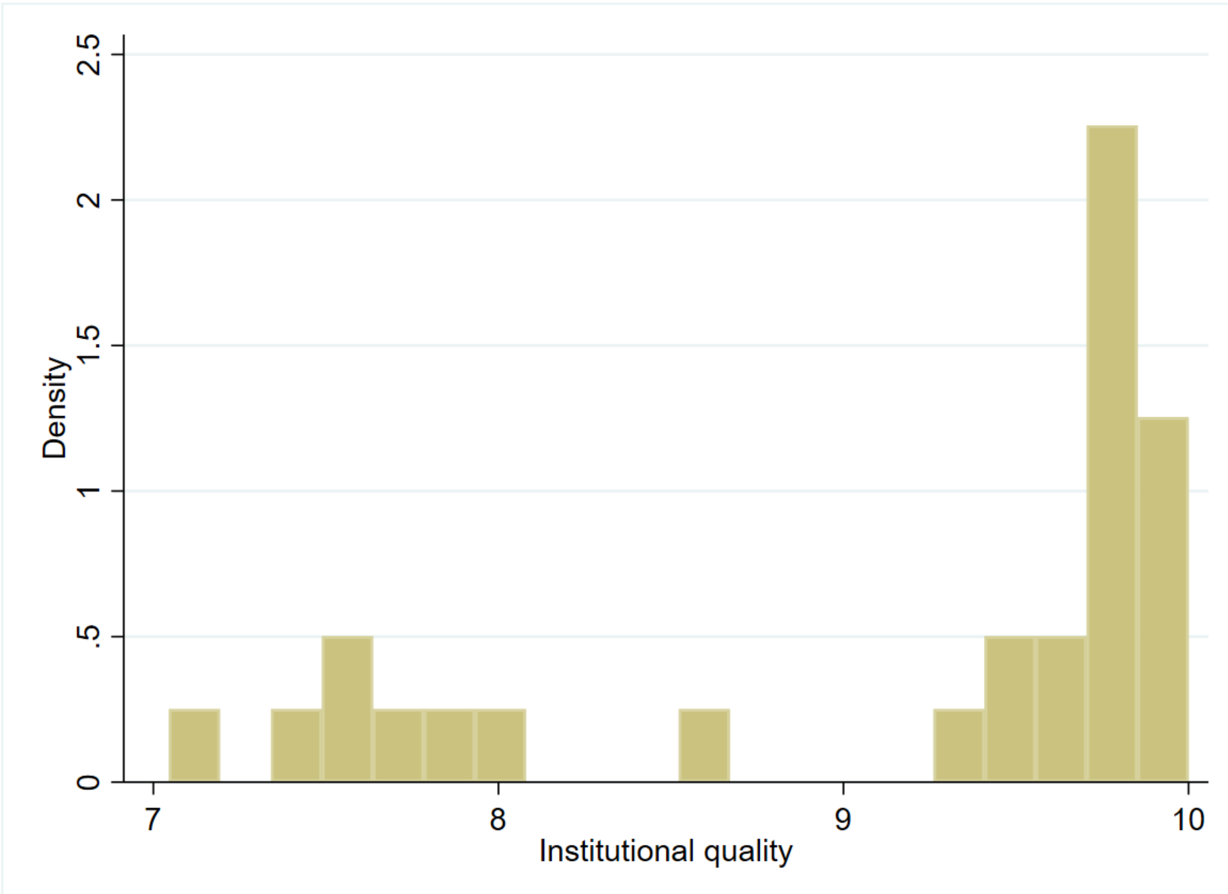


Figure B.2: Distribution of institutional quality index among rich countries

We can expect that richer countries would have higher institutional quality scores, ceterus paribus. Yet, the empirical estimation procedure requires a level of variation in this measure. Figure B.2 shows that most rich countries have a high level of institutional quality as expected, but a number of rich countries also have relatively lower scores. Quatar, Kuwait, Greece and Saudia Arabia, among others have scores lower than 7.8/10. We also look at the variable from the perspective of Figure B.3 which shows variation not only in institutional quality but also in average education spending in these rich countries.

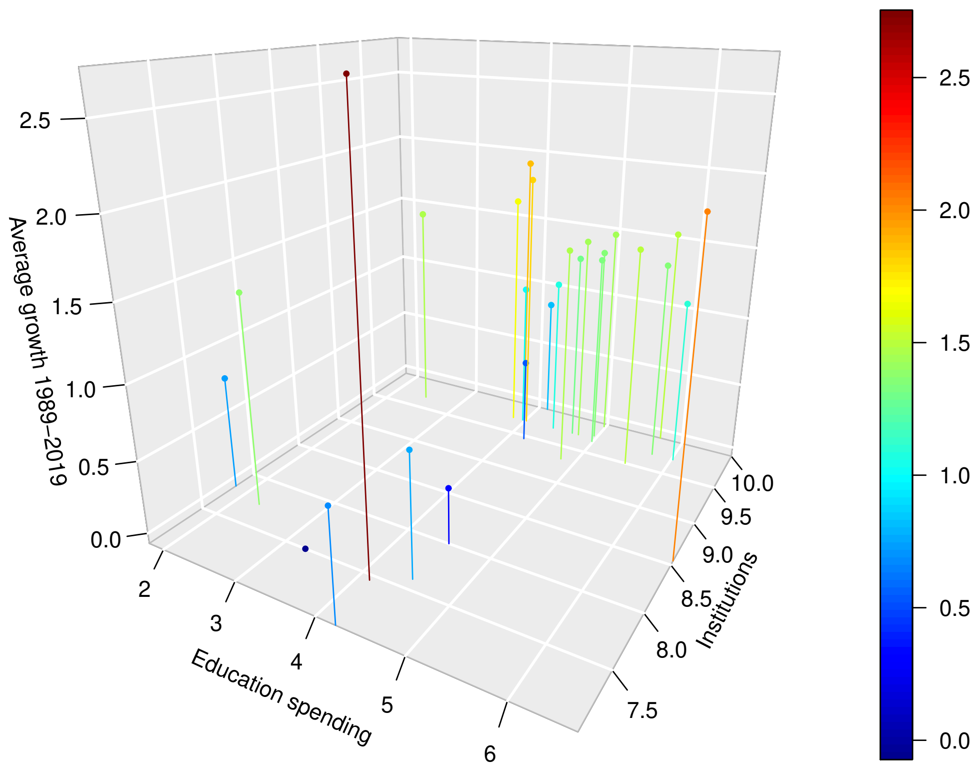


Figure B.3: Education spending, institutional quality and growth among rich countries.

B.3 Additional tables

Table B.3: Panel of middle income countries (1989-2019)

Variables	(1) Barro	(2) Barro	(3) Barro	(4) Barro	(5) Barro	(6) Barro	(7) Barro	(8) Barro+
Education spending	0.06		-0.14	-0.92	-0.77	-0.77	-0.55	-0.16
	(0.23)		(0.21)	(1.48)	(1.53)	(1.47)	(1.51)	(0.93)
Institutional quality		0.43*	0.32	-0.05	0.15	0.02	0.27	0.41
		(0.22)	(0.24)	(0.79)	(0.86)	(0.74)	(0.79)	(0.63)
Inst*Education Spending				0.11	0.10	0.10	0.08	0.01
				(0.22)	(0.23)	(0.21)	(0.23)	(0.15)
Government Expenditures						-0.06*	-0.08**	-0.02
						(0.04)	(0.04)	(0.03)
Y_{1970}					-1.17		-1.32	-0.91
					(0.87)		(0.81)	(0.65)
Observations	114	120	114	114	114	114	114	164
R-squared	0.59	0.13	0.13	0.13	0.17	0.15	0.20	0.15

Notes: The dependent variable in Column (1)-(8) is the average 10 year growth rate of log GDP per capita. Institutions are measured on a scale of 0 to 10 with higher scores indicating better institutional quality. The measure originates from Political Risk Services and is averaged between 1985 and 1995. Education spending is obtained from the World Bank World Development Indicators and is expressed as a percentage of GDP. Standard errors are in parenthesis. Asterisks between 1 and 3 respectively indicate significance at the 10%, 5% and 1% level. See Section 2.5 for a more detailed variable definitions and sources.

Cross sectional results

Table B.4 presents our cross sectional specifications of the baseline equation. The regressions are run in the same spirit but with a different measures of long run growth. We regress the 30 year average growth rate of real per capita GDP on institutional quality and education expenditures in the previous decade. The boundary years are 1989 and 2019. The education spending is the average in the previous decade that is 1969-1979.

Table B.4: Cross sections (1989-2019)

Variables	(1)	(2)	(3)	(4)	(5) Barro	(6) Barro	(7) Barro	(8) Barro
Cross section A: Rich countries								
Education spending	0.05		0.09	0.76	0.02		0.09	2.90***
	(0.10)		(0.10)	(0.89)	(0.12)		(0.15)	(0.87)
Institutional quality		0.12	0.10	0.41		-0.25	-0.29	0.78**
		(0.21)	(0.23)	(0.42)		(0.30)	(0.30)	(0.32)
Inst*Ed				-0.07				-0.30***
				(0.09)				(0.09)
y_{1970}	-0.21	-0.42	-0.11	-0.08	0.23	0.50	0.36	0.31
	(0.18)	(0.30)	(0.27)	(0.27)	(0.60)	(0.53)	(0.59)	(0.61)
Observations	31	28	27	27	21	21	21	21
R-squared	0.07	0.31	0.12	0.13	0.03	0.13	0.16	0.39
Cross section B: Developing countries								
Education spending	-0.11		-0.16	0.73	-0.11		-0.22	1.57
	(0.14)		(0.12)	(1.58)	(0.20)		(0.20)	(1.83)
Institutional quality		0.58***	0.62**	0.95		0.52*	0.57*	1.26*
		(0.20)	(0.23)	(0.60)		(0.28)	(0.29)	(0.72)
Inst*Ed				-0.13				-0.27
				(0.22)				(0.26)
y_{1970}	-0.94	-2.59***	-1.95**	-2.01**	-1.33	-1.81*	-1.65	-1.61
	(0.71)	(0.71)	(0.77)	(0.80)	(0.89)	(1.03)	(1.11)	(1.01)
Observations	46	38	34	34	26	26	26	26
R-squared	0.05	0.39	0.34	0.35	0.11	0.25	0.28	0.31
Cross section C: All countries								
Education spending	-0.11		-0.11	-0.08	-0.08		-0.14	-0.22
	(0.07)		(0.08)	(0.40)	(0.11)		(0.11)	(0.66)
Institutional quality		0.32***	0.29***	0.31		0.33**	0.33*	0.29
		(0.09)	(0.09)	(0.26)		(0.16)	(0.17)	(0.37)
Inst*Ed				-0.00				0.01
				(0.06)				(0.09)
y_{1970}	-0.41***	-0.79***	-0.69***	-0.69***	-0.38**	-0.85***	-0.77***	-0.78***
	(0.10)	(0.14)	(0.15)	(0.16)	(0.17)	(0.27)	(0.27)	(0.28)
Observations	138	112	103	103	75	77	75	75
R-squared	0.13	0.22	0.19	0.19	0.10	0.15	0.16	0.16

Notes: The dependent variable in Column (1)-(8) is the average 30 year growth rate of log GDP per capita. Institutions are measured on a scale of 0 to 10 with higher scores indicating better protection against expropriation. The measure originates from Political Risk Services and is averaged between 1985 and 1995. Education spending is obtained from the World Bank World Development Indicators and is expressed as a percentage of GDP. For rich countries, the Barro sample excludes Bahrain, Bahamas, Isral, Kuwait, Quatar, the Russian Federation and Saudia Arabia. Standard errors are in parenthesis. Asterisks between 1 and 3 respectively indicate significance at the 10%, 5% and 1% level. See Section 2.5 for a more detailed variable definitions and sources.

We note that relative to the panel specifications, the cross sectional approach severely reduces the number of observations per country. Each country only appears once in the regressions. The Barro sample is even smaller. In particular, the regression for rich countries has either 27 or 21 countries, developing countries either 34 ot 26 and all countries only either 103 or 75. To further clarify the rationale of the Barro sample, we note that the sample of rich countries in that specification excludes Bahrain, Bahamas, Kuwait, Quatar and Saudia Arabia among others. Two of these countries were listed in the 2000 OECD report reporting tax havens and the other have experienced large growth episode due in part to relatively recent oil production.

Overall, the results in the cross sectional approach mimic the findings of the panel specification at least in term of signs. In most specifications the log GDP per capita in 1970 has a negative significant sign suggesting that richer countries grow at a slower pace which is consitent with traditionnal growth theory.

Both in rich and developingcountries the inclusion of the interaction term shows a negative sign which is seldom significant. In Regression 8, however, we see significant results close to the panel specification for rich countries. Here, for a country with perfect institutions, we interpret that 1% increase in education spending would be associated with a -0.10% change in growth or $(2.9 - 3)$.

Table B.5: Cross section: Middle income countries (1989-2019)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables					Barro	Barro	Barro	Barro+
Education spending	-0.13		-0.13	-1.01	-0.10		-0.12	-2.34
	(0.10)		(0.14)	(0.79)	(0.20)		(0.19)	(1.67)
Institutional quality		0.32**	0.25	-0.30		0.30	0.22	-0.88
		(0.13)	(0.15)	(0.51)		(0.29)	(0.34)	(0.95)
Inst*Ed				0.14				0.32
				(0.13)				(0.24)
y_{1970}	-0.44	-0.83	-0.82	-0.74	-0.87	-1.15	-1.10	-0.87
	(0.55)	(0.66)	(0.69)	(0.72)	(0.88)	(0.93)	(1.02)	(1.03)
Observations	61	46	42	42	28	30	28	28
R-squared	0.04	0.10	0.10	0.12	0.07	0.09	0.09	0.15

Notes: The dependent variable in Column (1)-(8) is the average 30 year growth rate of log GDP per capita. Institutions are measured on a scale of 0 to 10 with higher scores indicating better protection against expropriation. The measure originates from Political Risk Services and is averaged between 1985 and 1995. Education spending is obtained from the World Bank World Development Indicators and is expressed as a percentage of GDP. For rich countries, the Barro sample excludes Bahrain, Bahamas, Isral, Kuwait, Quatar, the Russian Federation and Saudia Arabia. Standard errors are in parenthesis. Asterisks between 1 and 3 respectively indicate significance at the 10%, 5% and 1% level. See Section 2.5 for a more detailed variable definitions and sources.

Table B.6: Cross section (1989-2019): Alternative measures of institutional quality

VARIABLES	(1) All	(2) Developing	(3) Rich	(4) All	(5) Developing	(6) Middle Income	(7) Rich	(8) Barro+
Panel A: Institutions proxied by property rights								
Education Spending	0.17	0.76	0.65	0.13	1.53	-0.72	0.27	0.36
	(0.42)	(0.64)	(0.95)	(0.38)	(0.89)	(0.76)	(0.85)	(0.27)
Property rights	0.35	1.38***	0.39	0.49	1.59**	-0.06	0.34	0.53**
	(0.28)	(0.37)	(0.25)	(0.30)	(0.63)	(0.61)	(0.20)	(0.23)
Int(PR*ED)	-0.07	-0.27*	-0.08	-0.05	-0.43*	0.13	-0.03	-0.08*
	(0.06)	(0.13)	(0.11)	(0.06)	(0.22)	(0.13)	(0.10)	(0.04)
Human capital				0.50	0.60	0.24	-1.14*	0.52*
				(0.53)	(0.96)	(0.74)	(0.56)	(0.31)
Y_{1970}				-1.01***	-1.89	-1.07	0.41	-0.83***
				(0.27)	(1.18)	(0.82)	(0.64)	(0.16)
Observations	69	22	21	69	22	26	21	106
R-squared	0.06	0.26	0.09	0.27	0.43	0.30	0.22	0.26
Panel B: Institutions proxied by government integrity								
Education Spending	0.06	2.39***	0.36	0.05	2.39**	-1.20**	0.30	0.27
	(0.31)	(0.66)	(0.42)	(0.29)	(0.90)	(0.45)	(0.43)	(0.19)
Government Integrity	0.23	3.90***	0.16	0.33	3.85***	-0.53	0.16	0.45***
	(0.22)	(0.88)	(0.22)	(0.21)	(1.29)	(0.36)	(0.22)	(0.17)
Int(GVI*ED)	-0.05	-0.93***	-0.04	-0.04	-0.90**	0.26***	-0.03	-0.07**
	(0.05)	(0.24)	(0.05)	(0.05)	(0.34)	(0.09)	(0.05)	(0.03)
Human capital				0.74*	-0.10	0.46	-0.86*	0.65**
				(0.42)	(0.76)	(0.62)	(0.45)	(0.29)
Y_{1970}				-1.00***	-1.58	-1.10	0.46	-0.84***
				(0.28)	(1.22)	(0.75)	(0.70)	(0.16)
Observations	69	22	21	69	22	26	21	106
R-squared	0.03	0.42	0.04	0.23	0.54	0.35	0.13	0.24

Notes: The dependent variable in Column (1)-(8) is the average 30 year growth rate of log GDP per capita. Institutions are measured on a scale of 0 to 10 with higher scores indicating better institutional quality. The measure originates from Political Risk Services and is averaged between 1985 and 1995. The measure of property rights and government integrity come from the Heritage Foundation. Education spending is obtained from the World Bank World Development Indicators and is expressed as a percentage of GDP. Standard errors are in parenthesis. Asterisks between 1 and 3 respectively indicate significance at the 10%, 5% and 1% level. See Section 2.5 for a more detailed variable definitions and sources.

Table B.7: Additional controls: Middle income and all countries (1989-2019)

Variables	(1) Barro	(2) Barro	(3) Barro	(4) Barro	(5) Barro	(6) Barro	(7) Barro	(8) Barro+
Panel A: Middle income countries								
Education spending	-0.31	-0.21	-0.16	0.40	-0.19	-0.19	-0.04	0.42
	(0.77)	(0.83)	(0.93)	(0.68)	(0.81)	(0.73)	(0.84)	(0.67)
Institutional quality	0.21	0.37	0.41	0.55	0.42	0.35	0.46	0.54
	(0.52)	(0.59)	(0.63)	(0.48)	(0.57)	(0.49)	(0.60)	(0.42)
Inst*Ed	0.04	0.02	0.01	-0.08	0.02	0.02	-0.01	-0.08
	(0.13)	(0.14)	(0.15)	(0.11)	(0.14)	(0.12)	(0.14)	(0.11)
y_{1970}		-0.84	-0.91	-1.08*	-0.72	-1.33*	-0.93	-1.49**
		(0.65)	(0.65)	(0.56)	(0.66)	(0.73)	(0.68)	(0.72)
Government Exp.			-0.02					-0.04
			(0.03)					(0.03)
Human capital				1.77***				1.43**
				(0.50)				(0.54)
Depreciation					0.12			0.10
					(0.21)			(0.21)
Capital per person						0.47		0.45
						(0.34)		(0.38)
Latitude							1.29	1.12
							(1.58)	(1.43)
Observations	170	170	164	159	166	166	170	152
R-squared	0.14	0.16	0.15	0.24	0.16	0.19	0.17	0.26
Panel B: All countries								
Education spending	0.26	0.22	0.14	0.47*	0.14	0.19	0.46*	0.48*
	(0.29)	(0.25)	(0.28)	(0.25)	(0.24)	(0.25)	(0.27)	(0.28)
Institutional quality	0.47**	0.76***	0.69***	0.69***	0.75***	0.74***	0.81***	0.68***
	(0.24)	(0.21)	(0.22)	(0.20)	(0.20)	(0.22)	(0.21)	(0.21)
Inst*Ed	-0.06	-0.05	-0.04	-0.09**	-0.04	-0.05	-0.09**	-0.10**
	(0.05)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
y_{1970}		-0.93***	-0.92***	-1.14***	-0.92***	-0.97***	-0.99***	-1.09***
		(0.13)	(0.15)	(0.15)	(0.13)	(0.20)	(0.13)	(0.24)
Government Exp.			-0.02					-0.02
			(0.03)					(0.03)
Human capital				1.16***				1.01***
				(0.30)				(0.32)
Depreciation					0.19*			0.16
					(0.11)			(0.12)
Capital per person						0.04		-0.07
						(0.20)		(0.25)
Latitude							2.03*	2.00**
							(1.03)	(0.98)
Observations	412	412	385	392	408	408	412	365
R-squared	0.10	0.20	0.19	0.24	0.21	0.21	0.22	0.25

Notes: The dependent variable in Column (1)-(8) is the average 10 year growth rate of log GDP per capita. Institutions are measured on a scale of 0 to 10 with higher scores indicating better institutional quality. The measure originates from Political Risk Services and is averaged between 1985 and 1995. The measure of property rights and government integrity come from the Heritage Foundation. . Education spending is obtained from the World Bank World Development Indicators and is expressed as a percentage of GDP. Standard errors are in parenthesis. Asterisks between 1 and 3 respectively indicate significance at the 10%, 5% and 1% level. See Section 2.5 for a more detailed variable definitions and sources.

B.3.1 Additional information on the Penn World Table 10

Table B.8: Description of PWT variables

Variables	Description	Units	Usage
$CGDP^e$	Expenditure-side real GDP, using prices for final goods that are constant across countries	Millions of 2011 US $	Living standards across countries in each year
$CGDP^o$	Output-side real GDP, based on final goods prices, exports and imports that are constant across countries	Millions of 2011 US $	Productive capacity across countries in each year
$CCON$	Real consumption of households and government, using prices that are constant across countries	Millions of 2011 US $	Living standards across countries in each year
CK	Capital stock using prices for structures and equipment that are constant across countries	Millions of 2011 US $	Capital stock across countries in each year
$RGDP^e$	Expenditure-side real GDP, using prices for final goods that are constant across countries and over time	Millions of 2011 US $	Productive capacity across countries and across years
$RGDP^o$	Output-side real GDP, using prices for final goods exports and imports which are constant across countries and time	Millions of 2011 US $	Productive capacity across countries and across years
$RGDP^{NA}$	Real GDP at constant national prices, obtained from national accounts data for each country	Millions of 2011 US $	Growth of GDP over time in each country
PL_CON	Price level of $CCON$, equal to PPP divided by the nominal exchange rate	US value =1 in 2011 $	How consumption price levels differ across countries
PL_GDP^o	Price level of $CGDP^o$,equal to the PPP (ratio of nominal GDP to CGDP^o)	USA value =1 in 2005	How output price levels differ across countries

Notes: The extended version of this table is availble in Feenstra, Inklaar, and Timmer (2015). It presents further details on absorption measures and other measures of economic consumption and production.

Table B.8 shows a subsample of PWT variables and their prescribed usage. $CGDP^e$ is based on consumption investments and government expenditure alone and is a good measure of living standards. $CCON$ is a "consumption-equivalent" welfare measure based on real consumption, the sum of real consumption of households and government. This measure is especially suited for answering the question of indifference to life in the United States versus another country. By how much should the person's consumption be adjusted to achieve comparable welfare levels. The question was asked by Jones and Klenow (2011) and $CCON$ would be a good candidate in this case. Jones and Klenow (2011) incorporated further measure of welfare as leisure, mortality and inequality and found that Western Europe was closer to the United States in terms of needed adjustments. The next closest were emerging Asian countries and most developing countries after those. Another study, by Fleurbaey and Gaulier (2009), also compares living standards between countries. They include corrections for income, labor, risk of unemployment, healthy life expectancy households features and inequality as well. Their method consists in computing the equivalent variations that would make populations differing in non-income dimensions indifferent to living in one country over another. Their study is based on OECD countries which are, we note, more comparable to each other.

Starting from the $CCON$ variable, and adding the real investment and the real trade balance (Net Exports), the $CGDP^e$ is obtained. This measure from the consumer's perspective treats the net balance of trade as an income transfer which is deflated by local prices. This measure is a representation of living standards in a country with an extension to the trade balance. Its comparable measure from the output side $CGDP^o$ is most relevant for studies dealing with development accounting. Hall and Jones (1999) inquire as to why certain countries produce more output per worker than others. This seminal study explores the proximate determinants of GDP levels and identifies many with various levels of importance. Physical capital and educational attainment are shown to only partially explain the disparities. It shows that "social infrastructures", meaning the quality of institutions and government policies, are deeper drivers of disparities in productivity and output per workers. They show how these infrastructures are endogenous and determined historically and captured by languages. Caselli (2005) asks a similar question, but focuses on factors of production and efficiency. Hsieh and Klenow (2010) go further to study why these proximate determinants of growth vary and argue that total factor productivity (TFP) has a strong influence on output channeled though physical and human capital accumulation. They propose misallocation of inputs across firms and industries as a key explanatory variable for TFP disparities. In these studies and other related replication attempts, $CGDP^o$ would be a good candidate.

CK is a measure of capital stock. It is computed based on time series data of buildings and different types of machines investments and converted with relative prices for structure and equipment that are constant across countries.

Relative to past versions of the PWT, the growth rate of $RGDP^e$ and $RGDP^o$ which was only based on the growth rate of the real GDP emanating from national account data, since PWT8, a new method has been adopted. The measures of $RGDP^e$ and $RGDP^o$ are based on growth rates which are linked to many ICP benchmarks enabling a correction between those benchmarks. The measure relies on an interpolation between available benchmarks and as such is not necessarily the same with the national account growth rate [1]. Johnson, Larson, Papageorgiou, and Subramanian (2013) pointed out some concerns with the earlier method, thus the revision since PWT8. The study argues that two problems arise with the earlier approach. First, the estimates of growth varied substantially across different versions of the PWT (newer versions as

[1] Feenstra et al. (2005) explain that India for instance has a higher standard of living in the 1975 ICP benchmark compared to what was predicted from the 1985. This entails that the change in real GDP from 1975 is proportionately underestimated.

opposed to previous). This despite the underlying method of computation being preserved. The methodology led to systematic variability which was larger for smaller countries with further benchmark year. The second criticism was that the estimates were not valued at purchasing power parity which defeated the original intent of the PWT to adjust national estimates of GDP by valuing output at constant international prices for comparability across countries. Furthermore, they undertake a replication study showing that this variability is important for the growth literature. In response to this concern, the more recent version of the PWT includes a second real GDP variable "rgdpl2" which instead relied on national accounts growth of total absorption[2] and did not suffer this problem.

The measure of capital RK is also based on the cumulative investment on buildings and other machinery but unlike CK, it is deflated with national prices in a way that allows comparison between countries over time. The reference time period is 2011. The database also includes various measures of price levels as PL_GDP^o which is the ratio of nominal GDP in local currency to $CGDP^o$ providing the exchange rate relative to U.S. dollar. These estimates allow the study of prices levels disparities across countries when converted to the nominal exchange rate.

Figure 2.5, from the PWT documentation, shows us the time path of the estimated average schooling in Germany between 1950 and 2010 across the four datasets. Recall that Barro and Lee (2013) covers 146 countries at 5-year intervals, Cohen and Leker (2014) has 95 countries at 10-year intervals, De La Fuente and Domenech (2006) provide 21 countries' estimates at 5-year intervals and finally the UNESCO with 125 countries at annual frequency but only covering the 2000s. After 1985, the BL (2013) dataset shows a relatively sharp increase in schooling attainment until 2005 while DD (2006) and the Cohen-Soto-Leker dataset both register a more gradual increase. Moreover, DD (2006), CSL and the UNESCO data are close both in trend and levels in a way that argues against the BL data at least in the case of Germany. Nevertheless, for the computation in the PWT, this situation provides an opportunity for combining the different datasets. The authors of the PWT show that the datasets are broadly comparable except the slight different in mean (5.4 in the BL versus 5.6 in the CSL data). The correlation across countries/years pair is also high at 94% and even for Germany is as high as 80%.

Regarding the computation of the human capital index however, the choice of dataset turned out to be much more important due to the non-linear return to education based on the level achieved. Psacharapoulos (1994) provides global Mincerian return to education. Based on this calculation, the PWT undertakes to choose the most appropriate series on average years of education among the available datasets. Only BL and

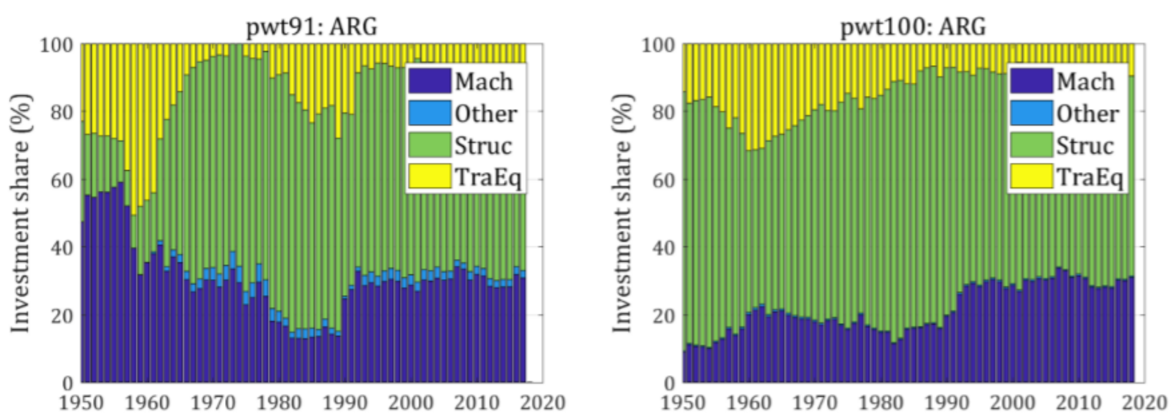
[2] The total absorbtion is the total demand for all marketed final goods and services regardless of their origin. It is equal to national income minus the balance of trade $Y = C + I + G + [X - M]$. The term was coined in 1953 by Sidney Alexander in his paper "*Effect of devaluation on a trade balance.*"

CSL cover a long enough period of time to be candidates, and they chose between the two whenever data was available. 56 countries are covered by BL exclusively and 5 covered by CSL exclusively. In summary, for 61 countries, the only available series where the ones used by default. The choice between the two datasets was motivated by the proximity to DD and/or UNESCO in trends and levels. If no other clear criteria allowed to make the cut, the PWT reverts to the BL series since it starts in 1950 versus only 1960 for the CSL data. After the necessary combinations, the PWT9.0 included 150 countries.

We use the 10th release of the PWT. It is very close to the earlier issues except for a few changes [3], that we discuss briefly. PWT 10.0 has a new purchasing power parity (PP) measure incorporated, revisited and extended national accounts data, the change of the reference year from 2011 to 2017, a reevaluation of the computation of employment and finally a change in the methodology to estimate investment by assets. Employment calculations changed as well as the source data. The incorporation of more up-to-date information has led to the improvement of estimates in African, South East Asian and Latin American countries.

Previous issues of the dataset relied on three main data sources: The conference Board's (TCB) Total Economy Database, the International Labor Office (ILO) and the World Bank's employment and labor force statistics in the WDI. In the PWT10, for countries where the TCB relied on secondary data, the researchers use employment data directly available from the Economic Transformation Database (ETD, de Vries et al. (2021)) combined with data from EASD (Mensah et al. (2018)). Whenever ETD or TCB data were unavailable, the PWT10 reports ILO data instead.

Figure B.4: Revision to nominal investment for Argentina. (Source: PWT10 Documentation)



The earlier version of PWT has asset specific data based on National Accounts statistics from TCB

[3] https://www.rug.nl/ggdc/docs/pwt100-whatsnew.pdf

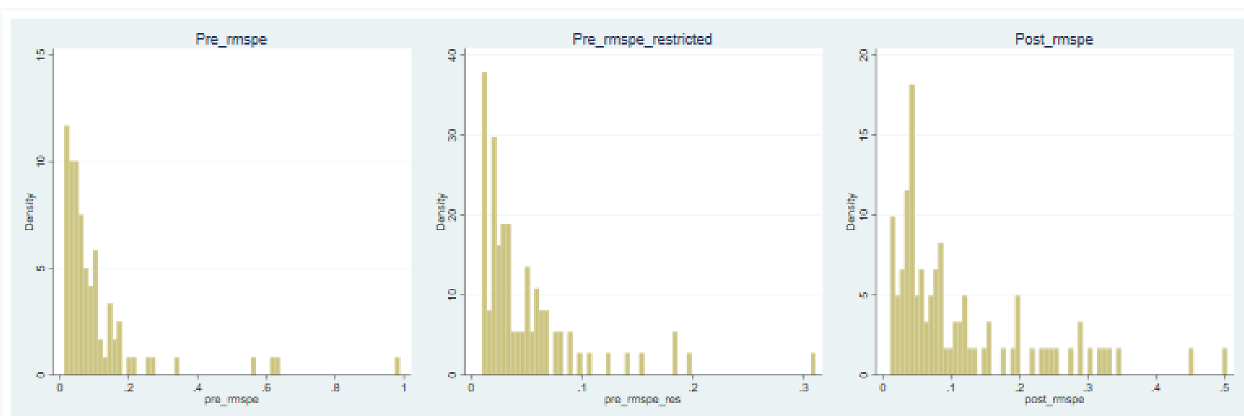
and estimates from the Commodity-Flow Method (CFM). This release, however, updated the connecting procedure between the two sources. Initially, there were only 9 levels of finals assets, which meant that TCB data were used at the most detailed level. The current release incorporates data only if it is of higher levels assets. In the organization, you have "children" referring to the nine lowest level assets and "parents/grandparents" for several higher level assets. Investment shares were expressed relative to the direct parent category. This revision impacted the investment component of the GDP measure as we can see on Figure B.4 with Argentina. We can see that the share of investment going to "Total Construction" (STRUC) is substantially different from the previous release as this correction is applied.

Appendix C

Chapter 3

C.1 Additional figures

We present the distributions of the pre-RMSPE, the restricted pre-RSMPE and the post RMSPE. We present the effects at different quarters for all industries given that the policy was in effect until 2016. We also show the linear relationship between industries' job creations and the level of pass-through employment. We present this relationship for each year between 2012 and 2016. In addition, we show the same relationship restricted to the industries which had a better fit in the pre-period[1].



[1]Industries for which the pre-period RMSPE was under the 50th percentile are considered to have a better fit compared to others.

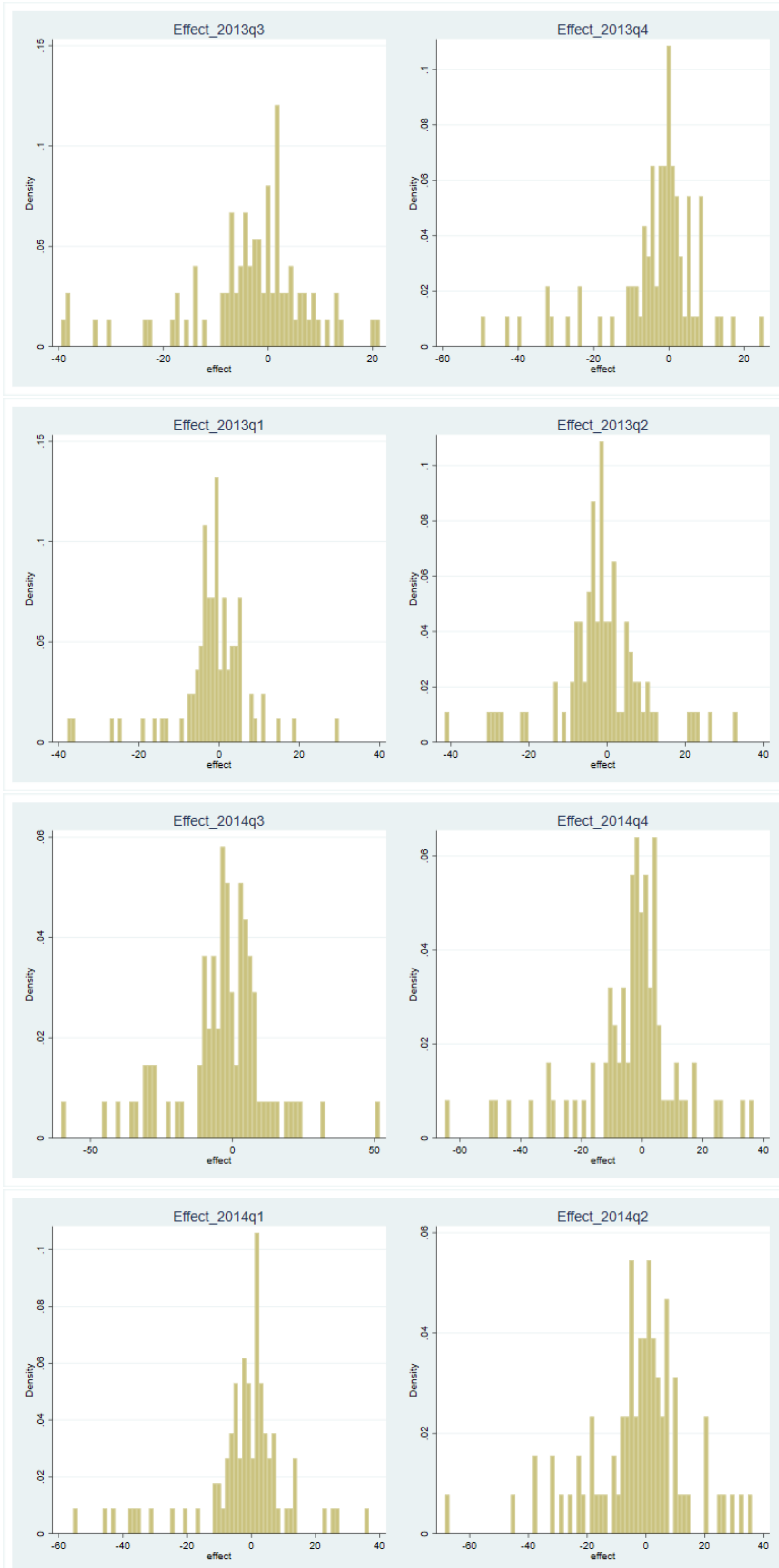

Effect_2013q3
Effect_2013q4
Effect_2013q1
Effect_2013q2
Effect_2014q3
Effect_2014q4
Effect_2014q1
Effect_2014q2
Density
effect

Figure C.1: 2012 All industries effects vs. pass-through percentages: All vs. better fit

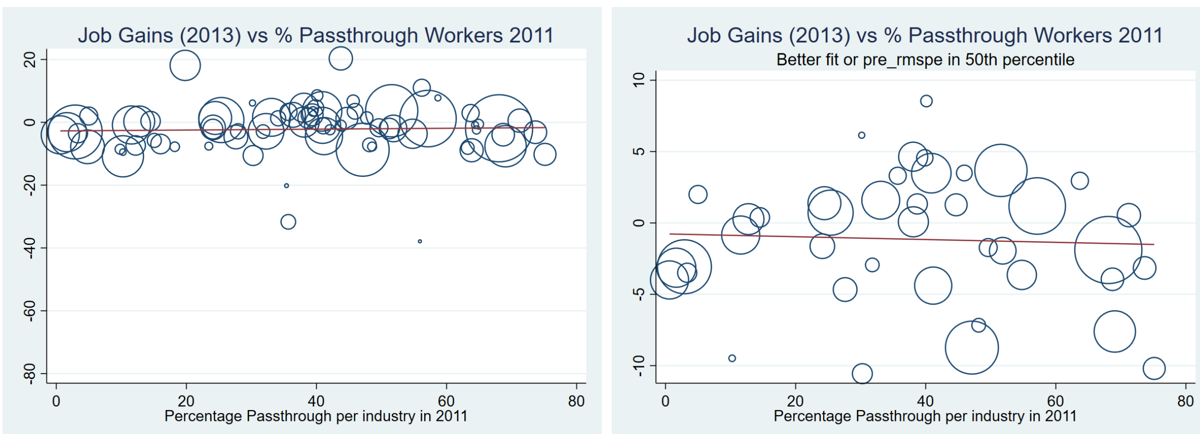


Figure C.2: 2013 All industries effects vs. pass-through percentages: All vs. better fit

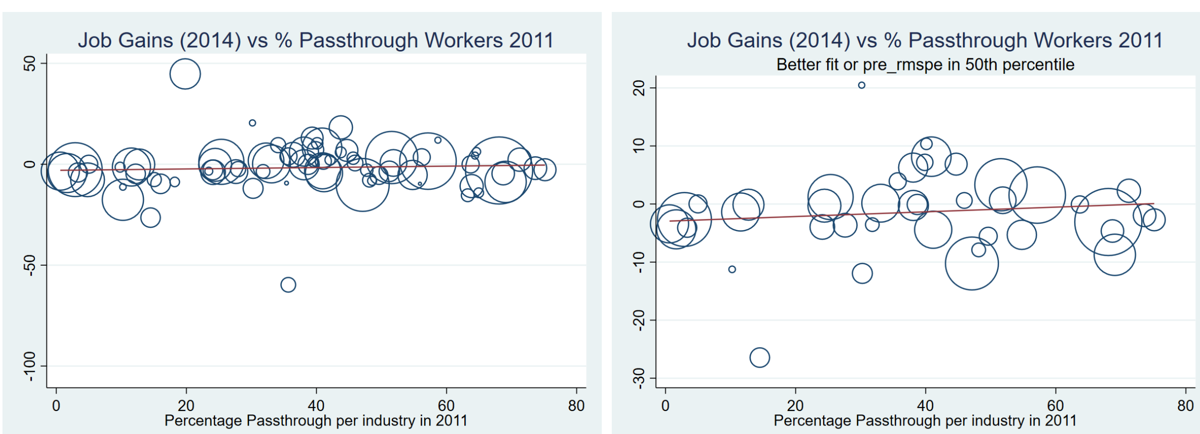


Figure C.3: 2014 All industries effects vs. pass-through percentages: All vs. better fit

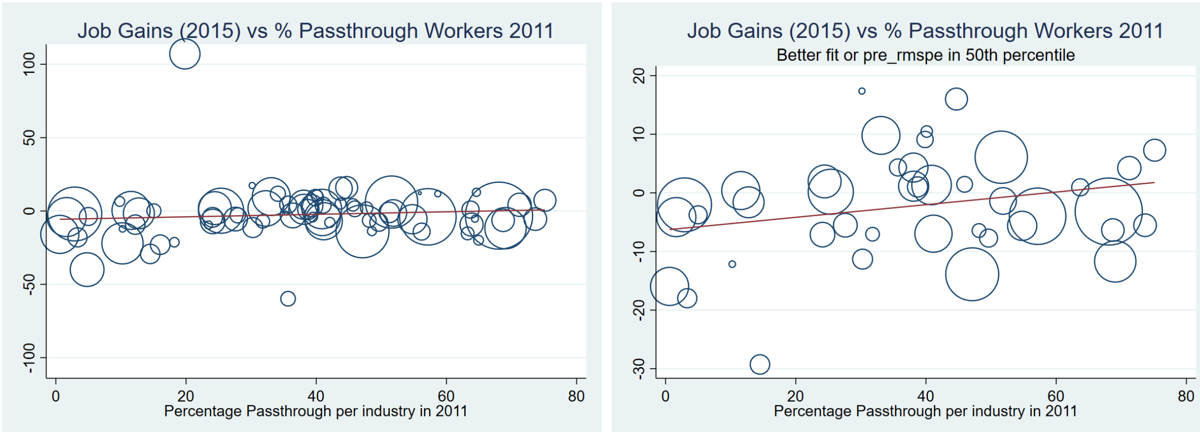


Figure C.4: 2015 All industries effects vs. pass-through percentages: All vs. better fit

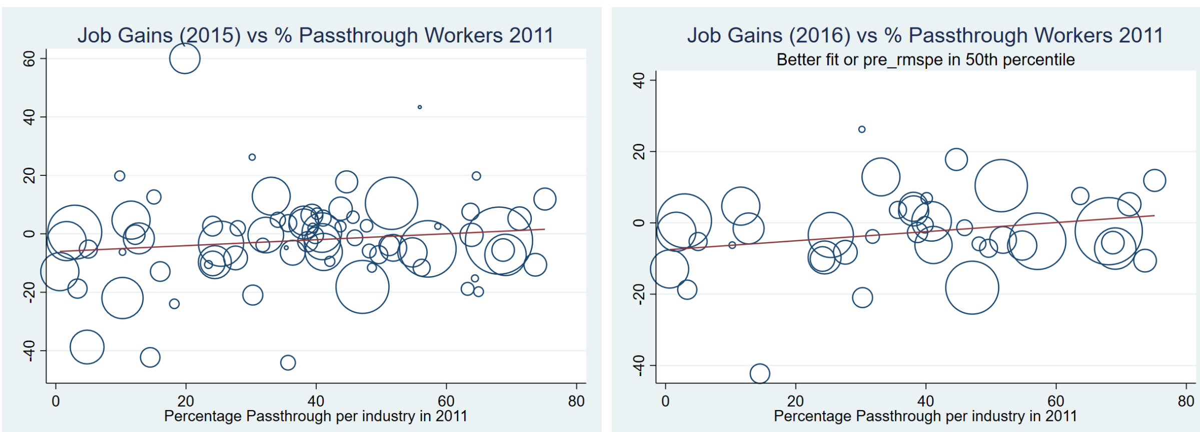


Figure C.5: 2016 All industries effects vs. pass-through percentages: All vs. better fit

C.2 Inference

In this section, we present the p-values for each outcome presented. This measure gives insights as to the likeliness of having the results occur randomly.

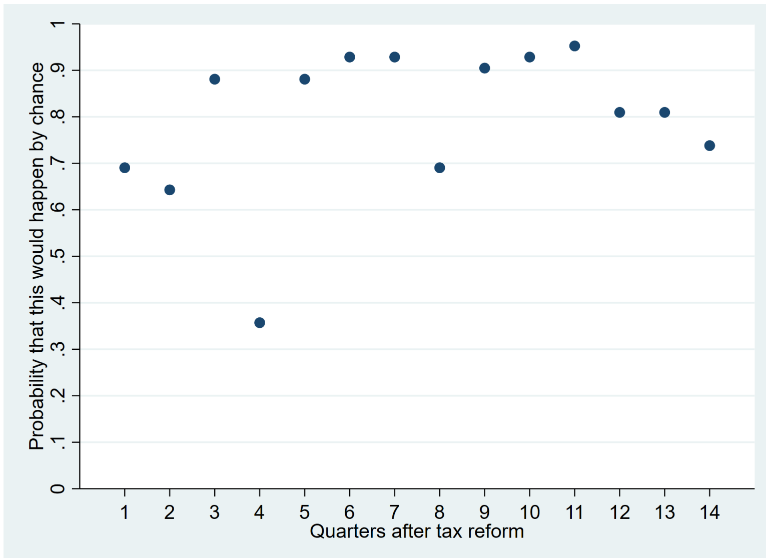


Figure C.6: Overall Kansas full quarter employment p-values.

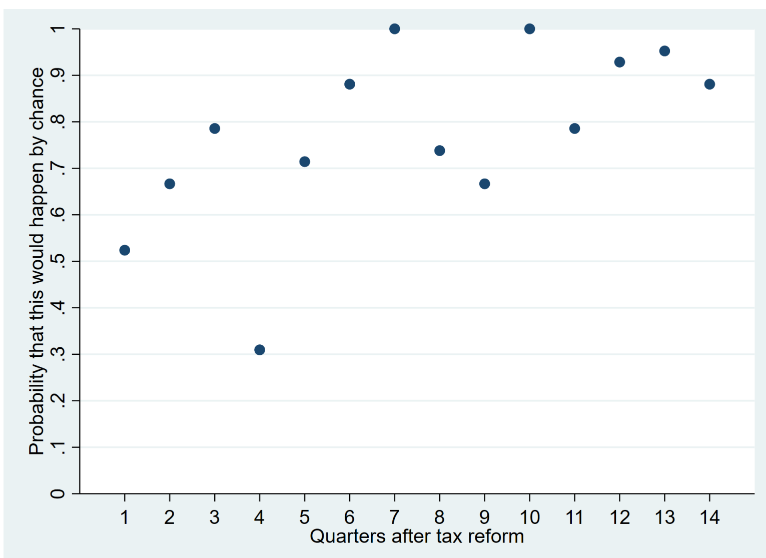


Figure C.7: Kansas full quarter employment p-values without aircraft manufacturing and energy sectors.

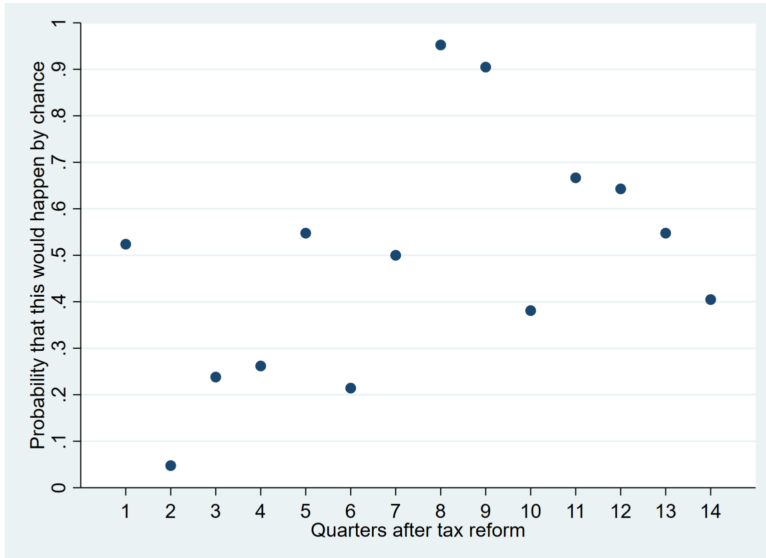


Figure C.8: Kansas without Wichita: p-values for full quarter employment.

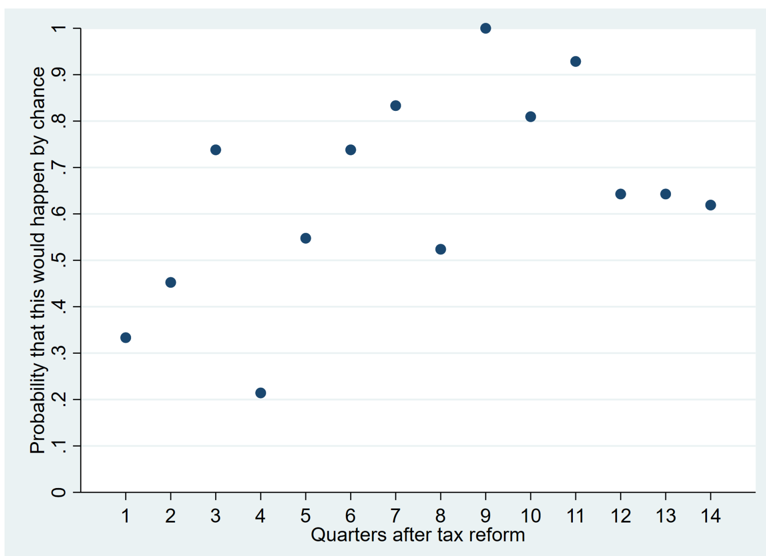


Figure C.9: Kansas without agricultural sector: P-values for full quarter employment.

C.3 On missing industries and states

For various reasons, certain industries in Kansas and some states do not appear in the analysis. Hereafter, we have given a summary of the missing and the reason for their absence. In terms of industries, the size or non-existence of a particular industry are the most common reasons found. For states as well, certain industries do not exist in certain states as well.

Table C.1: On missing Kansas industries

Industry	NAICS Code	Employment range	Comment on missing
Forestry and Logging	113	0-10 employees	Confidentiality
Rail and transportation	482	0-10 employees	Confidentiality, but also zero recorded. Non-zero payroll
Water transportation	483	No data	Non-zero payroll.
Scenic and Sightseeing Transportation	487	0-10 employees	Confidentiality with non-zero payroll
Postal service	491	0-20 employees	Confidentiality, but also zero recorded.
Monetary authorities Central bank	521	No data	Non-zero payroll
Funds, Trusts, and other financial vehicles	525	Over 200 employees	Only 2013q1 is missing
Space research and technology	927	No data	No data

Table C.2: On missing states in donor pools

NAICS	Missing	NAICS	Missing
114	Vermont, Oklahoma, North Dakota, New Mexico, New Hampshire, Nebraska, Iowa, Indiana, Delaware, Colorado, Kentucky, Montana, Arizona	211	South Carolina, Rhode Island, Georgia Oregon, North Carolina, Maine Minnesota, Maryland, Idaho, Hawaii Delaware, Connecticut, Arizona
212	Delaware	315	Alaska
213	Vermont, Rhode Island, Delaware, New Hampshire, Maine, Hawaii,	313	South Dakota, North Dakota, Nevada, Hawaii, Delaware,Alaska.
316	Vermont, South Dakota, North Dakota Hawaii, Delaware, Alaska	486	Vermont, Oregon New Hampshire, Hawaii, Delaware.
322	Montana, Alaska	324	South Dakota, Idaho
335	Hawaii, Alaska	331	North Dakota, Hawaii, Alaska.
524	Maine	533	Maine, Delaware, Alaska
611	Connecticut	924	Hawaii, Delaware
925	Delaware, Alaska	928	Utah, Rhode Island, Pennsylvania, New Mexico, Michigan, Maryland Illinois, Idaho, Hawaii, Delaware.

Notes: Massachussetts is out of the donor pools.

C.4 The synthetic control method for comparative studies

This section presents the detailed steps of the synthetic control method based on Abadie, Diamond and Hainmueller (2010) in the context of our particular study of tax reform. In this event study, we observe $J+1$ states and only Kansas is exposed to the income tax cuts. Based on the matching literature, we refer to all potential controls (New York, ..., Alaska) as the "donor pool". We also assume that the state of Kansas is uninterruptedly affected by the tax cut policy after the third quarter of 2012. Let Y_{it}^{N} be the outcome of interest in state i at time t in the absence of any intervention with $i = 1, ..., J+1$, and time periods $t = 1, ..., T$. Let T_0 be the number of pre-tax cuts quarters, with $1 \leq \mathrm{T}_0 < \mathrm{T}$. Let Y_{it}^{I} be the outcome observed for state i at time t assuming state i is exposed to the intervention in period $T_0 + 1$ to T. Our assumption is that the Kansas Tax Cuts have no effect on the outcome of interest before the implementation period (2012q3 in our case). In other words, for $1 \leq t \leq \mathrm{T}_0$ for all states we have $Y_{it}^{N} = Y_{it}^{I}$. Abadie, Diamond and Hainsmueller (2010) note that in practice, the impact of the policy change could be felt earlier than the legal enforcement date. In such cases they advise to reconsider T_0 in order to have it be the first period in which the outcome can possibly be affected.

The authors also assume that the notation implies no interference between units (see Rosenbaum (2007)). Let now $\alpha_{it} = Y_{it}^{I} - Y_{it}^{N}$ be the effect of the Kansas Tax Cuts for state i at time t, and let D_{it} be an indicator that takes value based on exposition. In other words, D_{it} is one if the state is Kansas and zero otherwise. The observed outcome for the state i at time t is:

$$Y_{it} = Y_{it}^{N} + \alpha_{it} D_{it}.$$

We consider Kansas as state 1. It is the only state exposed to the tax cuts and only after period T_0 (with $1 \leq T_0 \leq T$), we have that:

$$D_{it} = \begin{cases} 1 & \text{if } i = 1 \text{ and } t > T_0 \\ 0 & \text{otherwise.} \end{cases}$$

We target the estimation of $(\alpha_{1T_{0+1}}, ..., \alpha_{1T})$. For t $> T_0$,

$$\alpha_{1t} = Y_{1t}^{I} - Y_{1t}^{N} = Y_{1t} - Y_{1t}^{N}.$$

Each states beside Kansas is assigned a non-negative weight w_i such that all weights sum up to one. We thus have a $(J+1)$ vector of weights $W = (w_2, ..., w_{J+1})$. The weights defining a given synthetic control W^* are chosen to minimize the sum of squares:

$$\|X_1 - X_0 W\|_V = \sqrt{(X_1 - X_0 W)' V (X_1 - X_0 W)}, \tag{C.1}$$

where X_1 is a vector of predictor variables for Kansas, X_0 is a matrix of the same predictor variables for each donor pool state, and V is a symmetric, positive semi-definite matrix of weights assigned to the predictor variables. Abadie and Gardeazabal (2003) select predictor variables weights such that the outcome variable path for the treated unit in the pre-intervention period is best reproduced by the resulting synthetic control.

Once the weights vector W^* is obtained, we combine it with a matrix Y_0 of each donor state outcome values. We thus create the counterfactual outcome path $Y_1^* = Y_0 W^*$. The tax reform impact is given by the difference between the observed and the counterfactual value for Kansas after the reform. The dynamic treatment effect is thus:

$$\widehat{\alpha_{1t}} = Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt},$$

where $j = 1$ is Kansas and $j \in \{2, ..., J+1\}$ are the donor pool states, and T_0 is the number of pre-intervention quarters. The average treatment effect (ATE) is given by:

$$ATE = \frac{1}{T - T_0} \sum_{t=T_0+1}^{T} \widehat{\alpha_{1t}}.$$

The outcomes in both the treated and the donor pool states are assumed to follow a linear factor model:

$$Y_{jt}^0 = \delta_t + \theta_t Z_j + \lambda_t \mu_j + \epsilon_{jt}$$

where Y_{st}^0 is the outcome without intervention, δ_t are common time effects, θ_t is a vector of parameters, Z_j are observed covariates not affected by the reform, λ_t are unobserved common factor shocks, μ_j are unknown factor loadings, and ϵ_{jt} are unobserved, mean zero, state level transitory shocks. When $\lambda_t = 1$ and $\mu_j = \delta_j$, the model is simplified to a two-way fixed effects model. Hayes (2017) emphasizes that the SCM method has certain strengths, including:

- It is less arbitrary than many analogous methods of comparative studies because it uses a data driven process to the select the "control group". We show weights for each state involved.
- The SCM allows many robustness checks that include testing for statistical inference.
- The results can be reported visually, showing the disparity between actual Kansas and its synthetic control overtime.

Of these advantages, the last one is sometimes thought of as also the one that represents a challenge. In practice, the SCM does not provide an R^2 or other comparable statistics to rule for or against significance. To address this the authors expand on placebo procedures in Abadie, Diamond and Hainmueller (2015) and Abadie(2019).

C.4.1 An example with the crop production industry

We present a sample output from the SCM with the different weights and generated synthetic industry. Table C.3 shows that the actual crop production sector in Kansas is relatively similar to its constructed synthetic control. For each measure, the pre-treatment variables means are almost identical. Although this is not the case for every sub-sector, it is the ideal in the SCM framework.

Table C.3: Comparison of variables mean before the Kansas tax reform of 2012

Variables	Kansas crop production sector	Synthetic Kansas crop production sector
Full quarter employment	2667	2670.97
Quarter employment	3636.105	3641.215
Log payroll to workers	16.921	16.906

Notes: All variables except full quarter employment are averaged between the first quarter of 2006 and the first quarter of 2012. Full quarter employment is the variable of interest. A worker is recorded as employed only if he or she was employed before the quarter, during and after the quarter of interest. Quarter employment counts all workers employed in a quarter whether or not they were employed before and after. This measure is less stable due to possible turnover. The log payroll is the logarithm of the payroll received each quarter by workers of a particular industry.

Table C.4: States weights in the synthetic Kansas crop production industry

State	Crop production weight	State	Crop production weight	State	Crop production weight
Hawaii	0.144	Iowa	0.018	Maryland	0.839

Notes: The SCM does not allow extrapolation, so all weight are $0 \leq w_j \leq 1$ and $\sum w_j = 1$

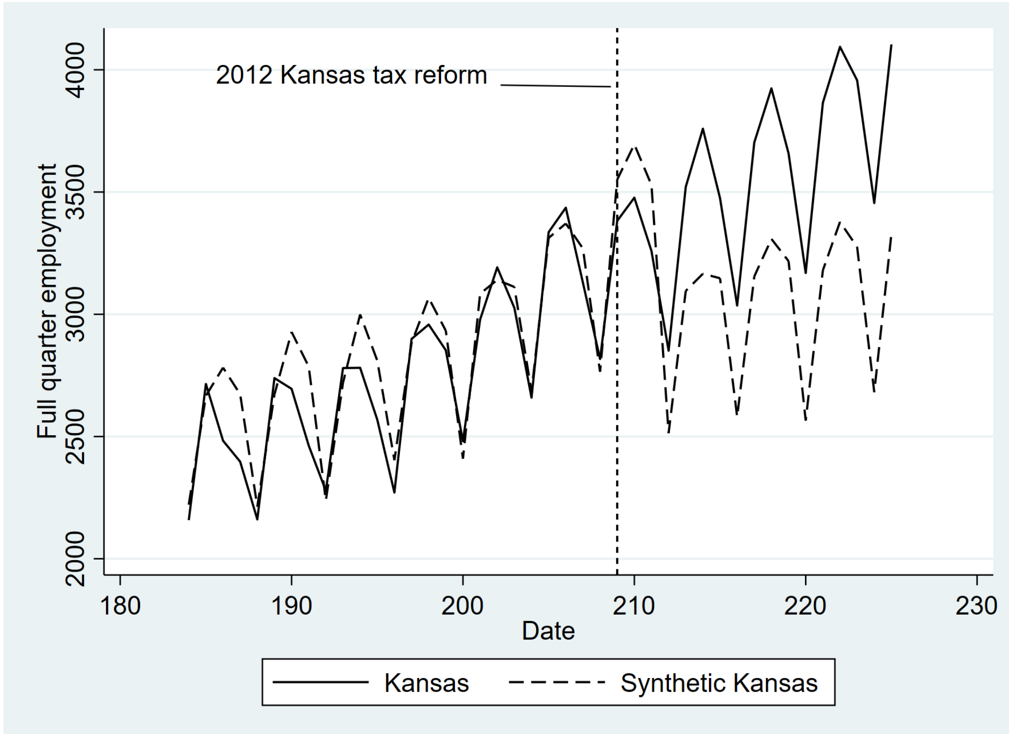


Figure C.10: Full quarter employment in crop production from 2005 to 2017: Kansas versus synthetic Kansas.