Unconventional Monetary Policy in a Modern Paradigm of Money and Two Other Essays

by

Ryan J Wessel

A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved March 2017 by the
Graduate Supervisory Committee:

Edward C. Prescott, Chair
Todd Schoellman
Bart Hobijn

ARIZONA STATE UNIVERSITY

May 2017

ABSTRACT

This dissertation contains a portfolio of papers in economics. The first paper, "Vehicle Emissions Inspection Programs: Equality and Impact," presents the results of a study of the Arizona Vehicle Emissions Inspection Program. Using a unique data set, I find that the Arizona Vehicle Emissions Inspection Program is regressive in that it constrains the vehicle repair decisions of people on the low end of the income distribution more than those on the high end. I also find that the social cost of the program in Arizona is more than twice the social benefit, assuming a $7 million value of statistical life. The second paper is "Fiat Value in the Theory of Value." Because of advances in information processing technology, it is now technically feasible to have a currency-less monetary system. This paper explores one such system. In the model, prices are in units currency-less fiat money called fiat value, fiat value is a form of government debt, and the services of the stock of fiat value are a factor of production. In this system, the National accounts must be revised to account for money as a production factor, Friedman satiation is possible even with positive inflation, and various monetary policy regimes are explored. The third paper, "Unconventional Monetary Policy in a Modern Paradigm of Money," uses the model developed in "Fiat Value in the Theory of Value" to evaluate quantitative easing and interest on reserves policies as a response to liquidity shocks. I find that quantitative easing is an effective response to liquidity crises because it drives the marginal product of money to zero. When the marginal product of money is zero, the business sector does not have to pay to rent the services of money, a production factor that is free to create. I also show that a positive interest on reserve policy hampers the effectiveness of quantitative easing, and that quantitative easing does not cause a high inflation rate.

Dedicated to my wife, Ambre.

Without her support, none of this would have been possible.

ACKNOWLEDGEMENTS

I wish to acknowledge the support of Edward C. Prescott, Todd Schoellman, Bart Hobijn, and Nick Kuminoff, who freely gave of their time and expertise in helping me with this research. I am grateful to the faculty and fellow students in the Economics Department of Arizona State University for many helpful comments. I also wish to thank the Arizona Department of Environmental Quality and the Arizona Motor Vehicle Division for allowing me access to useful data.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

This dissertation contains a porfolio of three papers. The first is "Vehicle Emissions Inspection Programs: Equality and Impact." In this paper, I evaluate the progressivity, environmental impact, and cost efficiency of Vehicle Emissions Inspection Programs. Using a unique dataset that combines vehicle emissions inspection results with owner address data, I find that the Arizona Vehicle Emissions Inspection Program is regressive in that it constrains the vehicle repair decisions of people in the low end of the income distribution more than people in the high end. Individuals with a lower annual income are both (i) more likely to drive vehicles that fail inspection at a higher average rate, and (ii) more likely to fail inspection conditional on vehicle characteristics. I also find that the social cost of administering the Vehicle Emissions Inspection Program in Arizona is more than twice the social benefit using a $7 million value of statistical life. Finally, I propose and test two counter-factual policies designed to increase the benefit/cost ratio and mute regressivity of Vehicle Emissions Inspection Programs.

The second paper is "Fiat Value in the Theory of Value," and is joint work with Edward C. Prescott. Because of advances in information processing technology, it is now technically feasible to have a currency-less monetary system. We explore one such system. We develop a model where the services of currency-less fiat money, called fiat value, are a form of interest bearing government debt, the services of which are a factor of production. Our main contributions include developing a general equilibrium theory-of-value model with currency-less fiat money, establishing a clear definition of government policy, showing how the national accounts must be revised to reflect a fiat value payment system, and exploring how various money interest rate target regimes and various inflation rate target regimes impact our measure of welfare. We also show that Friedman monetary satiation is possible without deflation.

The third paper is “Unconventional Monetary Policy in a Modern Paradigm of Money.” In this paper, I explore quantitative easing and interest on reserves policies in a currency-less fiat monetary system. Following the 2008 financial crisis, the Federal Reserve purchased government debt and real assets with central bank notes, swelling the size of the central banks assets to the unprecedented size of 25% of GDP. Also that year, Congress authorized the Federal Reserve to pay interest on excess reserves held by depository institutions at reserve banks. When evaluated in a fiat value general equilibrium framework, I find that quantitative easing is an effective response to liquidity crises because it drives the marginal product of money to zero. When the marginal product of money is zero, the business sector does not have to pay to rent the services of money, a production factor that is free to create. I also find that positive interest on reserves policies exacerbate a liquidity crisis by hampering the effects of quantitative easing. The interest on reserves rate is a lower bound on the marginal product of money. This study suggests that a central banking authority operating in this model world would insulate against liquidity crises by maintaining a permanently large balance sheet and setting the rate for interest on reserves to zero.

Chapter 2

VEHICLE EMISSIONS INSPECTION PROGRAMS: EQUALITY AND IMPACT

2.1 Introduction

The 1990 Amendments to the Clean Air Act mandated Vehicle Emissions Inspection Programs (VEIP) in large, metropolitan areas which do not meet certain federal air quality standards. The ostensible purpose of the program is to reduce pollution by identifying high polluting vehicles and requiring that owners have them repaired. Currently, 32 states, plus Washington DC, require some level of vehicle emissions testing in some areas. The purpose of this paper is to evaluate the progressivity, environmental impact, and cost efficiency of vehicle emissions inspection programs.

Data for this study comes from the Arizona Vehicle Emissions Inspection Program. Arizona is required by the Environmental Protection Agency (EPA) to run a VEIP in two cities (Phoenix and Tucson) that do not meet minimum air quality standards. The Arizona Department of Environmental Quality (ADEQ) administers the program and the program is implemented by a private contractor. The Arizona data is detailed, contains many data points, and contains information on many inspection methods. This makes it a good starting point. Future work to test the external validity of the Arizona results is needed.

One open question in the environmental economics literature is whether environmental policies are regressive, meaning do they impact the poor more than the rich. To address this question in the context of vehicle emissions inspection programs, I create a novel data set that combines emissions inspection data with confidential vehicle owner address data provided by the Arizona Motor Vehicle Division (MVD). Knowing owner address gives a measure of the vehicle owner's characteristics, including income, through the American Community Survey.

Using this combined dataset, I find that the Arizona VEIP is regressive in that it constrains the vehicle repair decisions of people in the low end of the income distribution more than people in the high end. Low income vehicle owners are both (i) more likely to drive vehicles that fail inspection at higher average rates, and (ii) more likely to fail an inspection conditional on vehicle characteristics. This implies that vehicle emissions abatement policies that subsidize vehicle repair or new car purchase will have a greater impact on pollution if participation in the program is subject to means testing. It also implies that programs designed to induce repair or update the fleet will have a different impact on pollution depending on the characteristics of the owners of the vehicles targeted.

Next, I ask whether vehicle emissions inspection programs reduce pollution, and whether they are cost effective. Using the universe of emissions inspection results from the 2013-2014 inspection cycle, I find that the Arizona VEIP does reduce pollution by identifying high polluting vehicles and mandating that they be repaired. However, the social cost of this program, paid in testing fees and vehicle repair costs, is approximately twice the social benefit using a $7M value of statistical life. The high social cost is primarily driven by testing fees as many vehicles must be inspected to identify only few violators.

In the final section of this paper, I propose and test two alternative policy implementation methods. In the first, I stratify vehicles based on observable characteristics, such as vehicle model year, and test the benefit/cost ratio of each stratum. I find that for vehicles registered in Tucson, in no stratum is the benefit of the inspection program higher than the cost. For vehicles registered in Phoenix, I find that the social benefit of the program exceeds social cost only for vehicles older than 2003 model year. Based on this finding, I suggest exempting from inspection the ten newest model years on a rolling basis. This will increase the overall benefit/cost ratio of the program and reduce the number of vehicles tested annually by half.

In the second alternative policy proposal, I explore ways to mute the regressivity of the program. Since owners with a higher annual income own a higher percentage of newer cars on average, a tax-and-transfer system that discriminates based on vehicle model year would disproportionately benefit lower income individuals, muting regressivity. I explain how such a system could be implemented in a politically feasible way.

The paper is organized as follows. Section two introduces the dataset created for this study. Section three evaluates the distributional impact of the program. Section four shows how the benefit/cost analysis was done. Section five discusses alternative policy schemes that would increase the benefit/cost ratio and mute the regressivity of the program. Section six concludes.

2.2 Data

The data used for this study was created by combining information from three government agencies:

1. *Arizona Department of Environmental Quality.* The ADEQ data contains the universe of emissions inspection results for the 2013-2014 emissions inspection cycle. It includes basic vehicle characteristics (including Vehicle Identification Number), whether the vehicle passed inspection, the level of pollutants emitted during each test (where available), and the price of repairs made between a failing test and a retest.

2. *Arizona Motor Vehicle Division.* The MVD data contains owner home address

data by VIN for every vehicle registered in Arizona during 2013-2014. Because of confidentiality concerns, zip code is the smallest statistical division allowed by the MVD.

3. *American Community Survey.* The ACS 2014 5-year estimates give average resident characteristics by home location, including annual income of households by zip code.

This study focuses on data from the 2013-2014 emissions inspection cycle. Using two years of data is appropriate for a number of reasons. First, most vehicles in the data set were inspected every other year, so the natural cycle of testing is two years. Second, there are systematic differences between vehicles tested during odd years and those tested during even years because the testing program was not implemented gradually. Averaging over two consecutive years alleviates these differences. Finally, there was concern that a longer study period would conflate cross-vehicle variation with long run advances in emission reduction technology.

There are four broad types of vehicle emissions tests used in Arizona. They are:

1. *On-Board Diagnostic (OBD).* Vehicles newer than 1995 model year are inspected using this test. Data that has been continually recorded by the vehicle's on-board sensors is used to evaluate whether the vehicles passes inspection. As long as certain on-board monitoring systems are working and monitored data did not exceed 2.5 times a federally mandated level, the vehicle passes inspection. In the 2013-2014 testing cycle, 66% of vehicles were tested with the OBD test.

2. *Inspection/Maintenance 147 (IM147).* Most 1981-1995 model year light duty gasoline-powered vehicles in Phoenix are inspected using the IM147 test. In this test, the vehicle is driven on rollers (called a dynamometer) at varying speeds to

simulate urban driving. The exhaust of three pollutants (hydrocarbons, carbon monoxide, and oxides of nitrogen) is measured. Levels of all three pollutants, measured in grams per vehicle mile, must be below a certain threshold to pass. In the 2013-2014 testing cycle, 7% of vehicles were tested with the IM147 test.

3. *Loaded/Idle*. Model year 1967-1980 vehicles (and some newer vehicles registered in Tucson), are inspected with the Loaded/Idle test. Exhaust is tested while the vehicle idles and again at approximately 25 miles-per-hour. Exhaust of hydrocarbons and carbon monoxide must be below a certain threshold to pass. About 9% of vehicles were tested with the Loaded/Idle test.

4. *Opacity Test*. Diesel vehicles are tested by measuring the opacity of the exhaust. Less than 5% of vehicles were inspected with this test.

Approximately two million vehicles are inspected annually in Arizona at an annual inspection cost of $36 million paid by vehicle owners. Table 2.1 reports summary statistics for emissions inspections in the 2013-2014 testing cycle. The majority of inspections were done in Phoenix. More than nine in 10 vehicles pass the inspection on the first try. Table 2.2 reports summary statistics for the vehicles tested during the 2013-2014 testing cycle. Vehicle characteristics are make, model, model year, and odometer reading. Makes are divided into the six most common manufacturers, plus a category for other vehicles. Vehicle models are grouped into one of four model categories by size. Examples of those categories are given in Table 2.2.

This study will focus on model year 1981-2008 non-diesel vehicles. Current policy exempts the five newest model years from inspection, so vehicles manufactured after 2008 are not fully represented in the 2013-2014 data. Figure 2.1 shows the number of vehicles by model year, divided among test type. Since the number of very old vehicles is low and since a new test type was introduced for model year 1981 vehicles,

Table 2.1: Emissions test summary statistics (annual average)

Number of Tests	1,905,159
Location	
Phoenix	78.6%
Tucson	20.1%
Other	1.3%
Pass on	
First test	91.7%
Retest	5.9%
Never	2.4%
Test Type	
OBD	65.6%
IM147	7.1%
Loaded/Idle	9.4%
Opacity	4.6%
Other/Missing	13.3%

all vehicles manufactured before this year were excluded.

Figure 2.2 shows the vehicle inspection pass rate for model years 1981-2008. Newer vehicles pass emissions inspections at a higher rate. Honda brand vehicles pass inspection more than average, and this is especially pronounced for newer model Hondas and for Hondas made during the 1980s. Ford vehicles made during the early 1990s pass inspection at a rate higher than trend. Across all vehicles and all model years in the study data set, 92% of vehicles pass the emissions inspection on the first try.

Table 2.2: Vehicle summary statistics

Vehicle Type (example)	
Cars (Fusion)	45.0%
Light Trucks (Ranger)	26.6%
Medium Trucks (F150)	16.9%
Heavy Trucks (F350)	11.5%
Vehicle Make	
Chevrolet	15.8%
Ford	15.3%
Toyota	11.1%
Honda	7.5%
Dodge	6.8%
Nissan	6.3%
Other	37.3%
Model Year	
Less than 1990	4.1%
1990-1995	8.2%
1996-2000	19.4%
2001-2005	37.6%
2006-2008	26.7%
2009+	4.4%
Ave. Odometer	116,340 miles

Figure 2.1: Number of vehicles inspected by model year

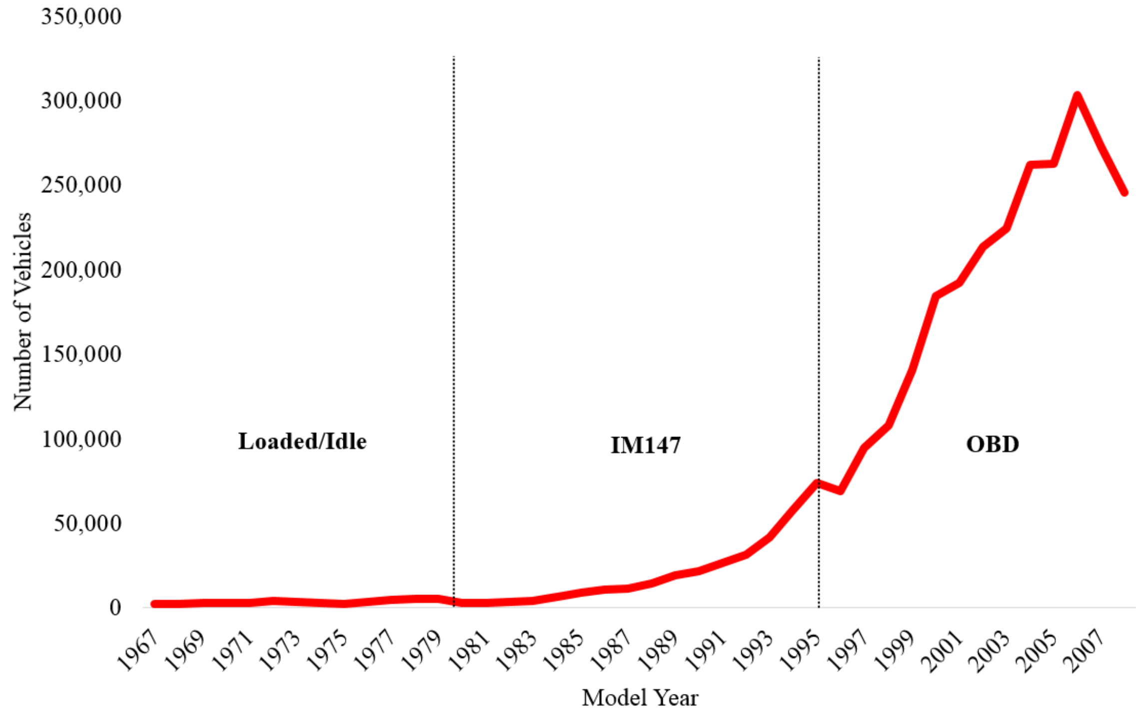
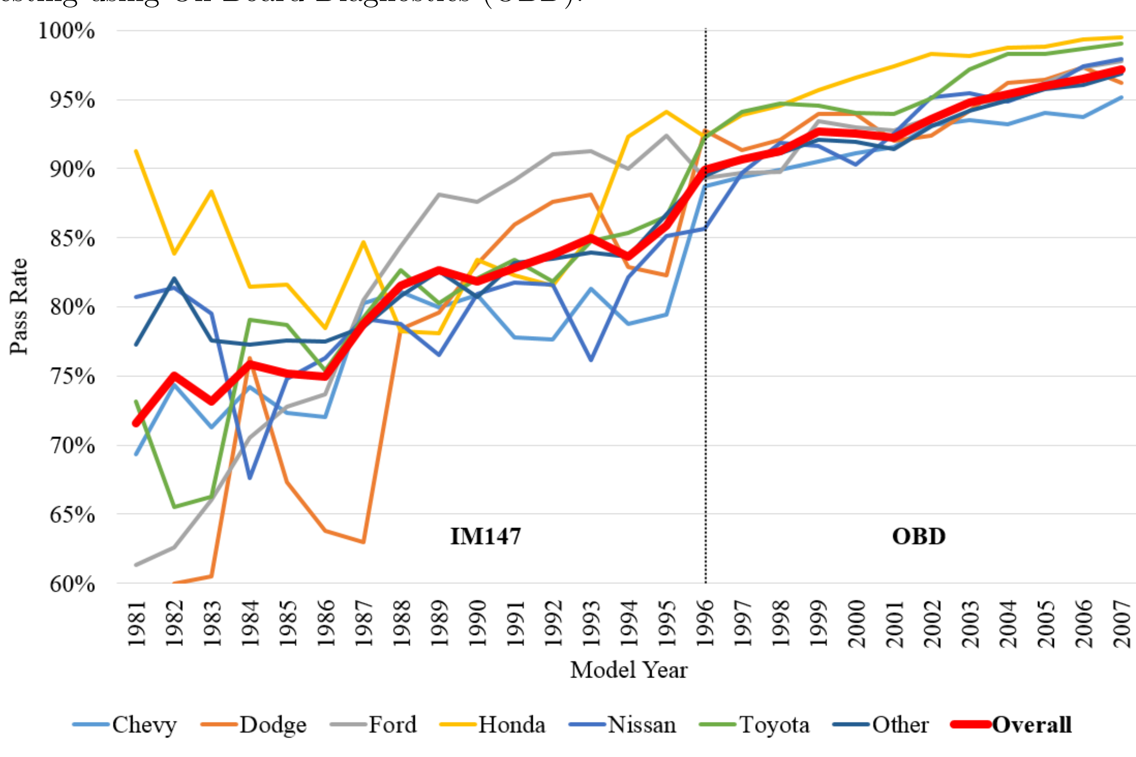


Figure 2.2: Percent of cars that pass on the first try by model year. Cars older than 1996 model year are tested with the IM147 test. Cars 1996 model year and newer are testing using On-Board Diagnostics (OBD).



2.3 Distributional Impact

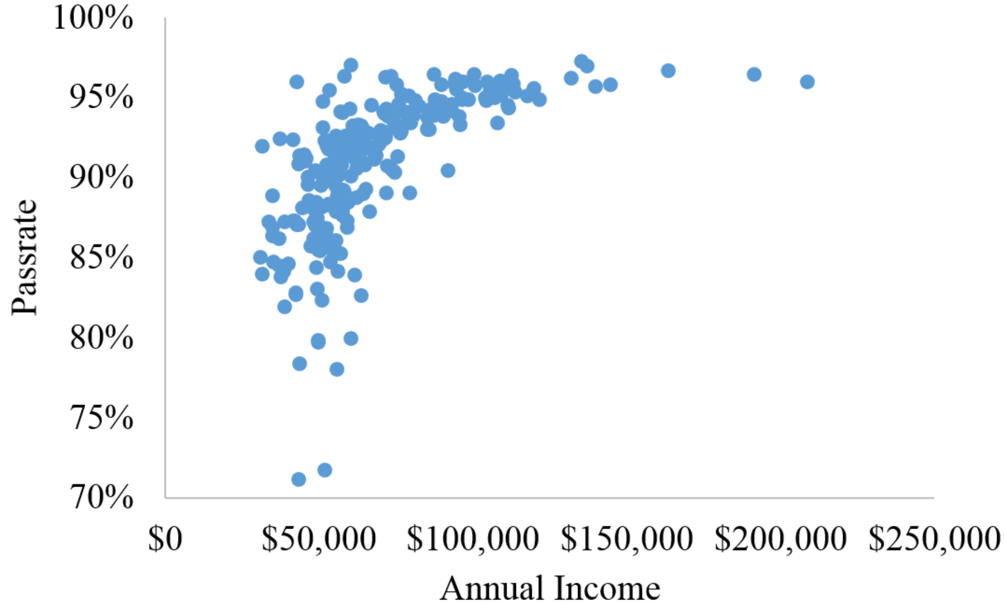
One open question in environmental economics is whether environmental policies are regressive in impact on people in the wealth distribution. Jacobsen 2013, Benzhaf 2011, Fullerton 2011, and Bento 2013 each show that various environmental policies are regressive, costing the poor more than the rich. However, Bento and Freedman 2014 find that air pollution mitigation programs increase home prices in poor areas more than in rich areas. They conclude that this one example of a progressive environmental policy.

In this section, I ask, "Are vehicle emissions inspection programs regressive?" I find that the Arizona VEIP is regressive in that it constrains the vehicle repair decisions of the poor more than the rich. Lower income owners fail initial emissions inspections more often than high income owners. Owners of vehicles that fail inspection are required to make vehicle repairs that they did not choose to make without the program. The regressivity works through two channels. Owners with lower average annual income are both (i) more likely to drive vehicles that fail the inspection at higher average rates, and (ii) more likely to fail an inspection, conditional on vehicle characteristics.

To assign ACS income data to specific vehicles, I define a household as one vehicle. About 61% of addresses in the study data have only one vehicle registered at that address. For the 24% of addresses with two vehicles and 15% of address with three or more vehicles, I assume that multiple households are residing at the same address. Eliminating addresses with multiple vehicles from the data set does not qualitatively change the results. Further research on multiple-vehicle households could yield fruitful results.

Figure 2.3 shows the percent of vehicles at each income level that passed the

Figure 2.3: Percent of vehicles that passed emissions testing on the first try, by annual income in each zip code in which the vehicle was registered.



vehicle emissions inspection on the first try. Vehicles associated with post office boxes, vehicles regiestered out of state, and zip codes with fewer than 50 observations were dropped. There is an upward trend, meaning that owners who live in areas with a higher average annual income are more likely to pass the emissions inspection on the first try.

A number of factors could contribute to a passing an emissions inspection, including both owner characteristics and vehicle characteristics. To understand what vehicles characteristics and owner characteristics contribute to passing the inspection, I use a linear probability model to regress owner and vehicle characteristics on inspection passage rate. The assumed data generating process is

$$E = \beta_0 + \beta_1 w + \beta_2 V + \beta_3 X + \epsilon \tag{2.1}$$

where

E=probability of passing the emissions test w = annual income of owner

V = vehicle characteristics (odometer, make, model, model year)

X = controls (test type, county, test station, observation year)

ϵ = error

Table 2.3 summarizes the results. Column (1) displays the results of a linear probability model. Because probability of passing is always close to 1, in Column (2) I repeat the regression with a logit model. Standard errors are clustered by zip code.

In both specifications, the coefficient on odometer is negative and the coefficient on model year is positive. This is expected. Newer vehicles pass more often. Vehicles with higher miles pass less often. The coefficients on vehicle make show that Hondas are more likely to pass an emissions inspection than any other model in the study. The reference vehicle make is Chevrolet. Since all the coefficients under vehicle make are positive, this means that Chevrolets are least likely to pass the emissions inspection on average.

The coefficient on income is significant and positive, even when controlling for vehicle characteristics and location fixed effects. This implies that a person with lower annual income is less likely to pass the emissions inspection, even if he drove the same make, size, and mileage of vehicle as a person with higher annual income. The magnitude of the effect is approximately the same as that of odometer reading: a $10k increase in the income of the owner has approximately the same effect on the probability of passing the emissions inspection as a reduction of 10,000 miles on the odometer.

The effect of income, even when controlling for vehicle characteristics, could be an indicator of how well different income groups service their vehicles. Perhaps individuals with a higher annual income change the oil more often, replace the tires

Table 2.3: Dependent variable is probability of passing emissions test. Linear model standard errors clustered by zip code. Logit coefficients converted to at-mean margins. Logit model standard errors calculated using delta method.

	(1)	(2)
	Linear	Logit
Income ($10k)	0.003**	0.003**
	(0.000)	(0.000)
Odometer (10k miles)	-0.003**	-0.002**
	(0.000)	(0.000)
Model Year	0.005**	0.004**
	(0.000)	(0.000)
Make		
Honda	0.045**	0.031**
	(0.001)	(.000)
Toyota	0.044**	0.030**
	(0.001)	(.000)
Nissan	0.021**	0.013**
	(0.001)	(.001)
Ford	0.019**	0.012**
	(0.001)	(.000)
Dodge	0.018**	0.011**
	(0.001)	(.001)
Other	0.018**	0.009**
	(0.001)	(.000)
N	2,243,195	2,243,195
(pseudo) R^2	.06	0.11
Clusters	358	

* 5%, **1%

more often, or get the vehicle aligned more often. These maintenance activities could contribute to the likelihood a vehicle will pass the emissions inspection.

There is a statistically significant income coefficient if I run the same long regression on the levels of each of the three measured pollutants (HC, CO, NOx) instead of on the probability of passing the emissions inspection. Even when controlling for vehicle characteristics and location fixed effects, higher income is associated with lower levels of HC, CO, and NOx. Results of these regressions are presented in Table 2.4.

The income effect is seen in other aspects of the data. In Table 2.5, I show the average number of tests before the vehicle passes, broken up by quintile of the income distribution. People with lower annual income retest more often before passing. In Table 2.6, I show the percent of vehicles tested that never pass the emissions inspection despite multiple tries, by quintile of the income distribution. People with lower annual income are more likely to never pass the emissions inspection.

These results suggest that the Arizona VEIP is regressive in the way it constrains the vehicle repair decisions of owners. Owners with lower annual income are more likely to be required to make vehicle repairs they did not choose to make prior to the inspection. Comparing an average lowest income quintile owner to an average highest income quintile owner, about half of the difference in inspection pass rate is attributable to vehicle choice and about half attributable to owner income.

This result is significant because it informs policy. A vehicle emissions abatement policy based on emissions monitoring will disproportionately constrain the vehicle repair choices of the poor. Further, a program designed to update or repair the fleet of vehicles will have a different impact on pollution depending on the characteristics of the owners of the vehicles targeted.

Table 2.4: Results of linear probability regression. Dependent variable is level of pollutant specified, measured in grams emitted during first failing test. Standard errors clustered by zip code.

	CO	HC	NOx
Income ($10k)	-0.301**	-0.019**	-0.035**
	(.046)	(0.003)	(0.005)
Odometer (10k miles)	0.015**	0.002**	0.004**
	(0.001)	(0.000)	(0.000)
Model Year	-0.716**	-0.052**	0.031**
	(0.053)	(0.004)	(0.005)
Make			
Dodge	-0.535	-0.074	0.493**
	(0.377)	(0.025)	(0.047)
Ford	-2.638**	-0.364**	-0.494**
	(0.297)	(0.022)	(0.026)
Honda	-1.753**	-0.371**	-0.447**
	(0.333)	(0.019)	(0.026)
Nissan	-1.742**	-0.337**	-0.203**
	(0.342)	(0.020)	(0.033)
Toyota	-4.637**	-0.472**	-0.539**
	(0.323)	(0.021)	(0.025)
Other	-1.234**	-0.201**	-0.059**
	(0.269)	(0.018)	(0.021)
N	109,172	109,172	109,172
R^2	0.07	0.374	0.448
Clusters	275	275	275

* 5%, **1%

Table 2.5: Average number of tests before the vehicle passes, by quintile of the income distribution.

Income Quintile	Number of Tests Before Pass
First ($13K - $49k)	1.31
Second ($49K - $59k)	1.25
Third ($59K - $71k)	1.22
Fourth ($71K - $91k)	1.18
Fifth ($91K +)	1.15

Table 2.6: Percent of vehicles that never pass emissions, by quintile of the income distribution.

Income Quintile	Percent Never Pass
First ($13K - $49k)	3.6%
Second ($49K - $59k)	2.5%
Third ($59K - $71k)	1.9%
Fourth ($71K - $91k)	1.3%
Fifth ($91K +)	0.9%

2.4 Impact and Cost Effectiveness

While it is clear that a Vehicle Emissions Inspection Program does induce some vehicle owners to make emissions reducing repairs, what is the overall effect of the program? Further, if vehicle inspection programs do reduce emissions, are the emissions reductions high enough to justify the cost of the program? These questions are explored in this section.

2.4.1 Impact

The total reduction in emissions from a VEIP is not straightforward to calculate. This is because the majority of vehicles inspected are tested by reading data from the vehicle's On-Board Diagnostic (OBD) system. OBD tests do not provide data on emissions levels of the vehicle, but only report binary data on whether the vehicle's engine monitoring systems are in working order, and whether certain values have stayed within a required range.

While the OBD tests does not provide a direct measures of pollution, it does have many advantages. It is more comprehensive than a tailpipe emissions test. A vehicle's OBD system *continuously* monitors up to 11 emissions control related subsystems. If more than one of these subsystems malfunctions, or if certain values related to emissions ever exceed predetermined limits, the vehicle cannot pass an OBD emissions inspection without repairs. It is also a faster, more convenient test. In the Arizona data, OBD tests took 93 seconds on average, while IM147 tests took 243 seconds.

While the OBD test does have the advantages discussed above, it also has disadvantages. As a computer-to-computer test, there is opportunity for fraud. Numerous websites offer software that will fraudulently eliminate diagnostic trouble codes. Volkswagen is infamously known for installing software that interfered with OBD tests; the Volkswagen software would not have interfered with a tailpipe emissions test. There is also concern over lack of overlap between the set of vehicles that fail the OBD test and those that fail a tailpipe emissions test (Canada 2004).

Despite these concerns, OBD is the standard method used by states that run a Vehicle Inspection/Maintenance program to test the majority of vehicles. As the percent of the vehicle fleet newer than 1996 model year increases over time, the portion of vehicle inspections done using the OBD test will increase.

Fortunately, a portion of the vehicles in this study were tested using the IM147 test, which measures levels of pollutants emitted by the vehicle. This allows for a direct calculation of pollution reduction on these vehicles. The method currently used by the EPA for measuring emissions reduction relies on differencing the pollution level of vehicles that fail the IM147 emissions inspection and the pollution level of those same vehicles when they pass a retest. The formula used, in units of grams per vehicle-mile, is

$$\Delta_{iyc} = \frac{\sum \frac{p_{iyc}^{fail}}{x_{yc}^{fail}} - \sum \frac{p_{iyc}^{retest}}{x_{yc}^{retest}}}{N_{yc}} \tag{2.2}$$

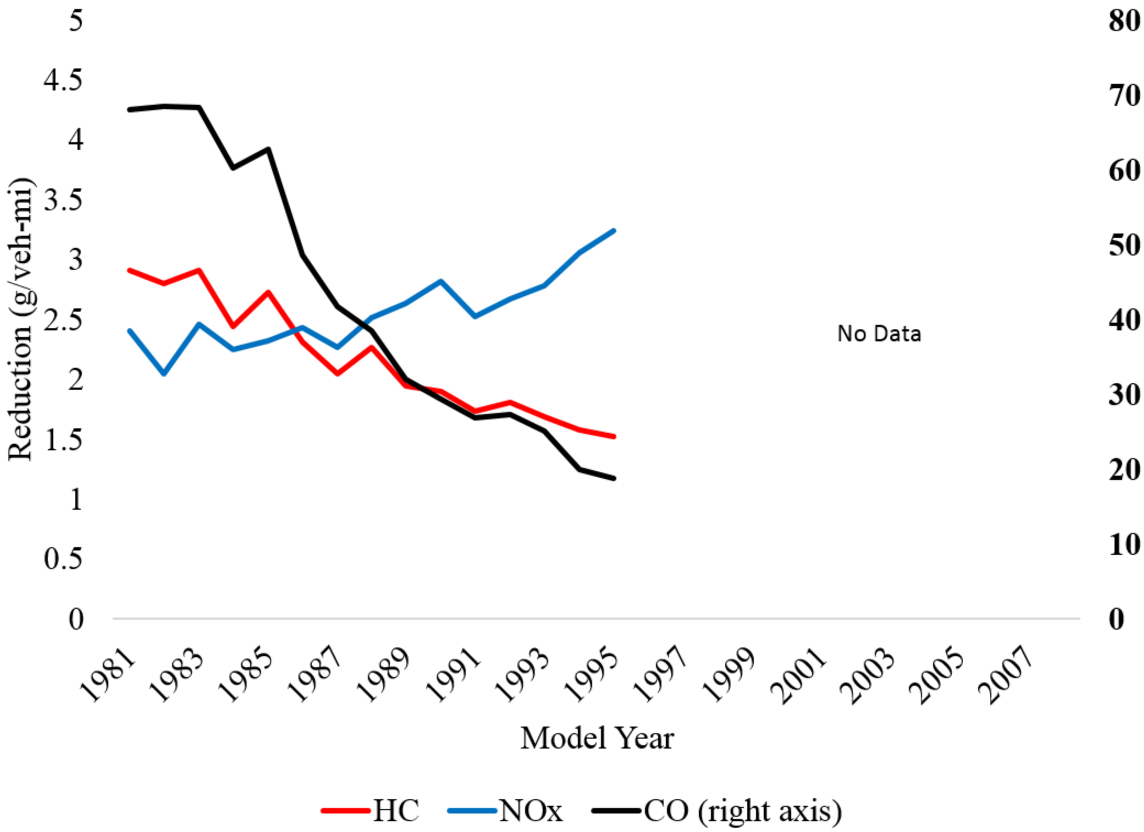
In (2.2), $i \in \{HC, CO, NOx\}$ is the measured pollutant, $y \in [1981, 1995]$ is vehicle model year, $c \in$ {light duty vehicles, light trucks, medium trucks} is a broad category of vehicle size, p is the total grams of pollutant emitted during the test, x is the miles driven during the test, and N is the number of vehicles in the bin.

Figure 2.4 shows average emissions reductions per vehicle-mile for each of the three measured pollutants across model years. No data is reported for model year 1996-2008 vehicles because they are inspected using the OBD test which does not provide emissions data.

Note that the data presented in Figure 2.4 only includes vehicles older than 1996 model year that fail the initial inspection and pass a subsequent inspection. This represents 1% of all vehicles inspections during the study period, and only 6% of the set of vehicles that fail the first test and pass a subsequent test. It also ignores the effect of the program on individuals who make emission reducing vehicle repairs *before* the first emissions inspection. This, however, may not be a bad assumption since retesting is free. An owner has incentive to try to pass an emissions inspection before paying for repairs.

Filling in the missing data for model year 1996-2008 requires an assumption. I assume that a smoothly varying inspection *pass rate* across model years equates to a smoothly varying *emissions reduction* across model years. The inspection pass rate

Figure 2.4: Reduction of pollutant by model year. CO is on right axis.

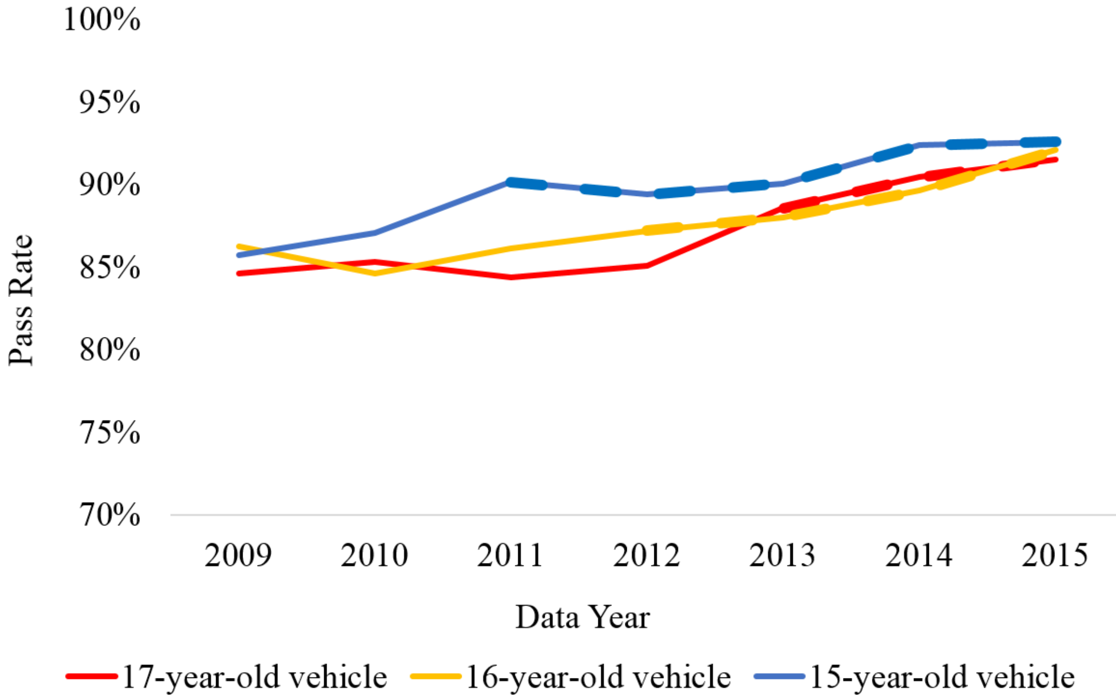


varies smoothly both across model year at one point in time, and across time in one model year. Figure 2.2 shows that the inspection pass rate varies smoothly across model year for the 2013-2014 emissions testing cycle. Figure 2.5 shows that 15-, 16-, and 17-year-old vehicles have a smoothly varying inspection pass rate across time and test types.

While there is a discontinuous change in emissions *monitoring* technology between 1995 and 1996 model years, there is no discontinuous change in emissions *abatement* technology. This is further evidence that emissions reduction levels might vary continuously across model years.

Admittedly, the assumption used to fill in the missing 1996-2008 data is important to the results of this section. A few alternative assumptions, such as applying the 1995

Figure 2.5: Inspection pass rate for 15-, 16-, 17-year-old vehicles across time. The smooth portion of the line means the vehicle was inspected with the IM147 test; the dotted portion means the vehicle was inspected using the OBD test.



reduction level to all subsequent model years, were explored. The results presented here are quite robust to the assumption used.

Figure 2.4 shows that in each of the three measured pollutants, there is a trend across model years, upward for NOx, and downward for HC and CO. I use OLS to estimate the trend and extrapolate emissions reduction levels for 1996-2008 model years from the 1981-1995 data. A simple data generating process with good fit is

$$ln(\Delta_{iy}) = \beta_0 + \beta_1 y \tag{2.3}$$

where Δ is measured emissions reduction, $i \in \{HC, CO, NOx\}$, and $y \in [1981, 1995]$ is vehicle model year. Here β_0 is a level parameter and β_1 is an exponential decay/growth parameter. Data is weighted by number of vehicles in each model year.

Using the estimated parameters $\tilde{\beta}_0$ and $\tilde{\beta}_1$, and the data generating process assumption, I extrapolate expected emissions reduction for $y \in [1996, 2008]$ model years.

Figure 2.6: Extrapolated reduction of pollutant for model years 1996-2008. CO is on right axis.

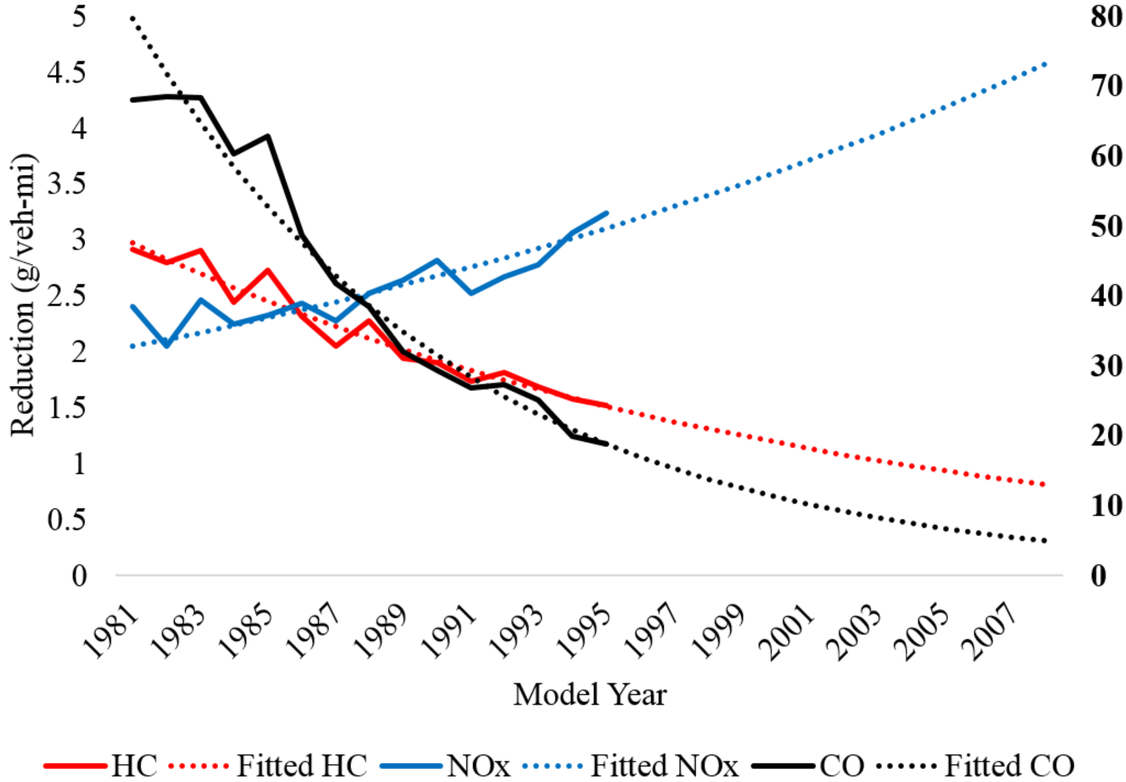


Figure 2.6 shows the OLS fitted trend line and extrapolated values for each of the three pollutants in all relevant model years.

With values for each model year, estimating the impact of the Arizona VEIP is straightforward. In Table 2.4.1, the per-vehicle-mile reduction in pollutant is estimated by taking a weighted average of emissions reductions for each model year 1981-2008, weighting each model year by the number of vehicles that fail an inspection and then later pass for that model year. If I assume each repaired vehicle is driven the national average of 13,500 miles per year, I can calculate the annual impact of the Arizona program in units of tons of pollutant per year. This is also shown in Table 2.4.1. For scale, the last column of Table 2.4.1 shows that the VEIP induced reduction of NOx is approximately 8% of the total NOx emission from on-road vehi-

Table 2.7: Reduction in grams per vehicle mile of Hydrocarbons (HC), Carbon Monoxide (CO), and Oxides of Nitrogen (NOx).

Pollutant	Extrapolated Reduction	Impact (tons/year)	Reduction (% of total)
HC	1.28 g/veh-mi	1612	
CO	14.5 g/veh-mi	18277	
NOx	3.57 g/veh-mi	4512	7.96%

cles in the Phoenix 8-hour ozone non-attainment area, as reported by the Maricopa County Air Quality Department.

2.4.2 Cost and Benefit

The monetary cost of the Arizona Vehicle Emissions Inspection Program is given in the data. Monetary costs come from two sources: the fee for taking the test and the cost of vehicle repairs. The test fee is approximately $20 per vehicle and is reported in the data. The cost of repairs is self-reported by the vehicle owner when a vehicle is brought back to the testing station for a retest. Time costs, psychological costs, or other intangible costs are not included in the data.

The average total annual cost for the 2013-2014 testing cycle is $36 million from testing fees and $12.6 million from *reported* vehicle repair costs. Only 17.1% of retests report any repair costs. This could be because the owner obtained free repairs, or because the owner chose not to report the cost of repair. Because of this, the number reported for repair costs represents a lower bound. The average repair cost for owners that reported a non-zero repair cost is $203 per vehicle. If I assume that the average repair cost applies to all repairs with a zero reported repair cost, then the total cost of repairs is $73.4 million and the total program cost is $109.5 million. Cost information is summarized in Table 2.8.

Table 2.8: Annual cost, averaged across the 2013-2014 testing cycle, of the Arizona Vehicle Emissions Inspection Program.

Average Annual Cost	$48,449,512	
Test fee	$35,861,995	74%
Repair cost	$12,587,517	26%

Table 2.9: Assumed benefits from a reduction of one ton of each measured pollutant. Prices in 2014 dollars.

Pollutant	**Benefit**	**Source**
Hydrocarbons	$1,141/ton	EPA, social cost of methane
Carbon Monoxide	$41/ton	EPA, social cost of carbon
Oxides of Nitrogen (Phoenix)	$6,824/ton	AP2 model, ground level
Oxides of Nitrogen (Tucson)	$2,675/ton	AP2 model, ground level

To calculate the benefit of the program, I use measures of social costs of pollutants from various published sources. The Environmental Protection Agency reports a social cost of carbon and a social cost of methane. I assume these costs represent the social benefit of a reduction in emissions of carbon monoxide and hydrocarbons, respectively. While methane is not the only hydrocarbon measured in the emissions tests, it is the closest proxy for which there is a published social cost. To measure the social benefit of a reduction in NOx, I use the Muller, Mendelsohn, Nordhaus (2011) AP2 model. The AP2 model gives a county-specific estimate of the marginal social damages of NOx.

The AP2 model assumes a $2 million value of statistical life (VSL), while the models used by the EPA have an implicit VSL assumption of approximately $7 million. All values are in 2014 dollars. Because VSL is a units conversion parameter in this exercise, I rescaled the values in the AP2 model to match a $7 million VSL assumption. These benefit value assumptions are summarized in Table 2.9.

Table 2.10: Benefit/Cost ratio of the Arizona Vehicle Emissions Inspection Program.

City	**Benefit/Cost Ratio**		**Break-even VSL**
	(1)	*(2)*	
Phoenix	1.01	0.22	\$6.9 M
Tucson	0.45	0.10	\$15.7 M

To calculate the benefit/cost ratio of the Arizona VEIP, I multiply annual emissions reductions by social benefit, and divide by total cost of the program. In Table 2.10, I report an upper and lower bound. The upper bound (reported as column *(1)* in Table 2.10) is calculated assuming that VSL is \$7 million and that *reported* repair costs represent all repair costs. The lower bound (reported as column *(2)* in Table 2.10) is calculated assuming VSL is \$3.5 million and that the average vehicle repair cost of \$203 was the true repair cost for each vehicle that did not report a repair cost. My preferred value for the Benefit/Cost ratio comes from assuming VSL is \$7 million, and that reported repair costs represent all repair costs. In this case, \$100 spent on the VEIP in Phoenix produces \$44 of social benefit, and \$100 spent on the VEIP in Tucson produces \$20 in social benefit. Adding time costs, psychological costs, and other intangible costs would further drive the benefit/cost ratio down.

In the final column of Table 2.10, I report the VSL assumption needed for the VEIP to break even, meaning the measured social cost of the program is equal to the measured social benefit. In this case, I assume that reported repair costs represent actual repair costs. In Tucson, break-even VSL is \$15.7 million and in Phoenix it is \$6.9 million. These numbers are approximately twice as big if I apply the average vehicle repair cost to all vehicles with a reported repair cost of zero. These results imply that it is difficult to justify the VEIP in Tucson based on a benefit/cost analysis. The Phoenix program is only justifiable under generous assumptions.

2.5 The Future of Emissions Testing

I have shown that the Arizona VEIP has a measured social cost higher than the measured social benefit. I have also shown that it is regressive, constraining the repair choices of the poor more than the wealthy. In this section, I ask the question, "How can the emissions inspection program be improved?" I define improvement as either (i) the measured cost is decreased relative to the measured benefit or (ii) the regressivity of the program is muted. The wealth of data about both vehicles and owners of those vehicles makes exploring such improvements possible.

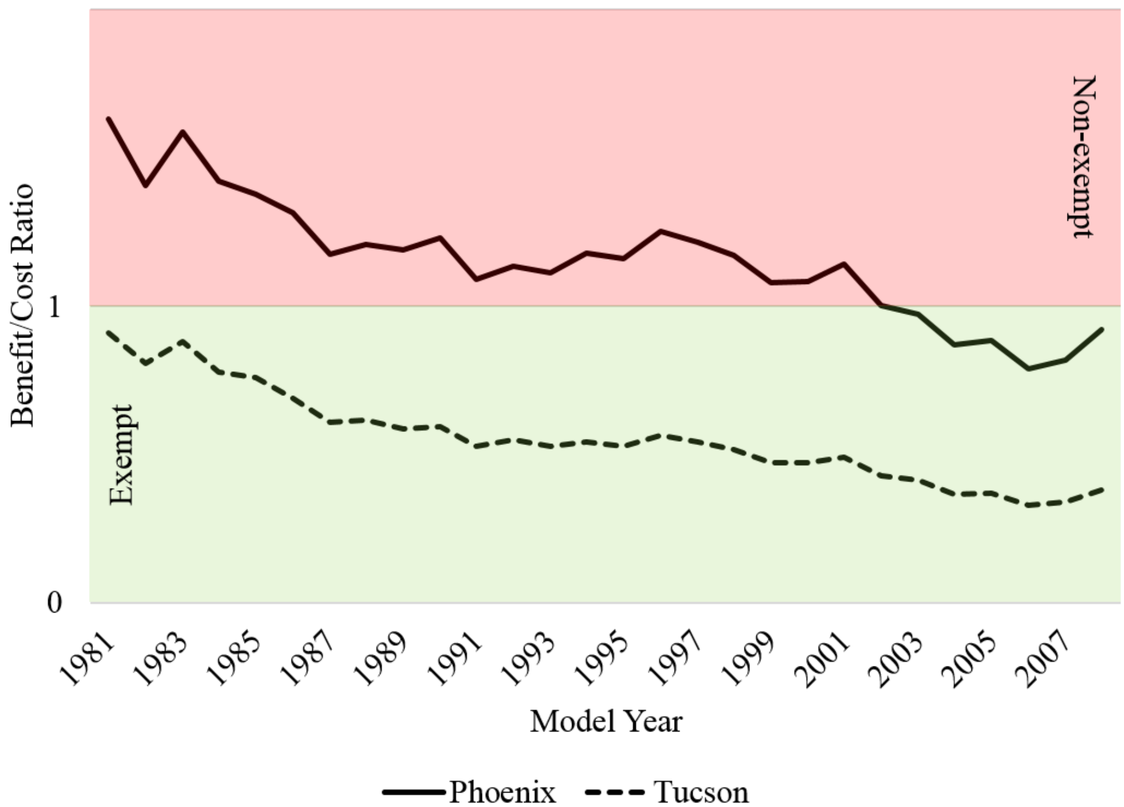
2.5.1 Improving Cost/Benefit

Different vehicle types have different pollution profiles (see Figure 2.6), different repair costs, and different inspection passage rates. Suppose the vehicle emissions inspection requirement were only imposed on those vehicle-type bins that have calculated social benefit higher than cost. For example, one could evaluate the benefit/cost ratio of a bin of 1995 Light-Duty Nissan Trucks. The results of evaluating the benefit/cost ratio of each possible vehicle-type bin are difficult to present in readable tables, but are unsurprising. Old, American-made vehicle bins tend to higher benefit/cost ratios.

It is not difficult, however, to present a series of benefit/cost analyses on vehicle-type bins discretized by only one vehicle characteristic. Considering the political feasibility of exempting some vehicles from inspection, perhaps model year is an acceptable stratification of vehicle-type bins. The five newest model years are already exempt from inspection.

Using the data on the 2013-2014 emissions inspection cycle, I ask, "Which model years would have been exempted from testing because the cost of testing that model

Figure 2.7: Benefit to cost ratio by vehicle model year. Assumes VSL is $7 million, reported repair costs represent all repair costs, and uses the extrapolation method for calculating emissions reduction for model years 1996-2008.



year exceeded the social benefit?" I use the benefit assumptions described in Table 2.9, a VSL of $7M, and only *reported* repair costs. I also assume that a counter-factual emissions inspection policy would have had no effect on the composition of the vehicle fleet, the repair decisions of owners, or the average annual miles driven. The results are summarized in Figure 2.7.

In this counter-factual policy, all vehicles would be exempt from inspection in Tucson because the measured benefit of inspection does not exceed the estimated social cost for each model year. In Phoenix, vehicles newer than model year 2002 would be exempt from inspection. The difference between Tucson and Phoenix arises because the marginal benefit of decreasing NOx emissions is lower in Tucson than in

Phoenix, as is shown in Table 2.9.

This result has policy implications. Policymakers could increase the benefit/cost ratio of the Arizona VEIP by canceling the Tucson program and exempting the 11 newest model years from inspection in Phoenix. Because of the downward trend in benefit/cost ratio across model years, exempting the newest model years is likely to have a positive effect on benefit/cost ratio of VEIPs.

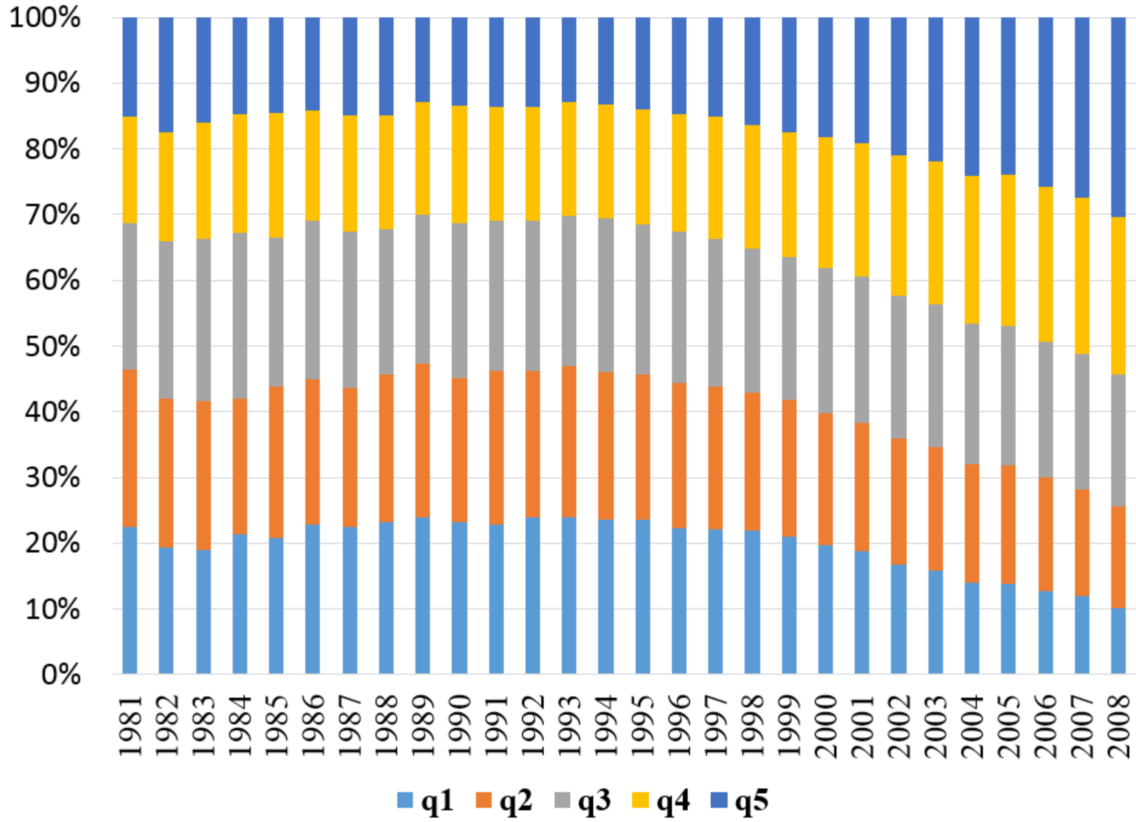
2.5.2 Improving Regressivity

How could a vehicle emissions inspection program provide targeted help to vehicle owners with the lowest annual income? Directly subsidizing individuals based on income is difficult both politically and administratively. However, patterns of vehicle ownership may help. Data tells us the older vehicles fail vehicle inspections more often than newer vehicles, and that lower annual income people own a higher percentage of these older vehicles on average. Figure 2.8 shows the percentage of vehicles owned by people in each quintile of the income distribution. There is a trend that the lowest income quintiles own a larger share of older vehicles that the highest income quintiles. Therefore, a program designed to subsidize the inspection of older vehicles would benefit those with lower annual income more than those with higher annual income.

Currently, most vehicles older than five model years must pass inspection to be registered for road use. When a vehicle is due to be inspected, the owner is sent a letter informing her that she must drive to a testing center, pay a fee, and pass an emissions inspection to maintain her vehicle registration.

Consider a change to the emissions inspection program where some vehicles are exempt from testing, but still must pay the fee, and other vehicles are exempt from paying the fee, but still must pass the inspection. Specifically, owners of newer model

Figure 2.8: Percent vehicle ownership by income quintile. Lowest income is q1. The highest income quintile owns a greater percent of newer cars than older cars.



year vehicles that have a very low emissions inspection failure rate are sent a letter stating that they must pay the emissions inspection fee, but do not need to have their vehicle inspected. The owner is better off by saving the time and hassle of the emissions inspection, and society is not harmed because the social cost of inspecting these newer vehicles is higher than the social benefit (as shown in section 2.5.1 herein).

Owners of older vehicles that have higher emissions inspection failure rates are sent a letter requiring an emissions inspection, but the inspection is free (subsidized by the fee paid by the owners of newer vehicles). The owner is better off because he does not have to pay the inspection fee, and society is not harmed because older, high polluting vehicles are still inspected and repaired.

Because people with lower annual income are more likely to own old vehicles on average, this proposed ”anti-Pigovian” tax and transfer system not only would improve the progressivity of the vehicle emissions inspection program, but also is a Pareto improvement!

The number of newer model year vehicles is many times higher than the number of older model year vehicles in the Arizona fleet. Exempting only one new model year from testing could pay for the inspections of many older model year vehicles. For example, exempting only 2008 model year vehicles would subsidize the inspection of all 1981-1995 model year vehicles. Or, exempting 2003-2008 model years would pay for all 1981-2002 inspections.

Under current policy, the lowest income quintile pays for 16.2% of total program costs (fees plus reported repair costs) in Phoenix. If 2008 model year vehicles were exempt from inspection, and the fee for that model year were used to subsidize the inspection of 1981-1995 model year vehicles, the lowest income quintile would pay 15.5% of total program costs. The best that this transfer system could do would be to exempt enough model years so that all other model years are subsidized. In that case, model years 2003 and newer would be exempt, and the lowest income quintile would pay only 12.6% of program costs.

2.6 Conclusion

I have shown that the Arizona Vehicle Emissions Inspection Program is regressive in that it constrains the vehicle repair decision of people with lower annual income more than people with higher annual income. Individuals with a lower annual income are both (i) more likely to drive vehicles that fail the inspection at a higher average rate, and (ii) more likely to fail an inspection conditional on vehicle characteristics.

This result is significant because it informs policy. A vehicle emissions abatement policy based on emissions monitoring will disproportionately constrain the vehicle repair choices of those with lower annual income. Further, a program designed to update or repair the fleet of vehicles will have a different impact on pollution depending on the characteristics of the owners of the vehicles targeted.

I have also shown that the Arizona VEIP does reduce emissions, but that the social benefit of the program does not exceed social cost in Tucson, and requires generous assumptions to exceed social cost in Phoenix. Even using generous assumptions, the social benefit of the program does not exceed social cost for model year 2003 and newer vehicles in Phoenix. This implies that exempting newer model year vehicles from VEIP program requirements could be an effective means of increasing the benefit/cost ratio of these programs.

Further, because people with lower annual income own a disproportionately high percent of older vehicles, an inspection/repair subsidy program that discriminates based on vehicle model year is a politically and administratively feasible way aid owners with lower annual income. As of this writing, Arizona began testing a program in which owners of vehicles older than 12 model years that failed inspection can receive a subsidy for vehicle repairs (ARS 49-474.03). Investigating the results of this trial program could yield interesting results.

Chapter 3

FIAT VALUE IN THE THEORY OF VALUE

with Edward C. Prescott

We explore monetary policy in a world without currency. In our world, money is a form of government debt that bears interest, which can be negative as well as positive. Services of money are a factor of production. We show that the national accounts must be revised in this world. Using our baseline economy, we determine the balanced growth paths for a set of money interest rate target policy regimes. Besides this interest rate, the only policy variable that differs across regimes is either the labor income tax rate or the inflation rate. We find that Friedman monetary satiation without deflation is possible. We also examine a set of inflation rate targeting regimes. Here, the only other policy variable that differs across policy regimes is the tax rate. There is a sequence of markets with outcome in each market being a Debreu valuation equilibrium, which determines the vector of assets and liabilities households take into the subsequent period. Evaluating a policy regime is an advanced exercise in public finance. Monetary satiation is not optimal even though money is costless to produce.

3.1 Introduction

Information processing technology is rapidly advancing and is changing the nature of the payment system. Currency is being used less and less to carry out transactions and to serve as a store of value. Indeed, a currency-less monetary system has become feasible and may be implemented. All monetary systems need a unit of value and the transition to a currency-less system would necessitate the creation of fiat value. A question is whether or not moving to a fiat-value monetary system is socially desirable. This paper is a step towards addressing this important social question.

The equilibrium concept used in this study is Debreu (1954) valuation equilibrium. The commodity space in his framework is restricted only to being a linear topological space. In this study, there is a sequence of valuation equilibria with the households entering a period with stocks of assets and liabilities. In the accounting period, economic outcomes are a valuation equilibrium. These outcomes among other things specify the stocks of assets and liabilities that households take into the subsequent accounting period. This is the way that the data are reported. These data are used to construct the national income and product accounts, and balance sheets of the household and government sectors.

Large amounts of cash reserves are held by businesses. The amount relative to GDP is of the order of 1.3 annual GDP. Businesses hold these low return assets for a reason, namely the services they provide. This leads us to treat the services of the money as a factor of production, or input to the aggregate production functions. Our production function is consistent with the money demand function when nominal interest rates are positive. It is also consistent with extended or even permanent periods of zero nominal interest rates. With the fiat value monetary system considered here, there is no currency, and for some policy regimes, the nominal interest rate paid on the money stock is negative and the real natural interest rate is positive.

A parametric set of neoclassical growth economies is considered. The benchmark economy is selected to match selected facts displayed by the pre-2008 US economy given the values of the policy parameters in that period. For a set of policy regimes, the steady state of the benchmark economy is determined and comparisons made. These regimes include interest rate targeting policy regimes and inflation rate targeting regimes. For the interest rate regimes both the inflation rate and the tax rate cannot be constant across regimes. We consider both a set of regimes for which the inflation rate is the same and the tax rate is different and a set of regimes for which the tax rate is the same and the inflation rate is different. One finding is that in our currency-less monetary system there can be Friedman satiation with positive inflation target regimes. This is possible because there is no currency that can be used as a store of value. Another finding is that monetary and fiscal policy cannot be completely separated. With the inflation targeting regimes, the tax rate on labor income is endogenous. This is because with interest rate targeting, the inflation rate has consequences for the government budget identity. We find that evaluating monetary policy is an advanced exercise in public finance.

In our model economies, there is a complete separation of the payment/transaction monetary system from the asset-management function system of the financial sector. Effectively it is a 100 percent reserve system. There are no financial businesses that borrow from one group at a low rate and lend to another at a higher rate, at least for limited liability businesses. There, of course, are financial businesses that pool and manage assets of households and their businesses. The investors share in the returns. This is the way that most of the financing of businesses is currently done in the United States. In our model world, there are no gains from having institutions that accept demand deposits and originate loans in order to make maturity transformation. There are no social gains from having fractional reserves. Further, there is no too-big-to-fail problem for financial institutions.

The paper is organized as follows. Section 2 specifies the parametric set of neoclassical growth model economies used in this study. Section 3 specifies the benchmark economy in this set which is specified by the policy, demographic, preference, and technology parameters. This economy is the model economy in our set that matches the pre-2008 US economy on selected dimensions. Section 4 transforms the variables in the standard way so that there is steady-state in the transformed variables. Only policies are considered for which there is a steady-state. For any such policy there is a unique steady-state equilibrium. Section 5 compares the balanced growth path for three sets of policy regimes. A policy is characterized by the values of seven variables. For a policy regime set, one of the seven variables is the target variable and one variable is endogenous across regimes. For three sets of policy regimes the steady states are determined. One has a money interest rate target with the tax rate endogenous. Another has a money interest rate target with the inflation rate endogenous. The third set has an inflation rate target with the tax rate endogenous. Section 6 discusses advantages and possible problems with the currency-less monetary system. Section 7 has some concluding comments.

3.2 The Model Economy

The analysis is steady-state and there is no uncertainty or growth in living standards. Consequently it does not matter whether an overlapping generation or an infinitely-lived household abstraction is used. We use the infinitely-lived abstraction because it is easier to use.

3.2.1 *Preferences*

There is a measure 1 of identical households with preferences ordered by

$$\sum_{t=0}^{\infty} \beta^t [log(c_t) + \alpha log(1 - h_t)] \tag{3.1}$$

where $c_t > 0$ is consumption and $h_t \in [0, 1]$ is the fraction of the time endowment allocated to the market. The parameter $\beta = 1/(1 + \rho) \in (0, 1)$ is the discount factor and ρ is the discount rate. The parameter α determines the relative shares of c_t and the leisure fraction $(1 - h_t)$.

For the balanced growth pather with balanced growth rate γ, the steady-state real interest rate is

$$i = \gamma + \rho + \gamma\rho \tag{3.2}$$

This fact will be exploited when characterizing the steady state for policies for which it exists.

Households hold two stocks of assets that they rent to the business sector. These stocks are non-human capital k_t and (real) money m_t. They also hold nominal government bonds, B_t. Therefore, the households' stock of real government bonds is $b_t = B_t/P_t$. These three stocks are the households' state variables. Households also supply labor services h_t to the business section.

3.2.2 *Price Level and Inflation*

There is a sequence of values of the composite output good in units of money. This is the definition of the *price level* P_t at date t. We break with tradition and define the date t inflation rate to be

$$\pi_t = \frac{P_{t+1} - P_t}{P_t} \tag{3.3}$$

We do this because it simplifies and unifies notation. When constructing the real value of a variable - whether it is a stock, flows, or prices - we simply divide its nominal value by by P_t.

3.2.3 Technology

Technology advances at rate γ and is labor augmenting. Inputs to the business sector are the services of non-human capital k_t, the services of human capital h_t, and the services on real money stock m_t. The structure of the production function is as follows. Let z be an aggregate of the tangible and human capital services where

$$z_t = k_t^{\theta}((1+\gamma)^t)h_t^{1-\theta} \tag{3.4}$$

For these two capital stocks, one unit of stock provides one unit of services. We use h and k to denote both stocks and service flows.

The aggregate production function is

$$y_t = \begin{cases} A z_t^{\phi} m_t^{1-\phi} & \text{if } m_t < \lambda z_t \\ A\lambda^{1-\phi} z_t & \text{if } m_t \geq \lambda z_t \end{cases} \tag{3.5}$$

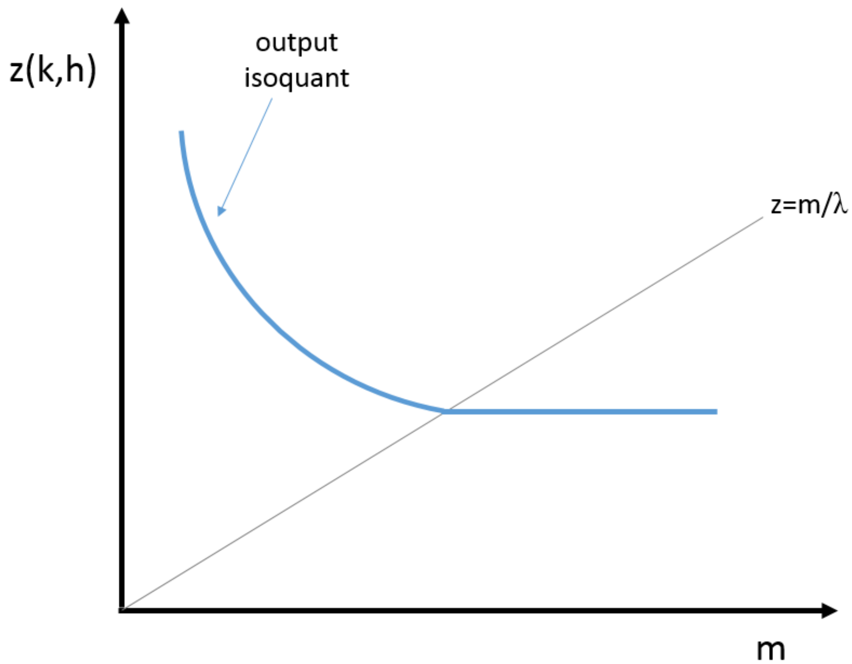
The aggregate production function is increasing, concave, and displays constant returns to scale. The marginal product of m is zero if $m \geq \lambda z$. Figure 3.1 depicts an isoquant of the aggregate production function.

3.2.4 Budget Constraints

Household

The assets held by the household are money, government debt, and capital. The inflation rate, possibly negative, is π; government lump-sum transfers in cash or in

Figure 3.1: A Production Function Isoquant



kind are ψ; r_k and r_m are the rental price of capital k and real cash balances m; i_b and i_m are the interest rates paid on the two forms of government debt. A primed variable is the next period value of that variable. With these notational conventions, the household budget constraint is

$$c + x + m'(1+\pi) + b'(1+\pi) = (1-\tau)wh + r_k k + r_m m + i_b b + i_m m + b + m + \psi \quad (3.6)$$

where x is capital investment given by

$$x = k' - (1-\delta)k \quad (3.7)$$

This states that expenditures are for consumption, investment, currency acquisition, and government debt acquisition and that the receipts are equal to the after-tax labor income, rental income on (non-human) capital k, rental income on money, interest payments on the two forms of government debt, and lump-sum transfers received from the government.

We use capital letters to denote nominal quantities. In nominal terms, the date t households budget constraint is

$$C_t+X_t+M_{t+1}+B_{t+1} = (1-\tau_t)W_th_t+r_kK_t+r_mM_t+i_bB_t+i_mM_t+B_t+M_t+\Psi_t \quad (3.8)$$

Here X_t is investment so $K_{t+1} = K_t + X_t - \delta K_t$.

Firm

Given constant returns to scale, revenue is equal to costs, or

$$y = wh + r_kk + r_mm \quad (3.9)$$

Government

The government's pure public consumption is g. The interest rates on the two types of government debt are i_m and i_b. The government's budget constraint (expenditures equal revenue plus deficit) is

$$g + \psi + i_mm + i_bb = \tau wh + [m'(1+\pi) - m] + [b'(1+\pi) - b] \quad (3.10)$$

Equivalently, the government budget constraint, using capital letters to denote nominal quantities, is

$$G_t + \Psi_t + i_{mt}M_t + i_{bt}B_t = \tau W_th_t + (M_{t+1} - M_t) + (B_{t+1} - B_t) \quad (3.11)$$

3.2.5 Equilibrium

Prices are $\{w_t, r_{kt}, r_{mt}, i_{bt}, i_{mt}\}_{t=0}^{\infty}$. Equilibrium conditions are

1. Households choose an optimal sequence of $\{c_t, h_t, k_{t+1}, m_{t+1}, b_{t+1}\}_{t=0}^{\infty}$ given prices and their budget constraints.

2. Firms choose the value maximizing $\{h_t, k_t, m_t\}$ given period t factor rental prices.

3. The government selection of $\{g_t, \psi_t, \tau_t, m_{t+1}, b_{t+1}, i_{mt}, \pi_t\}_{t=0}^{\infty}$ is such that its budget constraints for all t, given prices and the household's decision variables, are satisfied.

Comment 1: The firm faces a sequence of static problems.

Comment 2: The list of elements specifying government policy includes both the prices and the quantities of money it issues. It will not be possible to target both the price and the quantity of money.

3.3 Balanced Growth Analysis

The state of the household is its holdings at the beginning of the period of real money stock, real government debt stock, and real capital stock. One important point is that interest rates are nominal. Nominal values of stocks and flows grow at the rate of inflation. Prices, with the exception of the interest rates on government bonds and money, grow at the inflation rate.

There are 19 variables to be determined. They are:

$\{w, r_k, r_m, i_b, i_m, h, k, m, b, k', m', b', g, \psi, \tau, \pi, \phi_g, \phi_b, \phi_\psi\}$.

The following set of equilibrium conditions are necessary and sufficient for a steady-state for a given policy, and are used to find the steady-state.

From the firms maximization problem: Three marginal conditions are that the marginal products (MP) of the factors of production are equal to their rental prices. There is the zero profit condition given constant return to scale. Aggregate feasibility is another condition.

E1: $MP_k = r_k$

E2: $MP_h = w$

E3: $MP_m = r_m$

E4: $c + x + g = r_k k + r_m m + wh$

E5: $y = c + x + g$

There is an issue as to what the marginal product of money is when $m/z = \lambda$ as the production function is not differentiable at points along that line. The MP of money is bounded away from zero above the line and is zero below the line. The derivative from below is the value of the MP of money for points on this line.

Variable y is output of the business sector and does not include the government production of money.

From the households maximization problem: the intra-temporal marginal condition that the marginal rate of substitution between consumption and leisure is equal to the ratio of their after tax prices. The inter-temporal condition is that the marginal rate of substitution between this and next period's consumptions equals the ration of their prices. These conditions are:

E6: $\alpha c/(1-h) = (1-\tau)w$

E7: $1 + r_k = (1 + \gamma)(1 + \rho) + \delta$

E8: $1 + i_b = (1 + \pi)(1 + \rho)(1 + \gamma)$

E9: $i_b = i_m + r_m$

E10: $c + [k' - (1 - \delta)k] + m'(1 + \pi) + b'(1 + \pi) = (1 - \tau)wh + r_k k + (1 + i_m + r_m)m + (1 + i_b)b + \psi$

E8 and E9 are no arbitrage conditions. Because there is no uncertainty, the household return on money and government bonds must be equal, and the return on government bonds must be equal to return on investing in k.

Balanced growth requires:

E11: $b' = (1 + \gamma)b$

E12: $m' = (1 + \gamma)m$

E13: $k' = (1 + \gamma)k$

There is the law of motion of capital is

E14: $k' = x + (1 - \delta)k + x$

In each of the sequence of valuation equilibria, there are three government policy constraints and a government budget constraint (expenditure equals revenue plus deficit):

E15: $g = \phi_g y$

E16: $\psi = \phi_\psi y$

E17: $b = \phi_b y$

E18: $g + \psi + i_m m + i_b b = \tau wh + [m'(1+\pi) - m] + b'(1+\pi) - b]$

The set of policy variables is $\{i_m, m/y, \tau, \pi\}$. Values for two of these four variables are chosen. A restriction is that variables i_m and m/y are not both chosen. This adds two equations to our set of necessary equations. Thus there are 20 equations in 19 unknowns. By Walrus Law, one of the budget constraints is redundant.

3.3.1 Baseline Economy for Steady-State Analyses

A parametric set of economies has been specified. For the baseline economy, a parameter vector is chosen so that the baseline economy has a balanced growth that roughly matches the U.S. economy in consumption and investment shares, fraction of time worked, asset stocks to output ratios, factor income shares, inflation rate, and after-tax return on capital. Table 3.1 displays the national accounts for our chosen baseline economy. The annual growth rate is 3 percent.

The size of the stock of money may seem large. The 1.5 times annual GNP stock is much larger than M2, which is about 0.6. As pointed out by Williamson [2012], two types of money are used for transaction purposes. Much of the liquid government

Table 3.1: National accounts for the baseline economy.

Product and Income Accounts	
Product	**1.08**
Household Consumption	0.68
Government Consumption	0.05
Capital Investment	0.27
Money Investment	0.08
Income	**1.08**
Wages	0.64
Depreciation of Capital	0.15
Capital Rental Income	0.19
Money Rental Income	0.01
Central Bank Profits	0.08
Government Accounts	
Receipts	**0.43**
Tax Revenue	0.33
Money Issuance	0.08
Debt Issuance	0.03
Expenditures	**0.43**
Government Consumption	0.05
Transfers to Household	0.25
Bond Services	0.04
Money Services	0.10
Asset Stocks	
Capital	**3.81**
Money	**1.50**
Bonds	**0.50**
Other	
Hours Fraction	**0.40**
Labor Share	**0.64**

debt is held as cash reserves, and in 2015 the nominal return on this debt in the major advanced industrial countries was near zero. Businesses make large payments using the shadow banking sector and small payments using the commercial banking system. The proposed arrangement has only one type of money.

Because money services are a factor of production, the national accounts must be revised so that they are consistent with the theoretical framework being used. Money, like capital, provides services to the business sector; therefore, there must be a Money Rental Income entry on the income side of the accounts and a Money Investment entry on the product side of the accounts. The government costlessly produces money and earns monopoly profits. These profits are entered on the income side of the national accounts as the entry Central Bank Profits.

Table 3.2 displays the set of government policy parameters for the baseline economy. Note that the total factor productivity (TFP) parameter A is chosen for convenience so that y is one, and thus levels and levels relative to y are the same in the baseline economy. Also, the value of the satiation parameter λ is somewhat arbitrary. It was set high enough so that the baseline economy is not satiated with money. Table 3.3 lists the calibrated values of the preference and technology parameters.

3.4 Three Explorations

In this section, we will explore the consequences of various monetary policy regimes under our alternative financial system. Our assessment is that technology has changed sufficiently so that existing monetary theory does not provide predictions as to the consequences of monetary policy regimes. Currently, there is public discussion as to whether the interest rate should be increased and what the inflation rate target should be. Exploration 1 will explore the consequences of various money supplyor, equivalently, money interest ratepolicy regimes. Exploration 2 will explore the consequences

Table 3.2: Policy parameter values for the baseline economy

	Policy Parameters	
g/y	government public goods share	0.05
ψ/y	transfer share	0.25
m/y	money-output ratio	1.5
b/y	privately held debt gov. debt to output	0.5
τ	labor tax rate	0.52
i_m	interest rate on money	6.54 %
i_b	interest rate on gov. debt	7.21 %
π	inflation rate (annual %)	2.00 %

Table 3.3: Preference and technology values for baseline economy

	Preference/Technology Parameter	
α	relative preference for leisure	0.68
β	discount rate (annual)	0.98
δ	depreciation rate (annual)	0.04
θ	capital cost share	0.35
ϕ	money cost share	0.01
A	TFP	1.13

of various inflation rate targeting regimes.

For this analysis, we focus only on monetary policy and therefore minimize the role of fiscal policy. This is done by keeping fiscal policy parameters as fixed as possible. Thus, the lump-sum transfers and the size of public goods consumption relative to output are held fixed. We also keep the value of non-monetary government debt at a fixed fraction of output. The inflation rate has tax consequences; this requires that the labor tax rate be endogenous when comparing the balanced growth paths of policies with different inflation rates. The three remaining policy variables enter the government budget constraint and therefore have some fiscal consequences.

For our explorations, the set of government policy variables includes the inflation rate, the tax rate, and the interest paid on money. In each exploration, two of these policy variables are fixed, and two are endogenous.

Our measure of welfare across policy regimes is consumption equivalent (CE) welfare. We report the percentage change in consumption that must be given to an individual to make him indifferent among worlds with different policy regimes. We acknowledge that this measure of welfare is a steady-state comparison for one type and does not take into account transitional concerns. But given that the ratio of non-human capital to output is the same for all balanced growth paths, the consequences of transition for the policy regimes comparisons we consider should be small.

3.4.1 Exploration 1 - Money Supply with Endogenous Tax Rate Regimes

In response to the recession of 2008, those who make U.S. monetary policy have experimented with new monetary policy approaches. One of these approaches was quantitative easing, which increased the Federal Reserves assets and liabilities fourfold to over 4 trillion USD. The other approach was paying interest on excess reserves, which was permitted beginning in 2008. These experiments resulted in a large increase in private sector deposits and therefore in the money supply.

For the set of regimes considered in this exploration, the following policy variables are held constant at the following values:

$$\{g/y = 0.05, \psi/y = 0.25, b/y = 0.3\}$$

The government spends 5 percent of output and transfers 25 percent of output. The stock of government debt is 50 percent of output. This system keeps fiscal policy as fixed as possible.

The set of policy variables whose value varies across the regimes considered is

$$\{i_m, m/y, \pi, \tau\}$$

Two of these policy variables are held fixed, and two are endogenous. In the model, money stock and interest on money are tied together and cannot be chosen independently. Given the production function and preferences, the real or natural interest rate is determined. Given in addition to the inflation rate, the nominal interest rates of interest on the two forms of government debt as well as the real rental price of money are determined. From the production function laid out in full detail in the Appendix, the m/y ratio is determined. First, we explore interest on money policies. The inflation rate is held fixed at 2 percent. The tax rate varies endogenously in order to have government expenditures equal to government receipts.

Figure 3.2 shows that a higher tax rate is associated with a higher interest rate on money. Increasing the interest on money increases the stock of money relative to output. Thus, the total interest paid to owners of money is larger. Since the inflation rate is fixed, a higher labor tax rate is needed for government expenditure to be equal to the sum of government receipts and the deficit. With these policy regimes, the deficit-to-output ratio is fixed.

Figure 3.2: Labor tax rates for different interest rate targets

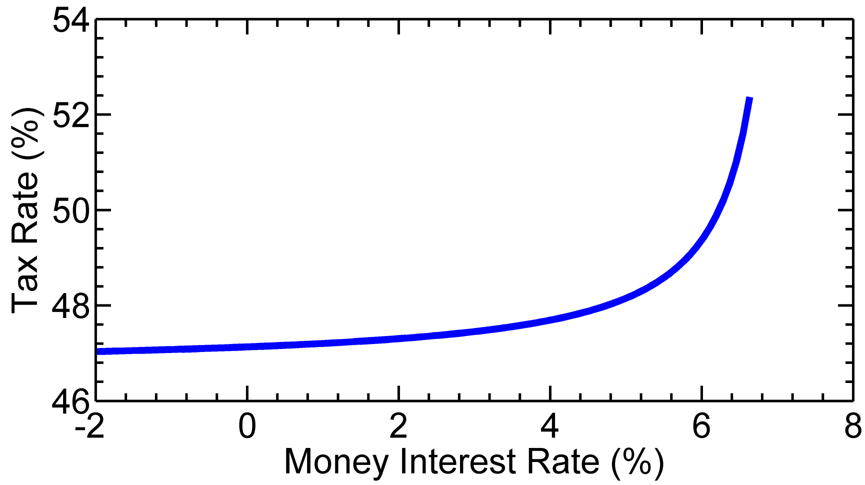
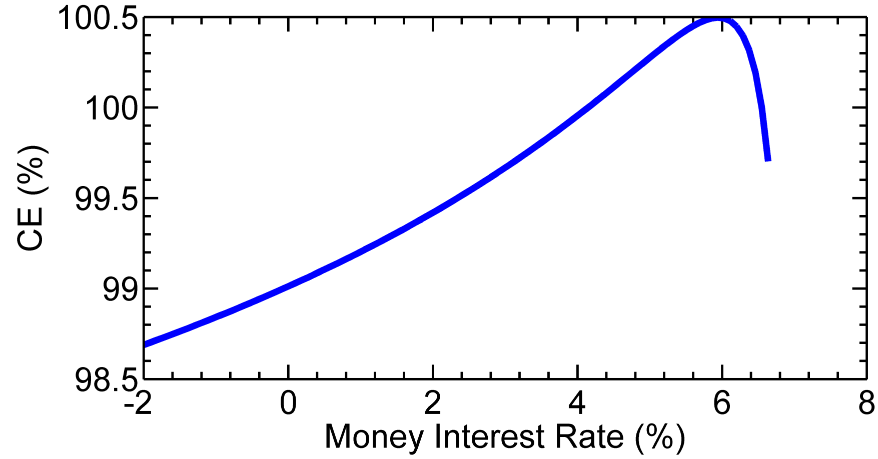


Figure 3.3 shows that there is a steady-state welfare-maximizing interest rate on money. A regime with a higher interest rate on money has a larger money services input to aggregate production. However, a higher interest rate regime also has a smaller labor input to aggregate production. For low interest rate regimes, the output increases because the larger money service input exceeds the output reduction arising from lower labor supply. For high interest rate regimes, output decreases because the reduction in output from lower labor supply exceeds the increase in output from larger money services. Figure 3 shows that, for our model economy, welfare is highest in a world where the interest rate on money is approximately 6 percent.

The nominal interest rate on government bonds is 7.2 percent. Why would the welfare-maximizing interest rate policy regime not completely eliminate the gap between the interest on money and bonds; that is, why is monetary satiation not optimal? Because we have fixed inflation and government spending, a labor tax rate change is needed for balance in the government accounts.

This highlights the importance of fiscal response to monetary policy. In a regime that targets the inflation rate, fiscal policy must respond to changes in interest rate policy.

Figure 3.3: Steady-state welfare indicator for various interest rate targets



3.4.2 Monetary Policy Regimes with Endogenous Inflation

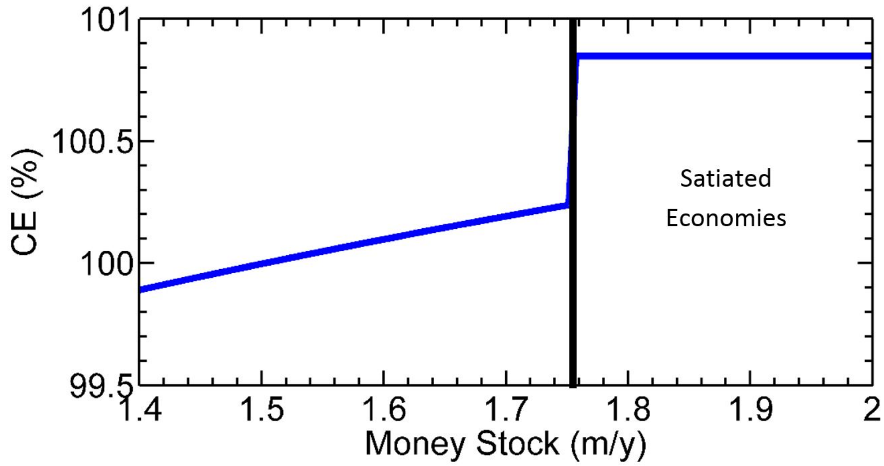
Next, we explore money stock policy regimes. We fix the labor tax rate at 52 percent and allow the inflation rate to vary endogenously to ensure that government expenditures are equal to government receipts. We consider money stock policies associated with both satiation and non-satiation.

Figure 3.4 shows that a larger money stock regimes has a higher steady-state welfare. However, increasing the money stock increases welfare only up to the satiation point, beyond which increasing the money stock does not increase welfare. For policy regimes with satiation, money and government debt are equivalent. In these regimes, money plus government debt is a constant, and consequently there is an unimportant indeterminacy.

In Figure **??**, we see that for satiated money stock regimes, the rental price of money services is zero. For these regimes, the marginal product of money is equal to the marginal cost of producing money (assumed to be zero). Interest rates on money and bonds are equal, and money and bonds are identical government debt instruments.

In the United States, policies that increase the money stock are enacted by the

Figure 3.4: Steady-state welfare indicator for various money stock regimes

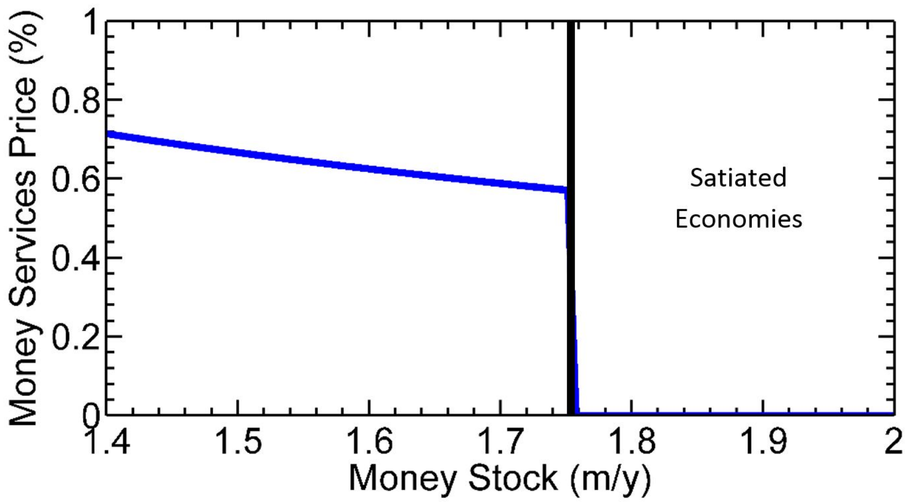


central bank purchasing government bonds from banks in exchange for money. Since money and bonds are identical in satiated economies, the split of total government debt between money and bonds is indeterminate. In the satiated region, the sum of money and bonds is constant.

The Friedman rule leads to satiation in economies in which money is not a factor of production. The Friedman rule is to deflate at the real interest rate [Friedman, 1960]. The return on currency is then equal to the return on capital. In the monetary system considered here, we eliminate the inefficiency not by deflating at the real interest rate but by choosing a money stock regime that leads to a satiated economy. We call this state Friedman satiation.

When money is a factor of production, Friedman satiation can occur with a range of inflation targets, including positive inflation. This feature allows for Friedman satiation without the difficulties associated with negative inflation rates [see McAndrews, 2015]. For example, Friedman satiation occurs when the target inflation rate is 2 percent, the tax rate is 53.5 percent, and the ratio of money stock to output is 1.75.

Figure 3.5: Marginal product of money for various money stock regimes



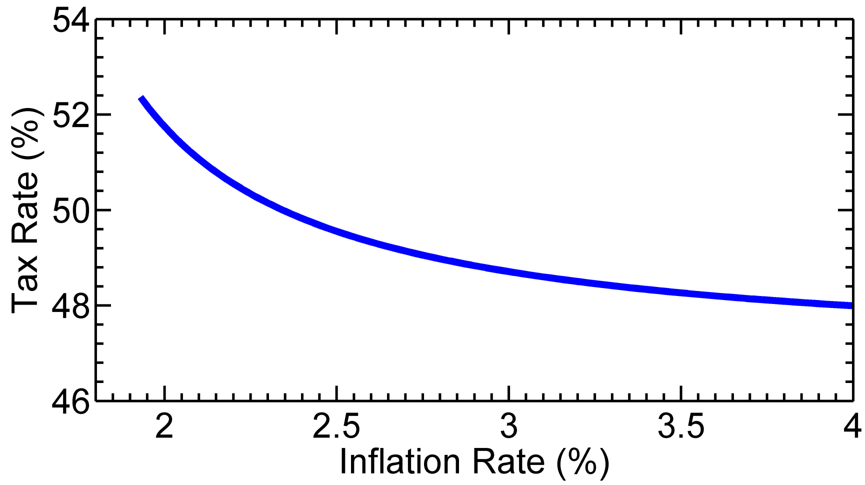
3.4.3 Exploration 3 - Inflation Rate Targeting

The inflation rate has been of particular interest of late. The U.S. Federal Reserve Board has been vocal about wanting to increase the inflation rate to the normal rate of 2 percent. Many have been puzzled by the persistently low inflation rate, which is currently near zero and is expected to stay under 2 percent for the next 30 years. [1] However, is low inflation a bad thing? Since price stability is part of a Federal Reserve congressional mandate, a theory that can address inflation rate targeting regimes is needed.

In this section, the interest rate on money is held fixed so that we can focus on the consequences of inflation rate targeting regimes. Various inflation rate policies are chosen. We consider only policies for which there is not satiation. This restricts the inflation rate target to be greater than or equal to 1.9 percent. The tax rate varies endogenously in order to have government expenditures equal to government receipts. Since interest on money is held fixed, the money stock also varies endogenously across

[1] Subtract the expected return on inflation-indexed Treasury securities from the expected return on nominal Treasury securities to see this.

Figure 3.6: Labor tax rates for inflation rate targeting regimes



policies.

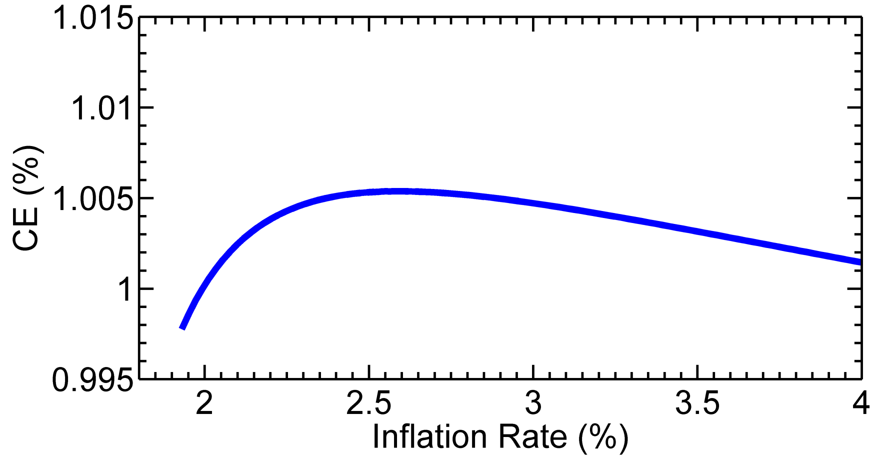
Figure 3.6 shows that a higher labor tax rate is associated with a lower inflation rate regime. Inflation is a form of tax on money. A higher inflation rate regime has a lower labor income tax rate, higher labor supply, and higher consumption. This raises the interesting possibility of using a money tax to reduce the labor distortion created by financing the government through labor income tax.

Figure 3.7 shows steady-state welfare as measured by consumption equivalents (CEs) for various inflation rate targeting regimes. Since higher inflation is associated with lower labor income tax, in a higher inflation rate regime, more labor is supplied and the consumption level is higher.The higher inflation increases hours worked (decreasing welfare) but also increases consumption (increasing welfare). This exploration shows that different inflation rates have, in fact, very little impact on steady-state welfare.

3.5 Possible Problems and Advantages

Some problems with this system are apparent. Privacy protection would need to be considered. We will not deal with this more general problem here. Also, in an

Figure 3.7: Steady-state welfare indicator for various inflation rate targets



environment in which banks are purely transactional institutions, shadow banking could be an issue.

We offer a possible solution to the shadow banking issue. To effectively eliminate businesses that borrow low from one group and lend high to another, the government could tax net interest income at a 100 percent rate for limited liability businesses. This approach would remove any incentive to engage in shadow banking.

Our proposed reforms also have possible advantages. First, bank runs would be prevented because banks would have nowhere to run. [2] Whenever a transaction takes place between private agents, one party's demand deposit account is credited by the amount of the transaction, and the other partys demand deposit is debited by the same amount. Second, our reforms would eliminate the need for costly regulations, as is associated with the U.S. deposit insurance system. A 100 percent reserve requirement would eliminate the need for stress tests and regulatory entities to ensure that banks are not taking on excessive risk. These activities cost about one-half percent per year per dollar deposited at commercial banks. This amount represents

[2] A number of economists have proposed a 100 percent reserve for demand deposits as an arrangement that is not prone to bank runs. They include Fisher [1936] and Friedman [1960], and more recently Cochrane [2014], Prescott [2014], and Smith [2013].

a non-negligible cost.

One claimed cost of the monetary system we explore is that it would increase the cost of financing because of the higher commercial bank equity cost. This argument is that with 100 percent reserve banking, bank equity would be higher and bank equity is costly. Admati and Hellwig [2013] establish that bank equity is not costly. With our monetary system, demand deposits are what our households and the businesses choose to hold. Another claim often made is that fractional reserve banking is valuable in providing maturity transformation, because agents want to lend short and borrow long. The agents in our world can hold as much money as they want; that is, they can lend short as much as they want. There is no need for maturity transformation.

We emphasize that much needs to be done before the theory can be used to make predictions as to the consequences of alternative policy. As done in McGrattan and Prescott [2016] for the consequences of an alternative tax policy regime, demographic projections must be made and introduced into the model economy being used. In addition, the equilibrium transition path to the balanced growth path for the alternative policy regime must be determined.

3.6 Concluding Comments

We explore an alternative financial system that is possible given the current state of information processing technology. Before this system could be implemented, existing law would have to be changed to permit business enterprises to hold interest-bearing money.

This exploration is necessary because, in our assessment, existing theory does not provide predictions about the consequences of alternative monetary policy regimes. The trial-and-error approach that characterizes current monetary policy is fraught with danger; therefore, better theory is needed. We hope that this paper fosters fruitful theoretical work on reforming the payment system.

By integrating money into valuation theory, the tools of aggregate public finance can be and are applied. This is not the first use of these tools to quantitatively predict the consequences of alternative monetary policy regimes. These studies modeled the households holding of M1, which was held for transaction purposes. It was motivated by Meltzers [1963] finding of a reasonably stable M1 velocity depending on the short-term interest rate. Lucas and Stokey [1987] develop a transaction-based theory of this transaction demand for money. Cooley and Hansen [1989] introduced the Lucas-Stokey theory with cash and credit goods into the neoclassical growth model and carried out a quantitative general equilibrium analysis of the cost of modest inflation.

This transaction-based theory does not account for the large holding of cash reserves by businesses. Hodrick [2013] reports that in 2013, the cash reserves of American businesses were nearly equal to annual GNP. This does not include the cash reserves of businesses in the household sector. Households accumulate cash reserves in order to be able to make a down payment on a residence or a car. One implication is that much of M3 is made up of the cash reserves held by household businesses. Cash reserves are held by businesses because they are productive assets that facilitate the operation of the business sector.

3.7 References

Admati, Anat R., and Martin F. Hellwig. 2013. *The Benker's New Clothes: What's WRong with Banking and What to Do about It.* New Jersey: Princeton University Press

Cochrane, John H., 2014. "Monetary Policy with Interest on Reserves." *Journal of Economic Dynamics and Control*, 49 (December), 74-108.

Cooley, Thomas F., and Gary D. Hansen. 1989. "The Inflation Tax in a Real Business Cycle Model." *American Economic Review*, 79 (4), 733-748.

Fischer, Stanley. 1974. "Money and the Production Function." *Economic Inquiry*, 12 (4), 517-533.

Fisher, Irving. 1936. *100% Money and the Public Debt.* Rev. ed. New York: Adelphia.

Friedman, Milton. 1960. *A Program for Monetary Stability.* New York: Fordham University Press.

Friedman, Milton. 1969. "The Optimum Quantity of Money." in *The Optimum Quantity of Money and Other Essays.* Chicago: Aldine.

Hodrick, Laurie Simon. 2013. "Are U.S. Firms Really Holding Too Much Cash?" SIEPR Policy Brief, July.

Lucas, Robert E., Jr., and Nancy L. Stokey. 1987. "Money and Interest in a Cash-in-Advance Economy." *Econometrica*, 55 (3), 491-513.

McAndrews, James. 2015. "Negative Nominal Central Bank Policy Rates: Where Is the Lower Bound?" Speech, Federal Reserve Bank of New York, May 8.

McGrattan, Ellen R., and Edward C. Prescott. 2016. "On Financing Retirement with an Aging Population." *Quantitative Economics*, forthcoming.

Meltzer, Allen H. 1963. "The Demand for Money: The Evidence from the Time Series." *Journal of Political Economy*, 71 (3), 219-246.

Orphanides, Athanasios, and Robert Solow. 1990. "Money, Inflation, and Growth." in *Handbook of Monetary Economics, Vol. 1*, edited by B. M. Friedman and F. H. Hahn, 223-261. Amsterdam: Elsevier.

Prescott, Edward C. 2014. "Interest on Reserves, Policy Rules and Quantitative Easing." *Journal of Economic Dynamics and Control*, 49 (December), 109-111.

Sargent, Thomas J., and Neil Wallace. 1981. "Some Unpleasant Monetarist Arithmetic." *Federal Reserve Bank of Minneapolis Quarterly Review*, 5 (3), 1-17.

Sinai, Allen, and Houston H. Stokes. 1972. "Real Money Balances: An Omitted Variable from the Production Function?" *Review of Economics and Statistics*, 54 (3), 290-296.

Smith, Andrew D. 2013. "How to Make a Run-Proof Bank: Achieving Maturity Transformation without Fractional Reserves." Paper presented at Australian Conference on Economics, July 10.

Williamson, Stephen D. 2012. "Liquidity, Monetary Policy, and the Financial Crisis: A New Monetarist Approach." *American Economic Review*, 102 (6): 2570-2605.

3.8 Appendix

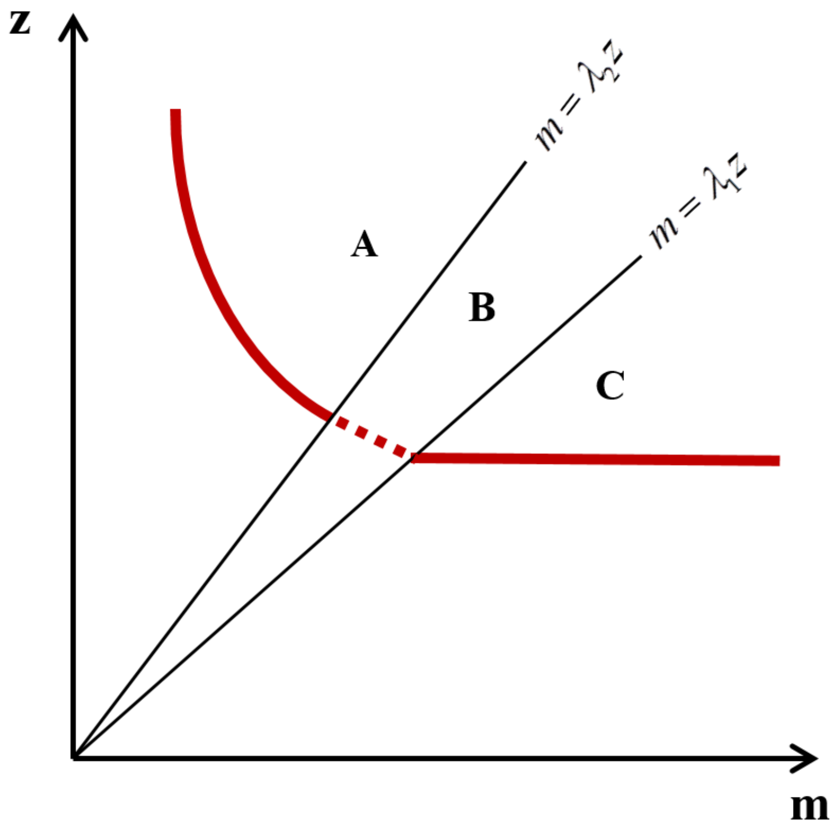
The production function used in this analysis is continuous but not differentiable everywhere. This appendix describes one way to smooth out the kink in the production function. This is a mathematical exercise with little influence on the economic reasoning of this paper, but is nonetheless important. For simplicity of exposition, the work presented in the main body of the paper did not include this mathematical detail except where noted.

To smooth the kink in the production function, we divide an isoquant of the production function into three segments, as shown in Figure 3.8. Because the production function exhibits constant returns to scale, one isoquant has the same properties as every isoquant as production is scaled up or down.

Let λ_1 and λ_2 be parameters of the production function and let $\lambda_1 > \lambda_2$. These parameters define segments of the aggregate production function isoquant with different elasticities of substitution between the composite capital-labor good and money. When $m < \lambda_2 z$, the production function is Cobb-Douglas and exhibits constant elasticity of substitution between the composite capital-labor good and money. The portion of each production function isoquant that has this property is identified as Region A in Figure 3.8. When $m > \lambda_1 z$, the production function exhibits zero elasticity of substitution between the composite capital-labor good and money. The portion of each production function isoquant that has this property is identified as Region C in Figure 3.8.

To smooth the non-differentiable portion of the aggregate production function, we introduce a segment of the production function defined when $\lambda_2 z \leq m \leq \lambda_1 z$. On this segment of the production function isoquant, the elasticity of substitution between the composite capital-labor good and money falls from the constant value is

Figure 3.8: Modified production function isoquant



Region A to zero in Region C. This transition region is labeled Region B in Figure 3.8.

In Region B in Figure 3.8, the marginal product of money transitions smoothly between a positive value in Region A and zero in Region C. Including the transition region, the marginal product of money is

$$\frac{\delta y}{\delta m} = \begin{cases} (1-\phi)\frac{y}{m} & \text{if } m_t < \lambda_2 z_t \quad \text{(constant elacticity region)} \\ (1-\phi)\frac{y}{m}[\frac{\frac{m}{z}-\lambda_1}{\lambda_1-\lambda_2}] & \text{if } \lambda_2 z \leq m_t \leq \lambda_1 z_t \quad \text{(transition region)} \\ 0 & \text{if } m_t > \lambda_1 z_t \quad \text{(zero elacticity region)} \end{cases} \tag{3.12}$$

When $m = \lambda_2 z$, the bracketed term in the second line is one and the marginal product of money is equal to that in the constant elasticity region. Similarly, when $m = \lambda_1 z$, the bracketed term in the second line is zero and marginal product of money is equal to the marginal product of money in the zero elasticity region. This smooths the kink in the production function.

We can recover the production function that gives this marginal product by solving (2.12) as a first-order differential equation and choosing integration constants in each region to ensure the production function is continuous. This yields a continuous, smooth production function as follows:

$$y = \begin{cases} Az^{\phi}m^{1-\phi} & \text{if } m_t < \lambda_2 z_t \quad \text{(constant elacticity region)} \\ Az^{\phi}m^{1-\phi}T(m, z, \lambda_1, \lambda_2, \phi) & \text{if } \lambda_2 z \leq m_t \leq \lambda_1 z_t \quad \text{(transition region)} \\ Az\lambda_1^{1-\phi}G(\lambda_1, \lambda_2, \phi) & \text{if } m_t > \lambda_1 z_t \quad \text{(zero elacticity region)} \end{cases} \tag{3.13}$$

This is similar to the production function presented in the main body of the paper, except for the transition region and functions T and G. The functions T and G are quite messy, but can be solved numerically. The functions are

$$T(m, z, \lambda_1, \lambda_2, \phi) = (\frac{\lambda_2 z}{m})^{\frac{\lambda_2(1-\phi)}{\lambda_2-\lambda_1}} e^{(\frac{1-\phi)}{\lambda_2-\lambda_1}(\frac{m}{z}-\lambda_2)} \tag{3.14}$$

$$G(\lambda_1, \lambda_2, \phi) = (\frac{\lambda_2}{m})^{\frac{\lambda_2(1-\phi)}{\lambda_2-\lambda_1}} e^{(\phi-1)} \tag{3.15}$$

Without the transition region, there is a discontinuous jump in Figures 3.4 and 3.5 of the main body of this paper. This occurs at the non-differentiable point of the production function. Allowing for a transition region as described above smooths this discontinuity.

For example, in Figure 3.5 of the main body of the paper (repeated as left panel of

Figure 3.9: Marginal product of money without (left) and with (right) transition region

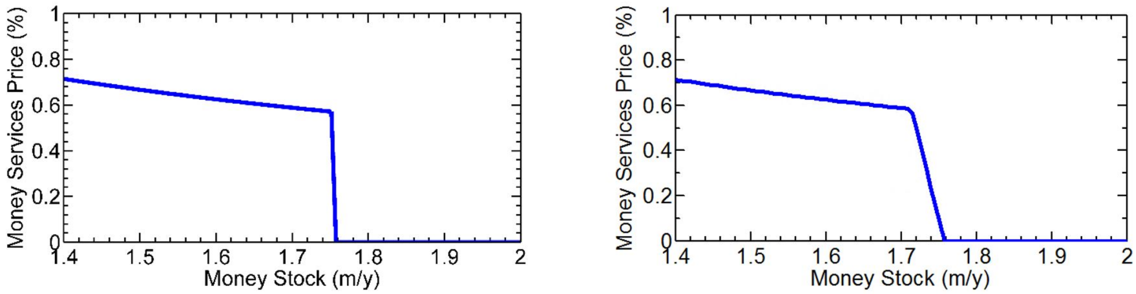


Figure 3.9 in this appendix), the marginal product of money discontinuously jumps to zero as the steady state growth money stock exceeds the satiation level. When we add in the transition region, the jump is smoothed (see right panel of Figure 3.9). The closer in value are the parameters λ_1 and λ_2 , the steeper the transition. For figures presented in the appendix, we chose $\lambda_1 = 2$ and $\lambda_2 = 1.95$.

Chapter 4

UNCONVENTIONAL MONETARY POLICY IN A MODERN PARADIGM OF MONEY

4.1 Introduction

There is currently discussion on the merits of moving to a currency-less fiat monetary system as technological advances have made such a system possible. India and the European Central Bank have already enacted policies that discourage the use of currency in transactions. India eliminated the 500 and 1,000 rupee note in 2016. That same year, the European Central Bank began phasing out the 500 euro note. Ostensibly, these policies were enacted to reduce tax evasion and give the government greater control over the financial system.

Establishing new economic theory based on these changes is an ongoing endeavor. The purpose of this paper is to evaluate unconventional monetary policy tools within a model that takes into account how advances in information processing technology are changing the way modern economies use money. Because electronic transfers make the velocity of circulation virtually infinite, theory based on the quantity equation may need to be revised. Stiglitz and Greenwald (2003) argue that there is no longer an opportunity cost of holding money at the margin, rendering obsolete monetary economics based on a money demand equation. New theory is needed.

Recently, Prescott and Wessel (2015) introduced a model that explored currency-less fiat money, called fiat value, in a general equilibrium theory-of-value framework. In this paper, I extend the fiat value model of Prescott and Wessel in a way that allows me to evaluate the consequences of unconventional monetary policy, namely quantitative easing and interest on reserves policies. The main assumptions of this model are that currency-less fiat money is a form of interest bearing government debt, the services of the stock of fiat value are a factor of production, and that there is a satiation level of money stock above which the marginal product of money is zero.

The two unconventional monetary policy tools that I evaluate are quantitative easing (QE) and interest on reserves (IOR). Following the 2008 financial crises, the United States Federal Reserve engaged in QE by purchasing government debt and real assets with central bank notes. This swelled the size of the central bank's assets from 5% of GDP in 2008 to 25% of GDP in 2015. This was the largest the Fed's balance sheet had ever been, including during the great depression (23% of GDP) and the end of WWII (20% of GDP). Additionally, on October 1, 2008, the Fed began paying interest on reserves held by depository institutions at reserve banks, a policy authorized by the Financial Services Regulatory Relief Act of 2006 and the Emergency Economic Stabilization Act of 2008. Since 2008, the IOR rate has varied between 25 and 140 basis points and, as of 2016, was 50 basis points for both required and excess reserves.

These policies were designed to increase liquidity and lower long-term yields (Bernanke 2015). Under traditional assumptions about the purpose of money, many models conclude that QE and IOR are either neutral or are effective policy tools in times of financial crisis (Wallace 1981, Bernanke and Reinhart 2004, Vayanos and Vila 2009, Gertler and Karadi 2013, Reis 2016).

I argue that with currency-less fiat money, the services of which are a factor of production, QE is a welfare increasing response to a liquidity crisis, but a positive IOR rate has a negative effect on a measure of aggregate welfare during a liquidity crisis. In this environment, QE works by driving the marginal product of money to zero, eliminating any gap between the marginal product of money and the marginal cost of producing money (assumed zero). When the economy is "satiated" in money, the business sector does not have to pay for the services of a production factor that is free to create. This increases total output and welfare. Additional QE in excess of the economy's satiation level has no effect, nominal or real, on output or prices. This suggests there may be benefit to maintaining a perpetually large Federal Reserve balance sheet.

Positive interest on reserves policies, however, mute the effect of quantitative easing. A positive IOR rate induces agents to deposit money at the central bank, restricting the availability of money to the business sector. This creates a positive lower bound on the marginal product of money which is equal to the IOR rate. Monetary satiation cannot be achieved when the IOR rate is positive.

Under current U.S. policy, the IOR rate is strictly positive and there is almost $4 Trillion in bank reserves on deposit at the central bank. I also ask, "Would a money outflow caused by reducing the IOR rate to zero cause excess inflation?" In this model, the answer is no. The price level would not significantly raise because money in a satiated economy is identical to bonds. Above the satiation level of money stock, withdrawing money from the central bank is analogous to swapping one type of government debt instrument for another identical type. This "shuffling" of the central bank balance sheet has no real or nominal effects in the model.

The paper is arranged as follows. Section II describes the model. Section III introduces a way to model a liquidity crisis, and explores the effects of quantitative easing and interest on reserves policies in response to a liquidity crisis. Section V concludes.

4.2 The Model Economy

The agents in this model are an infinitely-lived household, a government, and an aggregate production firm. There is constant growth and no uncertainty in living standards. While this model is based on the model of Prescott and Wessel (2015), the way I model the liquidity shock and policy response is unique to this paper.

4.2.1 Preferences

There is a measure 1 of identical households with preferences ordered by

$$\sum_{t=0}^{\infty} \beta^t [\log(c_t) + \alpha \log(1 - h_t)] \tag{4.1}$$

where $c_t > 0$ is consumption and $h_t \in [0, 1]$ is the fraction of the time endowment allocated to the market. The parameter $\beta \in (0, 1)$ is the discount factor. The parameter α determines the relative shares of consumption and leisure. This form of the utility function was assumed for convenience. Repeating the exercise with a different functional form (a different Frisch elasticity of labor supply for example) does not qualitatively effect the results.

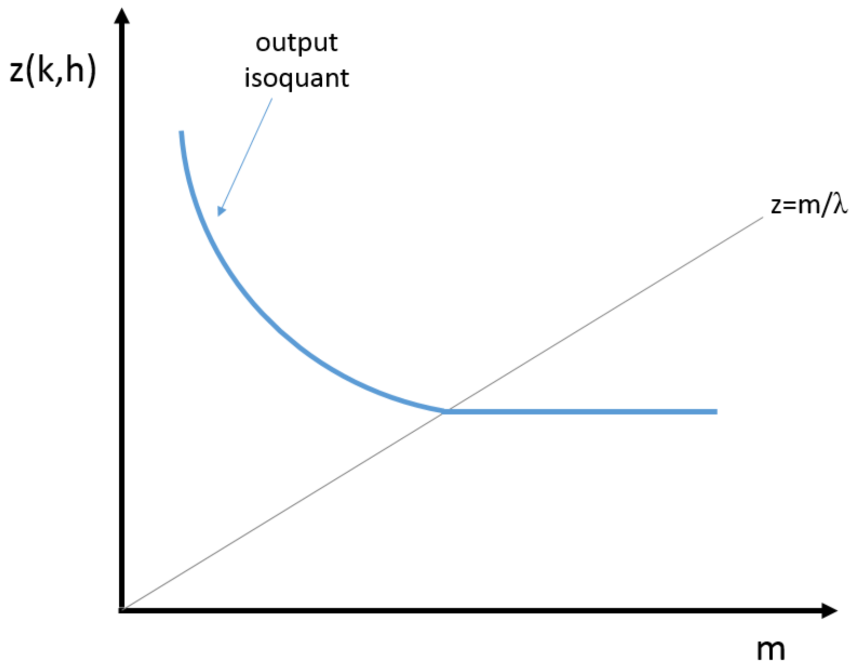
4.2.2 Technology

Inputs to the business sector are the services of non-human capital k_t, the services of human capital h_t, and the services of the money stock m_t. For convenience, I will use the simple term "money" when referring to currency-less fiat money. There is labor augmenting technical growth. The aggregate production function is

$$y_t = \begin{cases} A\lambda^{1-\phi} z_t & \text{if } m_t \geq \lambda z_t \\ A z_t^{\phi} m_t^{1-\phi} & \text{if } m_t < \lambda z_t \end{cases} \tag{4.2}$$

where

Figure 4.1: A Production Function Isoquant



$$z_t = k_t^{\theta}[(1+\gamma)h_t]^{1-\theta} \tag{4.3}$$

Figure 4.1 shows an output isoquant of the aggregate production function. The aggregate production function is increasing, weakly concave, and displays constant returns to scale. The marginal product of money m is zero if $m \geq \lambda z$.

λ is a parameter that determines the point at which the economy is satiated with money. This is a key parameter of the model.

4.2.3 Budget Constraints

Households hold three stocks of assets: capital k_t, money m_t, and government debt b_t. These are the individual state variables. Households also supply labor services h_t. The inflation rate, possibly negative, is $\pi_t = \frac{p_{t+1}}{p_t} - 1$; government lump-sum transfers in cash or in kind are ψ; r_k and r_m are the rental price of capital k and money m;

and i_b and i_m are the interest rates paid on the two forms of government debt, money m and bond b. I use capital letters to denote nominal quantities.

Household

In units of dollars, the date t household budget constraint is

$$C_t+X_t+M_{t+1}+B_{t+1} = (1-\tau_t)W_t h_t+(1+r_k)K_t+(1+i_b)B_t+(1+i_m+r_m)M_t+\Psi_t \quad (4.4)$$

where

$$X_t = K_{t+1} - (1-\delta)K_t \quad (4.5)$$

Insert equation (3.5) into (3.4) and divide by the date t price level. In units of the consumption/investment good, the date t household *real* budget constraint is

$$c_t + k_{t+1} + (1+\pi_t)m_{t+1} + (1+\pi_t)b_{t+1} = \quad (4.6)$$

$$(1-\tau)w_t h_t + (1-\delta+r_k)k_t + (1+i_b)b_t + (1+i_m+r_m)m_t + \psi_t$$

This states that expenditures are for consumption, investment in capital, currency acquisition, and government debt acquisition. Receipts are equal to the after-tax labor income, rental income on (non-human) capital less depreciation, rental income on money, interest payments on the two forms of government debt, and lump-sum transfers received from the government.

Firm

Given constant returns to scale, revenue is equal to costs, or

$$y = wh + r_k k + r_m m \quad (4.7)$$

Government

The government's pure public consumption in units of dollars is G. The interest rates on the two types of government debt are i_m and i_b. The government's nominal budget constraint is

$$G_t + \Psi_t + i_{mt}M_t + i_{bt}B_t = \tau W_t h_t + (M_{t+1} - M_t) + (B_{t+1} - B_t) \tag{4.8}$$

Equivalently, the government budget constraint can be written in real terms as

$$g_t + \psi + i_m m_t + i_b b_t = \tau w_t h_t + [m_{t+1}(1+\pi) - m_t] + [b_{t+1}(1+\pi) - b_t] \tag{4.9}$$

The government can finance expenditures through the labor tax (τ), increasing the money supply ($m_{t+1} - m_t$), running a deficit ($b_{t+1} - b_t$), or taxing through inflation (π).

4.2.4 Equilibrium

Prices are $\{w_t, r_{kt}, r_{mt}, i_{bt}, i_{mt}, \pi_t\}_{t=0}^{\infty}$. Equilibrium conditions are

1. Households choose an optimal sequence of $\{c_t, h_t, k_{t+1}, m_{t+1}, b_{t+1}\}_{t=0}^{\infty}$ given prices and their budget constraints.

2. Firms choose the value maximizing $\{h_t, k_t, m_t\}$ given period t rental prices.

3. The government selection of $\{g_t, \psi_t, \tau_t, m_{t+1}, b_{t+1}\}_{t=0}^{\infty}$ are such that its budget constraints for all t, given prices, are satisfied.

4.2.5 Balanced Growth

To define a baseline economy, I start with balanced growth. The state of the household is its holdings at the beginning of the period of money stock (m_t), government debt stock (b_t), and capital stock (k_t). Along the balanced growth path, these stocks grow at a constant rate γ.

Table 4.1: Government policy regime for the baseline steady-state economy.

	Government Policy	
g/y	government public goods share	0.05
ψ/y	transfer share	0.20
τ	labor tax rate	0.52
b	government debt to output	0.5
m	money debt to output	1.5
π	inflation rate	2.0 %

4.2.6 Baseline Economy

The baseline economy is on a balanced growth path that roughly matches the U.S. economy in consumption and investment shares, fraction of time worked, asset stocks to output ratios, and factor income shares. The growth rate is assumed 2.2%, which is roughly equal to U.S. growth in the 10 years leading up to the financial crisis of 2008.

Table 4.1 is the government policy regime chosen for the baseline economy. The high value of the money stock (1.5 GNP) is chosen to take into account what Williamson (2012) calls private and public liquidity. Businesses make large payments using shadow banking and small payments using the banking sector.

Table 4.2 presents the calibration results. The only parameter of note is the money cost share $(1-\theta)$. This parameter is not in standard models, and was first introduced by Prescott and Wessel (2015). This parameter controls how important money is in production. Further work is needed to determine the appropriate range of values for this parameter. I assume that the money cost share is 1%, the value used in Prescott and Wessel (2015). As a robustness check, I repeated all experiments in the range $1-\theta = [0.001, 0.05]$ and the results were qualitatively identical.

Table 4.2: Preference and Technology parameter values and targets for the baseline steady-state economy. All values are jointly determined. Because total output is normalized to 1, levels and shares are identical.

	Parameters			**Targets**	
α	preference for leisure	0.64	h	fraction worked	0.4
β	discount rate	0.96	x_k	investment	0.22
δ	depreciation rate	0.05	k/y	capital stock	3.04
θ	capital cost share	0.35	wh/y	labor share	0.65
$1-\phi$	money cost share	0.01	π	inflation rate	2.0%
A	TFP	1.2	y	output	1.0

4.3 Satiation, Quantitative Easing, and Interest on Reserves

In this section, I use the baseline economy to evaluate quantitative easing (QE) and interest on reserves (IOR) policies in response to a satiation parameter shock. The satiation parameter shock is designed to approximate the effect of an unexpected liquidity crisis. Stokey and Lucas (2011) argue that the recession of 2008 was exacerbated by a liquidity crisis where economic agents hoarded cash and the repo market experienced something similar to a bank run.

4.3.1 Satiation Parameter Shock

I model a liquidity crisis as an increase in the parameter λ, the satiation level of money stock. Satiation means that the marginal product of money is zero and occurs when the ratio of money to a composite of capital and labor z is sufficiently high, or $m \geq z/\lambda$.

I understand monetary satiation, consider a stylized business sector with one factory that produces output using only capital. Capital can only be rented using a type of government debt called money which the government issued in units it called dollars ($). Suppose the factory needed $10 of this government debt to resolve the time inconsistency between when the owners of capital required payment and when the output could be sold. If the government fixed the price level and only provided $8 in money to the economy, the factory would face a money constraint keeping it from producing maximum output. The marginal product of an additional dollar would be strictly positive. Now suppose the government fixed the price level and provided $12 in money. In this case, the marginal product of an additional dollar would be zero. In this example, the satiation level is $10.

What might cause an increase in the satiation level of the economy? Anything that raises the level of money stock needed to transact business: money hoarding, increased counter-party risk, decreased willingness to provide business-to-business credit, decreased bank lending, etc.

There is evidence that the level of money stock needed to transact business increased during the 2008 recession. Ivashina and Scharfstein (2010) show that bank lending decreased substantially during the financial crisis. They find that new loans to large borrowers during the peak of the financial crisis (2008Q4) fell by 79% relative to the peak of the credit boom (2007Q2). Becker and Ivashina (2011) argue that there was a sharp decrease in bank loan supply associated with the financial crisis. Further, from 2008 to 2012, U.S. Nonfinancial Corporate Businesses increased aggregate liquid assets from $1.5 Trillion to $1.8 Trillion, a 20% increase (Flow of Funds F.103).

For the experiments in this section, I wish to highlight the difference between economies that are satiated in money and those that are not satiated. To do this, I assume a government policy that produces a baseline economy that is just satiated in money. I then unexpectedly and permanently raise λ, the satiation parameter. I chose values of the satiation parameter (1.8 and 2.0) such that the economy switches from just satiated to just non-satiated. Because an increase in the satiation level is plausibly associated with the 2008 financial crisis, a model economy that can predict the results of a switch from satiation to non-satiation might be informative.

Figure 4.2 shows what happens to the balanced growth path when the satiation parameter is unexpectedly and permanently increased. In the figure, the shock happens unexpectedly at the end of period 3 and there is no policy response to the shock. The economy converges (convergence approximated by dashed line) to a new balanced growth path characterized by a lower level of output. Output is lower because non-satiation means there is a gap between the marginal cost of producing money (assumed zero) and the now positive marginal product of money.

For comparison, Figure 4.3 shows historical values of U.S. log GDP for 2005 to 2015. From 2009 to 2015, GDP was about 7% below historical trend. The model predicts that a shock to the satiation parameter at the levels chosen can account for about 15% of the reduction in output, assuming the money cost share is 1%. Incidentally, if I assume the money cost share is 20% (which most certainly is unrealistic!), the model generates a GDP drop approximately equal to that seen from 2009-2015.

In summary, when government monetary policy does not respond to an increase in liquidity needs in the economy, GDP can drop below trend. This is because firms must pay for the services of a factor of production (money) which is free to create. This is an inefficiency.

4.3.2 Quantitative Easing

Beginning in 2008, the Federal Reserve engaged in three rounds of QE, greatly increasing the size of its balance sheet. Figure 4.4 shows that the increase in assets came primarily from purchasing Mortgage Backed Securities and U.S. Treasury Securities with bank deposits. Base money, defined as the sum of (1) coin and currency

Figure 4.2: Model simulation of a shock to the satiation parameter in the economy. For periods one through three, $\lambda = 1.8$. For periods four through 11, $\lambda = 2$.

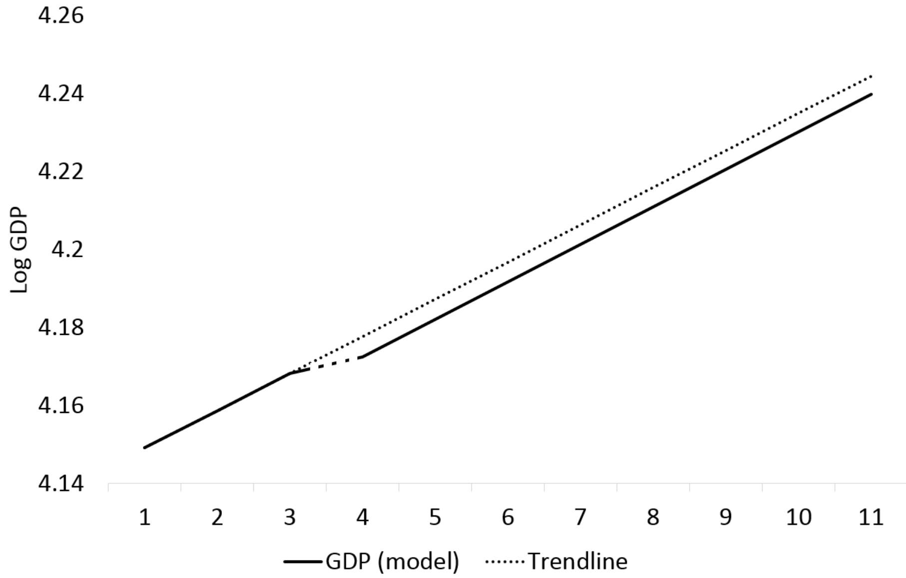


Figure 4.3: U.S. log GDP over time. Data from research.stlouisfed.org and author's calculations. Trendline refers to assume trend growth of 2.2%.

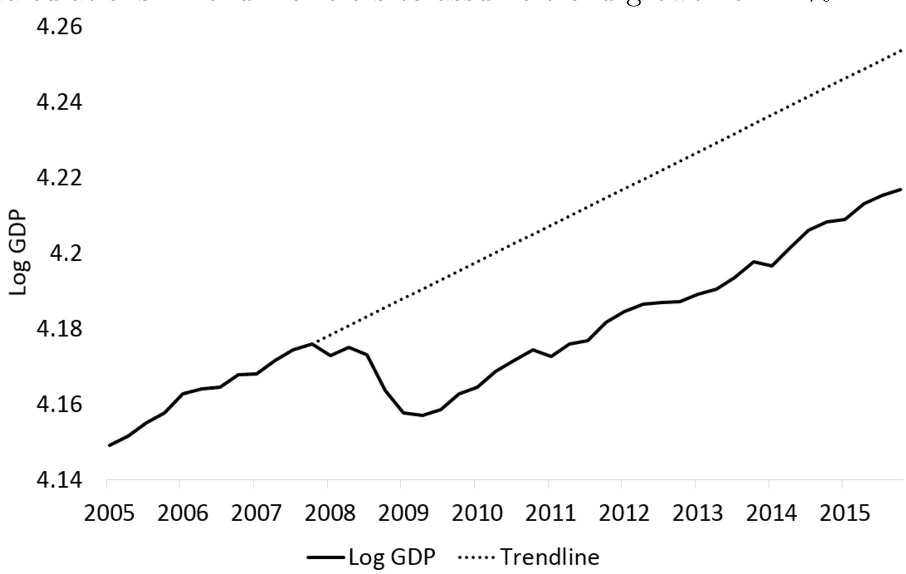
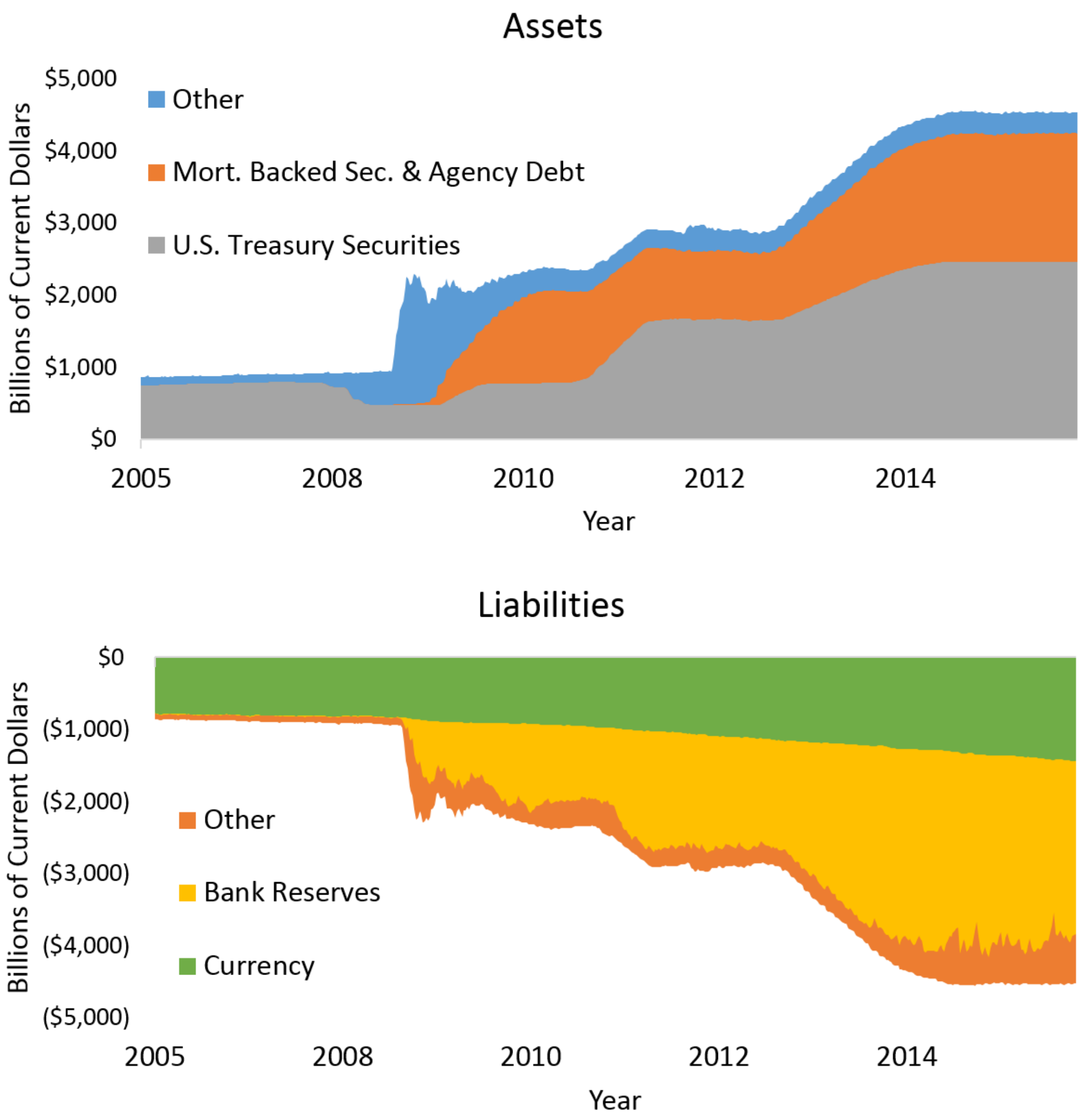


Figure 4.4: Federal Reserve Balance Sheet. Data from H.4.1 statistical release (weekly) and author's calculations.



held outside the Fed and Treasury and (2) deposits held by banks at the Federal Reserve, increased by almost 400%.

In this section, I will show how QE can be an effective response to a liquidity crisis, modeled here as a satiation parameter shock. For modeling purposes, QE is defined as a change from the current government policy regime to a new policy regime with higher money stock and lower bond stock. This way of modeling QE has the advantage of specifying the mechanism by which QE money is injected into the economy, namely it is traded for bonds.

To model a swap of money for government debt, let d_t be the total stock of government debt (money plus bonds) in units of fiat value, and let $\eta_t \in [0, 1]$ be the fraction of total government debt held as money. Thus

$$d_t = m_t + b_t \tag{4.10}$$

$$m_t = \eta_t d_t \tag{4.11}$$

$$b_t = (1 - \eta_t) d_t \tag{4.12}$$

With this definition of variables, a government policy regime is defined as

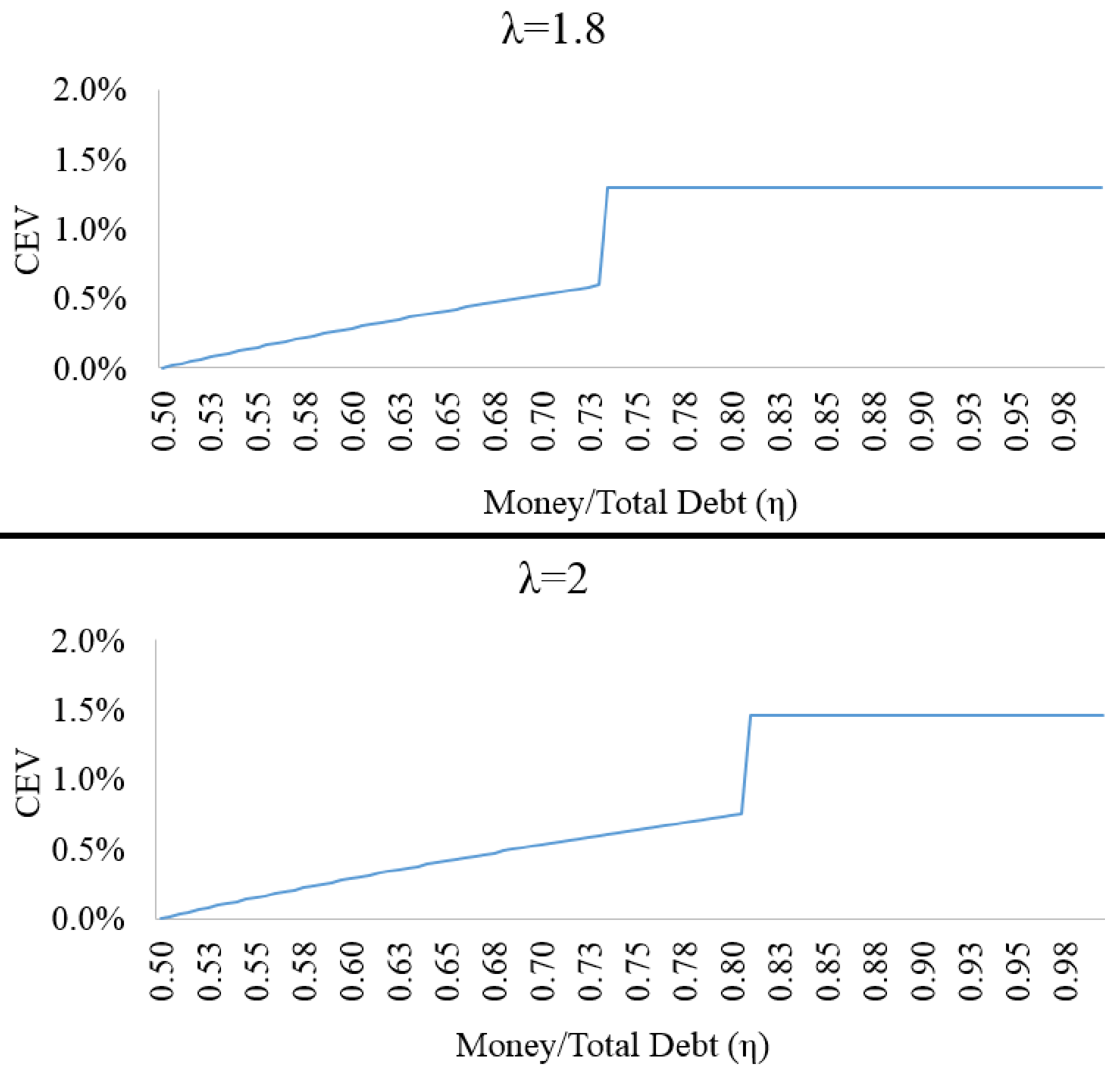
$$regime_t = \{g_t, \psi_t, \tau_t, d_{t+1}, \eta_{t+1}\} \tag{4.13}$$

In Figure 4.5, I compare the steady state equilibrium of government policy regimes that differ only in η, the fraction of government debt held as money. Government spending (g), government transfers (ψ), labor tax rate (τ), and total government debt (d) are held fixed. Output, inflation, and interest rates are determined in equilibrium. My measure of welfare is consumption equivalent variation (CEV), meaning the percent by which an individual's consumption must be changed in order to make him indifferent among policy regimes. This measure of welfare is for only one type and does not take into account transitions, but it is suggestive.

In the top panel of Figure 4.5, welfare increases with the fraction of debt held as money (η) in the economy. Welfare jumps when η is sufficiently high such that the economy is satiated in money, meaning that the marginal product of money is zero. Call this point η^*. [1] For the baseline economy with $\lambda = 1.8$, the satiation point is $\eta^* = 0.73$. Additional QE above the satiation point has no effect on welfare.

[1] The jump occurs because of the kink in the production function. The mathematical appendix of Prescott and Wessel 2015 shows one way to smooth out the kink.

Figure 4.5: Model predictions of welfare for various regimes of total government debt held as money. Quantitative easing is an increase in money to total debt ratio. Comparing the top and bottom panel, we see that a higher money to total debt policy (η) is needed to satiate the economy when the satiation parameter (λ) is higher. This implies that QE can be a welfare increasing response to upward satiation parameter shocks.



Additional QE above the satiation point η^* does not increase output because the economy is already satiated in money. On the production function isoquant in Figure 4.1, this represents points on the isoquant to the right of the diagonal line, where the marginal product of money is zero. Because the marginal product of money is zero, there is no balancing increase in capital stock or labor supply associated with the increase in the money stock.

Similarly, adding more money to an economy that is satiated has no negative effects. Since the marginal product of money is zero, money and government debt are identical government debt instruments. Additional QE above the satiation point is simply a balance sheet shuffle where one type of government debt instrument is traded for another identical government debt instrument. Neither the labor tax rate nor the inflation rate need to adjust to balance the government budget.

This theoretical finding is consistent with empirical observations that the first round of QE had a much larger influence on the U.S. economy than QEII and QEIII (Nellis 2013, Gagnon, et.al 2010, Krishnamurthy and Vissing-Jorgensen 2011). Perhaps this is because the first round of QE pushed the economy over the point where additional QE would be effective.

The bottom panel of Figure 4.5 shows that when the satiation parameter (λ) is higher, a higher η is needed to maximize this measure of welfare. When $\lambda = 2$, the satiation point occurs at $\eta^* = 0.82$.

Given a satiation parameter λ, any government policy regimes with $\eta > \eta^*$ is welfare maximizing. If one anticipates future upward shocks to the satiation parameter, the policy that most effectively insulates against satiation parameter shocks is one where $\eta = 1$, assuming that $\eta \in [0, 1]$. This implies that government policy can insulate against future liquidity crises by maintaining a permanently large Federal Reserve large balance sheet.

The interesting possibility of increasing the fraction of debt held as money such that $\eta > 1$ is not explored here. This would require assuming that government debt could be negative, which would be a *fiscal* policy exploration and is not the subject of this *monetary* policy study.

4.3.3 Interest on Reserves

In the previous section, it was shown that QE can be a welfare increasing policy response to an upward shock to the satiation parameter λ. In this section, I will show that positive interest on reserves (IOR) policies can work against QE in increasing the available stock of money in the economy, undoing the positive effects of QE.

Paying interest on excess reserves was legalized when Congress passed the Financial Services Regulatory Relief Act of 2006 and the Emergency Economic Stabilization Act of 2008. These acts authorized the Federal Reserve to pay interest on balances held by depository institutions at reserve banks beginning October 1, 2008. The Federal Reserve chose to immediately exercise that option. The IOR rate has varied between 25 and 140 basis points and was 50 basis points at the end of 2016. [2] The 2016 IOR policy regime allows an unlimited amount of money to be deposited at the Federal Reserve with a risk-free 50 basis point return.

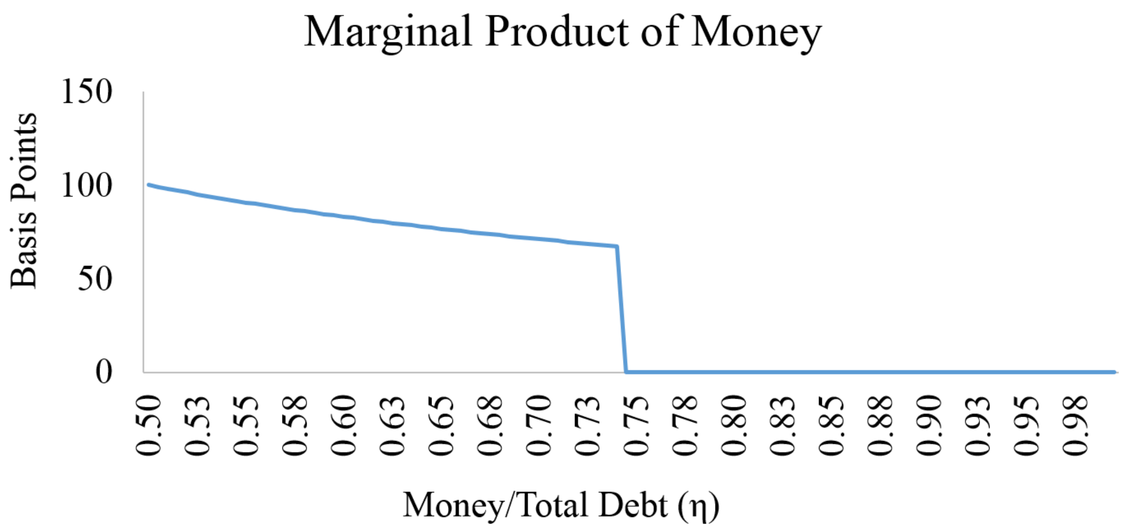
A no arbitrage condition of the model economy is that the rate of return on bonds (i_b) is equal to the total rate of return on money, where money is paid both from the government (i_m) and from the business sector (r_m).

$$i_b = i_m + r_m \tag{4.14}$$

In a satiated economy, the rental price of money services in the business sector

[2] For approximately 1 month in October 2008, the Federal Reserve paid a different rate of interest on required reserves than on excess reserves. For the sake of this analysis, I treat excess reserves and required reserves as identical.

Figure 4.6: Model predictions of marginal product of money for various money stock regimes in units of fraction of total government debt. The marginal product of money is zero for monetary policies that produce monetary satiation.



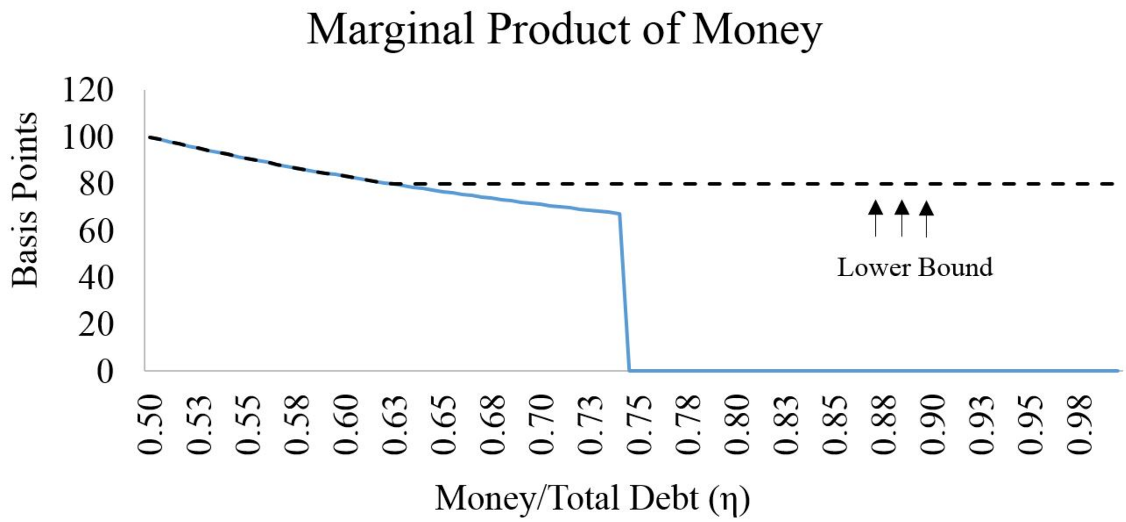
(r_m) is zero; money and bonds are identical debt instruments. The value of the rental price of money services is controlled by government policy. A higher money stock policy is associated with a lower rental price of money services. Figure 4.6 shows the marginal product of money (in basis points) associated with various money stock policies in the baseline model economy.

Consider a satiated balanced growth economy where the government unexpectedly announced a positive Interest on Reserves policy. A rational agent would redeployed money from the business sector, where the rental price of money is zero, to the Fed because the Fed offers a higher return. This reduces the stock of money available to the business sector. As money is deposited at the Fed, the government works down a money supply schedule where both the stock of money and the interest paid by the government (i_m) are lower.

In equilibrium, money deployed to the business sector and money deposited at the Fed earn the same total rate. In equilibrium,

$$r_m = i_{IOR} \tag{4.15}$$

Figure 4.7: Model predictions of marginal product of money for various regimes of total government debt held as money. A positive interest on reserves rate is a lower bound on the marginal product of money.



A strictly positive IOR policy regime bounds the marginal product of money away from zero (Figure 4.7). In effect, a positive IOR policy makes it impossible for government money stock policy, such as QE, to drive the marginal product of money to zero.

These results can be summarized in two propositions:

Proposition 1 (*Zero IOR Equivalence*): For every government monetary policy $[\eta, i_{IOR}]$ where $i_{IOR} > 0$, there exists a government policy $[\eta', i'_{IOR}]$ where $i'_{IOR} = 0$ and $\eta' \leq \eta$ with the same marginal product of money.

Proposition 2 (*Non-Satiation*): An economy with monetary policy where $i_{IOR} > 0$ cannot be satiated.

These results suggest that a rational monetary authority operating in this model world would not choose to implement a positive interest on reserves policy as a response to a monetary satiation shock.

4.3.4 Inflation

Currently there is public discussion surrounding the inflation rate. Base money (cash plus deposits held by banks at the Fed) has increased by 400% since 2008, but the inflation rate was less than 2% for at least 8 years following the 2008 recession, and as of 2016 was expected to stay under 2% for the next 30 years. [3] Why did the price level not increased more drastically?

One explanation for the lack of inflation is that money velocity has drastically decreased. Even though QE increased the stock of money, most of that money is on deposit at the Federal Reserve and is not involved in transactions.

In this section, I explore what this model predicts for the inflation rate when the money stock drastically increases. Specifically, I ask what would happen if member banks decided to withdraw their deposits from the Federal Reserve. Such a withdrawal would mean that member banks trade an IOU from the Fed for cash. In the model framework, this is equivalent to increasing η, the fraction of government debt held as money.

Would withdrawing large amounts of money from the Federal Reserve drastically increase the price level? The answer is no. Increases in the money stock can effect the price level only when the economy is not satiated. Additional increases beyond the satiation level have no effect on the price level.

This model relies on a fiscal theory of the price level to determine the inflation rate, meaning that the government's choice of tax and debt policy plays a crucial role in determining inflation. [4] In steady state, the government budget balances, or

$$g + \psi + i_m m + i_b b = \tau w h + \pi(m + b) \tag{4.16}$$

[3] To see this, subtract the expected return on inflation-indexed Treasury securities from the expected return on nominal Treasury securities

[4] See Kocherlakota and Phelan (1999) for a critique of the fiscal theory of the price level.

Recall that the no arbitrage equilibrium condition implies that the interest rate of money is equal the the return on bonds minus the marginal product of money, or $i_m = i_b - r_m$. Substitute this into (4.16):

$$g + \psi + i_b(m + b) - r_m m = \tau wh + \pi(m + b) \tag{4.17}$$

Equation (4.17) shows that only when the marginal product of money (r_m) is non-zero does a change in the *composition* of total government debt ($m+b$) have an effect on the government budget equation. When the marginal product of money is zero (i.e. the economy is satiated), money and debt are identical. Therefore, increasing the money stock (by withdrawing cash from the Fed, by government policy, etc.) can only influence the price level *up to* the satiation point. Beyond satiation, the composition of total government debt has no effect on the price level.

4.4 Conclusion

From recent developments, such as the European Central Bank phasing out the 500 euro note and India eliminating the 500 and 1000 rupee note, it seems that some economies are moving toward a currency-less fiat monetary system. It is my view that current theory lags these advances and may not provide accurate predictions as to the consequences of various government policies operating in such a system.

I have shown that in a currency-less fiat monetary system with money as a factor of production, government policy can have different consequences than in a model with more traditional assumptions about the use and definition of money. In a modern paradigm of money, upward satiation shocks can decrease output and welfare, quantitative easing is a welfare-increasing response to a liquidity shock, a positive interest on reserves policy decreases output, and the size of the money stock has no effect on the price level in a satiated economy.

The social desirability of moving to a currency-less fiat monetary system is a large, open question. Further research in this area may prove fruitful.

Chapter 5

CONCLUSION

The three papers presented in this dissertation are the culmination of my research work while in doctoral studies at Arizona State University. In the first, "Vehicle Emissions Inspection Programs: Equality and Impact," I presented the results of a quantitative study of the Arizona Vehicle Emissions Inspection Program. I found that the Arizona Vehicle Emissions Inspection Program is regressive in that it constrains the vehicle repair decisions of people in the low end of the income distribution more than people in the high end. Individuals with a lower annual income are both (i) more likely to drive vehicles that fail inspection at a higher average rate, and (ii) more likely to fail inspection conditional on vehicle characteristics. I also found that the social cost of administering the Vehicle Emissions Inspection Program in Arizona is more than twice the social benefit using a $7 million value of statistical life.

In the second, "Fiat Value in the Theory of Value," I presented the results of theoretical work. This paper was written jointly with Edward C. Prescott. Currency-less fiat money is now technically feasible and some governments are enacting policies that encourage a currency-less system. We explored one such system. We developed a general equilibrium theory-of-value model based on advances in the way modern industrial economies execute transactions. In our model, fiat value is a form of interest bearing government debt, the services of which are a factor of production. While much work remains to be done, this paper represents a first step in understanding the consequences of various monetary policy regimes in a currency-less fiat value system.

In the third paper, "Unconventional Monetary Policy in a Modern Paradigm of

Money," I explore quantitative easing and interest on reserves policies in a currencyless fiat monetary system. I argued that quantitative easing is an effective response to liquidity crises because it drives the marginal product of money to zero. When the marginal product of money is zero, the business sector does not have to pay to rent the services of money, a production factor that is free to create. I also argued that, contrary to previously published results, positive interest on reserves policies exacerbate a liquidity crisis by hampering the effects of quantitative easing. I suggested that a central banking authority operating in this model world would insulate against future liquidity crises by maintaining a permanently large balance sheet and setting the rate for interest on reserves to zero.

REFERENCES

Admati, Anat R., Peter M. DeMarzo, Martin F. Hellwig, and Paul Pfleiderer. 2011. "Fallacies, Irrelevant Facts, and Myths in the Discussion of Capital Regulation: Why Bank Equity is Not Expensive." Stanford GSB Research Paper No. 2063.

Banzhaf, H. Spencer. 2011. "Regulatory Impact Analyses of Environmental Justice Effects," *Journal of Land Use and Environmental Law* 27 (2011), 1-30.

Becker, B., and V. Ivashina, (2011) "Cyclicality of Credit Supply: Firm Level Evidence," NBER Working Paper No. 17392, September 2011.

Bento, Antonio, Matthew Freedman, and Corey Lang. 2014. "Who Benefits from Environmental Regulation? Evidence from the Clean Air Act Amendments," *Review of Economics and Statistics* 97(3), 610-622.

Bento, Antonio. 2013. "Enquity Impacts of Environmental Policy," *Annual Review of Resource Economics* 5 (2013), 181-196.

Bernanke, B, and V. Reinhart (2004), "Conducting Monetary Policy at Very Low Short-Term Interest Rates," *American Economics Review*, 94(2), 85-90.

Bernanke, B. 2015. *The Federal Reserve and the Financial Crisis.* Princeton University Presss, Princeton NJ.

Cochrane, John H., 2014. "Monetary Policy with Interest on Reserves." *Journal of Economic Dynamics and Control*, Vol. 49, Dec. 2014, pp. 74-108.

Cooley, Thomas F., and Gary D. Hansen. 1989. "The Inflation Tax in a Real Business Cycle Model." *American Economic Review*, 79 (4), 733-748.

Fischer, Stanley, 1974. "Money and the Production Function. *Economic Inquiry.* Volume 12, Issue 4, pp. 517-533.

Fisher, Irving. 1936. *100% Money and the Public Debt.* Rev. ed. New York: Adelphia.

Friedman, Milton, 1969. "The Optimal Quantity of Money, in *The Optimal Quantity of Money and Other Essays.* Chicago: Aldine Publishing Company.

Friedman, Milton. 1960. *A Program for Monetary Stability.* New York: Fordham University Press.

Fullterton, Don. 2011. "Six Distributional Effects of Environmental Policy," *Risk Analysis* 31 (2011), 923-929.

Gertler, M., and P. Karadi. 2013. "QE 1 vs. 2 vs. 3. . . : A Framework for Analyzing Large-Scale Asset Purchases as a Monetary Policy Tool," *International Journal of Central Banking*, 9(1), 5-53.

Hodrick, Laurie, 2013. "Are U.S. Firms Really Holding Too Much Cash? SIEPR policy brief, July 2013.

Jacobsen, Mark R. 2013. "Evaluating US Fuel Economy Standards in a Model with Prodcuer and Household Heterogeneity," *American Economic Journal: Economic Policy* 5(2): 148-287.

Lucas, Robert E., Jr., and Nancy L. Stokey. 1987. "Money and Interest in a Cash-in-Advance Economy." *Econometrica*, 55 (3), 491-513.

McAndrews, James. 2015. "Negative Nominal Central Bank Policy Rates: Where Is the Lower Bound?" Speech, Federal Reserve Bank of New York, May 8, 2015

McGrattan, Ellen R., and Edward C. Prescott. 2016. "On Financing Retirement with an Aging Population." *Quantitative Economics*, forthcoming.

Meltzer, Allen H. 1963. "The Demand for Money: The Evidence from the Time Series." *Journal of Political Economy*, 71 (3), 219-246.

Muller, Mendelsohn, Nordhaus, 2011. "Environmental Account for Pollution in the United States Economy." *American Economics Review* 101(5), 1649-75.

Muller, Nicholas Z. and Robert Mendelsohn. 2009. "Efficient Pollution Regulation: Getting the Prices Right." *American Economic Review* 99(5): 1714-39.

Orphanides, Athanasios, and Robert Solow. 1990. "Money, Inflation, and Growth." in *Handbook of Monetary Economics, Vol. 1*, edited by B. M. Friedman and F. H. Hahn, 223-261. Amsterdam: Elsevier.

Prescott, B. and R. Wessel, 2015. "Monetary Policy With 100 Percent Reserve Banking: An Exploration," NBER Working Paper No. 22431.

Prescott, Edward C., 2014. "Interest on Reserves, Policy Rules and Quantitative Easing, *Journal of Dynamics and Control*, Vol. 49, Dec. 2014, pp. 109-111.

Reis, Ricardo, 2016. "QE in the Future: The Central Banks' Balance Sheet in a Financial Crisis," NBER Working Paper No. 22415.

Sargent, Thomas J., and Neil Wallace. 1981. "Some Unpleasant Monetarist Arithmetic." *Federal Reserve Bank of Minneapolis Quarterly Review*, 5 (3), 1-17.

Sinai, Allen, and Houston H. Stokes. 1972. "Real Money Balances: An Omitted Variable from the Production Function? *The Review of Economics and Statistics*, Vol. 54, No. 3 (Aug., 1972), 290-296.

Smith, Andrew D. 2013. "How to Make a Run-Proof Bank: Achieving Maturity Transformation without Fractional Reserves." Paper presented at Australian Conference on Economics, July 10, 2013.

Stiglitz Joseph, and Bruce Greenwald. 2003. *Towards a New Paradigm in Monetary Economics*. Cambridge University Press, 2003.

Stokey, Nancy L., and Robert E. Lucas, Jr., "Liquidity Crises: Understanding sources and limiting consequences: A theoretical framework, Economic Policy Paper 11-3, Federal Reserve Bank of Minneapolis, May 2011

Vayanos, D., and J. Vila (2009), "A Preferred-Habitat Model of the Term Structure of Interest Rates," CEPR Discussion Paper 7547.

Williamson, Stephen D. 2012. "Liquidity, Monetary Policy, and the Financial Crisis: A New Monetarist Approach." *American Economic Review*, 102 (6): 2570-2605.

APPENDIX A

PREVIOUSLY PUBLISHED WORK

The paper "Fiat Value in the Theory of Value" was previously published with Edward C. Prescott as "Monetary Policy with 100 Percent Reserve Banking: An Exploration" in Minneapolis Fed Research Staff Report 530 June 2016, and in National Bureau of Economic Research Working Paper No. 22431 July 2016.