Timber Harvests and the Opportunity Cost of Capital: Evidence from the US Southland

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Abstract

The optimal timber rotation problem appears in many introductory environmental economics textbooks and has been a standard illustration of the relation between market rates of return and economic decision-making for decades. Thinking of optimal timber harvests as maximizing the value of timber by harvesting when marginal benefit of additional growth no longer exceeds opportunity cost dates at least to the 1700s, when William Marshall of England applied such thinking to oak trees.[1] In the twentieth century, Irving Fischer formalized the optimal timber harvest problem with mathematics in his book *The Theory of Interest*, in 1930.[2] Since then, myriad papers have considered the problem as well, contending that various factors such as harvesting cost, replanting cost, risk premiums for insect infestation, or the opportunity cost of the land's alternate uses should be included in an optimization equation. But rarely has Fisher's assumption faced empirical scrutiny. Using data from the southern US state of Alabama furnished by that state's forestry commission and county-level analysis of several other US South states, this paper finds that short-run fluctuations in market rates of return have no effect on timber harvester's decision-making process.

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[1] Gregory S. Amacher, Markku Ollikainen, and Erkki Koskela, *The Economics of Forestry Resources* (Cambridge, MA: MIT Press, 2009), p. 5, http://marno.lecture.ub.ac.id/files/2012/06/EKONOMI-SUMBERDAYA-HUTAN.pdf, accessed January 26, 2019.

[2] Irving Fisher, *The Theory of Interest, as determined by Impatience to Spend Income and Opportunity to Invest it* (New York, NY: MacMillan Books, 1930), pp. 161-166, https://oll.libertyfund.org/titles/fisher-the-theory-of-interest, accessed January 26, 2019.

Acknowledgements

I first conceived of this thesis topic in a very un-academic setting. While my fiancé Bethany and I drove the sand roads through the longleaf and slash pines that dominate the North Carolina Sandhills region during April 2018, looking for hog-nosed snakes, pigmy rattlers, and king snakes, we passed several controlled burns of underbrush and several other areas where the pines had recently been cut. It occurred to me that timber harvest times might be affected by exogenous changes in interest rates, such as a Federal Reserve decision to increase or decrease interest rates. This thought stuck in my head partly because, that night, we waded through ponds looking for Barking and Pine Barrens treefrogs, two species that are adapted to high-acidity ponds piney areas.[3] Where fire is suppressed, or timber rotations artificially elongated, other more generalist frogs and toads gradually outcompete these specialists. I wondered how the Federal Reserve's decision to suppress interest rates to near-zero for almost a decade had affected southern pinelands, and whether timber harvesters had adjusted to the "new normal" by lengthening rotations on their timber. This would disrupt the fire and cut-catalyzed equilibrium of the Deep South's forests.

Months later at Washington and Lee University, Professor Anderson entertained my incipient ideas and offered constructive pushback on my strategy for evaluating the empirical effect of interest rate changes, pushing me deeper into the existing literature and data. From there, the thesis that follows these acknowledgements gradually took shape.

I would like to extend my thanks to, first and foremost, my fiancé Bethany for enduring the elevator pitch for this thesis innumerable times and listening to reports on my progress when I needed someone to talk to. I'd also like to thank my parents, especially my mother, who early in life nurtured my interest for exploring Northern Michigan's woods.

In addition, I'd like to extend my thanks to those particular members of the Washington and Lee University community who most impacted the final outcome of this thesis by pushing me to achieve, suggesting edits, proofreading, and offering constructive and thoughtful feedback. Without the ECON 399 class members, Professor Michael Anderson, and my main thesis advisor Professor Joseph Guse, this thesis would not be possible.

[3] We ended up seeing the former frog and striking on the latter.

Introduction

Before the arrival of Europeans, the US Deep South contained an estimated 92 million unbroken acres of longleaf pine (*Pinus palustris*) forests, interspersed with bottomland hardwood swamps, stretching from Southeast Virginia to East Texas.[4] This ecosystem was naturally regulated by the periodic outbreak of wildfires, which prevented deciduous trees from overtaking more fire-tolerant pines like longleaf and slash. Organisms such as the red wolf, black bear, gopher tortoise, red-cockaded woodpecker, and indigo snake, which are rare in the region, were once common.

Today, the American Southland is a much different place. The region now plays host to intensive agricultural production and to metropolitan areas like Atlanta, Birmingham, Houston, Tallahassee, Jacksonville, and Mobile. A large portion of the region remains forested (a larger portion, in fact, than in 1920), but the forests are now actively managed, whether by individual owners, timber companies, corporate entities, or government.[5] The red wolf was re-introduced but its numbers remain in double digits, the indigo snake is extirpated from most of its former range, and introduced fire ant mounds are rapidly replacing gopher tortoise burrows as land's most common feature. The longleaf pines are mostly gone, save for a few isolated stands and small tracts like the Conecuh NF in Alabama, the Sandhills Gameland in North Carolina, and the De Soto NF in Mississippi.[6] Meanwhile, commercial timber harvesting operations throughout the region favor loblolly and shortleaf pines.[7] As opposed to hardwood trees, which have long rotation times of 50, 60, 70 years and upward, some pines in the US South can be harvested for sawtimber as little as twenty years after planting.[8] Such is the case with the loblolly pine, where

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[4] Christopher M. Oswalt, et al., "History and current condition of longleaf pine in the Southern United States," *US Forest Service Southern Research Station*, https://www.srs.fs.usda.gov/pubs/42259, accessed January 26, 2019.
[5] Author Unknown, "US Forest Resource Facts and Historical Trends," *United States Forest Service and United States Department of Agriculture*, https://www.fia.fs.fed.us/library/brochures/docs/2012/ForestFacts_1952-2012_English.pdf, accessed January 26, 2019.
[6] Ibid.
[7] Author Unknown, "Current US Forest Data and Maps," *Forest Inventory and Analysis,* https://www.fia.fs.fed.us/slides/current-data.pdf, accessed January 26, 2019.
[8] The long timber rotation for one particular deciduous tree, the Red Oak (*Quercus rubra*), is illustrated in this paper: Richard P. Guyette, Rose-Marie Muzika, and Aaron Stevenson, "Rotation Length Based on a Time-series Analysis of Timber Degrade Caused by Oak Borers," *Proceedings of the 15th Central Hardwood Conference*, 2002. Some areas of North Florida, where the growing season is year-round, as opposed to the rest of the region, can harvest as few as fifteen years after planting according to: https://www.orlandosentinel.com/business/os-ap-florida-timber-boom-20150908-story.html.

suggested rotation time is 25-35 years depending on growth rate and desired products.[9] In such a short-rotation environment, one would expect that marginal rates of return on capital would affect timber production decisions.

But this relies on the assumption that timber harvesters are acting under rationality with perfect access to credit markets and financial market information. As we shall see, the fallacious nature of that assumption renders the theory's predictions operationally null, at least in large swaths of the US South.

[9] Kyle Cunningham, Jon Barry, and Tamara Walkingstick, "Managing Loblolly Pine Stands…from A to Z," *University of Arkansas Division of Agriculture*, https://www.uaex.edu/publications/PDF/FSA-5023.pdf, accessed January 26, 2019.

Literature Review

In 1930, Irving Fisher postulated that foresters should cut their trees when the marginal rate of volume growth equals the opportunity cost of capital, or the interest rate, plus the yearly cost of forest maintenance (Fisher, 1930).[10] This approach to the "optimal timber rotation" problem is still the standard thinking on the issue. However, some environmentalists and a few economists contend that maximum sustainable yield (MSY) should govern timber rotations rather than the maximization of economic value. Most environmental economists reject the MSY approach in the context of forestry because it implicitly assumes a zero interest rate (Penttinen, 2000).[11] Generally, environmental economists have accepted Fisher's general frame of analysis but squabble amongst themselves over how to properly measure opportunity cost of capital. While many economists stick to Fisher's original formulation of maximizing return on investment (ROI), others use the internal rate of return on capital (IRR).[12] However, this formulation, proffered most famously by Kenneth Boulding (1955), assumes that capital is fixed in the short *and long-run.*[13] Boulding further assumes that the optimal timber rotation time is that which allows the forester to re-invest the maximum profit in more timberlands, assumed to be infinite.[14] Samuelson (1976) argues against this approach, saying that "Anyone who misguidedly adopts this foolish rotation period will find that he either goes broke or is permanently sacrificing return on original capital that could be his."[15] There is additional debate on whether the opportunity costs of alternative uses of the land are appropriate to include when calculating the opportunity cost of holding timber an additional year. But this does not affect the underlying assumption that the optimal harvest is when opportunity costs equal growth.

Despite some internal disagreement over appropriate ways to measure the return on capital and how to assess net present value (NPV), widespread consensus exists that the higher the rate of return on financial capital, the shorter the optimal timber rotation. Penttinen (2000) estimates that an increase in interest rates from 1.9% to 4% would decrease optimal rotation

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[10] Fisher, *The Theory of Interest*, pp. 161-166.
[11] Markku J. Penttinen, "Timber Harvesting with Variable Prices and Costs," August 2, 2000.
[12] Ibid.
[13] David H. Newman, "The Optimal Forest Rotation: A Discussion and Annotated Bibliography," *United States Department of Agriculture Forest Service*, 1988, p. 10, https://www.srs.fs.usda.gov/pubs/gtr/uncaptured/gtr_se048.pdf, accessed January 26, 2019.
[14] Ibid.
[15] Paul Samuelson, "Economics of forestry in an evolving society," *Economic Inquiry* 14(4), 466–492, 1976.

times for Scandinavian conifers from 83 to 66 years.[16] This aligns with the Fisher formulation and the sub-frameworks that have emerged. The debate is primarily over the optimal length of rotation times in the face of market rates of return, not *whether* timber rotations are determined by the return on capital at all. All authors not advocating for MSY to maintain flows of ecosystem services predict that higher marginal interest rates lead to higher opportunity costs of holding capital. They further assert that these higher opportunity costs induce more cutting earlier in rotation times.

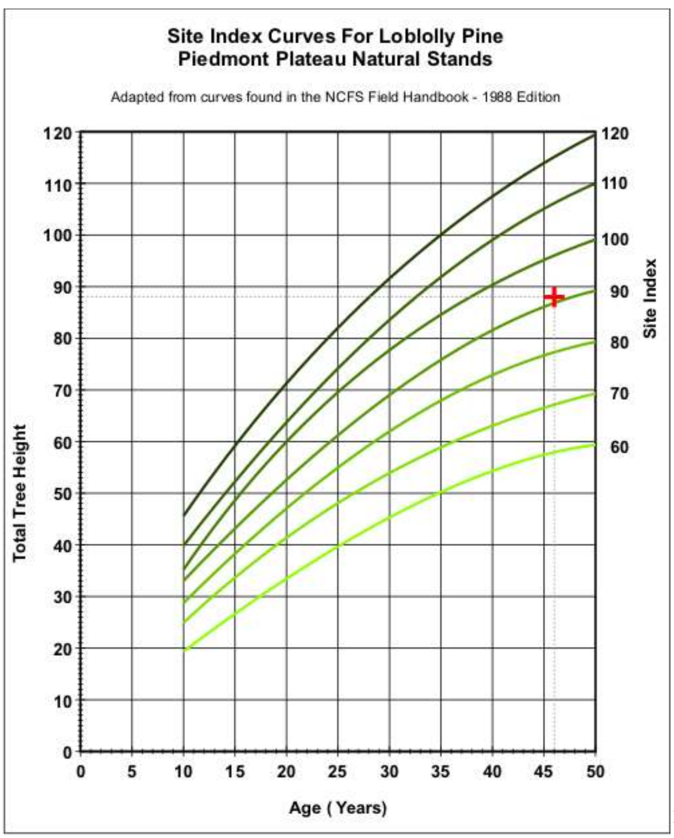
Using empirical evidence, this paper questions the underlying assumptions of the existing theories laid out above. We hypothesize that higher short-run market rates of return in the United States will induce higher timber production of America's fastest-growing trees, *ceteris paribus*. However, our results contradict this hypothesis and the existing literature. Instead, we show that interest rates are an insignificant factor in determining harvest amounts and times for southern timber owners. In only a few of our regressions does market rate of return assume statistical significance, and even where it does, its clinical effect on timber harvests is dwarfed by other variables. It is possible southern timber owners are constrained by imperfect access to credit or rationally choose to harvest during times of increased stumpage prices, causing the deviation from theory. It is also possible that timber owners wait for high prices to harvest and pay little attention to rate of return, which is subject to frequent change.

[16] Penttinen, "Optimal Forest Rotation."

Theoretical Model

It is assumed that timber harvesters are rational actors as proffered in the existing literature. Thus, they maximize the net present value of their timber stands by harvesting when the net growth of their trees equals the market rate of return on capital, assuming perfect access to credit markets and some constant risk of destruction from fire, disease, or storms. When market rates of return increases, as happens when demand for loanable funds increases during expansions or when the Federal Reserve adjusts benchmark interest rates, we'd expect landowners to increase their timber harvests. This follows from the fact that tree growth curves approach asymptotic limits, as shown by the growth curves for North Carolina loblolly pine on the next page. Theoretically, timberland owners should harvest any timber older than the age at which the straight-line rate of return is tangent to the growth curve, so when the interest rate increases (gets steeper), more of the age profile should be felled.

Figure 1-Loblolly Pine Growth Curves



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[17] Tim Cartner, "Estimating and Understanding Forest Soil Productivity," *Timberland Advisors*, https://www.timberlandadvisors.com/forest-soil-productivity/, accessed January 31, 2019.

But that is not the whole story. Demand-side influences such as new home construction and GDP growth are expected to increase timber harvest. The price of timber is included to capture any demand-side shocks not observed in housing booms or GDP growth trends, such as international demand-side shocks.[18] Price is also expected to put upward pressures on timber harvests.[19] Price increases move us further up the supply curve and increase the opportunity cost of holding onto growing stocks of timber, particularly if one expects the high prices are temporary. But with these factors held constant, the real return on financial capital should induce large increases in pine timber harvests. This effect should be particularly prominent for pulpwood-sized trees further down the growth curve. The following empirical model attempts to capture this framework and translate it into testable hypotheses.

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[18] Anecdotal evidence for the argument that international demand for finished wood products has some effect on American timber markets can be found in the following article, where an Austrian businessman is investing in North Florida pine timberlands and saw mills to ship finished products to Europe and Asia. Melissa Nelson-Gabriel, "Timber business booming throughout North Florida," *Orlando Sentinel*, September 9, 2015, accessed April 4, 2019, http://www.orlandosentinel.com/business/os-ap-florida-timber-boom-20150908-story.html.

[19] For instance, decreasing demand for pulpwood products in the face of improving synthetic substitutes or more efficient use of particle board would show up in lower prices, but not necessarily correlate with either housing prices or GDP. Although there is some multicollinearity inherent in the choice to keep the price variable along with GDP growth, the extent of said issue is small and tolerable when considering situations like the above.

Empirical Model

Regressions are run separately on two different sets of harvest volume data: statewide data from the US state of Alabama, dealt with first, and then county-level harvest volume data from the "Deep South" sections of eight southern US states: North Carolina, South Carolina, Georgia, Alabama, Florida, Mississippi, Louisiana, and Arkansas.[20]

Before proceeding to name and describe each of the variables in detail, we briefly consider the units of measurement on the harvest volume variables that will follow. Though convention and ease suggest reporting all such variables in a common unit, the differential systems for measuring hardwood and pine volume make it impossible to convert all my harvest variables to a single common unit like cubic feet or cords. While this is an annoyance, it does not affect the analysis, as we are interested in changes in relative volume, not the absolute measures. For visualizations of what a "thousand board feet" (Scribner or Doyle rule not specified) or a "cord" looks like, read on to the variable explanations.

Variables are presented all together, though some of them appear only in the county or statewide-level analyses. For this reason, each variable is preceded by a parenthetical phrasing indicating either statewide only (s), county-level only (cty), or both (b).

The Variables:

A. Harvest Volume and Ratio Variables

(b) *PineSaw_Harvest*, *HardwoodSaw_Harvest*- The annual harvest of pine sawtimber and hardwood sawtimber (larger trees) in the state of Alabama, or at the county-level, during the year in question. Both are measured in thousands of board feet. A "board foot" is one foot square and one inch thick. For reference, humungous trees may have up to 3,000 board feet of merchantable timber, but typical eastern conifers and hardwoods, with 2-foot diameter and 40-50 feet in height, have 300-500 board feet, so another way to think of my variable is in 2.5 tree increments.[21]

(b) *PinePulp_Harvest*, *HardwoodPulp_Harvest*- The annual harvest of pine pulpwood and hardwood pulpwood (younger/smaller trees) in the state of

[20] For an in-depth discussion of what is included in the definition of "Deep South" and how decisions for demarcating the boundaries of the region were made, see the Appendix discussion, "Justification of exclusion and regional boundaries."

[21] Estimates obtained from: Randall B. Heiligmann and Stephen M. Bratkovich, "Measuring Standing Trees," *Ohio State University Extension*, https://ohioline.osu.edu/factsheet/F-35-02, accessed January 30, 2019.

Alabama or the given county, both given in chords. One full chord of wood is a pile of logs four feet high, four feet wide, and eight feet long.[22]

(b) *TotalPulp_Harvest*- Total pulpwood harvested each year in Alabama or at the county-level, obtained by adding *HardwoodPulp_Harvest* and *PinePulp_Harvest.*

(b) *TotalSaw_Harvest*- Total sawtimber harvested each year in Alabama or at the county-level, obtained by adding *HardwoodSaw_Harvest* and *PineSaw_Harvest*.

(s) *PolesandPiles_Harvest*- Thousands of board feet of “poles and piles” harvested each year in Alabama. This is the most valuable wood product on the market, but the standards are high. This category encompasses barely 1% of the timber market in the US South.

(b) *PulptoSawRatio*- The ratio of pulpwood to sawtimber harvested each year, as expressed in decimal proportion, by dividing *TotalPulp_Harvest* by *TotalSaw_Harvest*. Though the units here do not match, both are measures of volume, and I seek to find meaning not in the level of this variable, but its changes. A higher number, while it has no intuition by itself, indicates a higher proportion of pulpwood to sawtimber in the harvest composition compared to a lower number.

(b) *lnpinesaw*- The log of pine sawtimber harvested.

(b) *lnratio*- The log of the *PulptoSawRatio*.

(b) *PineSaw_PinePulpRatio*- A similar ratio to the variable above in purpose and intuition, but specific to the pine part of the data, obtained by dividing *PinePulp_Harvest* by *PineSaw_Harvest*.

(s) *e1*- The residual series formed after fitting a trend line to the raw timber harvest data, in most cases, *PineSaw_Harvest*. In essence, this variable measures deviations from any trend lines thought to arise from exogenous technology changes. Units are still in thousands of board feet, as in the base set.

B. Right-hand side macroeconomic variables

(b) *GDPGrowth*- The annual average of US quarterly GDP growth rate for the year in question, expressed as a percentage.

(b) *Nominal30YearMortgage*- The annual average rate on a conventional 30-year fixed mortgage for the year in question, in percentages.

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[22] Mariette Mifflin, “How Much Firewood Is in a Chord and How to Store It,” *the Spruce*, https://www.thespruce.com/firewood-cord-storage-1907998, accessed January 30, 2019.

(b) *NominalFedFunds*- The annual average of the federal funds rate for the year in question, expressed as a whole number with trailing decimals. For instance, an FFR of 305 basis points is expressed as 3.05%.

(b) *NominalSandP500*- The annual increase in the S&P 500 stock index during the year in question. Expressed as a whole number percentage.

(b) *NominalTenYear_TreasuryYield*- The annualized average constant yield to maturity on the 10-year US Treasury Bill, considered a relatively good measure of "risk-free" rate of return. Given as a whole number percentage.

(b) *NewHousingStarts*- The annualized average of new single-family housing units under construction throughout the year, seasonally adjusted. This is naturally a monthly variable, and is measured by the US government as such. However, the annual data are merely an average of all the months of the year. For instance, a value of 3,000 implies that, on average, 3 million new homes were under construction at any given point in time during the year.

(b) *Inflation*- The annual increase in the CPI during the year in question, expressed as a whole number percentage.

(b) *IndexedReturn*- This is the main workhorse, along with its twin *RealReturn*, for capturing impacts from changes in market returns. This is an index of 30-year mortgage rates and 10-year Treasury bill yields, where the result is a whole number percentage. It is obtained by adding those two rates and dividing by two.

(b) *RealReturn*- This variable adjusts rates of market return for inflation by subtracting *Inflation* from *IndexedReturn* to arrive at the real rate of return on financial capital.

(cty) *DepositsperCapita*- The amount of bank deposits, in nominal USD, per resident of a given county. Obtained from FDIC.

(cty) *CountyPopulation*- The population of each county in the given year, obtained from the US Census.

(cty) *Branches*- Number of bank branches in the county in the given year, obtained from FDIC.

(cty) *ResidentsperBranch*- The number of residents per branch in each county, obtained by dividing *CountyPopulation* by *Branches* for each county of interest.

X_r- This symbol represents a vector of the various hypothetical combinations of market rate of return variables that one might choose in any given regression without duplicating one (for instance: X_r=*NominalFedFunds* + *NominalSandP500* + *RealReturn* or alternately, *IndexedReturn* + *NominalFedFunds*, etc., etc.)

Y_n- This symbol represents a vector of the various combinations of macroeconomic indicator variables in any given regression, whether one or multiple. For instance, Y_n might represent *GDPGrowth*, *NewHousingStarts*, *Inflation*, the relevant *Price* variable, or any combination thereof.

Stumpage Prices and Miscellaneous Other Manipulations

(b) *RealPineSaw_Price, RealHardwoodSaw_Price*- The stumpage price for pine sawtimber and hardwood sawtimber, respectively, in the year in question. Both are measured in USD/thousand board feet. From 2009-2016, this variable is obtained from averaging prices for the two halves of the state (of roughly equal size in timber production), as opposed to before 2009, where data came in statewide form already. In the county-level portion of the analysis, an average of North Carolina and Alabama price data is used except where only North Carolina data is available.[23] A more extensive discussion of price data in the county-level regressions can be found in the appendix discussion entitled "Stumpage Prices and County-level Regression."

(b) *RealPinePulp_Price, RealHardwoodPulp_Price*- The stumpage price for pine pulpwood and hardwood pulpwood in Alabama, both in USD/cord. All the comments on the nature of the stumpage price data from sawtimber variables above applies. As in sawtimber prices, county-level estimates use an average of North Carolina and Alabama stumpage prices, except for a smattering of years where only North Carolina data is available.

(s) *RealPolesandPiles_Price*- The stumpage price for poles and pilings in Alabama, in USD/thousands board feet.

______*lag*- Any macroeconomic variable can go in the blank and experience a "lag" of itself, although this approach has been used only on a couple of our macroeconomic variables, as explained in the results section and the appendix. For instance a *GDPGrowth_lag* would return the variable of the normal *GDPGrowth* for the year before the one in question (i.e. $GDPGrowthlag_{1961} = GDPGrowth_{1960}$).

*ln*________- The natural log of any given variable in the blank, whether that is a harvest volume variable, ratio, or right-hand side independent variable. This is done to increase ease of interpretation of elasticity of harvest and ratios to various variables, since in a double-log regression, the interpretation of the coefficient β_1 is that for every 1% increase in the variable, there is a β_1% increase in the dependent variable.

[23] Price information from Alabama was obtained from personal corroboration with James Chappell of the Alabama Forestry Commission. Stumpage prices from North Carolina courtesy of: Author Unknown, "Historic North Carolina Timber Prices, 1976-2017," *NC State Extension*, accessed April 4, 2019, https://content.ces.ncsu.edu/historic-north-carolina-timber-stumpage-prices-1976-2014.

The Regression Models

Note: By "preferred specification" in what follows, I do not mean the most common equation in the existing literature (mostly because there is very little existing literature in this area). Instead, I mean the commonest functional form for each of the three classes of regressions.

1) $PineSaw\_Harvest = \beta_0 + \beta_m Y_n + \beta_q X_r + \beta_5 t$

   Preferred specification:
   $PineSaw\_Harvest_{(\text{state or county})} = \beta_0 + \beta_1 NewHousingStarts_{(\text{national})} + \beta_2 GDPGrowth_{(\text{national})} + \beta 3 RealPineSaw\_Price_{(\text{state})} + \beta_4 RealReturn_{(\text{national})} + \beta_5 year$

   In the general and specific forms above, we are regressing pine sawtimber harvest on a constant, and several macroeconomic indicators, along with our rate of return variable and the time variable. The time variable is included to measure secular trends in timber harvest independent of our other variables. Ideally, we expect our constant to turn up equal to pine sawtimber harvest volume at the beginning of the period, β_5 to be indistinguishable from zero as well, and all other coefficients to be positive. A positive β_5 would indicate that timber production, independent of movements in other variables, is increasing as a function of time. This might be due to increased efficiency of sawmills and/or urbanization, necessitating a progression to the second regression model given in 2). This second equation is necessary not because of any bias in our beta-hat estimates or serial correlation of errors, but simply because, as we shall see in the results section below, the time variable is so significant that it drowns out the statistical significance of all our other right-hand side variables. This sort of regression model was run both on the Alabama statewide harvest data and on our county-level panel data.

2) $e1 = \beta_0 + \beta_m Y_n + \beta_q X_r$

   Preferred specification:

   $e1_{(\text{state})} = \beta_0 + \beta_1 NewHousingStarts_{(\text{national})} + \beta_2 GDPGrowth_{(\text{national})} + \beta_3 RealPineSaw\_Price_{(\text{state})} + \beta_4 RealReturn_{(\text{national})}$

   As with the regression model presented in 1), we have an expected value of zero for the coefficient on our β_0 and expected positive coefficients on all the other beta coefficients. We'd expect high new home construction, GDP growth, stumpage prices, or opportunity costs of capital to spur higher-than-expected timber harvests (above the fitted trend line-positive residual) and vice versa. The time variable has been eliminated through the trend line fitting process, thus we have no β_5. To check the robustness of results using regression models 1) and 2), model 3) was introduced. Because our panel data is not unique to each year, we are unable to find a residual series by running a tsline command in Stata for county-level harvest. Thus, this sort of regression is run only on our Alabama time-series data.

3) *PulptoSawRatio*= $\beta_0 + \beta_m Y_n + \beta_q X_r + \beta_5 t$

Preferred specification:
Ratio(state or county) = β_0 + β_1*NewHousingStarts*(national) + β_2*GDPGrowth*(national) + β_3*RealPineSaw_Price*(state) + β_4*RealPinePulp_Price*(state) + β_5*RealReturn*(national) + β_6*year*

As opposed to the other two regressions above, we have mixed expected signs here. We use the preferred specification to analyze the expected signs. Obviously, the constant term's coefficient still has an expected value equal to the ratio at the period's outset. We expect β_1, if the left-hand side variable is *PulptoSawRatio* rather than *PinePulp_PineSawRatio,* to be negative, since higher housing demand increases demand for larger timber. This sawtimber is used to fabricate housing frames and longer boards, but pulpwood is inconsequential home construction. We expect that β_2 will be approximately zero, since GDP growth increases national income across the board. This theoretically increases demand for pulpwood products and sawtimber products equally. However, much as we included a time trend despite its expected value of zero in earlier iterations, we include GDP to ensure that its value is truly zero. β_3 should have a negative sign, since higher sawtimber prices should incentivize higher sawtimber production (denominator) as opposed to pulpwood (numerator). But if we have a pulpwood stumpage price for our variable there, we'd expect a coefficient under the reciprocal logic. In any possible combination of variables in this ratio format, however, the β_4 coefficient is expected to be positive. The time variable's coefficient, β_5 in our example, is expected to be zero. If not, this equation will undergo modification to adjust for the trend as in equation 1). These ratio-based regressions are run both on the Alabama statewide data and the county-level panel data.

4) *ln*(harvest variable of choice or ratio)= $\beta_0 + \beta_m Y_n + \beta_q X_r + \beta_5 t$

Preferred specification:

lnRatio(state or county)= β_0 + β_1*lnNewHousingStarts*(national) + β_2*lnRealPineSaw_Price*(state) + β_3*RealPinePulp_Price*(state) + β_4*RealReturn*(national) + β_5*lnGDPGrowth*(national) + β_6*year*

The log-linear regression model given above is applied to both the Alabama statewide data and the panel county-level data in order to more directly examine elasticities of timber harvests and ratios to certain macroeconomic changes. In the preferred specification where regress *lnRatio* on the given right-hand variables, we have an expected negative sign on β_1, as we'd expect an increase in home construction to stimulate a larger increase in sawtimber harvest than pulpwood. The expected sign on β_2 is positive by the same logic, although if one views prices primarily as a signal of scarcity rent, one might expect the opposite. The expected sign on β_3's coefficient is positive, since a higher price for pulpwood should increase harvest of that product class relative to sawtimber. We expect β_4 to be positive, since a higher rate of return increases the opportunity cost of holding timber and incentivizes timber owners to harvest trees with faster growth rates (younger trees) than in an environment with lower rates of return on financial capital. We expect the sign on β_5 to be zero, since a general increase in income should theoretically increase demand for all wood products by the same amount. We also hope for a zero coefficient on β_6, although it may be more realistic to expect a positive coefficient, since sawmills are increasingly efficient at turning standing wood into finished products without waste, making smaller and smaller trees more marketable.

<u>Bifurcations on County Wealth and Credit Market Access Criterion</u>

Lastly, regression models 1), 3), and 4), all run on our county-level dataset with county fixed effects, were also run on bifurcated sections of the sample to test whether differences in owner wealth or access to credit markets change the validity of Fisher's theories and their latter-day variants. For county wealth and credit access bifurcations, I ran a summary of the variables *ResidentsperBranch* and *DepositsperCapita* in Stata and then dropped all but the top and bottom 10%, each saved in separate files. Once I obtained Stata files with exclusively the worst and best-banked 10% of counties in the geographic area, I re-ran all regressions on those separate .dta files and compared results directly. The same process performed on the *DepositsperCapita* variable allowed us to run our standard regressions on the wealthiest decile of southern counties vs. the poorest decile and similarly compare the coefficients.

Data

Harvest Data for the statewide portion project comes from the Alabama Forestry Commission (AFC). County-level harvest data was obtained from the US Timber Product Output (TPO) survey's online portal.[24] Meanwhile, data on timber stumpage prices from North Carolina and Alabama was obtained from the AFC and the North Carolina State University extension. Macroeconomic data comes from the St. Louis Federal Reserve's FRED, and from Aswath Damodaran, a professor at NYU. Demographic data, such as county population and median income, is gleaned from the US Census Bureau.[25] From Prof. Damodaran's collection I gleaned data on historical returns on the S&P 500, with dividends included.[26] From the Federal Deposit Insurance Corporation (FDIC), I obtained all data related to bank branch density and county deposits. This included the number of bank branches in each Deep South county of interest and the amount of deposits stored at banks within the county.[27]

Data obtained from St. Louis Federal Reserve comprises the macroeconomic variables of interest, including rates of return. In no particular order, the following data were gathered as far back as records existed from FRED: yield on the 10 year US Treasury Bill, the average rate on a 30 year fixed mortgage, the Federal Funds Rate, the national unemployment rate, year-over-year GDP growth rate, and new housing starts as measured in thousands of units. All other data sets collected from FRED are measured in terms of percentages. Some of these data sets stretched back into the 1940s and 1950s. But due to the central nature of the 30 year fixed mortgage in measuring rates of return on financial capital and the fact that these data are only available from 1970 onward, all regressions for the state of Alabama, for which harvest volume data is available for the whole postwar period, were run on 1970-2016 data, or subsets thereof.

[24] Author Unknown, "Timber Product Output (TPO) Reports," *United States Department of Agriculture*, updated 2019, accessed April 4, 2019, https://www.fs.usda.gov/srsfia/php/tpo_2009/tpo_rpa_int1.php.
[25] Author Unknown, "County Population Totals and Components of Change: 2010-2017," *US Census Bureau,* accessed April 4, 2019, https://www.census.gov/data/datasets/2017/demo/popest/counties-total.html. This same portal was used for the 1990-2000 estimates of county population and the post-2010 yearly estimates as well.
[26] Aswath Damodaran, "Annual Returns on Stock, YEAR.Bonds and YEAR.Bills: 1928 – Current," *NYU Papers*, January 5, 2019, http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/histretSP.html, accessed February 10, 2019.
[27] Author Unknown, "Branch Office Deposits-SOD Download," *Federal Deposit Insurance Corporation*, accessed April 4, 2019, https://www5.fdic.gov/sod/dynaDownload.asp?barItem=6.

Stumpage prices, or the price of timber paid to the landowner, is available via the AFC from 1977-1993 and again from 2000-2016. Stumpage prices are measured in dollars per cord (for pulpwood products) and dollars per thousand board feet (for sawtimber products, poles, and piles). In the 2009-2016 section of the stumpage price data, prices are given for each half of the state. A statewide average for Alabama is obtainable by simple average of the two halves in these years. Statewide in Alabama, I have obtained timber harvest volumes for pine sawtimber, hardwood sawtimber, poles and piles, and pulpwood from 1940-1992 and a separate set from 1996-2003 in addition to the more consistent later data. I aggregated the county-level data from post-1992 to yield statewide statistics in excel for the purposes of the regressions reported in my results. County-level harvest data are estimated from sample plots in each county. Meanwhile, state-level data are imputed from severance tax assessments and stumpage price data are from a private company that contracts with the AFC, Timber Mart South. In table one, we see variable summary statistics, produced in excel. Note the astronomical standard deviation on the S&P 500’s yearly return, thus its exclusion from any of the main rate of return averages used in reported regressions.

Table 1-Summary Statistics of All Alabama Statewide Variables

Summary Statistics for Alabama	Observations	Mean	SD	Min	Max
PineSaw_Harvest (mbf Scribner)	39	1,386,790	240,398	891,907	1,932,887
HardwoodSaw_Harvest (mbf Doyle)	39	233,916	49,854	119,971	358,570
PinePulp_Harvest (cords)	30	5,679,094	1,288,942	2,740,686	7,976,771
HardwoodPulp_Harvest (cords)	30	3,215,333	551,618	1,507,169	3,874,719
TotalPulp_Harvest	39	8,317,677	1,665,464	4,247,855	11,000,000
PolesandPiles_Harvest (mbf)	39	59,629	21,969	35,817	119,631
NominalFedFundsRate	39	5.15	4.11	0.09	16.38
NominalS&P500 Return	39	12.23	16.33	(36.55)	37.20
Nominal30YearMortgage	39	8.22	3.40	3.65	16.64
GDPGrowth	39	2.75	2.07	(2.70)	7.90
NewHousingPermits (thousands)	39	1,364	396.1	582.0	2,160
NominalTen-Year Trasury	39	6.45	3.24	1.80	13.92
RealReturn (Treasruy+Mortgage/2)	39	3.71	2.42	(0.93)	9.01
RealIndex (All Rates-Inflation)	39	3.74	4.64	(10.53)	10.84
PinePulp_PineSawRatio	30	4.04	1.24	2.62	7.17
PulptoSaw_Ratio	39	5.23	1.28	3.47	9.10
CPI	42	161.8	55.39	60.60	251.1
RealPineSaw_Price	31	144.7	42.63	78.90	228.7
RealHardSaw_Price	31	90.62	25.30	58.55	142.9
RealPinePulp_Price	31	14.43	3.86	8.11	21.63
RealHardPulp_Price	31	9.63	4.96	3.37	20.00
RealPolesandPiles_Price	24	260.0	60.83	180.3	376.9

Then we have the county-level, South-wide analysis portion of the data. This portion includes most of the variables from the state-wide portion, but adds county fixed effects and a series of credit market accessibility variables, including bank branches in each county, county population, residents per bank branch, and deposits per resident. Summary statistics for the county-level portion of the data are seen below in table 2. Harvest volume data for each county in the area of interest was obtained from the USDA’s Timber Product Output (TPO) biannual survey from 1995 to 2015. All nationwide macroeconomic variables used in the county-level analysis were taken from the same sources as in the Alabama statewide portion of the analysis, including GDP growth, new housing starts, the S&P 500 return, 30 year mortgage rate, federal funds rate, and averaged rates of return. These two datasets were merged on the state/county identifier variable by using the “merge” command in Stata, which also allowed me to import and integrate yearly data on county bank branch density, deposits per capita, and South-wide stumpage prices, discussed earlier. In table 2, we see the summary statistics for the variables that were used in county-level regressions.[28]

Table 2-Summary Statistics of County-Level Variables

County-level Summary Statistics	Observations	Median	SD	Skewness	Min	Max
RealPinePulp_Price	4472	8.91	2.73	0.16	4.78	13.18
RealPinePulp_Price	4472	9.89	0.97	-0.01	8.29	11.50
RealHardSaw_Price	4472	105.2	15.42	0.16	74.80	127.4
RealPineSaw_Price	4472	158.5	40.87	-0.40	81.86	197.5
CPI	4472	189.7	27.57	0.12	152.4	237
PinePulp_PineSawRatio	4285	2.52	158.5	36.61	0	7781
PulptoSaw_Ratio	4285	2.52	158.5	36.61	0	7781
NominalIndex	4472	4.93	4.89	-0.88	-6.72	11.06
RealIndex	4472	2.94	5.16	-1.05	-10.53	9.51
RealReturn	4472	2.39	1.22	0.14	0.66	4.56
IndexedReturn	4472	4.92	1.43	-0.09	2.73	7.12
NominalTenYearTreasury	4472	4.01	1.45	-0.05	1.8	6.44
Inflation	4472	2.3	0.81	0.37	1.3	3.8
NewHousingStarts	4472	1509	451.8	-0.27	604	2058
GDPGrowth	4472	2.7	1.88	-1.52	-2.7	4.9
Nominal30YearMortgage	4472	5.84	1.43	-0.11	3.65	8.05
NominalS&P500 Return	4472	12.09	19.05	-1.15	-38.49	26.67
NominalFedFundsRate	4472	1.35	2.26	0.56	0.09	6.24
PineSaw_Harvest (mbf Scribner)	4427	19508	20489	1.36	0	156062
HardwoodSaw_Harvest (mbf Doyle)	4472	2673	4848	2.17	0	40959
PinePulp_Harvest (cords)	4427	48433	59956	1.87	0	564241
HardwoodPulp_Harvest (cords)	4472	14163	26013	2.49	0	274428
Residents per Branch	4457	3030	4315	13.06	127	82078
Deposits per Capita	4457	9807	11129	19.55	0	338352
RawDeposits	4457	221656	558520	7.13	0	1.15E+07
County Population	4457	21683	51659	6.80	1346	737418

[28] A few variables that were gathered, like county-level unemployment and CPI, were never used, and some of them do not appear in the summary statistics table.

Results

Statistical testing indicates that fluctuations in market rates of return have no discernible effect on timber harvester's decisions. Prices, demand considerations, and the inexorable rise in efficiency are much more powerful factors in determining the quantity of timber harvested than rates of return. Results here are presented first for the state of Alabama, and subsequently for the entire Deep South on the county-level, as indicated by subheadings. Most findings are consistent across both series. Some preliminary regressions on groups of counties that differ by ownership class, determined by heuristic methods, are available in the appendix immediately following table 13 in a discussion entitled, "Timber Harvest and Ownership Pattern-An Experimental Approach."

a) Alabama Statewide Results

In a standard OLS regression of pine sawtimber harvests against new home construction, GDP growth, our time index, and the market rate of return (as measured by "RealReturn," the 30 year mortgage rate plus 10 year YEAR-bill divided by two minus the inflation rate) showed only the time variable itself and new home construction to be statistically significant. Results of this regression are given by column (1) in the figure 2.

As expected, new home construction, correlated with increased timber harvest, as did the passage of time. Between the two, new home construction is the more significant variable. Whereas a one standard deviation increase in home construction (about 400,000 homes) in a given year increase Alabama's pine sawtimber by 145 million board feet, the advance of the calendar by one year increases production by 12 million board feet. While our rate of return variable has a large coefficient in (1), due to the massive standard deviation, it turns up statistically insignificant. As we shall see in later regressions, the return on capital variable tends to vary between large positive and large negative coefficients (much as it does even within the series of regressions in the table below), but fails to register statistical significance.[29]

[29] For other iterations of statewide Alabama Pine Sawtimber regressed without a structural break, see appendix table 4.

Figure 2-Regressions of Pine Sawtimber and Residual Series (Alabama Statewide)

	(1) Pine Sawtimber Harvest (mbf Scribner)	(2) Pine Sawtimber Harvest (mbf Scribner)	(3) Residual Series of Pine Sawtimber	(4) Residual Series of Pine Sawtimber
New Housing Permits (thousands)	391.2*	375.7*	11.54	
	(2.62)	(2.14)	(0.08)	
GDPGrowth	-25876.6	-23307.5	10961.8	
	(-1.06)	(-0.87)	(0.49)	
RealPineSaw_Price	-1264.2	-2083.1	-553.5	-910.9
	(-0.86)	(-1.18)	(-0.38)	(-0.69)
Real Return	10600.8	-5166.3	853.0	
	(0.66)	(-0.28)	(0.06)	
year	9248.0*			
	(2.33)			
NewHousingStarts_lag				58.49
				(0.44)
RealReturn_lag				2859.8
				(0.19)
GDPgrowth_lag				10595.9
				(0.53)
Constant	-17413919.8*	1202151.8***	11588.8	-9826.0
	(-2.17)	(3.99)	(0.05)	(-0.04)
Observations	31	23	23	23

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The overwhelming significance of the time variable in (1) indicates an inexorable increase in timber production with the passage of time. This increase is independent of economic conditions in all but the most extreme cases, such as the 2008-2009 Atlantic Recession. Thus, to enhance the explanatory power of our variables of interest, I fitted a trend line to the data with a structural break in 2008. The Stata command “estat sbsingle,” run on a simple OLS of time against pine sawtimber harvest, indicated the best structural break date of 2008 and confirmed the existence of a break.[30]

Given the structural break's existence, regressions (2), (3), and (4) are run on pre-2008 data, hence the lower observation count. Further, regressions (3) and (4) are not run on pine sawtimber harvest directly, but on the residual series generated by fitting a trendline to the data. In theory, testing on the residual series of pine sawtimber harvests should allow us to quarantine the effects of generally increasing production. Thus, we may better derive significance from variables that coincide with periods when timber harvests either accelerate faster than the trendline predicts or drop below the general increase associated with population growth, increased efficiency, and more acreage for timber. These methods also fail to detect statistical significance for any measure of market rate of return on financial capital. This finding holds whether return is measured as returns on the stock market, YEAR-bill yields, mortgage rates, the federal funds rate, or any indexed combination.

For results of regressions on the pine sawtimber harvest data itself rather than the residual series, please see Tables 3 and 4 in the appendix. Conventional OLS linear regressions on variables of interest for 1970-2008 of the residual series around the trend are outlined in the Figure 4, where we see that our rate of return index winds up with the opposite of our expected sign. To boot, it is statistically insignificant. GDP growth, a demand indicator, appears as both clinically and statistically significant, with a 1% increase in GDP in a given year predicting a pine sawtimber harvest of 21.16 million board feet more than the trendline would predict for that year. Stumpage prices have the correct sign but barely miss statistical significance at the 90% confidence level, probably owing to missing observations.

When we restrict the limits of the regression to only the years for which we have near-continuous stumpage price data before the structural break (1977-2006), we find that the stumpage price of timber once again assumes a negative and insignificant value. This, in conjunction with previous results, strongly suggests that timber harvesters in Alabama do not respond in the face of changing opportunity costs for holding timber (curiously, it also suggests

[30] For Stata output confirming the break, see Appendix Table 6.

that higher prices do not affect decision-making). This contradicts the existing optimal rotation literature.

In regressions (3) and (4), we see that our main variable of interest, the real rate of return on financial capital, is nowhere near significant, statistically or clinically. Further, its coefficient changes signs depending on whether we lag rates of return (on the notion that it may take a year for rates of return information to alter decision-making), indicative of low robustness to sensitivity testing.

In anticipation of an objection, namely that timber harvesters may not immediately see the changes in market rates of return (or that the rates available to larger institutional investors, like 30 year mortgages, or active investors, like YEAR-bills, may take time to filter through the financial system to laymen), I also performed a regression identical to (3) but with lagged right-hand variables (as seen in (4) of figure 2). These lagged variables reflect values in the previous year (for instance: we regress the value of 1977 timber harvests on 1976 rates of return, GDP, etc.) on the belief that it may take up to a year for rates of return to register and affect harvesting behavior. As we see in the figure, this hypothesis is roundly rejected.[31] Market return on capital is still insignificant.

<u>Ratio-based results</u>

Next, I ran a series of regressions on the *PulptoSawRatio,* a fraction with quantity of pulpwood harvest in the numerator and sawtimber harvest in the denominator. None of the tests provided support for the hypothesis that timber harvesters cut their trees when marginal opportunity costs of forgoing harvest exceeds growth. In such a case, timberland owners should harvest younger trees (which have a faster volume growth rate) when marginal rates of return increase rapidly. This was the case in the early 1980s as the high interest rates of the 70s payed large returns when inflation subsided. Hence, we would expect that in years with higher interest rates, under the prevailing hypothesis, pulpwood harvests would increase as a ratio of total

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[31] For a discussion on multicollinearity between macroeconomic variables and why I chose to retain both new home starts and GDP growth in most regressions, see "Discussion on Multicollinearity in e1 Regression" in the Appendix.

timber cut. This result is not found mathematically nor graphically, and if anything, the opposite may be true.

We find that simply regressing the rate of return by itself in crude nature, as in regression (1) and (2) in figure 4, gives us a significant negative coefficient for nominal return and an insignificant negative coefficient for real rates of return. Seeing as pulpwood is in the numerator and sawtimber in the denominator of the ratio calculation, our interpretation here is that fewer young trees are cut for every older tree when rates of return increase. This is the opposite of the model's predictions. Regression model (3) in figure 4 similarly lends the existing theory no substantive support. When new housing permits are controlled for, returns remain insignificant, while new housing permits have the expected sign and significance to the 1% level. A one standard-deviation change of 396,000 permits would decrease the ratio by approximately 1, or about 75% of a standard deviation.[32]

Figure 4-Regressions on Ratio

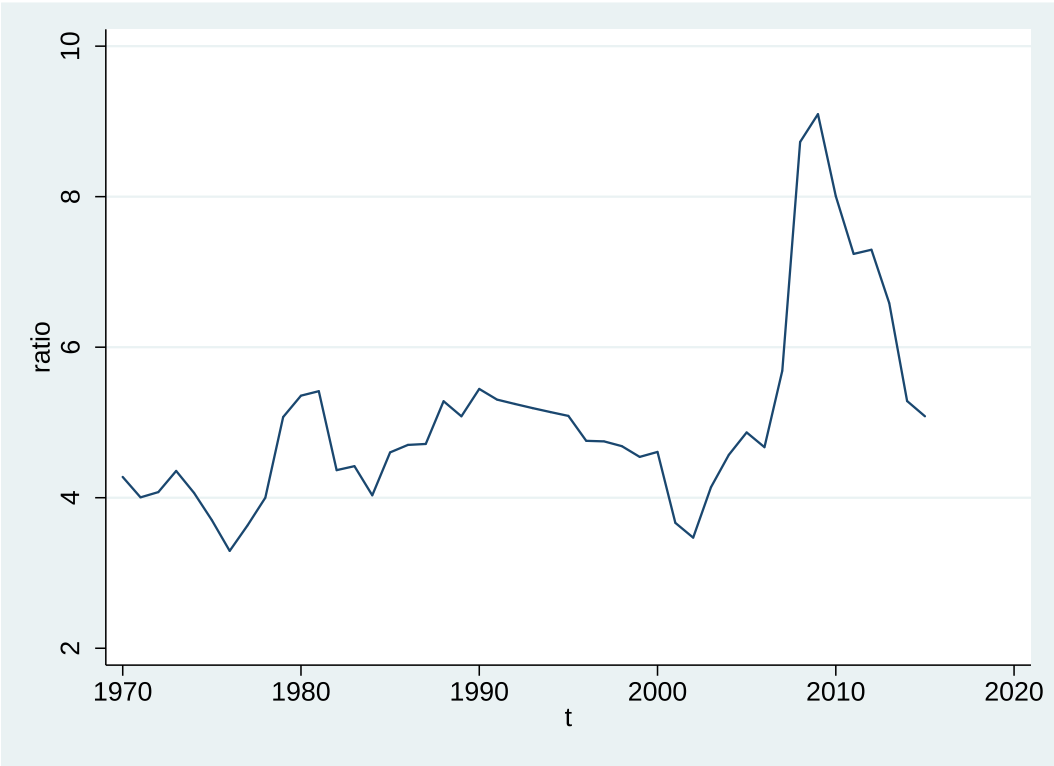
	(1) PulptoSaw_Ratio	(2) PulptoSaw_Ratio	(3) PulptoSaw_Ratio
Indexed Return	-0.157* (-2.70)		
Real Return		-0.125 (-1.48)	-0.0401 (-0.83)
New Housing Permits (thousands)			-0.00268*** (-9.10)
Constant	6.379*** (13.66)	5.690*** (15.22)	9.026*** (21.40)
Observations	39	39	39

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

[32] For more ratio-based results on the Alabama statewide data, please see Appendix Table 6. These regressions similarly show that rate of return, however measured, comes up as either insignificant or, curiously, significant in the negative direction, indicating decreased harvest of younger trees when rates of return are higher. This is the opposite of our expectations based on optimal timber harvesting theory.

In Figure 3 we see a Stata-generated graph of the ratio in cords pulpwood divided by mbf sawtimber, from 1970 to 2016. The ratio seems rather consistent between 3.5 and 5.5, dipping slightly lower in boom times like the mid-1980s and late 90s/early 2000s, and slightly increasing in the early 1980s recession. However, the Atlantic Recession's signature is unmistakable. The ratio of pulpwood to sawtimber more than doubled in 2008-2009 before slowly declining along with the national recovery. This indicates that many timber owners cashed out on young timber stands to make up for losses in other income, even in a time when the market rates of return crashed.

Figure 5-Ratio of Pulp to Sawtimber Harvest in Alabama 1970-2016



An additional pair of regressions of multiple the variables of interest against the ratio, as given in figure 6, paints a more complete picture that resolves the differences between figure 5 and the story emanating from the rest of our data. It appears as if the recession years are an anomaly in terms of price's effect of pulpwood vs. sawtimber harvests, and that higher prices for timber do induce timberland owners to increase harvests of smaller trees even more than larger ones, as can be seen in the positive and significant coefficient on pine pulpwood price.

Notably in figure 6, our return variable turns up statistically insignificant, again refuting standard optimal timber harvest interpretations. These two ratio regressions show that new home construction indeed does induce more sawtimber harvest relative to pulpwood harvest, as seen in large negative coefficients. Further, the price coefficients are as expected.

Figure 6- Ratio Regressions-Alabama Statewide

	(1) PulptoSaw_Ratio	(2) PulptoSaw_Ratio
Real Return	0.00196 (0.06)	
GDP Growth	-0.0639 (-1.34)	
New Housing Permits (thousands)	-0.000915^{**} (-2.96)	-0.00259^{***} (-5.45)
RealPineSaw_Price	-0.00426 (-1.37)	-0.000197 (-0.05)
RealPinePulp_Price	0.0503^{*} (2.34)	
Indexed Return		-0.0813 (-1.35)
GDPgrowth_lag		0.0266 (0.38)
RealPinePulp_Price		-0.0272 (-0.48)
Constant	5.996^{***} (9.10)	9.702^{***} (12.88)
Observations	23	31

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

<u>Log-linear form results</u>

Since we were unable to find evidence that higher returns on financial capital induce more voluminous timber harvests in Alabama with any of our first three models, we finally progress to a log-linear model. It might be that measuring elasticities of harvest to changes in price, rate of return, and macroeconomic conditions is a more appropriate empirical strategy given the demonstrated time trend and the ease of interpretation associated with this model (since rates of return are already in terms of 1% increases). However, as we can see in figure 7, the application of this log-linear model does not produce any support for the prevailing theoretical framework. In all 4 regression variants run with pine sawtimber harvest as our left-hand variable, whether rates of return were measured in nominal or real terms, rates of return wind up negative. In models (2) and (4) in figure 7, where nominal rates were chosen, these negative coefficients assume significance at the 90% confidence level. Curiously, the log of real prices for pine sawtimber also assumes a negative and significant value for models (1) and (3). In model (1), a 1% increase in real prices for sawtimber corresponds to a .3% decrease in harvest volume. Given that previous regressions have found either insignificant coefficients on price or the expected significant sign, it may be that this is an anomaly. Alternately, if price expectations are "sticky" intertemporally and current prices are thought to reflect scarcity rent, then higher prices would provide timberland owners with an incentive to conserve timber for even higher future returns. However, this scarcity rent model does not coincide well with the character of price data that we have, which shows periodic rise and fall rather than the sort of gradual rise theoretically associated with scarcity rent on truly depletable resources.

Figure 7- Log-linear Pine Sawtimber Harvest Regressions

	(1) lnPineSaw	(2) lnPineSaw	(3) lnPineSaw	(4) lnPineSaw
lnRealPineSawPrice	-0.300*	-0.157	-0.294*	-0.151
	(-2.73)	(-1.28)	(-2.71)	(-1.26)
lnNewHomeStarts	0.451***	0.364**	0.418***	0.345**
	(3.81)	(3.22)	(3.88)	(3.38)
GDPgrowth_lag	-0.0104	-0.00586		
	(-0.71)	(-0.42)		
Real Return	-0.00994		-0.00933	
	(-0.98)		(-0.93)	
Indexed Return		-0.0173*		-0.0177*
		(-2.11)		(-2.21)

Constant	12.42***	12.42***	12.59***	12.51***
	(19.34)	(20.84)	(21.52)	(22.94)
Observations	31	31	31	31

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In a final attempt to divine some sort of rate of return effect with our Alabama time-series data, we run a series of log-linear regressions with the log of our pulpwood to sawtimber ratio, rather than pine sawtimber harvest, on the left side. In models (3) and (4) in figure 8 below, we analyze on an even more granular level by using the ratio of pulpwood to sawtimber specifically for pines. In all cases, rates of return are either insignificant (as in (1) and (2)) or significant in the wrong direction (as in (3) and (4)). Our price indicators now assume expected signs, but miss statistical significance here, while new home permit applications continue their streak of clinical and statistical significance by assuming the correct sign in all four regressions with remarkable consistency. In all four regressions, a 1% increase in new home starts decreases the ratio of pulpwood to sawtimber by between .45 and .6%.

Figure 8- Log-linear Ratio Regressions

	(1) lnRatio	(2) lnRatio	(3) lnPineRatio	(4) lnPineRatio
lnNewHomeStarts	-0.578***	-0.551***	-0.483**	-0.460**
	(-6.13)	(-6.74)	(-3.43)	(-3.96)
GDPgrowth_lag	0.00650		0.00755	
	(0.60)		(0.30)	
lnRealPineSawPrice	-0.0981	-0.108	-0.0925	-0.0967
	(-1.14)	(-1.30)	(-0.78)	(-0.84)
lnRealPinePulpPrice	-0.104	-0.0883	0.155	0.180
	(-1.25)	(-1.14)	(0.83)	(1.10)
Real Return	0.000455	-0.000564	-0.0943**	-0.0970**
	(0.06)	(-0.07)	(-3.45)	(-3.85)
Constant	6.506***	6.343***	5.146***	4.970***
	(11.63)	(13.16)	(4.84)	(5.74)
Observations	31	31	22	22

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Satisfied that we have performed every manipulation of our long-term time-series data imaginable in search of significance for rates of return and have come up empty, we now turn to a panel analysis with county-level data.

b) County-level Results

Our county-level estimates incorporate biannual harvest data over the period 1995-2015 from nearly 400 counties considered "Deep South."[33] As previously discussed in the empirical model section, this strategy allows us to use panel regression and enlarges our observation count. On the other hand, it shortens the time window and includes fewer observations of rates of return, which are nationally-determined, than the time series approach. Much as in the Alabama statewide section, we began with a regression of pine sawtimber harvests on our macroeconomic indicators, time, and price. All county-level results that follow control for county-level fixed effects, and hence the random variation of such factors as demographic makeup and local labor market conditions are controlled. We now proceed to specific results.

As we see in figure 9, there is a significant downward trend in harvests over the time period, with a one-year progression corresponding to a decrease of 323 board feet in an average county, or roughly 1.5% of a standard deviation. This means that a decade of time decreases harvest by 15% of a standard deviation. This is likely because with data running 1995-2015, the Atlantic Recession falls near the period's end and thus drags down harvests. When we fail to control for this time trend, many things go askew. For instance, new housing permits obtain a negative coefficient unexpectedly and real returns become the most significant factor—in the wrong direction again. Curiously, when we control for time in (1), GDP growth's coefficient is negative, although new housing permits have the expected sign in that model.

Figure 9- County-level Regressions with Pine Sawtimber Harvest

	(1) Pine Sawtimber Harvest (mbf Scribner)	(2) Pine Sawtimber Harvest (mbf Scribner)
New Housing Permits (thousands)	9.138***	-3.848*
	(10.62)	(-2.44)

[33] For an in-depth discussion of regional boundaries for the county-level analysis, see the first entry in the appendix.

GDP Growth	-1274.0^{***}	-501.1^{*}
	(-7.94)	(-2.48)
RealPineSaw_Price	-33.49^{*}	-11.68
	(-2.48)	(-0.83)
Real Return	310.5	-1442.1^{***}
	(1.01)	(-4.01)
year	-323.6^{***}	
	(-4.20)	
Constant	667582.5^{***}	42243.8^{***}
	(4.29)	(10.45)
Observations	4427	2587

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Following the procedures in the statewide section, we progress to analyze ratios of pulpwood to sawtimber cut throughout the region, as shown below in figure 10. The astute reader will note that absolutely nothing is statistically significant here, though our point estimates on new home permits and real prices for pulpwood and sawtimber are at least the correct sign. Again, we find no support for the prevailing hypotheses, however. Even though real returns have the correct sign, they are statistically insignificant.

Figure 10- County-level Ratio Regressions without Bank Variables

	(1) ratio	(2) ratio
Real Averaged Return	1.265	
	(0.31)	
Average Real GDP Growth	-0.540	-0.420
	(-0.22)	(-0.24)
New Housing Permits (thousands)	0.00705	0.00672
	(0.54)	(0.52)
RealPineSaw_Price	-0.235	-0.240
	(-1.21)	(-1.17)

	(1)	(2)
Pine Pulpwood Price	1.109	
	(0.97)	
Nominal Averaged Return		-1.113
		(-0.29)
RealPinePulp_Price		2.389
		(0.86)
Constant	11.10	18.53
	(0.31)	(0.59)
Observations	4285	4285

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Next, we leverage our county-level data to control for access to the credit system, a central assumption in standard optimal timber rotation literature. Access to the credit system is proxied by residents per bank branch in the county and deposits per capita, which also measures accumulated wealth. We begin by regressing pine sawtimber harvests and ratios of pulpwood to sawtimber against the variables used in figures 9 and 10, but add in the bank-related variables. This not only helps us elucidate if controlling for access to credit will change point estimates on other variables of interest, but also to see if there is a correlation between harvest levels and county wealth. Results of these regressions are found in tables 7 and 8 of the appendix and are briefly summarized here. Deposits per capita appear to correlate with lower pine sawtimber harvests but have no effect on the pulpwood: sawtimber ratio, while residents per bank branch have no effect on either harvests or ratio. Interestingly, real rate of return achieves its first statistically significant and positive result in regression (2) of table 7, but its effect on harvest is much smaller than new home permits.[34] Whereas a one standard deviation increase in new housing starts induces a .15 standard deviation increase in sawtimber harvest, a one standard deviation increase in real returns induces only a .05 standard deviation increase in harvest. Once again, all variables in the ratio regressions presented in table 8 are insignificant.

[34] It might also be noted that as of table 7 in the appendix, we have run 35 separate regressions! If the chances of obtaining a false positive at the 95% confidence level are 1/20, we statistically should have obtained about 1.75 false positives by now if the true value of rate of return is zero.

Following the procedure set down in the Alabama-focused statewide section of the analysis, we now proceed to scrutinizing log-linear regressions, this time on the county-level. We see results in figure 11 below where the log of pine sawtimber is regressed on a slew of right-hand side variables.

Figure 11- Log-linear Regression of Sawtimber Harvest with Bank Variables

	(1) lnPineSaw	(2) lnPineSaw	(3) lnPineSaw	(4) lnPineSaw
lnRealPineSawPrice	0.183**	-0.0177	0.395***	0.254**
	(2.64)	(-0.20)	(7.05)	(3.18)
Deposits/Capita	-0.0000187***	-0.0000153**	-0.0000174***	-0.00000918
	(-3.79)	(-3.06)	(-3.52)	(-1.86)
Residents/Branch (nearest whole #)	-0.00000760	-0.00000765	-0.00000446	-0.00000309
	(-0.61)	(-0.62)	(-0.36)	(-0.25)
lnNewHomeStarts	0.402***	0.457***	0.257***	0.266***
	(8.00)	(8.84)	(6.10)	(6.07)
GDP Growth	-0.0470***	-0.0479***		
	(-5.26)	(-6.85)		
Real Return	0.0221		-0.0366**	
	(1.35)		(-3.04)	
Nominal Return		0.0585***		0.0199
		(3.67)		(1.33)
Constant	6.158***	6.488***	6.160***	6.504***
	(22.30)	(22.21)	(22.23)	(22.13)
Observations	4270	4270	4270	4270

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In the two regressions that use real returns ((1) and (3)), rate of return turns up insignificant or significant in the wrong direction. Meanwhile, in regressions (2) and (4) in figure 11, nominal return is significant and positive in one and insignificant in the other. New housing starts alone achieves statistical significance in the predicted direction across all four regressions. Depending on the model used, a 1% increase in new home starts corresponds to between a .25%

and a .45% increase in pine sawtimber harvested across the Deep South. A standard deviation increase of 451,000 starts, assuming we start at the median of 1.5 million per year, translates to a 30% increase in starts. According to regression (2), this would induce a 14% increase in pine sawtimber harvested. Meanwhile, a standard deviation increase of 1.43% in the nominal return, while it has statistical significance in regression (2), induces only an 8% increase in pine sawtimber harvest.[35] In three of the four models, return is insignificant, and where it does achieve statistical significance, its clinical importance is dwarfed once again by demand-side macroeconomic indicators. The story when we regress the log of the pulpwood to sawtimber ratio for the whole Deep South, as shown in appendix table 9, is much the same. Return is insignificant, while new home starts have overwhelming significance in the expected direction (negative for the ratio). The price variables are significant in the correct direction for this regression. Specifically, a 1% in prices for pine sawtimber decreasing the ratio by approximately .4% and a 1% increase in pine pulp prices increase the ratio by about .4%.

Now that we have thoroughly tested in the aggregate on both the state and county levels and come up mostly empty, we consider the possibility that unequal access to credit markets in different counties is causing timber owners to behave differently in different counties.[36] To test whether disparate access to the banking system or disparate personal wealth is causing distortions to our results, we look at four subsets of the Deep South's counties. First, we juxtapose the counties in the bottom decile of our residents per branch variable and those in the top decile. Then, we compare the counties in the top 10% of deposits per capita with those in the bottom 10%. We then run four identical standard regressions similar to those we've run on the whole sample specifically on those deciles, looking for large differences in the coefficients on price and market rate of return that would indicate a fundamental difference. Each of the four deciles of interest is regressed on ratio, on pine sawtimber harvest, and the log-linear form of both.

[35] Semi-log rule: .0585*100%=5.85% increase for a 1-unit increase in nominal return average. For a 1.43% (analogous with unit because the units are percentages) increase in nominal return, we have 1.43*5.85=8.36% response in pine sawtimber.

[36] This possible explanation is laid out more thoroughly in the "contending explanations" section below.

Due to the large number of additional regressions run, these tables have been relegated to the appendix to save space.[37] In only one of 16 regressions run on these deciles does rate of return emerge as a statistically significant determinant of timber harvest decisions, and ironically, it's a regression of pine sawtimber harvest for the poorest decile of counties in the South.[38] We would expect that if our findings are the result of bad access to credit markets, that we would find the exact opposite—that wealthier counties behaved more according to the theory than poorer ones, which held timber as an insurance policy to cash in when the macroeconomy sours. However, according to the results in appendix tables 10-13, it seems that there is little difference between wealthy and poor counties, or between well-banked and less-banked counties, in sensitivity to market rate of return.

On the main, our results strongly indicate that timber prices and demand-side signals like new housing starts are much more important in determining timber harvests in the US Deep South than market rate of return, which looks insignificant altogether. In only three of roughly 50 regression models did market rate of return register statistical significance in the expected direction (ironically, 3/50 is very nearly 1/20, or the amount of false positives we expect at 95% confidence if the true value is zero). Even when return did show some statistical significance, its clinical significance was dwarfed by new home starts, and where time was uncontrolled, the inexorable increase in timberland productivity as time progresses.

[37] Specifically, see appendix tables 10-13.

[38] Though this is probably an anomalous result. The other 7 regressions on poor/badly-banked counties turned up no statistical significance whatsoever.

Contending Explanations

1. Lack of access to credit/imperfect financial information- It is possible that in much of the Deep South, where timberland ownership is dominated by small individual owners, access to credit markets and information is imperfect, causing contradictions of theory. For instance, if one’s timber stocks are growing at 4% annually and the going opportunity cost of capital is only 3%, the theory says the timber owner should wait to harvest until the trees’ rate of growth falls to 3%. But suppose the owner is hit with an economic hardship, such as a lost job in the family, a medical bill, or an automobile breakdown. According to the theory, it is more economically efficient to borrow money at 3% interest to pay those expenses rather forgoing 4% appreciation on one’s forest. However, this assumes that all players in the market can access the credit market, and further, that they can borrow at the prevailing opportunity cost of capital.

That is not a reality for most Americans, who pay a premium to borrow capital from the bank or on credit cards. Under this framework, it makes sense for those small-plot timberland owners to cash out timber growing at 4% and pay the expenses with cash. The other options are racking up credit card debt at 20% interest or getting a 7-10% interest personal loan from the bank. However, the failure to see any significant difference in responsiveness to interest rates between counties in the South’s top decile of wealth and bank access and those counties in the bottom decile, along with preliminary heuristic evidence presented at the conclusion of the appendix, renders this explanation unlikely.

Our analysis suggests that while this might be part of the explanation for rate of return’s insignificance, it is not the whole story, as wealthy and well-banked counties exhibit the same patterns of responsiveness to rates of return. Preliminary regressions on state sub-regions with differential ownership also indicate little difference. Whether this is due to the Atlantic Recession’s universal impact and our short time span in the panel county-level analysis, or whether this relationship would hold with a longer panel, is anyone’s guess.

2. Rules of thumb and environmental conservation—not profit-maximizers-It is also possible that the theory is flawed from the start in that many timber owners simply do not operate as profit-maximizing actors. Rather, they may value environmental conservation of their land, its future productivity, or follow some simple rules of thumb. Living in a world of near-infinite knowledge but finite time necessitates that we find cognitive "shortcuts" to at least some of the decisions in our lives. No person could possibly know everything about the political system of their country, their own health, the economic literature pertinent to their landholdings, the current scientific literature about the Big Bang, and every choice the make in a day.

   Thus, we economize with rules of thumb and approximations of what we should do. In political science literature, this "cognitive miser" model is used to explain how voters can make reasonable choices without spending infinite time examining political issues. Voters utilize such short-cuts as taking cues from elite figures or using party labels to proxy for candidate positions.[39] If timber owners are acting as "cognitive misers," they may not consider harvesting until trees reach some specific arbitrary width or reach some arbitrary age. Of course, there is the other option that timber harvesters are behaving sub-optimally not because of ignorance or cognitive shortcuts, but because the negative consequences for their land of harvesting erratically (especially if profit-max calls for clear cutting rather than gradual selective cuts) are more important to avoid than the economic benefits are to gain. Particularly for small timber holders living and recreating on the timberlands they manage, this is particularly plausible. This is the hardest explanation to empirically test, however, as it would require a contingent valuation or choice experiment survey of timberland owners in the Deep South to determine the value of environmental services to owners.

3. The "Peso Problem" Explanation-Unique among the explanations offered, this one affirms that timberland harvesters are acting as rational actors, but that they will

[39] Richard R. Lau and David P. Redlawsk, "Advantages and Disadvantages of Cognitive Heuristics in Political Decision Making," *American Journal of Political Science* Vol. 45, No. 4 (Oct., 2001), pp. 951-971, http://www.uky.edu/AS/PoliSci/Peffley/pdf/Lau&RedlawskAJPSAdvntgs&DisofHeuristics2001-45(4).pdf, accessed January 31, 2019.

nonetheless not follow the Fischer/Fasutmann theory. The "Peso Problem" refers to the oft-observed tendency of foreign exchange markets to predict devaluations in second and third world nation's currencies that never seem to materialize. This is exemplified by risk premiums priced into currency future markets.[40] Many authors attribute this phenomenon to political uncertainty, particularly in the Latin American nations. Investors in these nations know that a populist, authoritarian, or socialist regime bent on devaluing the currency will eventually happen, but they are unsure of when it will occur.[41] Thus, they request a risk premium for holding the currency even though the event may not be imminent, or even remotely predictable.[42] In our case, the exact opposite is occurring. Timberland owners know that timber prices will increase by at least a standard deviation (unless they are already high), or 20-30%, but they don't know exactly when. In this environment, it sometimes makes sense to pay an economic price for a few years by forgoing harvest, even a decade, to eventually realize the benefit of much higher prices. Whether this strategy usually pans out is uncertain, and it entails significant sunk costs that skew decision-making if increases fail to materialize. This is a difficult hypothesis to empirically test, however.

4. Behavioral explanations-In conjunction with explanations number one and two, this one contends that timber harvesters are behaving irrationally. Perhaps there is a significant quantity of small land-holders who treat their forests as insurance against bad economic events, such as losses of jobs. These adverse shocks tend to happen when rates of return are low in bad economic times, so the effect of larger, more efficient land holders behaving rationally are cancelled out in the data. The large spike in the pulpwood/sawtimber ratio when rates of return plummeted during the 2008-2009 Atlantic Recession, discussed in brief in the results section, implies that many southerners do treat their timber holdings as insurance to augment outside income in hard times or economic emergencies.

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[40] Javier Garcia-Fronti and Lei Zhang, "Political Uncertainty and the Peso Problem," *Munich Personal Repec Library*, 2006, https://mpra.ub.uni-muenchen.de/18246/1/MPRA_paper_18246.pdf, accessed January 31, 2019.
[41] Ibid.
[42] Personal conversation with Professor Anderson on the nature of the "Peso Problem."

Conclusions

My results suggest that in the Southern US pine industry, Fischer's theories, and associated variations on his work, do not hold. Our initial finding that rate of return is predictive of neither pine sawtimber harvests nor overall timber harvest is robust to trend-fitting techniques, lagging variables, testing residual series to hold constant the effects of technological increase, regressing in log-linear fashion, trying several different measurements for rate of return, and doing all of these same processes on county-level data with over 4,000 observations. Given that the existing literature on optimal timber rotations assumes both perfect access to credit markets and strict rationality, it is unsurprising that the theory's projections are not fully borne out by real-world behavior. However, the utter absence of any significance in the market rate of return, even holding macroeconomic conditions, timber prices, and increases in efficiency constant, directly contradicts the veracity of the existing theories. Further, the fact that we find deciles of wealth and credit market access to have no effect on elasticity of harvest to return is puzzling. It suggests that while the assumption of perfect access to credit markets is problematic, the theory is more deeply flawed in the modern US. Our results indicate that even in fast-rotation trees like loblolly and shortleaf pine in the Southern United States, the price of timber and overall macroeconomic conditions have a larger influence on timber harvesters' decisions than market rates of return.

Perhaps this is a rational decision for timber owners to make in the face of fluctuating rates of return on capital, especially when coupled with the fact that real returns tend to converge to society's time preference in the long run.[43] For instance, a timber owner in Alabama who decided to cut his pine trees in 1982 or 1983 (which would occur if their growth rate did not exceed the breath-taking 9% real return in those years) would be disappointed after a few years when he found returns in money markets and treasuries back below 4% within seven years. A more rational approach in the face of such fluctuations might indeed treat the "rate of return" as fixed over the tree's useful lifetime. In the absence of an earth-shattering societal change, this

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[43] The view that nominal interest rates tend toward reflecting society's average time preference, or the "natural/real" interest rate, plus the rate of inflation, and over time converge based on borrowers' expected returns on capital, has been expressed by many economists. One articulation of this view of interest rates can be found in: Murray N. Rothbard, *Man, State, and Economy*, *with Power and Market 2nd Edition* (Auburn, AL: Ludwig von Mises Institute, 2009), p. 794. https://mises.org/sites/default/files/Man,%20Economy,%20and%20State,%20with%20Power%20and%20Market_2.pdf, Accessed January 31, 2019.

view of rates of return makes them a factor to be considered in the long-run to determine optimal cutting age, but not considered in making year-by-year decisions. However, a 50% increase or doubling in prices is a much more powerful incentive to cut in the short-run, and the invested capital from the cutting then grows at roughly the same rate, plus or minus, as capital invested a few years before or after would. An interesting future expansion of this project might design a computer program to assess what percentage of the time waiting for good prices versus following the rational-actor theories maximizes the landowners' NPV in this dataset. Future studies might also use county-level panel data and control for fixed effects, as we did, but use a longer time span than our twenty years and obtain a research grant to purchase more granular historical stumpage and lumber prices from Timber Mart-South. This would remove any uncertainty from the use of stumpage prices and ensure accurate point estimates for the coefficient on price.

My study may also serve as fodder for future researchers who might apply this new analysis technique to other regions of North America where ownership is dominated by the federal government to see whether public agencies take the opportunity cost of capital into consideration when negotiating concessions with private companies. Or an enterprising researcher armed with county or township-level ownership profile data for the US South, as compiled by researchers in an article cited in the appendix, might re-run our regressions on a series of ownership profile classes to see whether our findings are replicable with more granular ownership data. Through splitting the data based on percent owned by timber companies versus individuals in a region and comparing results, one could test whether the surprising result found here emanates from disparities in owner wealth and information about financial markets, though our results suggest otherwise.

In short, this revelation of imperfect behavior is robust across many statistical tests. It warrants tests for replicability in other states, other regions, and by other researchers, as well as explorations on smaller sub-units to divine the cause of the discrepancy between theory and practice. Empirically testing long-held dogma about optimal timber rotations, as we have attempted to do here, has potential implications for conservation policy, monetary policy, individual landowners, and other players in the timber market.

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Appendix

1. Justification of Exclusions and Regional Boundaries

County-level exclusions in the relevant portion of the paper

Data on bi-annual forest harvest on the county level was obtained throughout the entire Southern US courtesy the US Timber Product Output (TPO) survey, overseen by the US Forestry Service (USFS). I downloaded all available online reports for the Southern region, but to keep the question at hand relevant and to make sure the sample is relatively homogeneous in tree species cultivated and harvested, some cleaning was necessary. This project, initially focused only on Alabama, aimed from the start to isolate the effect of interest rate fluctuations on pine harvest patterns in the Deep South specifically, not trees across the board or across cooler, alpine regions of the South like Kentucky, Virginia, Tennessee, and Appalachian mountains and foothills in several states. Because recommended timber rotations under normal conditions are so much shorter for Deep South pines, like loblolly, longleaf, shortleaf, and yellow pine, than for deciduous trees or pines in cooler areas with slower growth (25-30 loblolly vs. 60-80 years deciduous average), short-run changes in market rate of return should impact Deep South pine harvest more than any other category of US trees. Thus, to ensure that the harvest data against which I will be running county-level regressions reflects the area of interest and minimizes the prevalence of other ecoregions, leaving only county and region-level differences, such as distance to market, wealth, access to credit, and labor force varied across the sample. This logic also necessitates the exclusion of urban counties where harvest is high in the short-run for development.

To keep the exclusion of counties from being too arbitrary, I use Forest Inventory and Analysis (FIA) regional definitions within each state and exclude all counties not inside those regions that are predominately in the Atlantic or Gulf Coastal Plains, the Lower Piedmont, or the Mississippi River Valley. The included regions are as follows, with stata-inserted identification numbers following in parentheses.

- NC-Northern Coastal Plain (21), Southern Coastal Plain (22), Piedmont (23)
- SC-Northern Coastal Plain (24), Southern Coastal Plain (25)
- GA-Central (10), Southeast (11), Southwest (12)

- FL-Northeast (8), Northwest (9)
- AL-Southeast (1), Southwest South (2), Southwest North (3), West Central (4)
- MS-South (17), Southwest (18), Delta (19), Central (20)
- LA-North Delta (13), Northwest (14), Southeast (15), Southwest (16)
- AR-Southwest (5), South Delta (6), Ouachita (7)

All other FIA regions of states, including the entire states of Tennessee, Oklahoma, and Kentucky, in addition to the East Texas counties, are excluded from the data for purposes of environmental consistency as described above. The same logic also motivated me to eliminate the western third of counties from the North Carolina Piedmont region, which is primarily hardwoods, partly urban, and backs up to the Appalachian foothills. The rural parts of the region's eastern two-thirds are retained due to their similarity to the pine-heavy coastal plain regions of that state.

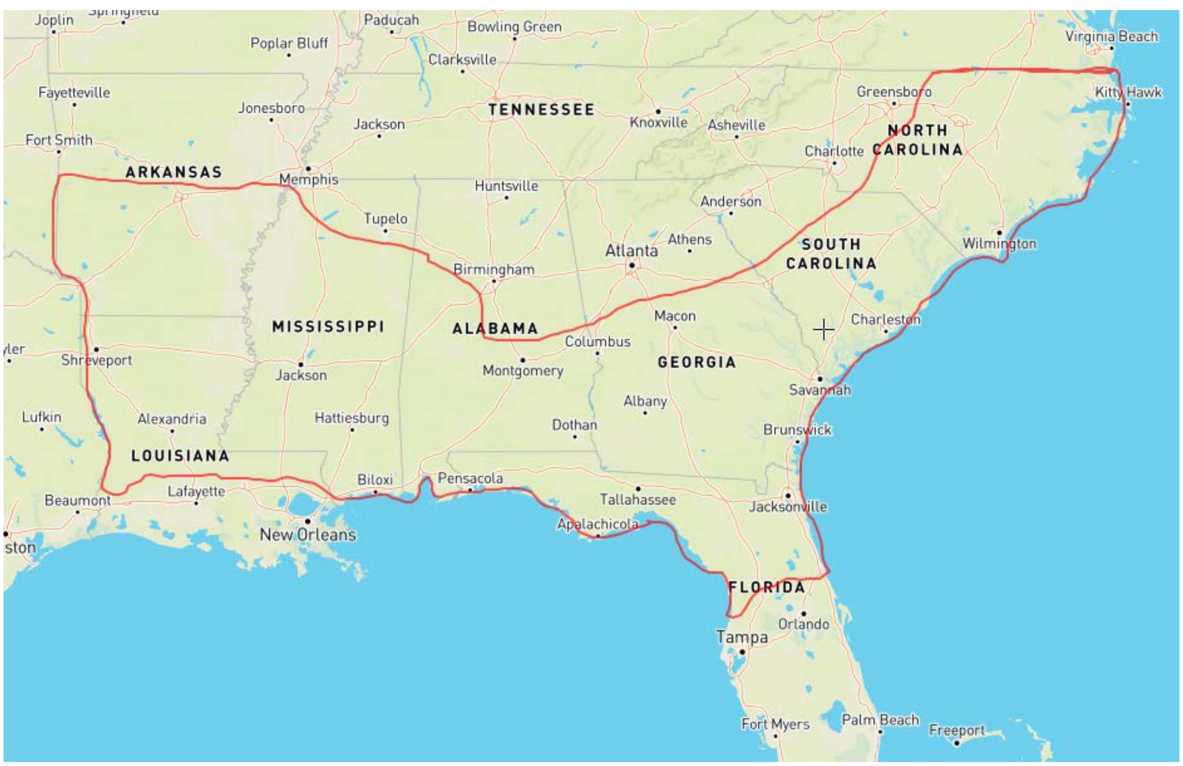
For the purposes of this study, urban counties that have large timber removals because of housing developments or commercial expansion would throw a monkey-wrench in our estimation technique, which seeks only to analyze timber rotation times where timber is the primary highest-value use of the land. The role of urbanization on land-use decisions is an interesting topic, but beyond our scope. Thus, we must exclude urban counties from the data. This is done by following a somewhat arbitrarily-drawn rule of thumb: counties in the US South with more than 175,000 residents (200,000 in Florida and SC, which have geographically larger counties) in 2017 census estimates are considered urban and excluded. The counties within the geographical scope of our county data that were excluded based on these population threshold criteria are as follows, with largest city or suburb center in parentheses for readers' perspective.

- North Carolina-Wake (Raleigh), Johnston (Raleigh suburbs), New Hanover (Wilmington), Pitt (Greenville), Onslow (Jacksonville), Cumberland (Fayetteville), Durham (Durham)
- South Carolina-Richland (Columbia), Lexington (Columbia suburbs), Charleston (Charleston), Berkley (Charleston suburbs), Horry (Myrtle Beach)
- Georgia-Chatham (Savannah), Richmond (Augusta), Muscogee (Columbus)

- Alabama-Tuscaloosa (Tuscaloosa), Baldwin (Mobile suburbs), Mobile (Mobile), Montgomery (Montgomery)
- Mississippi-Hinds (Jackson), Harrison (Biloxi)
- Louisiana-Caddo (Shreveport), Saint Tammany (New Orleans suburbs), Calcasieu (Lake Charles)
- Arkansas-Pulaski (Little Rock)
- Florida-Leon (Tallahassee), Duval (Jacksonville), Escambia (Pensecola), Okaloosa (Eglin AFB and various beach towns), Marion (Ocala and lots of retirees), Alachua (Gainesville), Volusia (Daytona), Clay (Jacksonville suburbs), St. Johns (Jacksonville suburbs)

All exclusions were executed by utilizing the "dropif" command in Stata after importing all harvest data for all years. Visually, the region included in my definition of the Deep South can be seen in the map below, where the area of interest is inside the red encircled area. Urban counties within the red are excluded as well, as discussed.

Figure 3-The "Deep South"



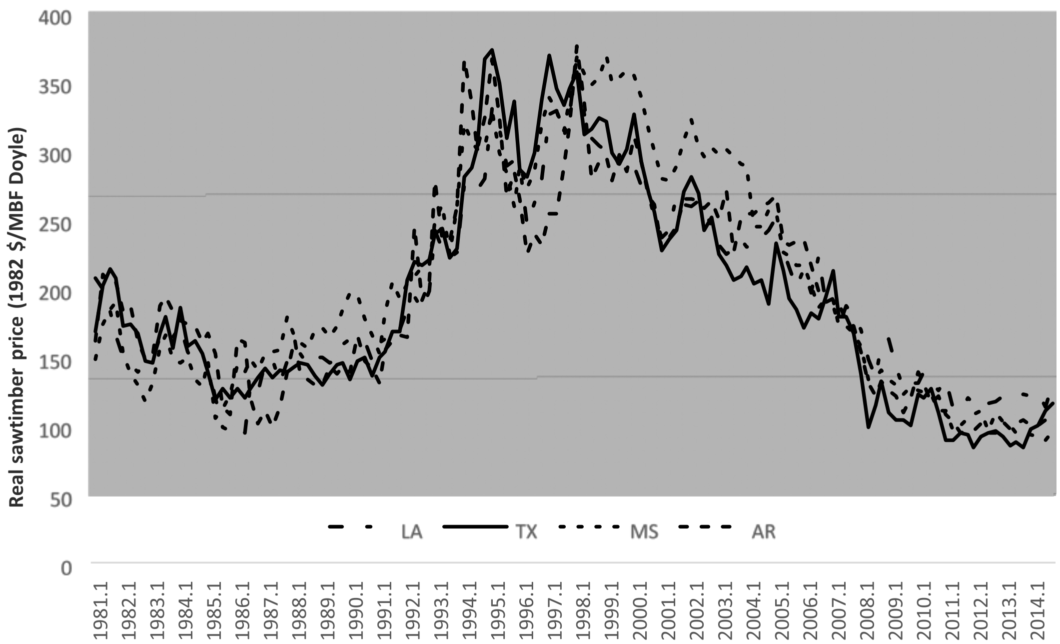
Stumpage Prices and County-level Regression: A Justification

For the county-level regression on counties in eight separate US South states, it would be ideal if I possessed the most granular data on stumpage prices possible, given their significance in signaling elements of national supply/demand dynamics uncorrelated with GDP growth (such as regulation changes and tariffs) and shocks to the international demand market. Excluding price from regressions, while theoretically acceptable, is sub-optimal. Of course, prices for timber products vary based on location throughout the South due to differing local supply conditions, different transportation costs for intermediaries like sawmills, and so forth. Thus, it would be ideal if I had stumpage prices for each county within the sample, or at the very least, each state.

However, historical timber prices, as opposed to current ones, are mostly proprietary to a company called Timber Mart-South, requiring payment for acquisition of data. For only two states in the sample, Alabama and North Carolina, was historical stumpage price data by product available in empirical form (Other states, like South Carolina, Mississippi, Arkansas, and Louisiana had some line graphs over time, but this would require estimation to the nearest dollar and high likelihood of mistakes in transferring the data to excel). Thus, I use an average of North Carolina's Eastern region and Alabama stumpage price data for each of the products of interest (hardwood sawtimber, hardwood pulpwood, pine sawtimber, pine pulpwood) to proxy for the entire Deep South. Though sub-optimal, there are several reasons that I am comfortable using these measures of stumpage prices in the county-level regressions (besides the fact that it averts the need for me to pay for data).

First, we are interested not in how the level of prices influence sawtimber harvests, but how *changes* in stumpage prices influence timber harvest decisions. Interestingly, although there are notable differences between the price levels for individual timber products throughout the region, the price series tend to move in unison, particularly for pine sawtimber, the product we are most interested in testing. For proof of this, see figure 14 below, a graph of pine sawtimber prices from the western South (TX, MS, LA, AR) between 1981 and 2014. We see that although there are some differences in price level between the states, they are rarely large differences, and more importantly, the prices move in near-perfect unison, rising all together in the late 1980s and early 1990s, stabilizing, and then gradually falling until the Atlantic Recession's 2007/2008 onset, at which point prices in all four states moved sharply downward.[44] Because we are interested in the *change* in things like the ratio of pulpwood to sawtimber harvested or the change of sawtimber harvest when the price changes by a given amount, if prices across the South are moving together, then we'd be justified in using any consistent price data set for these products.

Figure 14-Real Pine Sawtimber Prices in Four States, 1981-2014



[45]

That stumpage prices, though different, would move together across the US Deep South is somewhat intuitive if we assume that the market for finished wood products is region-wide, nation-wide, or international rather than mostly confined to within state boundaries and insulated from outside competition. This assumption about a nationally-integrated market for finished timber products is borne out by anecdotal and statistical evidence. A trip to a local home improvement store like Lowe's or Home Depot will reveal that finished timber products as small

[44] I personally emailed the lead author of the paper that produced this graph, Rajan Parajuli, but received no response to my request for the underlying source data for calculating real prices. Presumably this is because the information is proprietary to Timber Mart-South. A similar request to a Clemson University professor who produced a similar graph for South Carolina stumpage prices also earned a direct response that the information behind the graph was the sole property of Timber Mart-South and not sharable.

[45] Rajan Parajuli, Shaun Tanger , Omkar Joshi and James Henderson, "Modeling Prices for Sawtimber Stumpage in the South-Central United States," *Forests* 7(7), July 2016, accessed April 4, 2019, 148, https://www.mdpi.com/1999-4907/7/7/148.

as 2x4' boards are frequently shipped from several states away.[46] Further, though there are small differences in price level between different regions of the Southeastern US, the differences are not significant enough that we'd conclude that markets for finished timber products are strictly, or even mainly, local. A 2007 report from F&W Forestry Services on timber prices throughout the Eastern United States in the heat of the housing crisis illustrates this well.

As we see in the pine pulpwood, pine small sawtimber, and pine large sawtimber categories in figure 15 below, where I have excluded all market locations outside the area of study, every market location has overlap in its price range.[47] The odds that all these spot markets for pine lumber would independently arrive at consistently overlapping prices is slim to none. Lumber prices, of course, are not the same as the stumpage prices paid to owners of timberland (unless the timberland owner has vertically integrated by purchasing downstream processing facilities like sawmills). However, if the difference between stumpage prices and lumber prices is constant over time for each location, then we'd expect changes in prices to occur uniformly throughout the Deep South. Figure 14, combined with my own observations about the striking similarity between Eastern North Carolina and Alabama price data series, seem to bear this assumption out.

Figure 15-Southeastern and South-Central Stumpage Prices, 2007

2007 Fourth Quarter Pine And Hardwood Stumpage Price Range*

	Area	Pine Pulpwood	Pine Small Sawtimber	Pine Large Sawtimber	Hardwood Pulpwood	Hardwood Sawtimber
	Phenix City, AL	$6-9	$16-24	$30-44	$5-8	$22-28
	Gainesville, FL	$7-11	$15-21	$32-41	$2-6	$10-18
	Marianna, FL	$6-8	$16-22	$33-39	$2-7	$14-16
Southea	Albany, GA	$7-9	$17-23	$38-45	$3-5	$25-35
	Macon, GA	$5-8	$16-22	$35-45	$6-8	$25-35
	Statesboro, GA	$7-11	$15-22	$30-50	$7-10	$20-27
	Greenwood, SC	$6-8	$18-24	$38-45	$6-10	$20-30
	El Dorado, AR	$12-16	$20-25	$35-40	$12-16	$25-35

[46] Source: Professor of Economics Joseph Guse of Washington and Lee University, who made this observation a few weeks after becoming my formal thesis advisor.

[47] Figure 15 comes from the following publication meant for commercial timber harvesters: Marshall Thomas, "Timber Markets Slam Large Tree Prices in 2007," *The Forestry Report: A Publication of F&W Forestry Services, Inc. Albany, GA*, Winter 2008, no. 96, accessed April 4, 2019, http://www.afoa.org/PDF/CI0803_e.pdf.

West Gulf	Jackson, MS	$7-12	$18-23	$38-43	$4-7	$15-25

*All Prices in tons, based on sales handled by F&W offi ces. If no sales occurred, prior quarter's sales and other data are used to compile price range. Price ranges are due to different locations, timber quality, logging conditions, type of harvest, and local market conditions.To convert $/ton to $/cord multiply $/ton price by 2.7. The actual range for our sales, depending on region, is from 2.6 to 2.8.
**Virginia Pine Sawtimber is $90-100 MBF (I). (S) = Scribner, (I) = International, (D) = Doyle.

Further, as we briefly observed in the footnotes in the main part of the narrative, European companies own timberland in such places as North Florida, and sell the finished products across oceans to Europe and Asia. Surely if this cross-ocean transport is economically feasible for any timber products, then overland transport within the United States is the norm for most timber products, and competition is nationwide.[48]

In short, our average of Eastern North Carolina and statewide Alabama stumpage prices for our products of interest is an imperfect but satisfactory measure of stumpage price given the mostly uniform *movement* in prices across the Deep South counties we analyze and the nationally-integrated nature of timber markets.

[48] Nelson-Gabriel, "Timber business booming," *Orlando Sentinel.*

Table 4-Pine Sawtimber Regressions, Alabama Statewide

Regressions of Pine Sawtimber Harvest with Miscellaneous Combinations

	(1) Pine Sawtimber Harvest (mbf Scribner)	(2) Pine Sawtimber Harvest (mbf Scribner)	(3) Pine Sawtimber Harvest (mbf Scribner)	(4) Pine Sawtimber Harvest (mbf Scribner)
GDPgrowth_lag	3997.8	24490.6	5467.4	-10961.7
	(0.19)	(1.25)	(0.26)	(-0.51)
New Housing Permits (thousands)	333.1*		216.2	308.8
	(2.55)		(1.55)	(2.06)
Nominal Averaged Return	19505.3			
	(0.70)			
RealPineSaw_Price	-920.9	1485.6		-1557.6
	(-0.73)	(1.43)		(-0.95)
year	14576.5	13889.9**		
	(1.79)	(3.43)		
Real Averaged Return		22326.0	-2115.2	-9916.6
		(1.36)	(-0.13)	(-0.55)
Constant	-28207473.5	-26717707.8**	1058526.4***	1202725.3***
	(-1.71)	(-3.26)	(4.75)	(3.94)
Observations	31	31	29	23

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Here we see that the inclusion of price data over the entire span of statewide timber harvest and financial market data (1970-2016) did not yield any significance for prices. The coefficient is positive, and considering that values for the variable are missing from 1970-1976, 1994-2002, and 2006-2008, this may indicate a positive relationship indeed, explored more in later regressions restricted to the longest uninterrupted stretch of stumpage data (1977-1993) for pine sawtimber.

We also see that in the absence of new housing construction, GDP growth becomes large but misses statistical significance at even the 10% level Here, we see that a one percentage point increase in GDP growth rate (from 2-3% for example) increases Alabama pine sawtimber harvests by 29 million board feet, the only effect so far measured that is larger than the effect of time, which in the exclusion of new home construction, has an increased effect of 18 million board feet for every year. We also observe in Table 4 that both stumpage price and the rate of return remain insignificant, with the coefficient on our return variable “RealReturn,” having turned slightly negative in two of the regressions. Again, the insignificance of the stumpage price variable is likely due to the spotty nature of observations throughout the data set.

Table 5-Structural Break, Alabama Statewide

```
. reg PineSaw_Harvest t

      Source |       SS           df       MS      Number of obs   =        46
-------------+----------------------------------   F(1, 44)        =     15.36
       Model |  7.4945e+11         1  7.4945e+11   Prob > F        =    0.0003
    Residual |  2.1473e+12        44  4.8802e+10   R-squared       =    0.2587
-------------+----------------------------------   Adj R-squared   =    0.2419
       Total |  2.8967e+12        45  6.4372e+10   Root MSE        =    2.2e+05

------------------------------------------------------------------------------
PineSaw_Ha~t |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
           t |   9614.525   2453.439     3.92   0.000     4669.944    14559.11
       _cons |  -1.78e+07    4888585    -3.64   0.001    -2.77e+07    -7964807
------------------------------------------------------------------------------

. estat sbsingle
----+--- 1 ---+--- 2 ---+--- 3 ---+--- 4 ---+--- 5
................................

Test for a structural break: Unknown break date

                             Number of obs =        46

Full sample:                 1970 - 2015
Trimmed sample:              1977 - 2009
Estimated break date:        2008
Ho: No structural break

     Test          Statistic          p-value
---------------------------------------------
     swald           65.9964           0.0000
---------------------------------------------
```

Table 6- Pine Ratio and Ratio Regressions Miscellaneous, Alabama Statewide

	(1) PulptoSaw_ Ratio	(2) PulptoSaw_ Ratio	(3) PulptoSaw_ Ratio	(4) PinePulp_Pine SawRatio	(5) PinePulp_Pine SawRatio	(6) PinePulp_Pine SawRatio
Nominal Averaged Return	-0.157^{*}					
	(-2.70)					
Real Averaged Return		-0.125	-0.0401	-0.427^{**}	-0.116	0.0163
		(-1.48)	(-0.83)	(-3.09)	(-0.55)	(0.13)
New Housing Permits (thousands)			-0.00268^{***}			-0.00203^{***}
			(-9.10)			(-7.53)
GDPgrowth_lag					-0.302^{*}	
					(-2.70)	
year					0.0519	0.0643^{**}
					(1.40)	(2.93)
Constant	6.379^{***}	5.690^{***}	9.026^{***}	5.452^{***}	-98.56	-121.9^{*}
	(13.66)	(15.22)	(21.40)	(10.95)	(-1.31)	(-2.75)
Observations	39	39	39	30	30	30

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7- County-level Regressions on Pine Sawtimber Harvest with Bank Variables

	(1) Pine Sawtimber Harvest (mbf Scribner)	(2) Pine Sawtimber Harvest (mbf Scribner)
New Housing Permits (thousands)	9.002***	7.636***
	(10.40)	(9.83)
Deposits/Capita	-0.159*	-0.209***
	(-2.54)	(-3.42)
Residents/Branch (nearest whole #)	0.0210	-0.0150
	(0.11)	(-0.08)
Average Real GDP Growth	-1280.0***	-1120.1***
	(-7.97)	(-7.25)
RealPineSaw_Price	-32.54*	0.00149
	(-2.40)	(0.00)
Real Return	262.1	792.3**
	(0.85)	(2.93)
year	-281.6***	
	(-3.56)	
Constant	585185.0***	16805.3***
	(3.67)	(11.39)
Observations	4412	4412

year statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8- County-level Ratio Regressions with Bank Variables

	(1) ratio	(2) ratio
Real Averaged Return	2.504	
	(0.59)	
Average Real GDP Growth	-0.512	-0.0467
	(-0.21)	(-0.03)
Deposits/Capita	0.00145	0.00145
	(1.20)	(1.20)
Residents/Branch (nearest whole #)	-0.000909	-0.000844
	(-0.30)	(-0.28)
New Housing Permits (thousands)	0.00831	0.00781
	(0.63)	(0.60)
RealPineSaw_Price	-0.239	-0.249
	(-1.22)	(-1.20)
Pine Pulpwood Price	0.894	
	(0.77)	
Nominal Averaged Return		0.307
		(0.08)
RealPinePulp_Price		2.153
		(0.77)
Constant	-1.235	0.374
	(-0.03)	(0.01)
Observations	4270	4270

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 9- Log-linear Ratio Regression with Bank Variables

	(1)
	lnRatio
lnNewHomeStarts	-0.469***
	(-6.70)
GDP Growth	0.0287*
	(2.39)
lnRealPineSawPrice	-0.405***
	(-3.95)
lnRealPinePulpPrice	0.408**
	(2.61)
Real Return	0.000136
	(0.01)
Deposits/Capita	0.0000139*
	(2.12)
Residents/Branch (nearest whole #)	0.00000215
	(0.13)
Constant	5.059***
	(9.09)
Observations	4210

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Deciles-based Results

A. Deposits per Capita bottom 10%

Table 10- Regressions for Bottom Decile of Deposits per Capita (poorest)

	(1) ratio	(2) lnRatio	(3) lnPineSaw	(4) Pine Sawtimber Harvest (mbf Scribner)
Real Return	1.372	-0.0258	0.0857	1280.0
	(0.62)	(-0.40)	(1.07)	(1.22)
GDP Growth	0.0508		-0.0370	-460.2
	(0.04)		(-0.75)	(-0.70)
New Housing Permits (thousands)	-0.000568			3.585
	(-0.08)			(1.04)
RealPineSaw_Price	-0.000750			-13.31
	(-0.01)			(-0.32)
RealPinePulp_Price	-0.0130			
	(-0.01)			
lnNewHomeStarts		0.0899	0.178	
		(0.30)	(0.59)	
lnRealPineSawPrice		-0.330	-0.0799	
		(-0.82)	(-0.20)	
lnRealPinePulpPrice		0.234	-0.0388	
		(0.33)	(-0.07)	
Constant	4.484	1.632	8.517^{***}	11876.3^{***}
	(0.26)	(0.67)	(4.29)	(4.42)
Observations	425	425	425	444

year statistics in parentheses

B. Deposits/Capita top 10%

Table 11- Regressions for Top 10% of Deposits/Capita Counties (wealthiest)

	(1) ratio	(2) lnRatio	(3) lnPineSaw	(4) Pine Sawtimber Harvest (mbf Scribner)
Real Return	3.191	0.0315	-0.105	645.6
	(0.06)	(0.27)	(-0.47)	(0.26)
GDP Growth	-9.741		0.00681	-1151.6
	(-0.47)		(0.08)	(-1.03)
New Housing Permits (thousands)	0.0237			8.509
	(0.23)			(1.81)
RealPineSaw_Price	-0.419			10.53
	(-0.24)			(0.16)
RealPinePulp_Price	30.72			
	(0.88)			
lnNewHomeStarts		-0.489	-0.0213	
		(-1.84)	(-0.05)	
lnRealPineSawPrice		-0.563	0.675	
		(-1.12)	(0.82)	
lnRealPinePulpPrice		-0.256	0.203	
		(-0.22)	(0.13)	
Constant	-241.6	7.535	5.872	12652.0**
	(-0.60)	(1.96)	(1.10)	(3.23)
Observations	427	418	427	459

year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

C. Residents/Branch bottom 10% (worst-banked)

Table 12- Regressions for Bottom 10% of Bank Accessibility Counties

	(1) ratio	(2) lnRatio	(3) lnPineSaw	(4) Pine Sawtimber Harvest (mbf Scribner)
Real Return	-0.461	-0.0205	0.0919	1968.4*
	(-1.36)	(-0.36)	(1.56)	(1.98)
GDP Growth	0.278		-0.0635	-998.1
	(1.44)		(-1.96)	(-1.73)
New Housing Permits (thousands)	-0.00151			6.054*
	(-1.55)			(2.16)
RealPineSaw_Price	0.00744			-72.64*
	(0.58)			(-2.09)
RealPinePulp_Price	0.205			
	(0.90)			
lnNewHomeStarts		-0.0821	0.523**	
		(-0.38)	(2.93)	
lnRealPineSawPrice		-0.298	-0.538*	
		(-0.98)	(-2.07)	
lnRealPinePulpPrice		0.530	-0.229	
		(0.88)	(-0.54)	
Constant	3.757	1.932	8.924***	17905.2***
	(1.43)	(0.93)	(6.08)	(8.46)
Observations	459	459	459	461

year statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

D. Best-banked decile of counties

Table 13- Regressions for Best-banked counties

	(1) ratio	(2) lnRatio	(3) lnPineSaw	(4) Pine Sawtimber Harvest (mbf Scribner)
Real Return	-0.372	0.0183	0.0583	211.3
	(-0.85)	(0.28)	(0.40)	(0.10)
GDP Growth	0.179		-0.0231	-996.0
	(0.74)		(-0.30)	(-0.82)
New Housing Permits (thousands)	-0.00133			6.744
	(-1.04)			(1.11)
RealPineSaw_Price	-0.0110			55.67
	(-0.63)			(0.70)
RealPinePulp_Price	0.223			
	(0.77)			
lnNewHomeStarts		-0.221	-0.0326	
		(-0.91)	(-0.07)	
lnRealPineSawPrice		-0.607	0.155	
		(-1.70)	(0.23)	
lnRealPinePulpPrice		0.522	-0.473	
		(0.78)	(-0.46)	
Constant	5.499	4.090	9.993^{**}	11504.1^{*}
	(1.67)	(1.81)	(2.87)	(2.49)
Observations	401	391	401	442

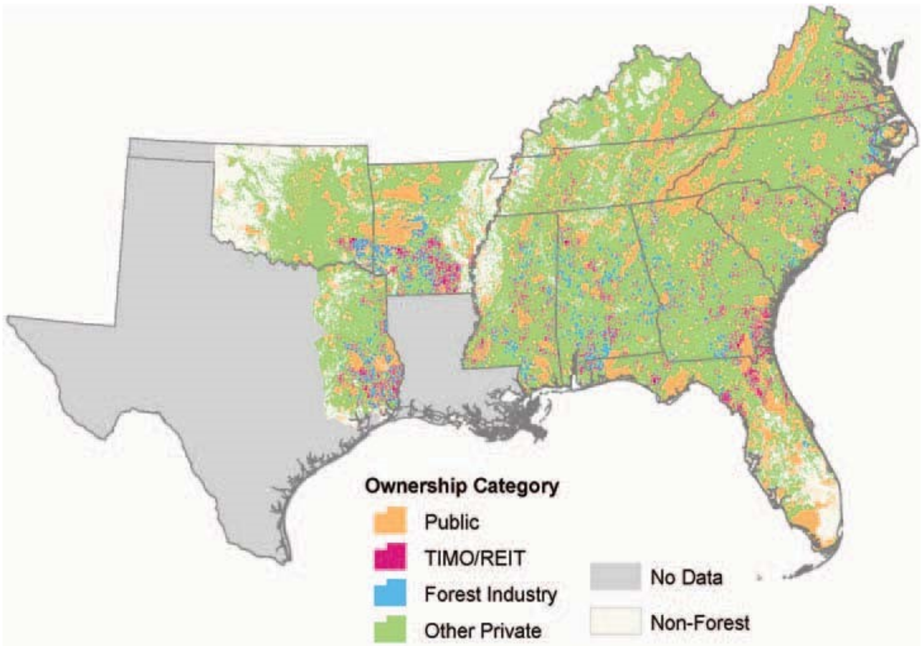
year statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Timber Harvest and Ownership Pattern-An Experimental Approach

Though our attempt to bifurcate the sample into top and bottom deciles of wealth and credit market access failed to detect any meaningful difference between the two in terms of responsiveness to interest rates, what if county wealth is a bad proxy for wealth of *timber owners* in that county? This is certainly possible, as not everyone in a given Deep South, perhaps not even a majority, own more than an acre or two of timberlands. It is also possible that many counties that are, on the median, very poor, have a few wealthy landowners or corporations that own the majority of the land in the county. Neither entity would have trouble accessing credit markets, despite the relative poverty of the counties in which they own timberlands. However, if we knew the ownership distribution of counties or some other sub-region of states, we'd have a more direct way of testing whether our counterintuitive findings are the result of imperfect access to credit markets.

Obviously, large timber companies, real estate trust funds, hedge funds, and pension funds can all access credit markets with more ease and at more favorable rates than individual owners. Thus, it follows that regions where more of the timberland is in corporate hands would be more responsive to exogenous shocks to interest rates. If not, then a different explanation must be behind the non-existent significance in rates of return. Conveniently, I ran across the interesting map in figure 12. It shows exact timberland ownership patters throughout the entire South, with the exception of Louisiana. This map encompasses the other seven states for which we have county-level panel data on timber harvests (NC, SC, GA, FL, AL, MS, AR).

Figure 12-Timberland Ownership in the Southern United States, 2010



49

Though it is a somewhat imprecise method, I felt it worth the minimal effort to see if there was anything radically different going on between regions heavily shaded with pink (hedge funds, retirement funds, real estate trusts) and blue (forest industry) on the one hand, and on the other, those with near-uniform green (non-industrial private). Conveniently, there are several regions within the US Deep South that are adjacent to each other, demographically similar, ecologically near-identical, and yet have big differences in timberland ownership. Further, our counties are also coded as members of "FIA Regions," a variable not listed in the Data section because it was never used in main regressions. FIA Regions are "Forest Inventory and Analysis" regions, used by the federal government in forest surveys to sub-divide the states into 2-5 sections, as in figure 13, a map of Georgia's FIA regions. These divisions exist for all eight states in our county-level sample.

[49] Daowei Zhang, Brett J. Butler, and Rao V. Nagubadi, "Institutional Timberland Ownership in the US South: Magnitude, Location, Dynamics, and Management," *Journal of Forestry,* Vol. 110 no. 7, accessed April 4, 2019, http://www.auburn.edu/~zhangd1/RefereedPub/JOF2012.pdf.

Figure 13-Map of Georgia's FIA Regions

[50]

I manually coded each state-county pair's FIA region by looking at a map of these regions and typing in the appropriate number for each of the 4200 observations of county-level data. Thus, it's an easy exercise to find a few adjacent FIA regions with different ownership using the map in figure 12. Three stark contrasts in particular stand out. While Northeast Florida is comparatively heavy with corporate ownership, Northwest Florida is a mix of national forest and non-industrial private. Similarly, Southeast Georgia appears to have a healthy percentage of its land owned by forest industry and other corporate interests, while Southwest Georgia is almost exclusively nonindustrial private landowners. Further west, at the foot of the Ouachita Mountains, Southwest Arkansas is perhaps the most corporate-owned region in the entire Southeast, while the neighboring Arkansas delta's forests (such as they are—the delta is a much more agricultural region than further west) are mostly held by individuals.

We perform three regressions on each of these three pairs of regions—a regression on the log of ratio, the log of harvest, and pine sawtimber harvest itself. All regression results are given below, starting with the Southeast/Southwest Georgia pairing. For less voracious readers, the

[50] Lambert, S. and Brandeis, YEAR, "Forests of Georgia, 2016," Resource Update FS–176, Asheville, NC: *U.S. Department of Agriculture Forest Service*, Southern Research Station, 4 p.

results can be summed up simply: returns still do not matter. Only in one single regression for Southwest Georgia does real rate of return take on a positive and significant coefficient, and even then, only to the 90% confidence level.[51] For all 17 other regressions, including the other two in Southwest Georgia, return is either the wrong sign or insignificant. Such results are not definitive, as this approach is highly informal and does not have empirical data on ownership by region. However, taken in conjunction with earlier results, these results tell the same story from a different angle.

a) Southeast vs. Southwest Georgia

I. Southeast (corporate heavy)

i. Log-linear on ratio

Source	SS	df	MS
Model	.954704393	4	.238676098
Residual	.141909846	7	.020272835
Total	1.09661424	11	.099692204

Number of obs	=	12
F(4, 7)	=	11.77
Prob > F	=	0.0032
R-squared	=	0.8706
Adj R-squared	=	0.7966
Root MSE	=	.14238

lnRatio	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnNewHomeS~s	-.4582059	.1774125	-2.58	0.036	-.8777199	-.038692
lnRea~wPrice	-.0989492	.2557651	-0.39	0.710	-.7037375	.5058391
lnRea~pPrice	.414766	.4810337	0.86	0.417	-.7226981	1.55223
RealReturn	-.0905153	.0467606	-1.94	0.094	-.2010864	.0200559
_cons	4.452742	1.63825	2.72	0.030	.5788952	8.326589

ii. Log-linear on harvest

Source	SS	df	MS
Model	.110587308	5	.022117462
Residual	.049771977	6	.008295329
Total	.160359284	11	.014578117

Number of obs	=	12
F(5, 6)	=	2.67
Prob > F	=	0.1322
R-squared	=	0.6896
Adj R-squared	=	0.4310
Root MSE	=	.09108

lnPineSaw	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnNewHomeS~s	.4393778	.1366708	3.21	0.018	.1049564	.7737992
lnRea~wPrice	-.3815183	.2000588	-1.91	0.105	-.8710444	.1080079
lnRea~pPrice	-.1266265	.3100438	-0.41	0.697	-.8852763	.6320234
GDPGrowth	-.043807	.0237064	-1.85	0.114	-.1018144	.0142004
RealReturn	.067972	.0432047	1.57	0.167	-.0377461	.1736901
_cons	12.59323	1.051562	11.98	0.000	10.02015	15.16631

[51] Also, the fact that the positive result came in Southwest Georgia, which is dominated by small landowners, is something of a puzzlement.

iii. Ratio

```
.  reg PulptoSaw_Ratio RealReturn GDPGrowth NewHousingStarts RealPineSaw_Price
> RealPinePulp_Price if fiaregio == 11
```

Source	SS	df	MS			
Model	19.7581495	5	3.9516299	Number of obs	=	12
Residual	3.03047171	6	.505078619	F(5, 6)	=	7.82
				Prob > F	=	0.0132
Total	22.7886212	11	2.07169284	R-squared	=	0.8670
				Adj R-squared	=	0.7562
				Root MSE	=	.71069

PulptoSaw_~o	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
RealReturn	-.8300663	.3579713	-2.32	0.060	-1.70599	.0458579
GDPGrowth	.353913	.2035311	1.74	0.133	-.1441096	.8519356
NewHousing~s	-.0028595	.0010569	-2.71	0.035	-.0054456	-.0002734
RealPineSa~e	.0115125	.0140898	0.82	0.445	-.022964	.0459889
RealPinePu~e	.1863049	.2377584	0.78	0.463	-.3954689	.7680786
_cons	5.949633	2.738292	2.17	0.073	-.7507268	12.64999

II. Southwest (individual heavy)

i. Log-linear on ratio

Source	SS	df	MS			
Model	.299053397	4	.074763349	Number of obs	=	12
Residual	1.0841878	7	.154883971	F(4, 7)	=	0.48
				Prob > F	=	0.7489
Total	1.3832412	11	.1257492	R-squared	=	0.2162
				Adj R-squared	=	-0.2317
				Root MSE	=	.39355

lnRatio	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnNewHomeS~s	.3322536	.4903772	0.68	0.520	-.8273042	1.491811
lnRea~wPrice	.0477302	.7069476	0.07	0.948	-1.623935	1.719396
lnRea~pPrice	1.127626	1.329602	0.85	0.424	-2.016382	4.271634
RealReturn	-.1036358	.1292485	-0.80	0.449	-.40926	.2019884
_cons	-3.725537	4.528207	-0.82	0.438	-14.43305	6.981972

ii. Log-linear on harvest

Source	SS	df	MS			
				Number of obs	=	12
				F(5, 6)	=	5.16
Model	.388628094	5	.077725619	Prob > F	=	0.0351
Residual	.090384778	6	.01506413	R-squared	=	0.8113
				Adj R-squared	=	0.6541
Total	.479012872	11	.043546625	Root MSE	=	.12274

lnPineSaw	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnNewHomeS~s	.2684224	.1841751	1.46	0.195	-.1822378	.7190827
lnRea~wPrice	-.1758889	.2695956	-0.65	0.538	-.8355656	.4837877
lnRea~pPrice	-.6726951	.4178095	-1.61	0.159	-1.695038	.3496478
GDPGrowth	-.0296814	.0319463	-0.93	0.389	-.1078511	.0484884
RealReturn	.1419167	.0582219	2.44	0.051	-.000547	.2843805
_cons	12.88289	1.417066	9.09	0.000	9.415455	16.35033

iii. Ratio

```
. reg PulptoSaw_Ratio RealReturn GDPGrowth NewHousingStarts RealPineSaw_Price R
> ealPinePulp_Price if fiaregio == 12
```

Source	SS	df	MS			
				Number of obs	=	12
				F(5, 6)	=	0.55
Model	4.53723669	5	.907447337	Prob > F	=	0.7388
Residual	9.98499825	6	1.66416638	R-squared	=	0.3124
				Adj R-squared	=	-0.2605
Total	14.5222349	11	1.32020318	Root MSE	=	1.29

PulptoSaw_~o	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
RealReturn	-.3988414	.6497811	-0.61	0.562	-1.988798	1.191116
GDPGrowth	.1555886	.3694448	0.42	0.688	-.7484103	1.059588
NewHousing~s	.0011819	.0019184	0.62	0.560	-.0035123	.0058762
RealPineSa~e	-.0013449	.0255755	-0.05	0.960	-.0639258	.061236
RealPinePu~e	.2910549	.4315734	0.67	0.525	-.7649671	1.347077
_cons	-.1740351	4.970484	-0.04	0.973	-12.33637	11.9883

b) Northeast vs. Northwest Florida

I. Northeast Florida (corporate-heavy)

i. Log-linear on harvest

Source	SS	df	MS			
				Number of obs	=	12
				F(5, 6)	=	8.08
Model	.146494892	5	.029298978	Prob > F	=	0.0122
Residual	.021754561	6	.00362576	R-squared	=	0.8707
				Adj R-squared	=	0.7630
Total	.168249453	11	.015295405	Root MSE	=	.06021

lnPineSaw	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnNewHomeS~s	.3227774	.0903563	3.57	0.012	.1016835	.5438713
lnRea~wPrice	.0013147	.1322636	0.01	0.992	-.3223226	.324952
lnRea~pPrice	.0796815	.2049773	0.39	0.711	-.4218799	.5812429
GDPGrowth	-.0346104	.0156728	-2.21	0.069	-.0729605	.0037396
RealReturn	.01859	.0285636	0.65	0.539	-.0513027	.0884827
_cons	10.41965	.6952124	14.99	0.000	8.718525	12.12077

ii. Log-linear on ratio

```
. reg lnRatio lnNewHomeStarts lnRealPineSawPrice lnRealPinePulpPrice RealReturn
>  if fiaregion == 8
```

Source	SS	df	MS			
				Number of obs	=	12
				F(4, 7)	=	15.67
Model	1.44777756	4	.36194439	Prob > F	=	0.0013
Residual	.161635486	7	.023090784	R-squared	=	0.8996
				Adj R-squared	=	0.8422
Total	1.60941305	11	.146310277	Root MSE	=	.15196

lnRatio	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnNewHomeS~s	-.460641	.1893417	-2.43	0.045	-.908363	-.0129189
lnRea~wPrice	-.528643	.2729627	-1.94	0.094	-1.174097	.1168113
lnRea~pPrice	.4390135	.5133785	0.86	0.421	-.7749336	1.652961
RealReturn	-.0225867	.0499047	-0.45	0.665	-.1405926	.0954192
_cons	6.508997	1.748406	3.72	0.007	2.374673	10.64332

iii. Ratio

```
.  reg PulptoSaw_Ratio RealReturn GDPGrowth NewHousingStarts RealPineSaw_Price
> RealPinePulp_Price if fiaregio == 8

      Source |       SS           df       MS      Number of obs   =        12
-------------+----------------------------------   F(5, 6)         =     10.97
       Model |  45.0429065         5  9.00858129   Prob > F        =    0.0056
    Residual |  4.92626919         6  .821044865   R-squared       =    0.9014
-------------+----------------------------------   Adj R-squared   =    0.8193
       Total |  49.9691756        11  4.54265233   Root MSE        =    .90612

------------------------------------------------------------------------------
PulptoSaw_~o |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  RealReturn |  -.9268883   .4564068    -2.03   0.089    -2.043676     .189899
   GDPGrowth |   .5469268   .2594984     2.11   0.080    -.0880429    1.181896
NewHousing~s |  -.0037269   .0013475    -2.77   0.033    -.0070242   -.0004297
RealPineSa~e |   .0030161   .0179642     0.17   0.872    -.0409408     .046973
RealPinePu~e |   .2859554   .3031375     0.94   0.382    -.4557955    1.027706
       _cons |   7.974731   3.491272     2.28   0.062    -.5681049    16.51757
------------------------------------------------------------------------------
```

II. Northwest Florida (individual-heavy)

i. Log-linear on harvest

```
. reg lnPineSaw lnNewHomeStarts lnRealPineSawPrice lnRealPinePulpPrice GDPGrowt
> h RealReturn if fiaregion == 9

      Source |       SS           df       MS      Number of obs   =        12
-------------+----------------------------------   F(5, 6)         =      7.51
       Model |  .327964928         5  .065592986   Prob > F        =    0.0146
    Residual |   .05240929         6  .008734882   R-squared       =    0.8622
-------------+----------------------------------   Adj R-squared   =    0.7474
       Total |  .380374218        11  .034579474   Root MSE        =    .09346

------------------------------------------------------------------------------
   lnPineSaw |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
lnNewHomeS~s |  -.0062682    .140245    -0.04   0.966    -.3494354    .3368989
lnRea~wPrice |  -.1249483   .2052907    -0.61   0.565    -.6272765      .37738
lnRea~pPrice |   .1818105   .3181521     0.57   0.588    -.5966796    .9603006
   GDPGrowth |  -.0655233   .0243263    -2.69   0.036    -.1250477   -.0059989
  RealReturn |  -.0235941   .0443346    -0.53   0.614    -.1320769    .0848888
       _cons |   12.72838   1.079062    11.80   0.000     10.08801    15.36875
------------------------------------------------------------------------------
```

ii. Log-linear on ratio

```
. reg lnRatio lnNewHomeStarts lnRealPineSawPrice lnRealPinePulpPrice RealReturn
>  if fiaregion == 9

      Source |       SS           df       MS      Number of obs   =        12
-------------+----------------------------------   F(4, 7)         =      0.77
       Model |  1.13261078         4  .283152696   Prob > F        =    0.5774
    Residual |  2.57341771         7  .367631102   R-squared       =    0.3056
-------------+----------------------------------   Adj R-squared   =   -0.0912
       Total |  3.70602849        11  .336911681   Root MSE        =    .60633

------------------------------------------------------------------------------
     lnRatio |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
lnNewHomeS~s |   .1687448   .7554977     0.22   0.830    -1.617723    1.955213
lnRea~wPrice |  -1.389333   1.089156    -1.28   0.243    -3.964778    1.186112
lnRea~pPrice |  -.3473425   2.048446    -0.17   0.870    -5.191146    4.496462
  RealReturn |   .1138308   .1991262     0.57   0.585    -.3570279    .5846895
       _cons |   8.061325   6.976365     1.16   0.286    -8.435156    24.55781
------------------------------------------------------------------------------
```

iii. Ratio

```
.  reg PulptoSaw_Ratio RealReturn GDPGrowth NewHousingStarts RealPineSaw_Price
> RealPinePulp_Price if fiaregio == 9

      Source |       SS           df       MS      Number of obs   =        12
-------------+----------------------------------   F(5, 6)         =      0.89
       Model |  191.285796         5  38.2571591   Prob > F        =    0.5398
    Residual |  257.148642         6  42.8581071   R-squared       =    0.4266
-------------+----------------------------------   Adj R-squared   =   -0.0513
       Total |  448.434438        11  40.7667671   Root MSE        =    6.5466

------------------------------------------------------------------------------
PulptoSaw_~o |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  RealReturn |  -2.693977   3.297503    -0.82   0.445    -10.76268    5.374722
   GDPGrowth |   2.007584   1.874855     1.07   0.325    -2.580021     6.59519
NewHousing~s |   -.005892   .0097357    -0.61   0.567    -.0297143    .0179304
RealPineSa~e |  -.0046686   .1297901    -0.04   0.972    -.3222536    .3129163
RealPinePu~e |  -.2177799   2.190145    -0.10   0.924    -5.576871    5.141311
       _cons |   21.20579   25.22416     0.84   0.433    -40.51551     82.9271
------------------------------------------------------------------------------
```

c) Southwest vs. South Delta Arkansas

I. Southwest (corporate-heavy)

i. Log-linear on harvest

```
. reg lnPineSaw lnNewHomeStarts lnRealPineSawPrice lnRealPinePulpPrice GDPGrowt
> h RealReturn if fiaregion == 5

      Source |       SS           df       MS      Number of obs   =        12
-------------+----------------------------------   F(5, 6)         =     33.73
       Model |  .427473596         5  .085494719   Prob > F        =    0.0003
    Residual |  .015210206         6  .002535034   R-squared       =    0.9656
-------------+----------------------------------   Adj R-squared   =    0.9370
       Total |  .442683802        11  .040243982   Root MSE        =    .05035

------------------------------------------------------------------------------
   lnPineSaw |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
lnNewHomeS~s |   .3477808   .0755528     4.60   0.004     .1629097     .532652
lnRea~wPrice |   .3310533   .1105943     2.99   0.024     .0604388    .6016677
lnRea~pPrice |  -.266089     .171395    -1.55   0.172    -.6854775    .1532995
   GDPGrowth |  -.0285132   .0131051    -2.18   0.072    -.0605802    .0035538
  RealReturn |  -.0461411   .0238839    -1.93   0.102     -.104583    .0123008
       _cons |    10.3719   .5813128    17.84   0.000     8.949482    11.79432
------------------------------------------------------------------------------
```

ii. Log-linear on ratio

```
. reg lnRatio lnNewHomeStarts lnRealPineSawPrice lnRealPinePulpPrice RealReturn
>  if fiaregion == 5

      Source |       SS           df       MS      Number of obs   =        12
-------------+----------------------------------   F(4, 7)         =      2.14
       Model |  .482977037         4  .120744259   Prob > F        =    0.1782
    Residual |  .394392889         7  .056341841   R-squared       =    0.5505
-------------+----------------------------------   Adj R-squared   =    0.2936
       Total |  .877369926        11  .079760902   Root MSE        =    .23736

------------------------------------------------------------------------------
     lnRatio |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
lnNewHomeS~s |  -.2124986   .2957621    -0.72   0.496    -.9118649    .4868676
lnRea~wPrice |  -.5648082   .4263826    -1.32   0.227    -1.573043    .4434265
lnRea~pPrice |   .3592752   .8019251     0.45   0.668    -1.536976    2.255527
  RealReturn |   .0991857   .0779539     1.27   0.244     -.085146    .2835174
       _cons |   4.070112   2.731106     1.49   0.180    -2.387928    10.52815
------------------------------------------------------------------------------
```

iii. Ratio

```
.  reg PulptoSaw_Ratio RealReturn GDPGrowth NewHousingStarts RealPineSaw_Price
> RealPinePulp_Price if fiaregio == 5
```

Source	SS	df	MS
Model	2.41398838	5	.482797677
Residual	2.15027793	6	.358379655
Total	4.56426631	11	.414933301

Number of obs	=	12
F(5, 6)	=	1.35
Prob > F	=	0.3594
R-squared	=	0.5289
Adj R-squared	=	0.1363
Root MSE	=	.59865

PulptoSaw_~o	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
RealReturn	.1991745	.3015368	0.66	0.533	-.5386595	.9370086
GDPGrowth	-.0421623	.1714442	-0.25	0.814	-.4616713	.3773466
NewHousing~s	-.0004009	.0008903	-0.45	0.668	-.0025793	.0017775
RealPineSa~e	-.0086172	.0118685	-0.73	0.495	-.0376585	.020424
RealPinePu~e	.1117007	.2002756	0.56	0.597	-.3783559	.6017574
_cons	2.690812	2.306598	1.17	0.288	-2.953231	8.334855

II. South Delta (individual-heavy, agricultural opportunity cost)

i. Log-linear on harvest

```
. reg lnPineSaw lnNewHomeStarts lnRealPineSawPrice lnRealPinePulpPrice GDPGrowt
> h RealReturn if fiaregion == 6
```

Source	SS	df	MS
Model	1.55388206	5	.310776411
Residual	.26666234	6	.044443723
Total	1.8205444	11	.165504036

Number of obs	=	12
F(5, 6)	=	6.99
Prob > F	=	0.0173
R-squared	=	0.8535
Adj R-squared	=	0.7315
Root MSE	=	.21082

lnPineSaw	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnNewHomeS~s	.1566755	.3163473	0.50	0.638	-.6173984	.9307494
lnRea~wPrice	-.8722878	.4630693	-1.88	0.109	-2.005378	.2608019
lnRea~pPrice	.7977774	.717648	1.11	0.309	-.958244	2.553799
GDPGrowth	.0677424	.0548723	1.23	0.263	-.0665254	.2020101
RealReturn	-.1254964	.1000044	-1.25	0.256	-.3701985	.1192056
_cons	11.04975	2.434015	4.54	0.004	5.093928	17.00557

ii. Log-linear on ratio

```
. reg lnRatio lnNewHomeStarts lnRealPineSawPrice lnRealPinePulpPrice RealReturn
>  if fiaregion == 6
```

Source	SS	df	MS		
				Number of obs =	12
				F(4, 7) =	5.60
Model	4.68946107	4	1.17236527	Prob > F =	0.0242
Residual	1.46628699	7	.209469569	R-squared =	0.7618
				Adj R-squared =	0.6257
Total	6.15574805	11	.559613459	Root MSE =	.45768

lnRatio	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnNewHomeS~s	-.0857123	.5702792	-0.15	0.885	-1.434208	1.262784
lnRea~wPrice	.2600919	.8221375	0.32	0.761	-1.683954	2.204138
lnRea~pPrice	-.2681386	1.546247	-0.17	0.867	-3.924431	3.388154
RealReturn	-.542048	.1503083	-3.61	0.009	-.8974706	-.1866255
_cons	2.932543	5.266032	0.56	0.595	-9.519644	15.38473

iii. Ratio

```
.  reg PulptoSaw_Ratio RealReturn GDPGrowth NewHousingStarts RealPineSaw_Price
> RealPinePulp_Price if fiaregio == 6
```

Source	SS	df	MS		
				Number of obs =	12
				F(5, 6) =	2.01
Model	130.43152	5	26.086304	Prob > F =	0.2094
Residual	77.709004	6	12.9515007	R-squared =	0.6267
				Adj R-squared =	0.3155
Total	208.140524	11	18.9218658	Root MSE =	3.5988

PulptoSaw_~o	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
RealReturn	-1.655769	1.812712	-0.91	0.396	-6.091314	2.779777
GDPGrowth	-.8047893	1.03065	-0.78	0.465	-3.326699	1.717121
NewHousing~s	.0013991	.0053519	0.26	0.803	-.0116966	.0144948
RealPineSa~e	-.0181814	.0713485	-0.25	0.807	-.192765	.1564022
RealPinePu~e	-.3665594	1.203972	-0.30	0.771	-3.312572	2.579454
_cons	16.85141	13.86629	1.22	0.270	-17.07819	50.781

A Discussion on Multicollinearity in e1 Regression, Alabama Statewide

If one were to remove either the GDP growth or new home construction variables in the regressions in figure 1 and re-run them (save for the lagged model), the remaining macroeconomic indicator is both clinically and statistically significant. This large difference in the variables' statistical significance when the other is excluded indicates missing variable bias upon exclusion, justifying inclusion of both. One might suspect that since both variables measure a facet of national economic growth, they also exhibit severe multicollinearity. However, DW stats turn up a 2.47 for the residual series regression model, and 1 for the regression on raw sawtimber harvest data, both signs only of very mild multicollinearity.

To further explore this, I ran a VIF score of the whole regression above, and no variable had a VIF of above 2, which also points to minimal multicollinearity.

Regardless, I feel it is valuable to include both GDP growth and new home construction figures in our regressions for two reasons: first, new home construction has a more direct impact on the demand equation for southern timber products while GDP growth measures more general economic health and demand for other non-construction wood products.

Secondly, if we excluded one of these macroeconomic variables from the equation on the belief that they proxy for each other, we'd end up with a bias correlated with time. For instance, suppose we decide to drop new home construction and include only GDP growth to measure the US macro economy and proxy for national wood demand. Since the birth rate and population growth rates vary across the timeframe of my sample (first much higher than today, then lower in the mid-70s and climbing into the early 2000s before falling back off again), one would expect that demand for housing, a major component of the timber industry, is not exactly correlated with GDP growth.[52] Housing timber demand is dependent on population growth and GDP growth, and only including GDP would bias estimates due to the missing demand-side variable.

On my Honor, I have neither given nor received any unacknowledged aid on this thesis.

Nathan J. Richendollar

[52] Author Unknown, "The U.S. Recession and the Birth Rate," *PRB*, https://www.prb.org/usrecessionandbirthrate/, accessed January 27, 2019.