Cropland Investment Booms and Groundwater

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Abstract

We study the remarkable boom in California tree nut investment that began in the mid-2010s drought. We build a rich dataset tracking ownership, crop allocation, and groundwater well drilling at the farm level. We show that large investors with very little ex-ante exposure to nuts ("non-specialists") played a key role in driving the boom. These investors do more groundwater well drilling than other investors, especially during drought. Notably, nut farms owned by non-specialists account for one-fifth of all agricultural well drilling in California over 2013-2023, and nut farms overall account for half of drilling. Relative to other investors, non-specialists reallocate away from short-duration annual crops to long-duration nuts, as if trying to earn a risk premium. Moreover, they do not attenuate their own nut expansion in response to competitors' nut expansion, consistent with a model of herding or competition neglect. Overall, these findings point to potentially significant environmental impacts of investment booms, amplified by deep-pocketed investors that seem to exhibit over-optimism about the boom's persistence.

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1 Introduction

U.S. history is replete with boom-bust episodes in various real asset classes (e.g., Glaeser 2013). We show how these episodes can have real effects on a scarce natural resource: groundwater. Globally, groundwater levels have been declining at a rapid and accelerating rate, especially in dry, crop-intensive regions like California's Central Valley, which serves as the setting of our analysis (e.g., Scanlon et al. 2023; Jasechko et al. 2024). For instance, Jasechko et al. (2024) indicate that half a dozen regions in California rank among the world's most rapidly depleting aquifers, while such declines are absent in areas without agricultural activity. In response to these alarming trends, the California Legislature enacted a series of laws in 2014 aimed at curbing excessive groundwater extraction. Despite these regulatory efforts, conflicts arose, and groundwater depletion continued largely unchecked (Becker 2021).

Against this backdrop of falling groundwater levels, California experienced a spectacular boom in tree nut production from 2013 through 2020, especially almonds and pistachios. California is a major global producer of both nuts, accounting for around 80% and 60% of global production of each, respectively (e.g., Klein 2024). For example, domestic and foreign demand for almonds exploded after the Great Recession, and almond prices skyrocketed until they peaked in 2014. These price increases came amid a severe drought that lasted from 2013 through 2016. Since nut trees require several years from planting before they bear fruit, the quantity of almonds produced did not respond to match the steep rise in prices. Instead, the planting of new almond trees surged during the drought. Once the drought ended, the quantity of almonds produced surged, while almond prices collapsed. By 2023, almond prices had dropped to their lowest levels in 20 years, even in nominal terms. Thus, the nut boom in California resembles classic boom-bust episodes studied in various other real asset classes.

We build a rich dataset that allows us to track the ownership, crop allocation, and groundwater well drilling on land parcels in California over 2013 through 2023. Then, we focus our analysis on understanding the characteristics of the investors (i.e., landowners) driving the nut boom; and we relate their decisions to a theory of portfolio allocation across land uses with fixed adjustment costs in the form of groundwater wells.

The results are striking: large investors with very little ex-ante experience in nut growing account for most of the expansion in nut cropland and in groundwater well drilling. Specifically, most of the expansion in tree nut cropland over 2013 through 2023 is due to investors that, as of 2013, had less than 10% of their total agricultural land allocated to nuts. The market share, in acres, of these large nut "non-specialists" grew fourfold, from around 5% in 2013 to around 20% in 2023. Interestingly, non-nut specialists expanded primarily through

land they already owned in 2013, not by purchasing new land.

The pattern of reallocation between nut cropland, annual cropland (e.g., cotton), non-nut permanent cropland (e.g., pomegranates), and non-cropland over the nut boom bears similarity to the logic of canonical portfolio choice. Large non-specialists accommodate the increase in nut cropland by reallocating away from annual cropland, which produces cash flows with much shorter duration and much lower volatility than the cash flows of long-duration, risky nut cropland (Sherrick 2020). This finding is consistent with large non-specialists perceiving an increase in the expected risk-adjusted return to nut cropland and seeking to realize a risk premium by reallocating away from annual cropland. By contrast, when large nut specialists expand nut cropland, they do so by reallocating away from other, non-nut permanent cropland. By definition, nut specialists already have significant exposure to risky nut cropland, so it seems plausible that this result reflects their unwillingness to increase their overall portfolio risk. By accommodating any increase in risky nut cropland by a one-for-one reduction in exposure to other risky permanent cropland, the total volatility in their portfolio remains about the same.

Moreover, we find that small investors who expand their nut exposure do so by planting nut trees on non-cropland, whereas their larger competitors are more likely to reallocate away from other types of crops, as just described. We interpret this finding as reflecting how non-cropland has real option value, in that it can be used to take advantage of profitable investment opportunities that arrive in the future. Since small investors may lack the capital to take advantage of such opportunities, they are more willing to convert non-cropland into nut cropland than larger investors, who may wish to preserve the optionality of non-cropland (e.g., Novy-Marx 2007). These results are robust to the inclusion of granular zip code fixed effects. This supports their interpretation as reflecting differences in optimal asset allocation across types of investors, not differences in the soil, climate, or pollination activity of the land they own.

Turning to groundwater, we document that land parcels with nut growth account for around half of all groundwater well-feet drilled on agricultural land in California between 2013 and 2023. In line with the interpretation of groundwater wells as a fixed capital adjustment, large non-specialist investors account for 35% of drilling on land with nut growth, and they account for 20% of all drilling on agricultural land. These results, like our findings on crop reallocation, are robust even when we include granular geographic fixed effects, ensuring that we compare investors who face similar groundwater levels beneath their land.

An expansion of nut cropland and well drilling of these magnitudes must reflect expectations that the initial spike in nut prices during the beginning of the mid-2010s drought would persist. We present evidence that, in the aggregate, the cash flow from nut farms is very

difficult to forecast beyond a one-year horizon. If anything, valuation ratios suggest that the market expects booms in nut prices to last longer than they actually do. For example, over the past 30 years, professional land appraisals of nut cropland rise sharply during transitory booms in nut prices and remain elevated well into the subsequent busts, consistent with appraisers expecting that these short-term booms will persist over the long-term. If the market, as a whole, seems to hold overly optimistic expectations about the persistence of tree nut booms, then it seems plausible that such over-optimism would be even more pronounced among large nut non-specialists, which we explore next.

We find that a given investor's nut expansion depends on the nut expansion of nearby competitors, and this effect varies significantly across types of investors. Both large nut specialists and small investors attenuate their own nut expansion when their competitors expand. This behavior is consistent with these investors internalizing how the expansion activity of their competitors may put downward pressure on prices in equilibrium. In contrast, greater nut expansion by competitors does not attenuate nut expansion by large nut non-specialists, and, for some nuts, it actually increases their expansion. This finding suggests that non-specialists may not internalize the response of their competitors ("competition neglect"). Consistent with competition neglect, we find reduced nut expansion activity by large non-specialists with farms in multiple counties and, thus, more information about the contemporaneous growth in aggregate nut supply.

An alternative interpretation is that nut non-specialists perceive their competitors to have superior information and, so, attempt to mimic them ("herding"). However, the herding channel would also predict that a large non-specialist would expand less into a given nut type (e.g., pistachios) when their competitors expand into a substitute nut type (e.g., almonds). If some of the expanding investors have superior information about the persistence of a particular nut type's price, then less well-informed investors will mimic them and "herd" on that particular nut type. On the contrary, we find that large non-specialists do not exhibit such cross-nut substitution: increasing their competitors' expansion into almonds while holding their competitors' expansion into non-almond nuts fixed, large nut non-specialists are no less likely to expand into non-almond nuts – and vice versa. This finding loosely suggests that competition neglect may be a more appropriate explanation of why large non-specialists seem to expect elevated nut prices to persist. However, we acknowledge that this test does not isolate competition neglect as the dominant model of expectation formation, so we remain cautious in our claims about the precise behavioral mechanism.

A "contrarian" investor wishing to profit from the nut boom would ideally short-sell nut cropland or a nut futures contract. Practically, real estate cannot be short-sold, and a futures market for tree nuts did not exist over most of our sample period. So a second-

best strategy for such an investor would be to reduce their own nut cropland. We find that nut non-specialists that enter the boom with positive, but small, exposure to nuts are much less likely to reduce their nut cropland relative to large nut specialists with a similarly small, albeit slightly higher nut exposure. This finding is again consistent with the general interpretation of the nut non-specialists, who drive aggregate growth in nut cropland, as overly optimistic about the persistence of the nut boom.

Taken together, our results suggest that the costs of real estate boom-bust episodes crucially depend on the characteristics of the investors driving the boom. In our setting, large investors new to nut growing account for a significant share of overall well drilling during the boom, potentially putting stress on overall groundwater supply.

Related Literature

We make four main contributions. First, we contribute to the financial economics literature by documenting how the entry of new (i.e., non-specialist) investors can amplify investment booms and, as a consequence, affect composition of goods in the economy and the supply of scarce natural resources. Many studies have used the mid-2010s housing boom as an empirical laboratory for understanding the role of new investor entry in investment booms. Our paper corroborates several key ideas from this literature.[1] A key difference relative to many of these studies is that the new investors in our setting actively develop the land and transact relatively little, whereas much of the literature focuses on new investors in the housing boom who transact frequently and on already-developed land.[2] Our main contribution is to link the entry of new investors to both the allocation of crop types (i.e., from annual to permanent) and the supply of a scarce natural resource, groundwater.

Our second contribution concerns the friction leading to ex-post overinvestment in nut cropland, and, in particular, our evidence consistent with competition neglect. This concept,

[1]For example, our finding that non-specialist investors drive the over-expansion of nut cropland during the mid-2010s nut boom parallels evidence that out-of-town homebuyers (e.g., Chinco and Mayer 2016) or novice investors (e.g., Bayer, Mangum and Roberts 2021) underperformed in the mid-2000s housing boom. Furthermore, the fact that even nut specialists expanded their acreage during the nut boom mirrors the result from Cheng, Raina and Xiong (2014) that even specialists in mortgage securitization also bought homes during the housing boom.

[2]We stress that few papers link over-investment in new housing supply over the mid-2000s to the entry of new investors (i.e., builders) that develop that supply, not that there is an absence of literature on the role of supply constraints. Indeed, Rognlie, Shleifer and Simsek (2018) and Gao, Sockin and Xiong (2020) provide theoretical and empirical evidence, respectively, that supply overhang from overbuilding contributed to the mid-2000s bust, but without variation across builders. Nathanson and Zwick (2018) show theoretically how more-optimistic builders drive housing expansion in supply-elastic cities and provide stylized facts consistent with their model, but they do not use microdata to identify which investors act optimistically. Concerning papers that focus on investors that transact frequently ("flips"), see, for example, Mian and Sufi (2022) and DeFusco, Nathanson and Zwick (2022).

rooted in the "cobweb" theories of Kaldor (1934) and Ezekiel (1938), suggests that suppliers of a good requiring a time-to-build act as if the current price will persist until the good is produced, leading to ex-post oversupply. This theory has been used to explain volatility in price and output of annual crops, as summarized by, for example, Gouel (2012). We apply these ideas to permanent cropland, where the time-to-build is longer. Greenwood and Hanson (2015) also study investment booms in an asset with significant time-to-build, dry bulk shipping, and, like us, argue that competition neglect on the part of ship builders contributes to boom-bust cycles in ship prices. We differ by utilizing detailed microdata to provide evidence consistent with the role of competition neglect as the behavioral mechanism contributing to the expansion in nut cropland. In particular, our empirical methodology resembles Povel et al. (2016), who study booms in hotel investment and consider both competition neglect and herding as candidate explanations, ultimately finding stronger support for herding. In contrast, applying the same test to our setting implies a stronger role for competition neglect. This may be because nut prices are very difficult to forecast over long horizons, leaving little room for "informed investing" on which to herd.

Third, we contribute to the agricultural economics literature by relating shifts in cropland composition between permanent, annual, and non-cropland to a dynamic portfolio choice problem. A large literature in agricultural economics studies how investors (i.e., farmers) allocate across different types of annual crops, summarized in Chavas, Chambers and Pope (2010). For example, Holmes and Lee (2012) show how investors allocate corn, wheat, and other annual crops across fields to trade off optimal soil for a given crop type with scale economies from planting all crops of the same type nearby each other. Our focus on the margin of adjustment between annual and permanent crops, which take longer to mature than annual crops, requires us to specify a more-dynamic problem that incorporates ideas from Q-theory. In particular, developing almond cropland entails fixed, non-convex adjustment costs, which may explain why large investors drive most of the growth in nut cropland, which relates to a broader trend toward consolidation of U.S. cropland (e.g., MacDonald, Korb and Newton 2013; MacDonald, Hoppe and Newton 2018).

Fourth, we complement recent and contemporaneous research on groundwater by linking well drilling to the owner's expected return on its cropland portfolio. For example, Burlig, Preonas and Woerman (2023) show how changes in the cost of groundwater drilling affect crop allocation, whereas we show how shifts in crop allocation affect groundwater drilling. Rempel et al. (2024) show that agricultural land purchases by non-individuals are associated with higher greater well depth, while Reisman and Macaulay (2022) document significantly higher well drilling on permanent cropland. Our results complement both sets of findings, in that we show how large landowners new to a particular permanent crop, nuts, drill significantly

more than both specialists in nuts and smaller landowners.

2 Theory and Institutional Details

In describing the theory, we introduce various institutional details about cropland investing that will be important for interpreting our empirical results. To highlight the intuition, consider a two-period setup. The first period begins at date $t = 0$, and it can be thought of as an extended growing season. In California, the growing season typically begins in the late winter or early spring, the harvest arrives in the late summer or the fall, and the early winter is a period of dormancy. The second period begins at $t = 1$, and the economy ends at $t = 2$. At date 0, an investor endowed with land L decides how to allocate that land across three potential uses: annual cropland, permanent cropland, or non-cropland. We abstract from the possibility of selling or buying land, which matches our finding that land transactions do not seem to drive the expansion into nuts that we document shortly.

2.1 Types of Cropland

Annual crops, denoted by a, are planted, grown, and harvested within the same calendar year. Common examples include corn, cotton, and wheat. In our framework, each unit of annual cropland in place at the start of date t produces D_a units of cash flow at the end of the period. So, annual cropland functions similarly to a "risk-free asset" with a coupon of D_a. This is of course a simplification, but it helps clarify the intuition in a way that is not unreasonable given the empirical returns across crop types, as we describe next.[3]

Permanent crops, denoted p, are the second form of cropland. Unlike annual crops, permanent crops typically take three to seven growing seasons before they can bear fruit. This lag stems from the fact that permanent crops grow on trees (e.g., citrus, almonds) or vines (e.g., grapes), which take time to mature. So, loosely, permanent cropland would resemble "capital" in a standard Q-theoretic framework with a time-to-build lag. Under this interpretation, we assume permanent cropland planted at date 0 produces cash flow of $D_{p,1}$ at date 1. Empirically, the returns to permanent cropland are higher in both expected value and variance than annual cropland. Consider, for example, the return to cropland investments made by the National Council of Real Estate Fiduciaries (NCREIF), a set of large fiduciaries that invest largely on the behalf of tax-advantaged institutions (e.g., pensions). Over 1992 through 2023, the income return (i.e., excluding price appreciation) to the permanent crop

[3]Widespread use of crop insurance for annual cropland provided by the U.S. government further reduces the risk born by investors (e.g., O'Donoghue, Roberts and Key 2009; Glauber 2013).

sub-portfolio was 8.7%, versus 4.5% for the annual crop sub-portfolio, on an annualized basis. Moreover, the corresponding volatility for the permanent and annual sub-portfolios equal 11.6% and 1.1%, respectively.

Our paper is focused on a particular kind of permanent crop, tree nuts, denoted n. The most important tree nuts grown in California are, in order of share of acres, almonds, pistachios, and walnuts. Relative to other crops, tree nuts require substantially more water, even when conditioning on their relatively high nutritional content per unit produced (e.g., Fulton, Norton and Shilling 2019). Due to a combination of regulatory and climatological features of California agriculture, the most practical way to tap new sources to water during periods of water scarcity (e.g., a drought) is through drilling a well to tap groundwater.[4] So, to match our empirical setting, we suppose that expanding nut cropland by ΔL units of land comes at the fixed cost W paid at the end of the first period.

The third main land use is non-cropland that is either fallow or can be transformed into cropland. We denote this land use by v, to stress that it has option value from the potential of future development. A proper modelling of this option value requires a dynamic setting. Instead, we simply assume that a profitable development opportunity arrives at the start of the second period with expected net present value of $V(L)$. A dynamic setting would likely imply that V is increasing in L, especially if the arriving investment opportunity requires a fixed, upfront cost, and so we assume $V(L)$ is increasing. If investors turn down this opportunity, then they optimally convert non-cropland into annual cropland.

2.2 Portfolio Choice

Investors approach date 0 with predetermined portfolio shares $\alpha_{0,a}$ $\alpha_{0,n}$, and $\alpha_{0,p}$ that solve their portfolio choice problem before the nut boom begins, where we now use p to denote permanent crops excluding nuts. At date 0, the cash flow from nuts $D_{0,n}$ significantly increases and is expected to persist. Without expected persistence, investors would have no incentive to expand their nut crop.

[4]Climatologically, California's dry climate necessitates that cropland be irrigated, as there is not enough rain to cultivate most types of crops. There are two principal forms of expanding irrigation. The first method is to drill groundwater wells to tap water stored in aquifers. The second is to buy rights to one of California's major aqueducts, which carry water from the rivers of Northern California south to major cropland in Central and Southern California, or, for the southernmost part of California, to buy rights to the water from the Colorado river. This second route comes with political or regulatory costs, which partly explain why we find that nut non-specialists are more likely to tap groundwater to irrigate nut cropland than their specialist competitors, who may already have already paid the soft costs required to access river water. Either way, it seems reasonable to depart from the canonical Q-theoretic convex adjustment costs, with a fixed cost W being the simplest way to incorporate non-convex costs. Moreover, both forms of expanding irrigation become costly in a drought: the lack of rainfall lowers the level of the aquifer, necessitating deeper wells; and regulatory agencies restrict access to drying riverbeds.

The cash flow per unit of land in the first and second periods are, respectively,

$$\frac{\Pi_1}{L} = \alpha_{0,n} D_{0,n} + \alpha_{0,p} D_{0,p} + \alpha_{0,a} D_{0,a} - \frac{W}{L} \cdot 1[\Delta\alpha_{1,n} > 0], \tag{1}$$

$$\frac{\Pi_2}{L} = \alpha_{1,n} D_{1,n} + \alpha_{1,p} D_{1,p} + (1 - \alpha_{1,n} - \alpha_{1,p}) \max\{D_{1,a}, V(L)\}, \tag{2}$$

where $\Delta\alpha_{1,\cdot}$ denotes the change in allocation from the first to the second period. Given a homogeneous flow utility function u and a time discount factor δ, it is straightforward to show that investors solve

$$\max_{\alpha_{0,a}, \Delta\alpha_{1,n}, \Delta\alpha_{1,p}} \left\{ u\left(\frac{\Pi_1}{L}\right) + \delta \mathbb{E}\left[u\left(\frac{\Pi_2}{L}\right)\right]\right\} \tag{3}$$

$$s.t.$$

$$1 \geq \alpha_{0,a} + \Delta\alpha_{1,n} + \Delta\alpha_{1,p} + \alpha_{0,p} + \alpha_{0,p}$$

where strict inequality of the constraint means that investors hold non-cropland in the first period.

Empirical Predictions

Equations (1)-(3) along with the remaining setup suggest the following empirical predictions

1. *Small investors are less likely to increase nut allocation, and, when they do, they are more likely to do so through a drop in non-cropland.* The first prediction follows from the fact that earnings-per-acre are weakly increasing in L, and strictly so if nut allocation increases. The second prediction follows from the assumption that $V(L)$ is increasing: since small investors have fewer resources to undertake future development, they value the real option of non-cropland land less than their larger peers.

2. *Nut specialists accommodate nut expansion by reducing other permanent crop exposure.* Letting M_1 denote the stochastic discount factor at time 1, no-arbitrage requires $\mathbb{E}[M_1 D_{1,n}] = \mathbb{E}[M_1] D_a$. A nut specialist already has exposure to nut returns: $\alpha_{0,n} > 0$. Thus, for any given increase in nut exposure $\Delta\alpha_{1,n} > 0$, a nut specialist will have lower marginal utility and, thus, a lower M_1, when nut payoffs $D_{1,n}$ are high, and vice versa when nut payoffs are low. Consequently, the investor has a relatively low value of $\mathbb{E}[M_1 D_{1,n}]$. However, the investor can raise $\mathbb{E}[M_1 D_{1,n}]$ while holding the increase in nut exposure, $\Delta\alpha_{1,n}$, fixed, by reallocating away from non-nut permanent crops and

towards annual crops. Consequently, relative to a non-specialist, the specialist's allocation to non-nut permanent crops falls. Put simply, a nut-specialist enters the boom already bearing substantial risk that taking further risk through nut investing requires substituting away from other risky permanent cropland.[5]

3. *Non-nut specialists accommodate nut expansion by reducing annual crop exposure.* The logic for this prediction is symmetric to that of the previous prediction. Since non-specialists enter the drought with less nut exposure than their specialist peers, they are willing to accommodate the same increase in nut exposure, $\Delta\alpha_{1,n} > 0$,by reducing annual crop exposure rather than exposure to non-nut permanent crops. This enables them to still earn a risk premium through exposure to non-nut permanent crops.

We reiterate that the purpose of this section was to lay out a framework for thinking about our empirical results, not to formally derive the set of theoretical conditions that would generate our results. That said, even these informal conjectures provide us with useful structure entering our main empirical analysis.

3 Data

Our analysis relies on a dataset that tracks the ownership, crop allocation, and groundwater well drilling on land parcels in California over 2013 through 2023. We describe the data and how we construct key variables used in our analysis.

3.1 Datasets

Cropland Data Layer

Data on crop allocation come from the United States Department of Agriculture's (USDA) Cropland Data Layer (CDL). The CDL data contain an annual snapshot of the type of vegetation covering a given unit of land, based on satellite imagery. Since nut trees require between three to eight years from planting until a tree can bear fruit, we work at five-year frequencies and obtain data for 2013, 2018, and 2023.

The data are stored as rasters, which can be downloaded from the USDA's website. Each pixel in the image has a color, and the color is associated with a given crop (e.g., pumpkins,

[5]We have been silent on the covariance of cash flow across broad crop types. Positive covariance between nut cash flow and cash flow from other non-nut permanent crops (e.g., grapes) seems plausible and would provide an additional motive for large nut specialists to accommodate nut expansion by reducing other permanent crop exposure.

radishes) or other agricultural land use (e.g., fallow cropland, open space). We work with a resolution 30m, meaning that each pixel has an area of $900m^2$ (0.22 acres).

We begin with the master shapefile of land parcels in California obtained from the Los Angeles County Data Hub, described in Appendix A. We sort California counties by total agricultural acres according to the USDA's 2022 Census of Agriculture, and we restrict attention to the counties within this sorted list that cumulatively account for 95% of agricultural land in California. For each land parcel, we compute the number of pixels associated with a given crop. We group certain types of crops (e.g., vegetables) into a single category, as described in Appendix A.

To compute the share of land allocated to that crop, we divide by the total number of pixels associated with a parcel. Lastly, we filter the data to parcels of at least one acre, where an acre equals around five pixels given our resolution. Our "cleaned CDL dataset" contains the share of land allocated to a given crop at five-year intervals over 2013 through 2018 on all land parcels within the California counties that comprise 95% of the state's agriculture.

CoreLogic

We obtain data on the ownership and characteristics of agricultural properties from the CoreLogic Assessment Database, as documented by tax assessors, from 2013 to 2023. The data derive from county tax assessor offices and other third-party sources proprietary to CoreLogic. The tax assessments are annual and contain the full name and mailing address of the land owner, the address and geographic coordinates of the parcels, the number of acres, description of the land use and the assessed value of the property. We merge the tax assessment data from CoreLogic with the Cropland Data Layer data using the unique parcel identifier that is common in both datasets. Overall, we obtain a 95% match of the parcels.

To study ownership changes and obtain the value of the property at the time of the transaction, we merge the Cropland Data Layer data with the CoreLogic Transaction Database. This database contains all ownership transfers of properties in the U.S. as recorded by the county deeds. We focus on the deeds from January 1st, 2013 to December 31st, 2023. We use extensive information from each deed, such as the name of the buyer, the name of the seller, the date of the transaction, the address of the property, the mailing address of the buyer, the price at which the property was sold and the loan amount on the property.

We use a rigorous methodology to classify the land owners into different categories, depending on their size, the types of crops they own, and how the land size and crop types evolved from 2013 to 2023. First, for each year we calculate the total acreage that corresponds to each owner name. To achieve that we employ fuzzy matching of the owner names and meticulously check and revise these matches. Second, for the largest owners, we search for

subsidiary names in public databases, and revise the matching of those owner names to include subsidiaries. This improves the accuracy of the holdings of the large owners. Third, after we obtain the total acreage of each owner in 2013 and 2023, we calculate the share of land of each owner allocated to nuts (almonds, pistachios, walnuts, and pecans). With this information we classify owners as "Large" or "Small", and "Specialists" or "Non-Specialists", as we define in the next subsection.

California Department of Water Resources

Data on groundwater well drilling are from the California Department of Water Resources (DWR) Well Completion Reports, accessed via the California Natural Resources Agency Open Data Platform. We restrict attention to new wells drilled from 2013 through 2023, based on the date at which the work on the well ended. We observe the latitude and longitude of the well, which enables us to assign a new well record to a given parcel in our cleaned CDL data. We also observe the well's depth, in feet.

Other Datasets

Appendix A describes additional datasets used either directly in our analysis or as intermediate steps to build and merge the main datasets. These datasets are: cropland returns from the National Council of Real Estate Fiduciaries (NCREIF); county-level drought data from the National Drought Mitigation Center; aggregate California almond statistics from the Almond Board of California; and land parcel shapefiles from the Los Angeles County Data Hub.

3.2 Key Variables

Much of our analysis makes use of two variables that describe the size and specialization of investors that own a given land parcel, which we shall occasionally refer to as a "farm". In keeping with our focus on portfolio allocation, we use the term "investor" in reference to any owner of cropland in our data.

The first key variable, $LargeOwner_i$, describes the size of the owner of land parcel i in 2013, at the start of the drought. In particular, this variable takes on a value of one if either: the owner of parcel i in 2013 is in the top 25% of owners sorted by total acreage owned in 2013 and i was not sold over 2013-2023; or, the owner of parcel i in 2023 was in the top 25% of owners sorted by total acreage owned in 2013 and purchased parcel i over 2013-2023. The second key variable, $NonSpecialist_i$, describes the owner's degree of specialization in nut cropland at the start of the drought. This variable takes on a value of one if either: the

owner of parcel i in 2013 has less than 10% of total acreage owned allocated to nuts in 2013 and i was not sold over 2013-2023; or, the owner of parcel i in 2023 had less than 10% of total acreage owned allocated to nuts in 2013, and purchased parcel i over 2013-2023.

Table 1 summarizes the farms used in our analysis by ownership category. The table includes all farms, not just those with growth in nut acreage. Briefly, the largest group, in terms of number of farms, is the set of farms associated with small owners ($LargeOwner_i = 0$). However, farms owned by large non-nut specialists are the largest. The smallest group, again in terms of number of farms, is the set of farms associated with large nut specialists. In 2013, the plurality of land on the average farm associated with small owners or large non-nut specialists was allocated to non-cropland, while the plurality of land for farms associated with large nut specialists was allocated to nuts.

4 Aggregate Dynamics

Our empirical setting is the market for nuts during the mid-2010s drought in California, which Lund et al. (2018) summarize.[6] The price of several tree nuts surged over this period, especially almonds and pistachios. California is a major global producer of both nuts, accounting for around 80% and 60% of total production globally, according to the USDA Foreign Agricultural Service. So, the surge in nut prices during the California drought is consistent with a negative aggregate supply shock, especially given the intense water requirements of nut cropland described in Section 2.

We walk through this episode taking the specific case of almonds, for which the Almond Board of California provides useful aggregate statistics complementing our main datasets. Figure 1 documents prices, quantities, and almond acreage around the drought. During the drought, prices surge and quantity produced exhibits a negative break from trend (panel (a)). Acreage comprised of young almond trees also surges during the drought (panel (b)). We interpret this as increased investment in new almond trees. Note that acreage consisting of matured trees exhibits a positive break from trend shortly after the investment in new almond trees.

In relation to our theory from Section 2, this episode is consistent with an increase in the expected cash flow from nut cropland ($\mathbb{E}[D_{1,n}]$) leading to investment in new nut trees

[6]By our classification, the drought lasted from 2013 through 2016. We classify a drought as a year in which the average Drought Severity Combined Index (DSCI) produced by the National Drought Mitigation Center is at least 50% of the maximum value the index can take (500). The DSCI data are available through the University of Nebraska-Lincoln at the county by week level. We aggregate to the state by year level by taking the average across all county-weeks in California, weighting counties by their share of agricultural land in California according to the 2022 USDA Census of Agriculture.

($\alpha_{1,n}$) with a corresponding increase in aggregate nut supply once these trees have matured.[7] Using our framework as a guide, we next examine how the market shares and groundwater drilling by different types of nut investors change during and after the drought.

4.1 Dynamics of Market Share

Figure 2 plots the share of total nut cropland across different categories of investors over five-year intervals from 2013, the start of the drought, to 2023. From here on, we use "nuts" in reference to almonds, pistachios, walnuts, and pecans. Throughout the sample, the majority of nut cropland is owned by investors that specialized in nuts in 2013, as defined precisely in Section 3. However, their market share falls from 70% in 2013 to 50% in 2023. Most of this drop in the market share of large nut specialists is accounted for by an increase in the market share of large investors that, as of 2013, had little specialization in nuts.

The market share of these large non-nut specialists grows fourfold, from around 5% in 2013 to around 20% in 2023. Interestingly, non-nut specialists expand primarily through land they already owned in 2013, not by purchasing new land. This is shown by comparing the leftmost and second-from-leftmost sets of bars in the figure. In terms of the level of nut acreage, Appendix Figure A.1 shows how non-nut specialists account for around 40% of aggregate (i.e., statewide) expansion of nut cropland over 2013-2023.

4.2 Dynamics of Water Supply

Our framework would predict that the expansion in nut cropland comes with an increase in groundwater well drilling to irrigate it. Figure 3 plots cumulative groundwater well-feet drilled over 2013-2023 on parcels in our Cropland Data Layer database. We decompose this drilling into well-feet from parcels experiencing positive growth in nut cropland over 2013-2023 and the remaining land parcels in our data, which we call "All other agricultural land". The figure show show parcels with nut growth account for around half of all well drilling over this period.

Interpreting groundwater wells as a fixed capital adjustment cost, our simple framework predicts that large, non-specialist investors should account for a larger share of aggregate well drilling. Figure 4 supports this conjecture by plotting the share of all groundwater well-feet drilled on agricultural land over 2013-2023 due to different types of investors. Large non-specialist investors account for more well drilling than all other types of investors. In terms of magnitude, they account for around 20% of all well drilling on agricultural land and, when restricting to cropland with positive growth in nut acreage, they account for 35%.

[7] We postpone our analysis of how this expectation is formed until Section 6.

5 Large Nut Non-Specialists

We provide evidence from parcel-level data that the large nut non-specialists driving the boom documented in the previous section differ in their expansion strategy. In particular, we find that they make room for the increase in nut cropland through a different rebalancing strategy than other investors, and they irrigate their new nut cropland with more groundwater well drilling.

5.1 Nut Cropland Expansion

First, we test for differences in nut cropland expansion by investor type. We estimate regression equations of the general form

$$Y_i = \beta_0 LargeOwner_i + \beta_1 LargeOwner_i \times NonSpecialist_i + \zeta_{g(i)} + u_i, \tag{4}$$

where i indexes land parcel and $\zeta_{g(i)}$ is a geographic fixed effect at either the county or zip code level. The outcomes Y_i are various measures of nut expansion from 2013 through 2023: an indicator for whether parcel i experiences growth in nut acreage ($\mathbf{1}[NutGrowth_i]$), the change in the share of land on the parcel allocated to nuts ($\Delta NutShare_i$), the change in log acres allocated to nuts $\Delta \log(NutAcres_i)$, and the second order Taylor approximation of $\Delta \log(NutAcres_i)$ around zero, which we shall refer to as the "symmetric growth rate" or $SymGrowth(NutAcres_i)$. Unlike $\Delta NutShare_i$, the symmetric growth rate allows for entry and exit into nut growing, and, unlike $\Delta NutShare_i$ or $\mathbf{1}[NutGrowth_i]$, it excludes parcels that never had nut cropland over our analysis period. Formally, for a given variable x observed at time t_0 and later at t_1, $SymGrowth(x_{t_0 \to t_1}) \equiv 2\frac{x_{t_1} - x_{t_0}}{x_{t_0} + x_{t_1}}$. See Chodorow-Reich (2014) for an example use case.[8]

Column (1) of Table 2 demonstrates that large investors are more likely to expand nut acreage on their land than small investors within the same county, as controlled for by the county fixed effects. Specifically, the outcome variable is an indicator for growth in nut acreage. When considering large specialists and non-specialists separately, the coefficient on the interaction term in column (2) implies that non-specialists are actually less likely to expand than their specialist peers within the same county, although, taking the sum of the estimated β_0 and β_1 implies that they are still more likely to expand than small investors. However, narrowing the comparison to investors within the same zip code, column (3) shows that non-specialists actually have a slightly higher propensity to expand. This suggests that

[8] We cluster standard errors by the parcel's owner in 2013, and, unlike in our aggregate figures, we restrict the sample to parcels with a known owner in 2013 and that have no more than half of their land allocated to forest, wetlands, or barren land in 2023. We repeat all of these details in the notes to our tables and figures.

the average specialist and non-specialist may operate in different geographies and, thus, face different growing conditions. For this reason, we conduct robustness to zip code fixed effects in our regressions.

Columns (4)-(5) of Table 2 examine the magnitude of expansion, measured as share of land allocated to nuts. Note that the size of each land parcel is fixed over time, and so positive values of $\Delta NutShare_i$ actually reflect growth in nut acreage (i.e., the level), not just an increase in relative share due to reduced acreage of other crops. Consistent with Table 1, large investors increase their nut share by more over the sample relative to small investors within the same county or zip code. The marginally significant estimate of β_1 suggests that non-specialists expand nut acreage to about the same degree as specialists. However, the sample in columns (4)-(5) includes all non-specialists. When we restrict to parcels with positive nut land in both 2013 and 2013 by considering $\Delta \log(NutAcres_i)$ as the outcome, we find that parcels owned by non-specialists grow at a much higher rate than do those owned by specialists.[9] A similar result obtains when studying the symmetric growth in nut acres in columns (8)-(9), which allows for entry and exit but excludes parcels that never grow nuts over 2013 through 2023.

The pattern in Table 2 indicates that large investors expand more into nut cropland at the farm (i.e., parcel) level, relative to their smaller peers. This interpretation is consistent with the first prediction from Section 2.2. It also implies that the outsized role of large investors in the aggregate dynamics in Section 4 is not simply due to the fact that they own more land. It is also worth noting that, while large non-specialists do not have strikingly larger measures of nut expansion than their specialist competitors, they still drive aggregate dynamics because, as in Table 1, they own twice as many farms.

5.2 Reallocation from Other Land to Cropland

A one acre increase in nut cropland must come from land that was previously in one of the following broad categories: annual cropland; non-nut permanent cropland; or non-cropland, which we define broadly to include fallow cropland.[10] We estimate how the former use of nut cropland varies across land owned by different types of investors, which enables us to evaluate our theory's empirical predictions regarding crop allocation.

[9] Since acres per parcel never varies, the outcome is essentially the log change in the share of land allocated to nuts. The negative estimate of β_0 reflects large specialists already have a large share of their land allocated to nuts in 2013, and so, relative to that base, they expand less than small investors.

[10] We measure annual cropland as land with: soybeans, rice, corn, cotton, wheat, vegetables, non-tree fruit, and hay. We measure non-nut permanent cropland as land with: citrus, other tree fruit, and grapes. We measure non-cropland as: wetland, forest, open space, lightly developed land, shrubland, and grassland or pasture.

Our regression equation is

$$\begin{aligned}\Delta Share_i(k) = {} & \beta_{0,k}\Delta NutShare_i + \beta_{1,k}\Delta NutShare_i \times LargeOwner_i \\ & + \beta_{2,k}\Delta NutShare_i \times LargeOwner_i \times NonSpecialist_i \\ & + \psi_{0,k}LargeOwner_i + \psi_{1,k}LargeOwner_i \times NonSpecialist_i + \zeta_{g(i)} + u_i, \\ & k \in \{Annual, NonNutPermanent, NonCropland\}\,.\end{aligned} \tag{5}$$

By construction, the sum of the change in the shares of land allocated to nuts, annual crops, non-nut permanent crops, and non-cropland equals zero: $\Delta NutShare_i = -\sum_k \Delta Share_i(k)$. Consequently, $\sum_k \beta_{0,k} = 0$, and one can interpret $\beta_{0,k}$ as the share of each unit of new nut cropland that came from prior land use k, for small investors. A similar interpretation holds for large specialists in terms of the sum $\beta_{0,k} + \beta_{1,k}$ and likewise in terms of the sum $\beta_{0,k} + \beta_{1,k} + \beta_{2,k}$ for large non-specialists.

The first row of the results in Table 3 shows that small investors accommodate around half (55%) of their nut expansion by planting nuts on non-cropland, and they reallocate around a quarter away from annual cropland (23%) and non-nut permanent cropland (22%) each. By contrast, large nut specialists within the same county reallocate 18 percentage points (pps) less away from non-cropland while reallocating 15 pps more away from non-nut permanent cropland, which follows from the estimated coefficients $\beta_{1,k}$. This finding is consistent with the second prediction from Section 2.2: large nut specialists already have substantial exposure to risky, long-duration nut cropland, and so they accommodate any further increases in nut exposure by reducing exposure to other risky, long-duration permanent crops; moreover, their size enables them to better take advantage of the real option value of non-cropland, and so they are less willing to convert it to nut cropland than their smaller competitors.

When comparing large non-specialists to small investors, we find that the former reallocate 22 pps (i.e., $18.7 + 3.4$) more away from annual cropland and 15 pps (i.e., $18.3 - 3.0$) less away from non-cropland. As in the previous paragraph, the second result is consistent with the interpretation that large investors value the optionality of non-cropland, and so they prefer to reallocate away from other crop categories. The first result, that large non-specialists accommodate 45% (i.e., $22.7 + 18.7 + 3.4$) of their nut expansion through a reduction in annual cropland, is consistent with the third prediction from Section 2.2. Planting nuts enables these investors to earn a risk premium over short-duration, less-risky annual cropland. However, unlike their specialist competitors, they enter the boom with less exposure to permanent cropland of all forms and more exposure to annual crops. So, converting annual cropland into nut cropland comes with a smaller increase in total volatility for large non-specialists than it would for specialists, who instead convert other non-nut permanent

cropland.

Appendix Table A1 replicates these findings with zip code fixed effects. Including such granular geographic fixed effects ensures that we compare investors facing similar growing conditions and, thus, likely face a similar distribution of returns for a given crop type.

Anecdotal Evidence

Appendix Tables A2 and A3 provide several examples consistent with our theory of portfolio rebalancing. The largest nut non-specialist, shown in the first row of Table A2, is J.G. BOSWELL COMPANY. This company specializes in growing cotton, an annual crop, and was founded in the 1920s by James Griffin Boswell, who moved to California from Georgia, one of the major cotton-producing states in the U.S. This particular case exemplifies how a large "investor" in an annual crop reallocated towards nuts, a permanent crop with high prices that investors plausibly expected to persist, a question to which we return in Section 6. By contrast, the largest overall owner of nut cropland, shown in the first row of Table A3 is THE WONDERFUL COMPANY, a firm owned by the Resnick family that specializes in almond and pistachio production and, according to the company's website in 2024, is the world's largest producer of these nuts. This "investor" increases its allocation to almonds by only 10 pps, from 86% to 96%, whereas J.G. BOSWELL COMPANY experiences an 88 pps increase in nut allocation.

5.3 Groundwater Well Drilling

Expanding nut cropland likely requires that investors also expand their irrigation infrastructure, given the substantial water requirements of tree nuts described in Section 3. This is especially likely to be the case in a period of drought, as in our sample. We now estimate whether nut investors, especially large ones, tap groundwater more intensively than other cropland investors to irrigate their new nut cropland. Figures 3 and 4 already suggest this is the case, but these aggregate figures do not rule out, for example, that nut investors may simply operate in regions of California with a deeper drought.

We estimate regressions of the form

$$\begin{aligned} WellFeet_i = {} & \beta_0 \mathbf{1}[NutGrowth_i] + \beta_1 \mathbf{1}[NutGrowth_i] \times LargeOwner_i \\ & + \beta_2 \mathbf{1}[NutGrowth_i] \times LargeOwner_i \times NonSpecialist_i \\ & + \psi_0 LargeOwner_i + \psi_1 LargeOwner_i \times NonSpecialist_i + \zeta_{g(i)} + u_i, \end{aligned} \tag{6}$$

where $WellFeet_i$ the number of wells drilled on i over 2013-2023 multiplied by their depth,

in feet; and, as in Table 2, $\mathbf{1}[NutGrowth_i]$ indicates whether i experiences growth in nut acreage over this period.

Table 4 reports the result. Focusing on column (2), the estimate of β_0 implies farms with nut growth owned by small investors experience 20.1 more feet of total drilling than other farms owned by small investors in the same county. Moving down the column, this effect rises by 13.5 feet (67%) when the owner is instead a large nut specialist, and it rises by 33 feet (164%) when the owner is a large non-specialist in nuts. These differences are of an even greater magnitude when comparing investors in the same zip code, as in column (3).

The fact that large nut investors are more likely to drill groundwater wells than small nut investors is consistent with the result from Table 2 that they also expand nut acreage by more, as the greater expansion in acreage requires greater development of irrigation infrastructure. Together, these results are consistent with the basic idea from Section 2 that nut expansion entails a significant fixed investment, in the form of new irrigation infrastructure such as groundwater well drilling, that is easier for larger investors to make. As also noted in Section 2, the fact that large non-specialists drill more than large specialists on parcels with nut growth may reflect how the latter may be able to irrigate the new cropland using existing infrastructure.[11]

6 Role of Expectations

The economic channel leading large nut non-specialists to expand more intensely than large specialists helps to understand both the current episode as well as how these results apply to other booms, whether in cropland or in other real asset classes. We now evaluate the possibility that large non-specialists form expectations about the persistence of the nut boom differently than do large specialists (Section 6.1). This exercise informs why non-specialists behave differently than other large investors, but it leaves open the question of why other investors still expand, despite the sharp reversion of nut prices after the boom. So, we also use present-value logic to assess whether the market, as a whole, may have overestimated the persistence of the boom (Section 6.2).

6.1 Beliefs of Nut Specialists versus Non-Specialists

Models of how producers form expectations often start with the idea that the response of competitors contains information, which a producer may or may not account for. We are

[11] Or, as noted in footnote 4, they may better be able to expand irrigation by buying rights to the major California aqueducts because, for example, they have already paid the requisite political or regulatory costs.

particularly interested in how the differential nut expansion of large non-specialists changes in more competitive environments. We measure competition by the nut expansion activity of other investors in the same county. Since each type of nut comes in different variants that are best-produced in particular counties (e.g., the Carmel almond variant vs. the Butte almond variant), this variable captures nut expansion by the most direct competition faced by a farm. Moreover, it seems plausible that investors form forecasts about changes in aggregate nut supply based on the expansion activity of other growers in the same county.

We estimate

$$\begin{aligned} Y_i = {} & \beta_0 LargeOwner_i + \beta_1 LargeOwner_i \times NonSpecialist_i \\ & + \beta_2 LargeOwner_i \times CompetitorNutGrowth_{c(i)} \\ & + \beta_3 LargeOwner_i \times NonSpecialist_i \times CompetitorNutGrowth_{c(i)} \\ & + \psi_0 CompetitorNutGrowth_{c(i)} + \zeta_{g(i)} + u_i, \end{aligned} \tag{7}$$

where $CompetitorNutGrowth_{c(i)}$ equals the share of land parcels in county c with a different owner in 2013 than the owner of parcel i that experience positive change in the share of land allocated to nuts over 2013-2023, which is then standardized to have mean of zero and unit variance. The coefficient of greatest interest is β_3, which captures how the differential response of large non-specialists varies according to the growth of competitors, as measured by $CompetitorNutGrowth_{c(i)}$. For ease of language, we shall refer to $CompetitorNutGrowth_{c(i)}$ as "competitor expansion".

Table 5 reports the results. The outcome in column (1) is the symmetric growth in nut cropland over 2013-2023, which captures both extensive and intensive margins of nut growth. As described in 5.1, the symmetric growth rate is the second-order Taylor approximation of the change in log nut cropland, and it has the advantage of allowing for entry and exit (i.e., $NutAcres_{i,t} = 0$).

The negative estimate of β_2 in column (1) of Table 5 implies that large nut specialists and small investors attenuate their own nut expansion when their competitors expand by more. Specifically, raising competitor growth by one standard deviation lowers the nut growth of a small investor by 10.3 pps and of a large specialist by a statistically indistinguishable 8.6 pps. By contrast, the positive estimate of β_3 implies that the same increase in competitor expansion actually raises the nut growth of a large non-specialist by a small 0.4 pps. Appendix Table A5 finds similar results in terms of other outcomes from Table 2.

These results do not mechanically reflect how a large non-specialist's nut growth may disproportionately contribute to the county's overall nut growth; $CompetitorNutGrowth_{c(i)}$ varies owner-by-owner and thus excludes the owner of the given parcel, i, when it is calcu-

lated. We also clarify that we control for zip code fixed effects, so that the comparison is between parcels that face very similar growing conditions. So, even if $CompetitorNutGrowth_{c(i)}$ correlates with the overall suitability of growing nuts in the county over this time period, it is unlikely that this suitability would directly generate differences in nut growth between large specialists and non-specialists except insofar as it contains information that is processed differently by these two types of investors.

The results in column (1) are consistent with models of competition neglect and herding. According to the former class of models, investors understand that the equilibrium price is decreasing in aggregate nut supply, but they partially neglect the extent to which their competitors will expand and, thus, put downward pressure on prices (e.g., Ezekiel 1938; Kaldor 1934). Under this interpretation, the positive estimate of β_3 would imply that large non-specialists attenuate their nut expansion by less than other investors when their competitors expand by more. However, the estimate is also consistent with a model of herding, in which large non-specialists are more likely than other investors to learn from their competitors (e.g., Povel et al. 2016). Seeing other investors expand their nut cropland, large non-specialists understand that some of these investors are acting on superior information that the nut boom will persist, and so they, too, expand their own nut cropland.

Columns (2)-(3) of Table 5 attempt to make progress on the role of competition neglect versus herding by separately estimating equation (7) in terms of almond and non-almond nut cropland. Specifically, the variable $CompetitorNutGrowth_{c(i)}$ is replaced by two variables, $CompetitorAlmondGrowth_{c(i)}$ and $CompetitorNonAlmondNutGrowth_{c(i)}$, which are defined similarly in terms of competitor expansion in almond cropland and in pistachio, walnut, or pecan cropland, respectively. The outcome in column (2) is i's growth in almond cropland. Focusing on the coefficients associated with variables multiplied by $CompetitorAlmondGrowth_{c(i)}$: the results imply that, all else equal, a one-standard deviation increase in competitor expansion into almond cropland reduces large specialists' almond growth by 5.2 pps relative to small investors in the same zip code, while it raises large non-specialists almond growth by 3.9 pps ($9.1 - 5.2$). This finding is consistent with a model of competition neglect, in which large specialist investors attenuate their almond expansion in response to competitor expansion the most, whereas large non-specialist investors attenuate their almond expansion the least.[12] A similar result obtains in column (4), where the

[12]For example, suppose equilibrium cash flow from nut cropland depends on aggregate nut supply, Y_n^S, according to the inverse demand curve $D_n = \delta(Y_n^S)$ with $\delta'(\cdot) < 0$. An investor who partially neglects competition forecasts future cash flow from nut cropland as $\mathbb{E}^C[D_n] = \delta(y_{i,n} + \theta(Y_n^S - y_{i,n}))$, where $y_{i,n}$ is the nut output of i's farm, $\theta < 1$ governs the degree of competition neglect, and $\mathbb{E}^C$ emphasizes that the expectation is taken when not fully accounting for the response of competitors. In the extreme case were $\theta = 0$, this investor neglects all competition and severely overestimates the expected future cash flow from nut cropland.

outcome is i's growth in non-almond cropland: when competitors expand their non-almond cropland by more, large specialists attenuate their own non-almond nut expansion the most, followed by small investors, and, lastly, large non-specialists exhibit the least attenuation. Also consistent with greater competition neglect by large non-specialists, Appendix Table A4 documents that the differential expansion into nut cropland by large non-specialists relative to large specialists is weaker for non-specialists with farms in multiple counties. It seems plausible that such non-specialists have greater information about the supply response of the aggregate nut market than non-specialists that operate in a single county, and so, knowing that this aggregate supply response will lower equilibrium nut prices, they attenuate their own expansion.

A model in which non-specialists exhibit herding behavior would generate similar results, but it would also predict that greater competitor expansion into non-almond cropland would predict *less* expansion into almond cropland, and vice versa. Intuitively, if non-specialists interpret competitor expansion into non-almond cropland as indicative of well-informed investors acting on their beliefs that elevated non-almond prices will persist, then non-specialists would mimic the "herd" and also expand into non-almond cropland. [13] However, returning to column (3) and focusing on the coefficients associated with variables multiplied by $CompetitorNonAlmondGrowth_{c(i)}$, the estimates actually imply that large non-specialists exhibit no significant difference relative to large specialists in how their almond expansion responds to competitor expansion into non-almonds. Similarly, the results in column (4) imply that large non-specialists exhibit no difference relative to large specialists in how their non-almond cropland expansion responds to competitor expansion into almonds.[14] Further inconsistent with herding as the dominant driver of large non-specialists'

[13]Capturing the logic in a stylized way: suppose a share ι of investors are "informed" and know with certainty that the cash flow from nut type 1 (e.g., almonds) will exceed the cash flow from nut type 2 (e.g., pistachios): $D_{n_1} > D_{n_2}$. Supposing the two nut varieties are otherwise equal (e.g., irrigation, covariance with other crops returns), then informed investors will plant only type-1 nuts. If the remaining $1 - \iota$ of investors are "noise growers" who produce type-1 and type-2 nuts with equal probability, then aggregate supply of the two nut types are $Y^S_{n,1} = \frac{1}{2}\iota + \frac{1}{2}$ and $Y^S_{n,2} = \frac{1}{2} - \frac{1}{2}\iota$, assuming all investors are endowed with one unit of land that yields one unit of nuts. Noting that $Y^S_{n,1} > Y^S_{n,2}$, an atomistic investor who wishes to "herd" on informed investors will also invest only in type-1 nuts.

[14]Interestingly, the results in column (3) also imply that large specialists exhibit a 10 pps higher growth rate in almond cropland than small investors when competitor expansion in non-almond cropland rises by one standard deviation, and, symmetrically, their growth in non-almond cropland is 9 pps higher when competitor expansion in almond cropland rises by one standard deviation. This finding is also broadly consistent with large specialists exhibiting greater responsiveness to competitor expansion, in that they switch to a close substitute of a given nut type when their competitors expand heavily into that type. For example, Bakhtavoryan et al. (2022) estimate positive cross-price demand elasticities among walnuts, almonds, and pistachios, suggesting they are consumption substitutes. Note that large non-specialists are also more likely than small investors to demonstrate this crop substitution effect, per, for example, the insignificant coefficient on $LargeOwner_i \times NonSpecialist_i \times CompetitorNonAlmondNutGrowth_{c(i)}$ in column (4). This result may reflect positive correlation in almond and non-almond cropland expansion by large non-specialists:

behavior is the result, documented shortly in Section 6.2, that total returns to both almond cropland and pistachio cropland, the largest non-almond category, both fall to zero or become slightly negative shortly after the mid-2010s drought ends and the nut boom subsides (Appendix Figure A.3).

Overall, these results suggest that large non-specialists process information about their competitors differently than do large specialists. In particular, they act in a way consistent with competition neglect, that is, by attenuating their own expansion by less in response to their competitors' expansion than large specialists. Loosely, this would suggest that large specialists contain superior information, plausibly due to experience in prior booms. If so, then they would presumably be more likely to take a contrarian position and reduce ("short") their own nut cropland. Indeed, column (1) of Table 6 finds that, based on a similar specification as the baseline equation (4), large nut specialists are more likely to reduce their nut cropland than small investors, while large non-specialists are less likely than small investors to reduce nut cropland. A drawback to this specification is that non-specialists, by definition, already have little if any nut exposure, and so this results may simply reflect that non-specialists have no nut cropland to reduce. However, column (2) of Table 6 shows how, even when restricting the sample to investors with positive but small nut exposure in 2013 ($0 < NutShare_{i,13} \leq 0.25$), large non-specialists are 6.5 pps less likely than small investors to reduce nut cropland, while large specialists are 1.9 pps more likely. This finding further supports the general interpretation that the remarkable nut expansion by large non-specialists relative to other investor types reflects more-optimistic expectations about the duration of the mid-2010s nut boom.

6.2 Aggregate Beliefs

We conclude with an assessment of whether the aggregate nut market may have overestimated the persistence of the nut boom. This assessment builds on the previous results in Section 6.1, which focuses on difference in measures of expectation formation across types of investors.

The logic of our exercise in this section is to ask whether professional valuations of nut cropland forecast changes in nut prices. Our analysis relies on the NCREIF dataset, which, as described in Section 3, describes the returns for the cropland portfolio of fiduciaries that invest on the behalf of large tax-advantaged institutions. Importantly, even if the NCREIF portfolio does not perfectly replicate the unobserved portfolio of all nut investors, in aggregate, the valuations of NCREIF properties are performed by professional rural land appraisers associated with the California Chapter of the American Society of Farm Managers and Rural

competitor expansion into nuts of a given type predict positive expansion into nuts of a substitute type.

Appraisers (ASFMRA). Farms in the NCREIF portfolio are appraised every quarter, and it seems plausible that the appraised value of an acre of nut cropland owned by NCREIF would be similar to the appraised value of an acre of nut cropland for other investors.

Figure 5 begins by plotting the long time series of real almond nut prices and the real price-per-acre of almond cropland, based on quarterly appraisals of farms in the NCREIF dataset.[15] We plot the time series begining in 1991, the earliest date in the NCREIF dataset.

There are two notable features about the results. First, there is a recurring pattern of sharp booms in real almond prices followed by reversion within a few years. This wave-like pattern in commodity prices is also present to a lesser extent among short-duration, annual cropland, and it was the motivation for early "cobweb" models of supply neglect (e.g., Ezekiel 1938; Kaldor 1934). The more extreme price variation shown in Figure 5 may reflect how permanent crops, like almonds, require a time-to-build that inhibits the ability of a short-term supply response to reduce the initial spike in commodity prices.

Second, the price of almond cropland rises sharply with a short lag of around one year after the start of the boom, but it remains elevated even as almond prices begin to revert to their pre-boom levels. Since cropland prices presumably forward-looking, then expectations of only a temporary boom would not give rise to such significant increases in land prices as shown in the figure. Instead, the sustained increase in land prices suggests that the market expects almond prices to persist well into the future. We also note that the land prices shown in the figure are based on professional appraisals; it seems plausible that, if anything, professional appraisers would be less likely than the average almond investor to overestimate the persistence of the boom.

Appendix Figure A.2 extends Figure 5 in two ways. First, we show that growth in the quantity of almonds produced does not coincide with price spikes but rather, as in Figure 1, comes within a few years. This delayed supply response is consistent with the basic fact from Section 2 that permanent crops require time from planting until they can bear fruit. Second, Figure A.2 shows a slight trend growth in nominal almond prices, reflecting inflation.

Introducing slightly more structure, the logic of present-value relations would imply that higher capitalization rates on almond cropland (i.e., ratio of net operating income to appraised value) should forecast either lower income growth or higher total returns to cropland.[16] Since almonds are a long-duration crop, forecasting long-horizon cash flow from

[15] While the appraisals are conducted quarterly, we aggregate to the annual level by taking the average within each year to match the frequency of our data on almond prices. There is a very strong seasonal component in cropland returns, since, as described in Section 2, most cash flow comes in the harvest in the late summer or early fall. As in Section 4, we focus on almonds because the California Almond Board makes aggregate data on the almond market readily available, but, when possible, we check that the same results obtain for pistachios, the other main nut crop in the NCREIF portfolio.

[16] See Campbell and Shiller (1989). At a high level, a high capitalization rate ("dividend-price ratio")

almond cropland is important when making initial decisions about cropland expansion or groundwater well drilling. The USDA's National Agricultural Statistics Service produces a short-term forecast each May for California almond production in the coming harvest season, but such a forecast is likely less useful for a longer-horizon investors deciding whether to plant new trees that would not produce cash flow for at least three years. Instead, we ask whether valuation ratios (i.e., capitalization rates) of almond cropland can provide such a longer-term forecast.

Panel (a) of Figure 6 presents a scatterplot of the relation between capitalization rates and three-year-ahead growth in net operating income on almond or pistachio cropland. As with the other analysis in this subsection, the data cover cropland within the NCREIF portfolio and so represent land owned by fiduciaries that manage money for large tax-advantaged institutions. We pool data for the almond and pistachio sub-portfolios, such that each point in Figure 6 represents a year-by-nut-type pair (e.g., almonds in 2005, pistachios in 2010). The relatively flat and statistically insignificant slope of the best fit line implies that current capitalization rates do not forecast nut price growth. However, consistent with present value logic, panel (b) shows how high capitalization rates forecast a higher three-year-ahead total return.

Putting these results together: land prices seem to rise during nut booms in a way that suggests elevated nut prices will last longer than they actually do (Figure 5), and this apparent mis-pricing of nut cropland may reflect the more general challenge of forecasting the prices of nuts themselves (e.g., Figure 6). Notably, these results describe average beliefs. Moreover, based on the results from the previous subsection, the large nut non-specialists driving the boom appear to invest even more optimistically than the average investor.

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means that cash flow from almond cropland is value at a relatively low multiple. This low multiple may reflect how future cash flow is likely to be low, so that market participants are unwilling to pay for the underlying cropland today. Or, a low multiple could imply that cash flow is simply under-priced today, in which case total returns will rise as prices increase in the future. Plazzi, Torous and Valkanov (2010) apply these ideas to commercial real estate and show

$$\log(CapRate_t) = \Xi + \mathbb{E}_t\left[\sum_{k=0}^{\infty} \xi^k TotalReturn_{t+1+k}\right] - \mathbb{E}_t\left[\sum_{k=0}^{\infty} \xi^k \Delta \log(Income)_{t+1+k}\right], \tag{8}$$

where $TotalReturn_{t+1+k}$ is the total return from time $t+k$ to time $t+1+k$ and, similarly, $\Delta \log(Income)_{t+1+k}$ is the change in log net operating income; and Ξ and ξ are constants. We use equation (8) as a guide, but we do not seek to actually estimate it.

7 Conclusion

This paper connects investment booms with groundwater utilization, highlighting the environmental impact of agricultural expansion. Groundwater is a vital resource, with approximately 83% of Californians relying on it for part of their water supply. Many communities are entirely reliant on groundwater for their water needs.[17]

We build a novel and rich database that allows us to study agricultural land use, groundwater drilling and ownership of land for California between 2013 and 2023. Our analysis uncovers several striking facts. Notably, we show that the increase in almond prices in the early 2010s was followed by large increases in the share of land allocated to almonds. Most of the growth is accounted for by large investors who were not producing almonds at the start of our sample. These investors rely heavily on groundwater to irrigate their newly planted nut crops, exacerbating groundwater depletion.

To advance the policy discussions raised by our findings, further research is needed to explore the welfare and productivity implications of the dynamics we uncover. We leave this open for future research.

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[17] https://water.ca.gov/water-basics/groundwater

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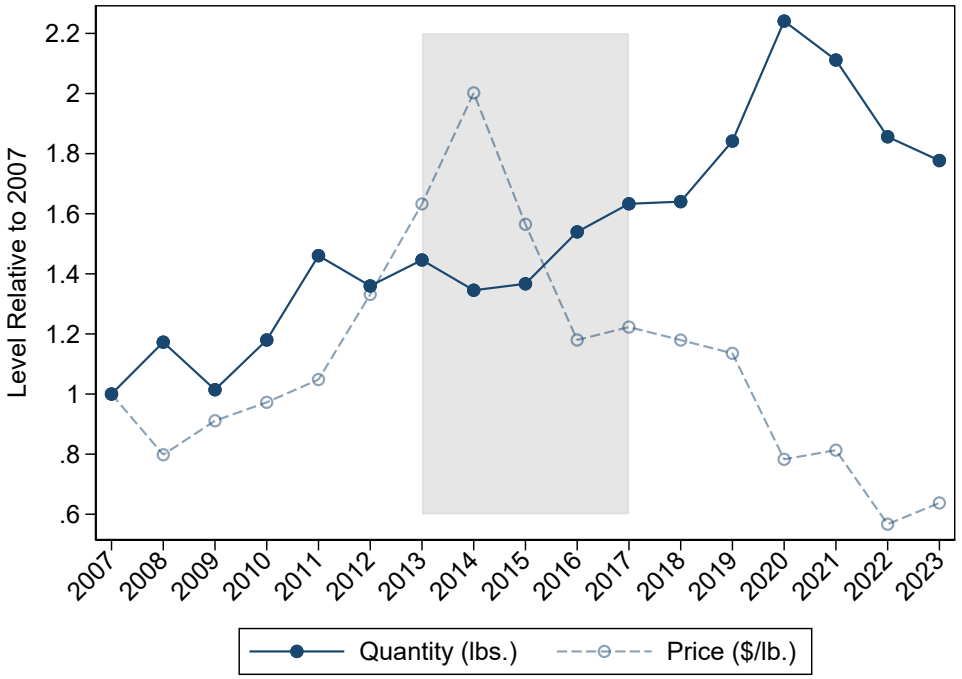
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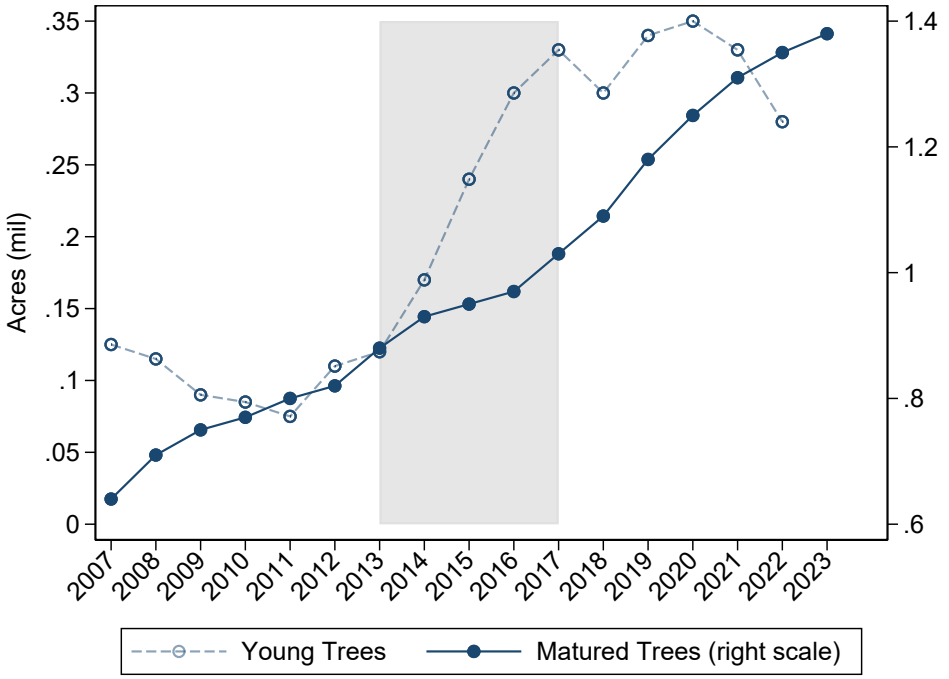
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Figure 1: Almond Real Prices, Quantities, and Acreage during Drought.

(a) Almond Quantities and Prices



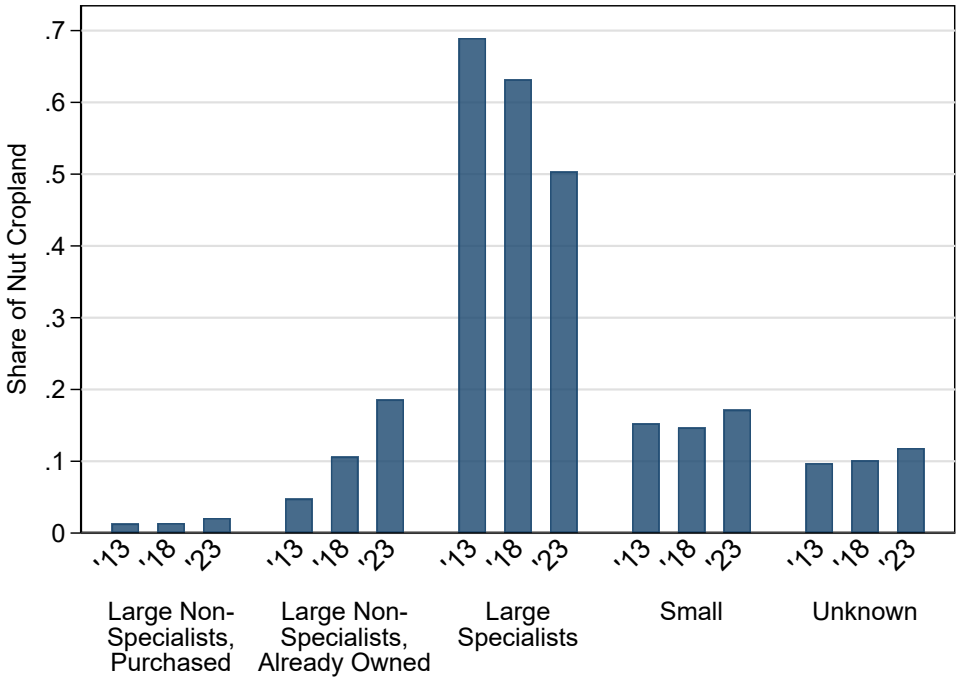
(b) Young and Matured Almond Trees



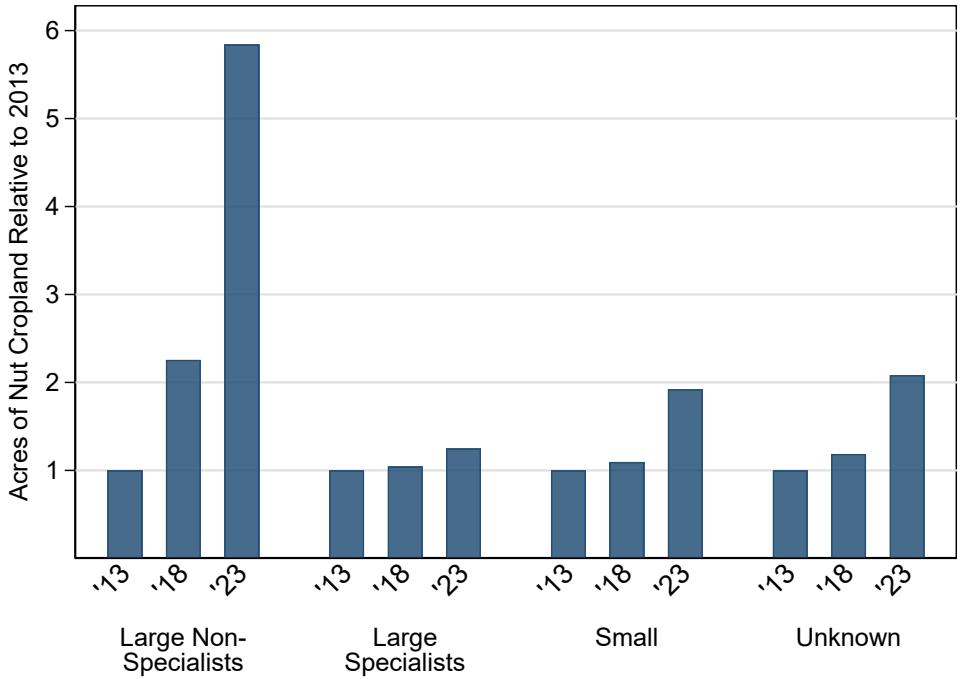
Note: This figure plots the time series of various aggregate metrics of the California almond industry. Gray bars correspond to the 2010s drought in California, corresponding to a Drought Severity Index greater than half of its maximum value (500). Panel (a) plots quantities of almonds, in pounds, and average price, in real dollars per pound, for almonds produced in California. Real prices are computed using the full CPI basket and are in 2010 dollars. Both series are normalized to equal one in 2007. Panel (b) plots total almond acreage in California for matured treeds ("bearing acres") and young trees that cannot yet year ("non-bearing acres"). Data on droughts are from the National Drought Mitigation Center at the University of Nebraska-Lincoln. Data on almond prices, quantities, and acreage are from the Almond Board of California.

Figure 2: Nut Cropland Market Share and Growth in Nut Cropland by Investor Type.

(a) Market Share

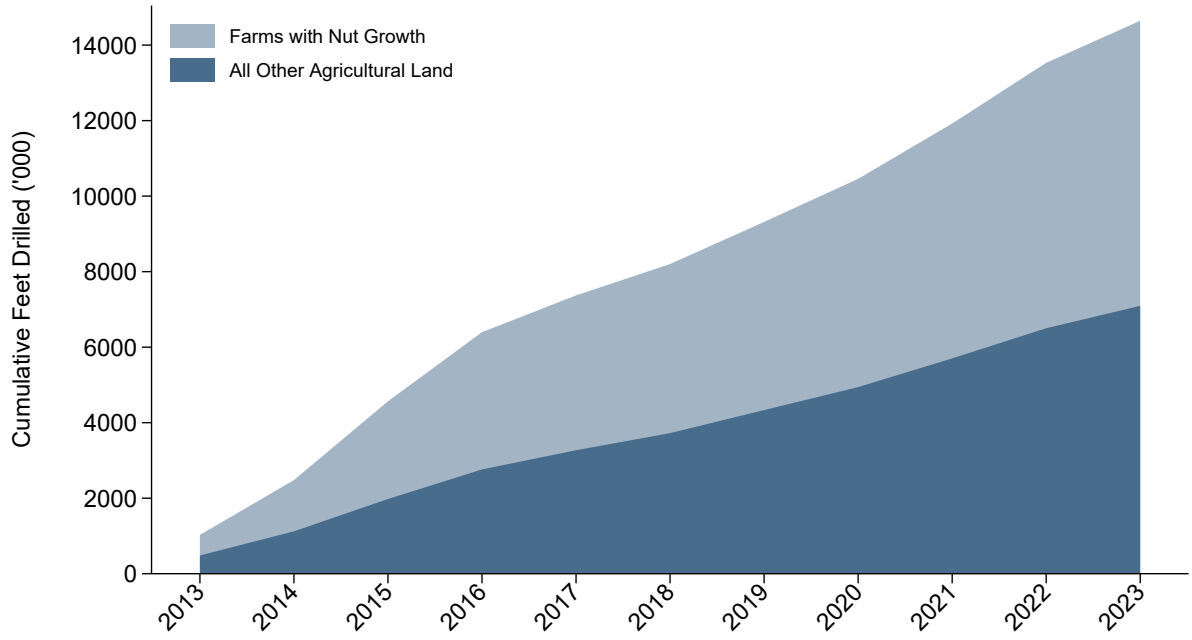


(b) Growth in Cropland



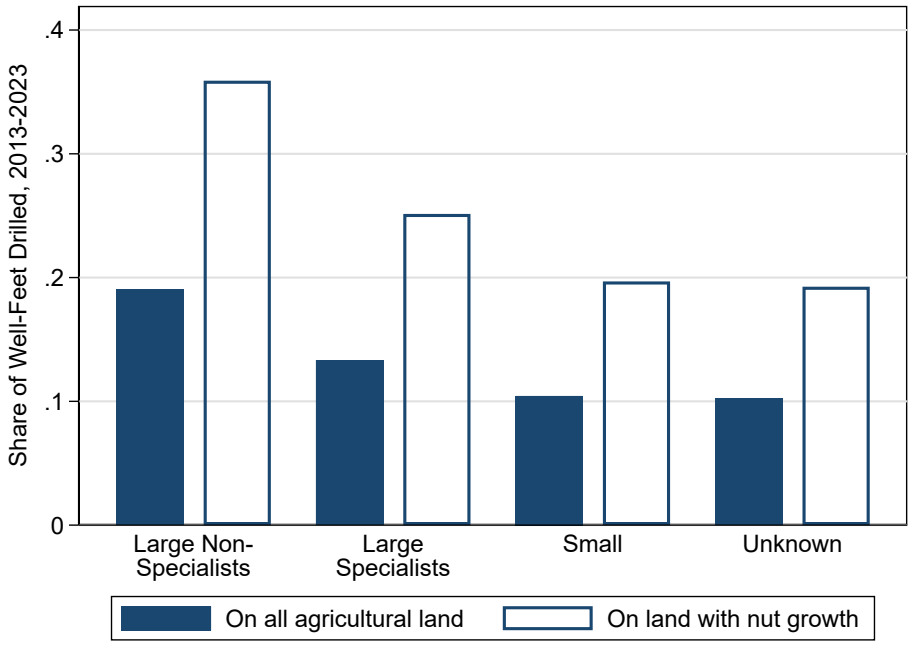
Note: Panel (a) plots the share of total nut cropland owned by different types of investors in 2013, 2018, and 2023 on parcels in the Cropland Data Layer database. Panel (b) does similarly in terms of the growth in acres of nut cropland by each investor type relative to 2013. Investor type refers to the ownership of the land parcel, and there are five groups. Groups with "Large" in their name are those associated with an owner that was in the top 25% of the size distribution across agricultural land in 2013. Precisely, these parcels have a value of $LargeOwner_i = 1$, where $LargeOwner_i$ is defined in the note to Table 1. Groups with "Non-Specialist" in their name are those for which the owner had less than 10% of their land allocated to nuts in 2013. These parcels have a value of $NonSpecialist_i = 1$, where $NonSpecialist_i$ is also defined in the note to Table 1. Within the "Non-Specialist" groups, panel (a) of the figure further shows the market share for parcels that did not transact (Already Owned) and that were purchased by a large non-nut specialist owner over 2013-2023 (Purchased). The "Small" category consists of parcels for which $LargeOwner_i = 0$. The "Unknown" category consists of parcels for which the owner's name is either missing from the count tax assessments in 2013 or the parcel is not in the assessment data. Data on parcel-level crop allocation are from the Cropland Data Layer database. Data on ownership are from the CoreLogic Assessment database.

Figure 3: Decomposing Well Drilling on Agricultural Land by Nut Growth.



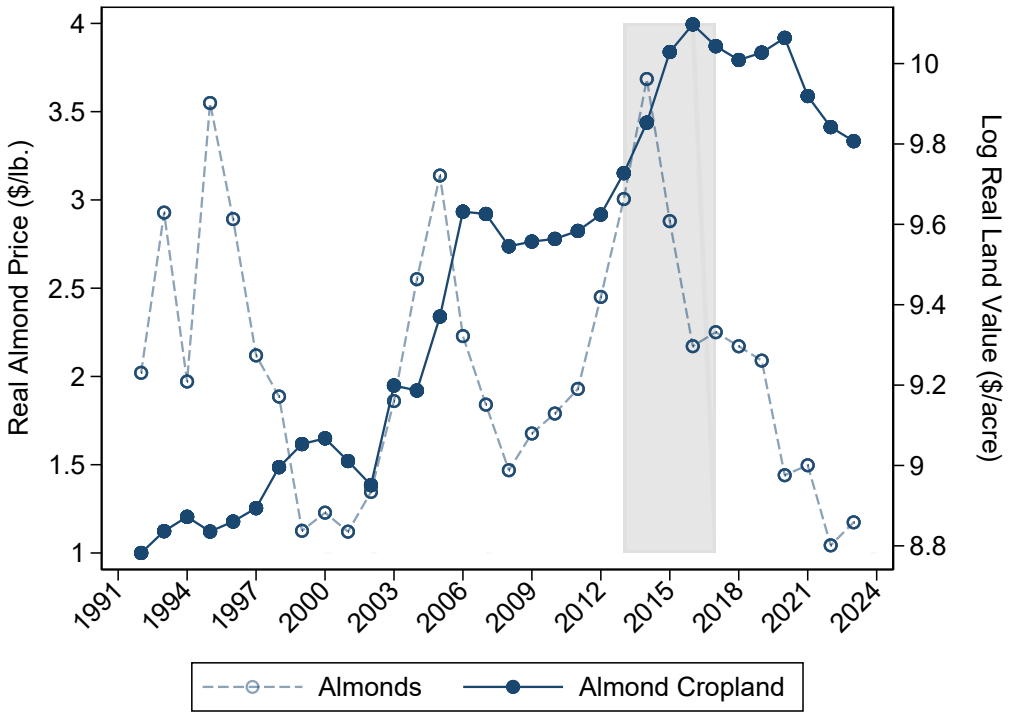
Note: This figure plots the cumulative number of feet of groundwater wells drilled from 2013 through 2023 on parcels in the Cropland Data Layer database. The figure decomposes this number into: the part from parcels with positive growth in the share of land allocated to nuts grew over 2013-2023 (Farms with Nut Growth); and the part from the remaining parcels in the Cropland Data Layer database (All Other Agricultural Land). Total land acreage is approximately fixed over time within each parcel, and so positive growth in nut share reflects growth in the quantity of nut trees. Data on crop allocation are from the Cropland Data Layer database. Data on groundwater wells are from the California National Resources Agency Well Completion Reports.

Figure 4: Decomposing Well Drilling by Investor Type.



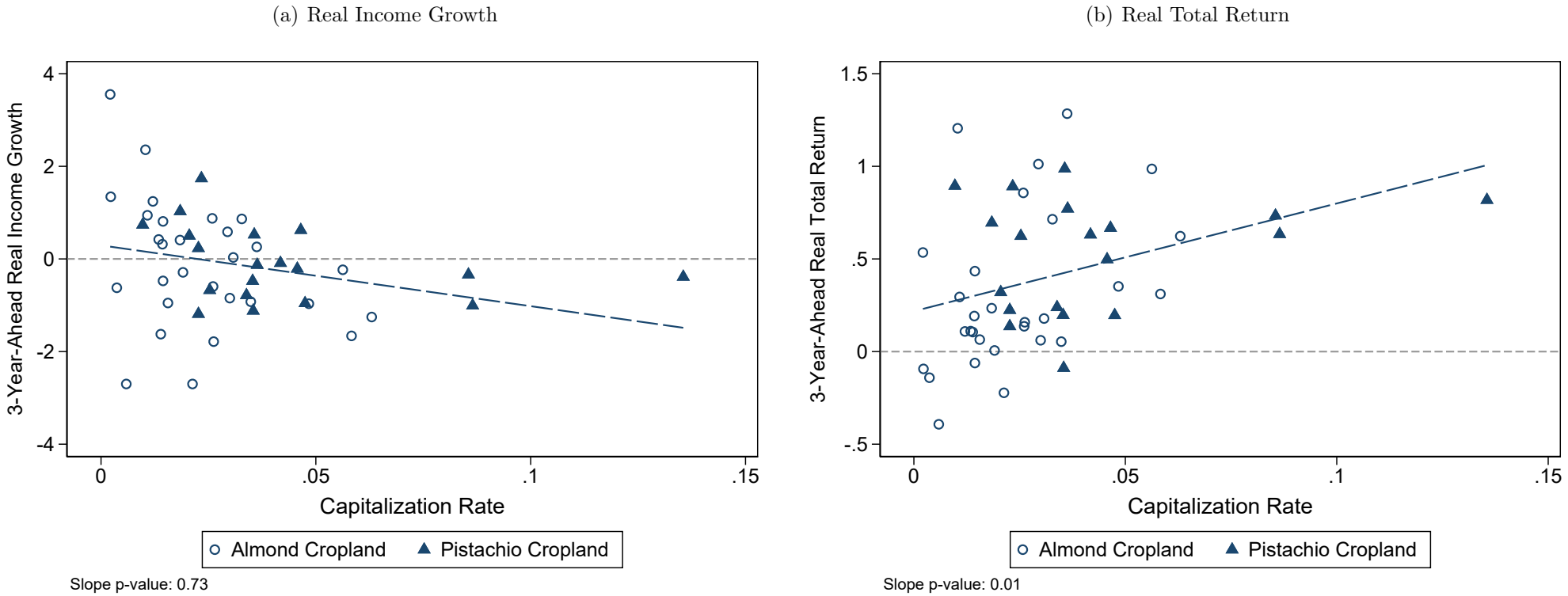
Note: This figure plots the share of the cumulative number of feet of groundwater wells drilled from 2013 through 2023 on parcels in the Cropland Data Layer database by different types of investors. This share is computed relative to groundwater well-feet drilled on all parcels in the data (on all agricultural land) and relative to the subset of parcels with positive growth in the share of land allocated to nuts over 2013-2023 (on land with nut growth). The investor types are the same as in Table 2 after consolidating the "Non-Specialist, Purchased" and "Non-Specialist, Already Owned" types into a single "Non-Specialist" category. Data on ownership are from the CoreLogic Assessment database. The remaining notes are the same as in Table 3.

Figure 5: Real Price of Almonds and Value of Almond Cropland.



Note: This figure plots the time series of real almond prices and the real appraised value of almond cropland, which approximates the market price of almond cropland. This exercise assesses whether land values change during booms in a way that suggests the boom will persist. Both nut prices and land values are in real terms (2010 dollars), based on total CPI. Data on cropland appraisals are from the NCREIF dataset and so represent land owned by fiduciaries that manage money for large tax-advantaged institutions. The remaining notes are the same as in Figure 1.

Figure 6: Nut Cropland Real Income Growth and Real Total Return by Cap Rate.



Note: This figure plots the relationship between the capitalization ("cap") rate on nut cropland in the NCREIF aggregate portfolio and future growth in real income (panel (a)) or future real total return (panel (b)). Each observation is a year. This exercises assesses the ability of cap rates to forecast income growth or total return according to present-value accounting (e.g., Campbell and Shiller 1989). Income Growth is defined as the change in log net operating income (NOI) from year t to year $t+3$. Since NOI can be negative, but never equals zero in our data, we use the symmetric log transform, $\text{sign}(NOI_t) \cdot \log(|NOI_t|)$ studied in, for example, Christoffersen and Diebold (2006). To fit all points on the figure, we bound income growth below by the second-lowest value in the data (-2.7). Total Return is defined as the cumulative return from year t to year $t+3$, inclusive of both income return and price appreciation based on quarterly land appraisals. Both Total Return and Income are observed at the quarterly frequency and are aggregated to the annual frequency by taking the average. Data are from the NCREIF dataset and so represent land owned by fiduciaries that manage money for large tax-advantaged institutions. The remaining notes are the same as in Figure 5.

Table 1: Summary of Cropland Allocation by Investor Size and Nut Specialization.

	Almonds		All Nuts		Annual		Non-Nut Perm		Non-Cropland	
	2013	2023	2013	2023	2013	2023	2013	2023	2013	2023
$LargeOwner_i = 1$, $NonSpecialist_i = 1$	0.02	0.06	0.02	0.1	0.23	0.22	0.13	0.13	0.62	0.55
Farms: 92273, Acres per Farm: 108										
$LargeOwner_i = 1$, $NonSpecialist_i = 0$	0.29	0.32	0.45	0.54	0.11	0.08	0.18	0.17	0.26	0.21
Farms: 41888, Acres per Farm: 62										
$LargeOwner_i = 0$	0.1	0.13	0.15	0.21	0.11	0.12	0.13	0.11	0.61	0.56
Farms: 97366 , Acres per Farm: 24										

Note: This table summarizes the average of the share of agricultural land allocated to the indicated use across land parcels in 2013 and 2023. The table reports these averages by the owner's size and specialization in nuts and includes parcels with zero nut cropland. Subscript i indexes land parcel. The area of a land parcel is fixed over time and includes cropland and non-cropland. The variable $LargeOwner_i$ indicates if either: the owner of parcel i in 2013 is in the top 25% of owners sorted by total acreage owned in 2013 and i was not sold over 2013-2023; or, the owner of parcel i in 2023 was in the top 25% of owners sorted by total acreage owned in 2013 and purchased parcel i over 2013-2023. The variable $NonSpecialist_i$ indicates if either: the owner of parcel i in 2013 has less than 10% of total acreage owned allocated to nuts in 2013 and i was not sold over 2013-2023; or, the owner of parcel i in 2023 had less than 10% of total acreage owned allocated to nuts in 2013, and purchased parcel i over 2013-2023. The classifications of agricultural land categories are as follows. All nuts include: almonds, pistachios, walnuts, and pecans. Annual Crops include: soybeans, rice, corn, cotton, wheat, vegetables, non-tree fruit, and hay. Non-Nut Perm (i.e., Permanent) Crops include: citrus, other tree fruit, and grapes. Non-Cropland includes: wetland, forest, open space, lightly developed land, shrubland, and grassland or pasture. The sum of $\Delta Share_i$ on parcel i across Annual Crops, Non-Nut Permanent Crops, and Non-Cropland equals the change in the share of cropland allocated to All Nuts. The sample is restricted to parcels with less than 50% of their acreage allocated to forest, to wetland, or to barren land and to parcels with a known owner in 2013. Data on ownership are from the CoreLogic Assessment database. Data on crop allocation are from the USDA's Cropland Data Layer satellite imagery.

Table 2: Nut Growth by Large and Non-Specialist Investors.

	$\mathbf{1}[NutGrowth_i]$			$\Delta NutShare_i$		$\Delta \log(NutAcres_i)$		$SymGrowth(NutAcres_i)$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$LargeOwner_i$	0.130***	0.217***	0.102***	0.030***	0.017***	-0.147***	-0.107***	-0.484***	-0.351***
	(0.003)	(0.008)	(0.004)	(0.004)	(0.003)	(0.019)	(0.014)	(0.015)	(0.011)
$LargeOwner_i \times NonSpecialist_i$		-0.108***	0.017***	-0.008**	0.008**	1.066***	0.930***	0.852***	0.645***
		(0.008)	(0.005)	(0.004)	(0.003)	(0.026)	(0.021)	(0.020)	(0.014)
County FE	Y	Y		Y		Y		Y	
Zip Code FE			Y		Y		Y		Y
R-squared	0.216	0.220	0.321	0.043	0.102	0.107	0.170	0.166	0.264
Number of Observations	522267	522267	329880	522267	329880	99052	69796	171213	119140

Note: This table estimates equation (4), which assesses the relationship between nut growth on agricultural land and the landowner's size and specialization in nut growing. Subscript i indexes land parcel. The area of a land parcel is fixed over time and includes cropland and non-cropland. The outcome $\mathbf{1}[NutGrowth_i]$ indicates positive growth in the share of land allocated to almonds or to the sum of almonds, pistachios, walnuts, and pecans, respectively, over 2013 through 2023. The other outcomes are: $\Delta NutShare_i$, which is the change in the share of land on parcel i allocated to nuts over 2013 through 2023; $\Delta \log(NutAcres_i)$, which is the analogous change in the log of land, in acres, allocated to nuts; $SymGrowth(NutAcres_i)$ which is the symmetric growth rate in land allocated to nuts, where the is the second order Taylor approximation of $\Delta \log(NutAcres_i)$ around zero. Explicitly, $SymGrowth(x_{i,t_0 \to t_1}) = 2\frac{[x_{i,t_1} - x_{i,t_0}]}{x_{i,t_0} + x_{i,t_1}}$. The variable $LargeOwner_i$ indicates if either: the owner of parcel i in 2013 is in the top 25% of owners sorted by total acreage owned in 2013 and i was not sold over 2013-2023; or, the owner of parcel i in 2023 was in the top 25% of owners sorted by total acreage owned in 2013 and purchased parcel i over 2013-2023. The variable $NonSpecialist_i$ indicates if either: the owner of parcel i in 2013 has less than 10% of total acreage owned allocated to nuts in 2013 and i was not sold over 2013-2023; or, the owner of parcel i in 2023 had less than 10% of total acreage owned allocated to nuts in 2013, and purchased parcel i over 2013-2023. The sample is restricted to parcels with less than 50% of their acreage allocated to forest, to wetland, or to barren land and to parcels with a known owner in 2013. Data on ownership are from the CoreLogic Assessment database. Data on crop allocation are from the USDA's Cropland Data Layer satellite imagery. Standard errors clustered by the owner of parcel i in 2013 are in parentheses.

Table 3: Reallocation of Agricultural Land by Large and Non-Specialist Investors.

	$\Delta Share_i$					
	Annual Crops		Non-Nut Perm Crops		Non-Cropland	
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta NutShare_i$	-0.226***	-0.227***	-0.223***	-0.221***	-0.551***	-0.552***
	(0.006)	(0.006)	(0.004)	(0.004)	(0.006)	(0.006)
$LargeOwner_i \times \Delta NutShare_i$	-0.125***	-0.034***	-0.043***	-0.149***	0.168***	0.183***
	(0.009)	(0.010)	(0.008)	(0.011)	(0.009)	(0.011)
$LargeOwner_i \times NonSpecialist_i \times \Delta NutShare_i$		-0.187***		0.217***		-0.030**
		(0.013)		(0.012)		(0.014)
$LargeOwner_i$	-0.005***	-0.011***	0.017***	0.026***	-0.012***	-0.015***
	(0.001)	(0.002)	(0.001)	(0.003)	(0.001)	(0.004)
$LargeOwner_i \times NonSpecialist_i$		0.010***		-0.014***		0.004
		(0.002)		(0.003)		(0.004)
County FE	Y	Y	Y	Y	Y	Y
R-squared	0.129	0.135	0.131	0.143	0.188	0.188
Number of Observations	522267	522267	522267	522267	522267	522267

Note: This table estimates equation (5), which assesses the relationship between crop allocation on agricultural land and the landowner's size and specialization in nut growing. Subscript i indexes land parcel. The area of a land parcel is fixed over time and includes cropland and non-cropland. The outcome $\Delta Share_i$ is the change in the share of land on parcel i allocated to the indicated use of agricultural land from 2013 through 2023. Annual Crops includes: soybeans, rice, corn, cotton, wheat, vegetables, non-tree fruit, and hay. Non-Nut Perm (i.e., Permanent) crops include: citrus, other tree fruit, and grapes. Non-Cropland includes: wetland, forest, open space, lightly developed land, shrubland, and grassland or pasture. The sum of $\Delta Share_i$ on parcel i across Annual Crops, Non-Nut Permanent Crops, and Non-Cropland equals the change in the share of cropland allocated to nuts, $\Delta NutShare_i$. The remaining notes are the same as in Table 2.

Table 4: Groundwater Well Drilling by Large and Non-Specialist Investors.

	$WellFeet_i$	$WellFeet_i$	$WellFeet_i$
	(1)	(2)	(3)
$\mathbf{1}[NutGrowth_i]$	18.467***	20.065***	11.956***
	(0.938)	(0.947)	(0.911)
$LargeOwner_i \times \mathbf{1}[NutGrowth_i]$	21.314***	13.569***	13.945***
	(1.562)	(1.743)	(1.855)
$LargeOwner_i \times NonSpecialist_i \times \mathbf{1}[NutGrowth_i]$		19.523***	17.510***
		(5.195)	(5.663)
$LargeOwner_i$	6.273***	29.210***	24.970***
	(0.619)	(2.025)	(2.038)
$LargeOwner_i \times NonSpecialist_i$		-26.596***	-17.086***
		(2.099)	(2.142)
County FE	Y	Y	
Zip Code FE			Y
R-squared	0.019	0.020	0.033
Number of Observations	521843	521843	329586

Note: This table estimates equation (6), which assesses the relationship between groundwater well drilling on agricultural land and the landowner's size and specialization in nut growing. Subscript i indexes land parcel. The outcome $WellFeet_i$ is the number of wells drilled on i over 2013-2023 multiplied by their depth, in feet. Data on groundwater wells are from the California Department of Water Resources Well Completion Reports. The remaining notes are the same as in Table 2.

Table 5: Response to Competitors by Investor Type.

	$SymGrowth(NutAcres_i)$		
	All Nuts	Almonds	Non-Almonds
	(1)	(2)	(3)
$LargeOwner_i$	-0.359***	-0.351***	-0.566***
	(0.019)	(0.021)	(0.023)
$LargeOwner_i \times NonSpecialist_i$	0.570***	0.634***	0.663***
	(0.025)	(0.024)	(0.029)
$LargeOwner_i \times ...$	0.017		
$... \times CompetitorNutGrowth_{c(i)}$	(0.014)		
$LargeOwner_i \times NonSpecialist_i \times ...$	0.090***		
$... \times CompetitorNutGrowth_{c(i)}$	(0.019)		
$LargeOwner_i \times ...$		-0.052**	0.090***
$... \times CompetitorAlmondGrowth_{c(i)}$		(0.023)	(0.025)
$LargeOwner_i \times NonSpecialist_i \times ...$		0.091***	-0.003
$... \times CompetitorAlmondGrowth_{c(i)}$		(0.027)	(0.032)
$LargeOwner_i \times ...$		0.100***	-0.056**
$... \times CompetitorNonAlmondNutGrowth_{c(i)}$		(0.021)	(0.024)
$LargeOwner_i \times NonSpecialist_i \times ...$		-0.035	0.067**
$... \times CompetitorNonAlmondNutGrowth_{c(i)}$		(0.024)	(0.029)
$CompetitorNutGrowth_{c(i)}$	-0.103***	-0.039*	-0.133***
	(0.021)	(0.024)	(0.028)
Zip Code FE	Y	Y	Y
R-squared	0.265	0.282	0.242
Number of Observations	119140	106144	85662

Note: This table estimates equation (7), which assesses whether the differential nut expansion by large nut non-specialists relative to other investors varies by the degree of competition in the same county. Subscript i indexes land parcel. The outcome variable is the second-order approximation to the change in log nut acres (i.e., symmetric growth rate), defined in the note to Table 2. Column (1) considers the full definition of nuts used in most of the results. Columns (3)-(4) consider two subsets of nuts: almonds and non-almonds, defined as pistachios, walnuts, and pecans. The variable $CompetitorNutGrowth_{c(i)}$ equals the share of land parcels in county c with a different owner in 2013 than the owner of parcel i that experience positive change in the share of land allocated to nuts over 2013-2023 (i.e., the share with $\mathbf{1}[NutGrowth] = 1$). The variable is then standardized to have mean of zero and variance of one. The variables $CompetitorAlmondGrowth_{c(i)}$ and $CompetitorNonAlmondNutGrowth_{c(i)}$ are defined similarly in terms of competitor growth in almond cropland or in pistachio, walnut, or pecan cropland. The remaining notes are the same as in Table 2.

Table 6: Propensity to Retreat from Nut Cropland.

	$\mathbf{1}[NutRetreat_i]$	
	(1)	(2)
$LargeOwner_i$	0.129***	0.019***
	(0.004)	(0.007)
$LargeOwner_i \times NonSpecialist_i$	-0.155***	-0.065***
	(0.004)	(0.007)
Sample Restriction	None	$NutShare_{i,13} \in (0, 0.25]$
Zip Code FE	Y	Y
R-squared	0.217	0.151
Number of Observations	329880	43193

Note: This table estimates a variant of equation 4 that assesses the differential propensity of large nut non-specialists to reduce nut cropland. Subscript i indexes land parcel. The outcome $\mathbf{1}[NutRetreat_i]$ indicates whether i experiences a decrease in the share of total land allocated to nuts over 2013 through 2023, which, since total land is fixed implies a reduction in nut cropland. Column (1) imposes no sample restriction apart from the baseline filters in Table 2. Column (2) limits the sample to parcels with a positive share of land allocated to nuts in 2013 that is less than or equal to 25%, which since large nut specialists are defined to have at least 10% of land allocated to nuts in 2013, ensures that the comparisons are between farms with similar ex-ante nut allocations. The remaining notes are the same as in Table 2.

Online Appendix

A Data

A.1 Details on Additional Datasets

We describe the additional datasets referenced in Section 3.

- **NCREIF.** Data on returns to institutional investment in cropland are from the National Council of Real Estate Fiduciaries (NCREIF) Farmland Index. NCREIF is an industry group consisting of large fiduciaries that invest largely on the behalf of tax-advantaged institutions (e.g., pensions). Sherrick (2020) provides a summary of the NCREIF data and its use in studying cropland investing.

- **Drought Severity.** Data on drought severity are from the Drought Severity Combined Index (DSCI) produced by the National Drought Mitigation Center. The index ranges from zero to 500. Higher values imply a more severe drought. The DSCI data are available through the University of Nebraska-Lincoln at the county by week level.

- **Almond Board of California.** Data on aggregate quantity of almond produced, average price per pound of almonds, acres of bearing almond cropland ("existing trees"), and acres of non-bearing almond cropland ("new trees") are from the Almond Board of California.

- **Land Parcel Shapefiles.** Data on the the master shapefile of land parcels in California are from the Los Angeles County Data Hub. We work with the 2014 shapefile. The data contain the assessor's parcel number (APN) of each parcel. When merging between the cleaned CDL dataset, described above, and the CoreLogic data, we work with the APN in CoreLogic associated with the year 2014 or the year closes to 2014 to maximize our match rate between the CLD data and the CoreLogic data. The master shapefile does not contain parcels for the following counties: Colusa, Inyo, Mariposa, Modoc, Plumas, San Luis Obispo, and Siskiyou.

A.2 Details on Crop Type Classification

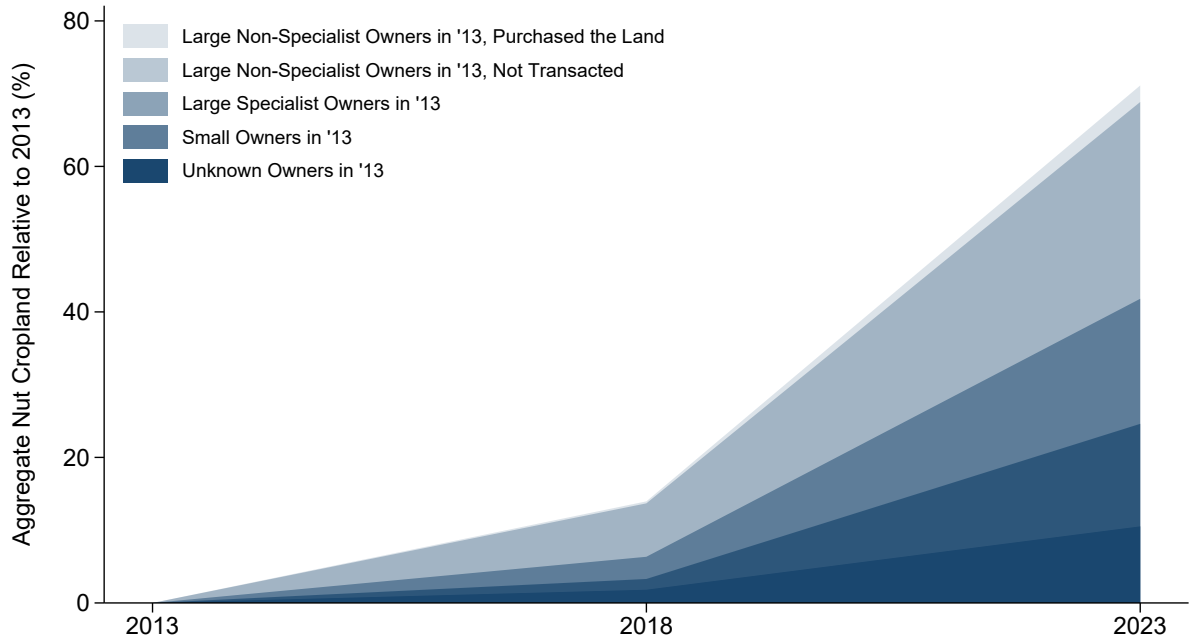
We group the raw pixel values in the CDL data into the following categories. The numbers correspond to the values from the USDA's codebook.

- Almonds: 75
- Nuts: Almonds (75), pistachios (204), walnuts (76), pecans (74)
- Corn: 1, 12, 13
- Hay: 36, 37
- Soybeans: 5
- Cotton: 2
- Tree Fruit: 66, 67, 68, 77, 211, 217, 218, 220, 223
- Rice: 3
- Grassland or Pasture: 171 (for 2023), 181 (for 2023), 176 (before 2023), 152, 62, 64
- Forested Land: 141, 142, 143, 63
- Wetland: 190, 195
- Barren Land: 131, 65
- Wheat: 22, 23, 24
- Citrus: 212, 72
- Grapes: 69
- Fallow Land: 61
- Vegetable and Non-Tree Fruit: 41, 43, 46, 47,49, 50, 54, 48, 55, 206, 207, 208, 209, 213, 214, 215, 216, 219, 221, 222, 227, 229, 231, 242, 243, 244, 245, 246, 247, 248, 249, 250
- Other: the remaining categories, the vast majority of which is Open Space (121)

As described in the text, we further group each of these grouped crop types into nur cropland, non-nut permanent cropland, annual cropland, and non-cropland. We define non-nut permanent cropland as the sum of: Tree Fruit; Citrus; and Grapes. We define annual cropland as the sum of: Corn, Hay, Soybeans, Cotton, Rice, and Vegetable and Non-Tree Fruit We define non-nut permanent cropland as the sum of: Grassland, Forested Land, Wetland, Barren Land, Fallow Land, and Other.

Additional Figures and Tables

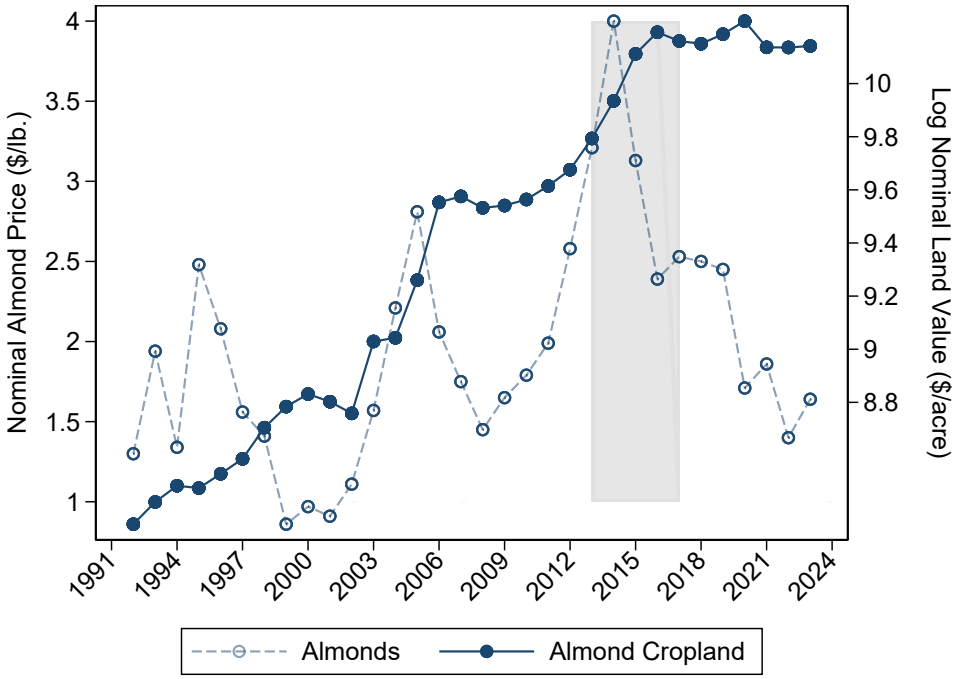
Figure A.1: Decomposing Nut Cropland Expansion.



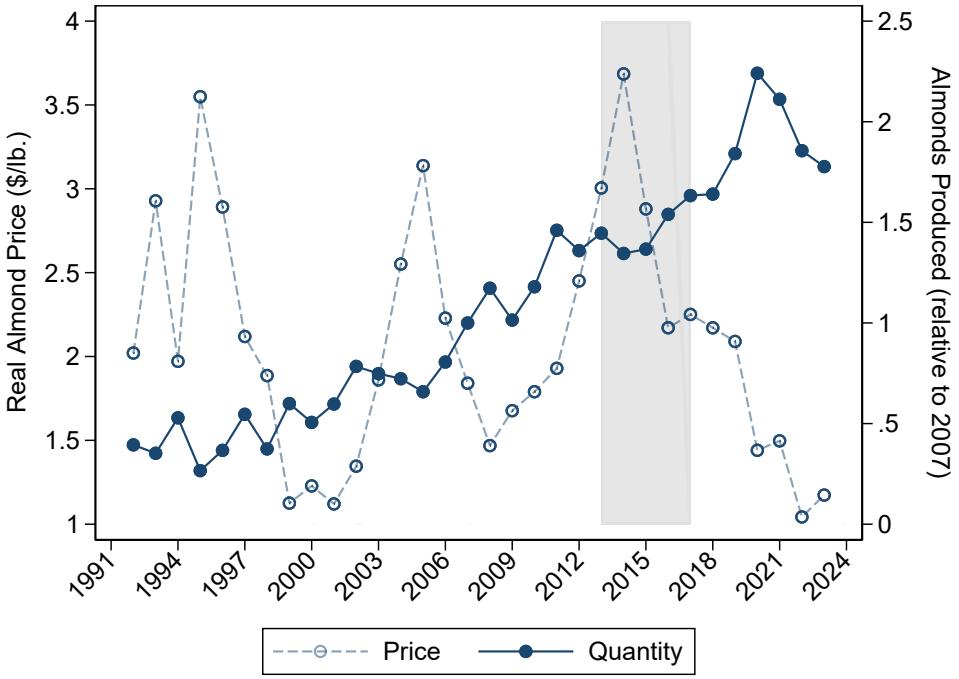
Note: This figure plots total cropland allocated to nuts in 2013, 2018, and 2023 on parcels in the Cropland Data Layer database, in acres relative to the the value in 2013. The figure decomposes this number into the part from land parcels owned by different types of investors, as in Figure 2. The remaining notes are the same as in Figure 2.

Figure A.2: Additional Long-Run Almond Dynamics. Nominal Prices and Quantities.

(a) Nominal Price of Almonds and Almond Cropland

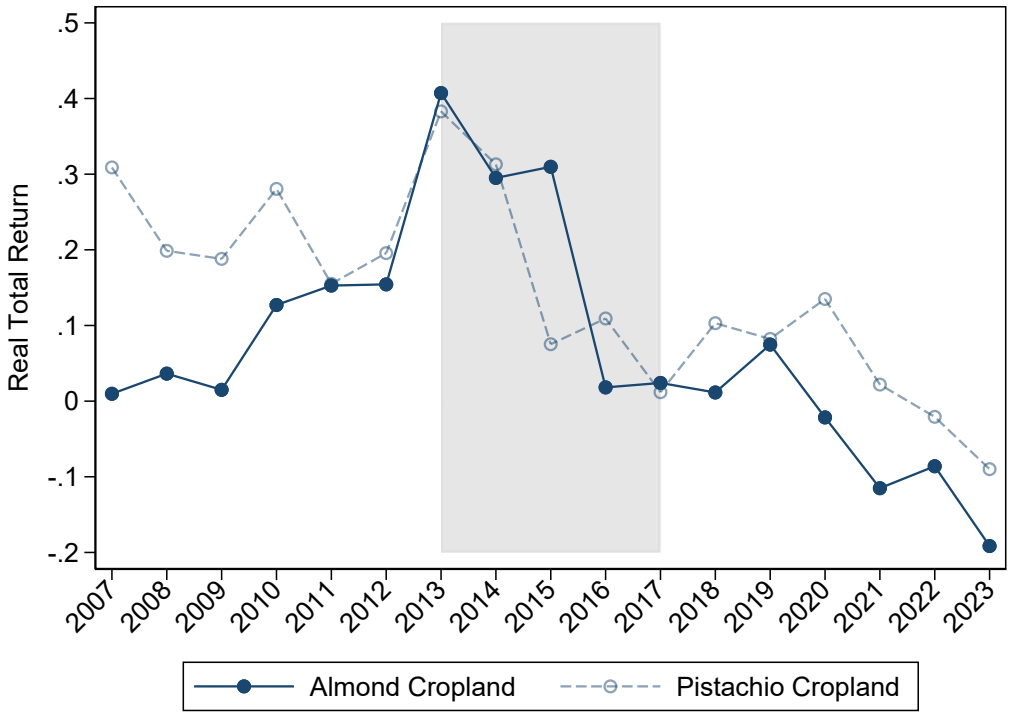


(b) Real Almond Prices and Quantity Produced



Note: This figure performs two extensions of Figure 5. Panel (a) is similar to Figure 5 except in nominal prices, not real prices. Panel (b) replaces the real price of land from Figure 5 with quantity of amonds produced, normalized to equal one in 2007. As in Figure 5, data are from the Almond Board of California.

Figure A.3: Total Returns to California Nut Cropland.



Note: This figure plots real total returns to almond and pistachio cropland in the NCREIF portfolio. Data are from the NCREIF dataset and so represent land owned by fiduciaries that manage money for large tax-advantaged institutions. The remaining notes are the same as in Figure 5.

Table A1: Robustness of Land Reallocation to Zip Code Fixed Effects.

	$\Delta Share_i$		
	Annual Crops	Non-Nut Perm Crops	Non-Cropland
	(1)	(2)	(3)
$\Delta NutShare_i$	-0.198***	-0.218***	-0.585***
	(0.005)	(0.004)	(0.005)
$LargeOwner_i \times \Delta NutShare_i$	-0.061***	-0.132***	0.194***
	(0.009)	(0.010)	(0.010)
$LargeOwner_i \times NonSpecialist_i \times \Delta NutShare_i$	-0.177***	0.185***	-0.008
	(0.013)	(0.011)	(0.013)
$LargeOwner_i$	-0.016***	0.023***	-0.007***
	(0.002)	(0.002)	(0.002)
$LargeOwner_i \times NonSpecialist_i$	0.020***	-0.006***	-0.014***
	(0.002)	(0.002)	(0.002)
Zip Code FE	Y	Y	Y
R-squared	0.169	0.211	0.274
Number of Observations	329880	329880	329880

Note: This table is analogous to Table 3 after including zip code fixed effects. Subscript i indexes land parcel. The area of a land parcel is fixed over time and includes cropland and non-cropland.

Table A2: The Largest Non-Specialist Nut Farm Owners and Nut Allocation.

Name	Number of acres 2023	Share allocated to nuts 2023	Number of acres 2013	Share allocated to nuts 2013
J.G. BOSWELL COMPANY	22,389	0.88	22,581	0.005
E.W. MERRITT FARMS	4,177	0.95	5,248	0.014
MFC KERN I LLC	3,349	0.91	3,349	0.001
SAGEBERRY IV LLC	2,767	0.95	768	0.013
TOV ORCHARDS LLC	2,268	0.98	2,268	0.001
WESTERN FARMLAND LLC	1,947	0.75	431	0.070
STUEVE BROS FARMS LLC	1,818	0.88	2,101	0.001
MERRITT RICHARD W	1,617	0.91	2,554	0.021
GOLDEN OLIVE RANCH LLC	1,375	0.96	1,526	0.049
MAZAL ORCHARDS LLC	1,251	0.88	1,137	0.000
DIXIELAND FARMS LLC	1,167	0.93	1,167	0.005
S3 GROUP LLC	1,142	0.91	179	0.000
DEHBALA ORCHARDS	1,098	0.98	1,260	0.056
ZENITH RANCH LLC	1,088	0.96	1,728	0.001
WARMERDAM DAIRY INC	1,056	0.96	1,056	0.019
MISSION ORCHARDS LLC	1,055	0.97	1,067	0.024
LOYOLA PROP I	1,031	0.95	1,031	0.001
DELANO 2665 LLC	991	0.97	991	0.001
VANDER EYK CORNELIUS JR	986	0.97	995	0.027
HANSEN JOHN M	970	0.86	970	0.007
MOJAVE PISTACHIOS LLC	959	0.93	1,131	0.000
MYERS JOHN II	953	0.76	989	0.012
LYONS LAND MANAGEMENT	943	0.85	935	0.045
TULE FOG FARM LAND LLC	920	0.86	920	0.065
OLD GOLDEN OAKS LLC	909	0.65	909	0.000

Note: This table lists the top 25 "non-specialist" nut owners by acreage of nut cropland in 2023, their total nut acreage in 2013 and 2023, and the share of acreage in their portfolio allocated to nuts in 2013 and 2023. In this table, we define non-specialist owners as the ones who had less than 10% of their total acreage allocated to nuts in 2013.

Table A3: The Largest Overall Nut Farm Owners and Nut Allocation.

Name	Number of acres 2023	Share allocated to nuts 2023	Number of acres 2013	Share allocated to nuts 2013
THE WONDERFUL COMPANY	80,173	0.96	83,440	0.86
FARMLAND RESERVE INC	39,545	0.90	35,978	0.76
J.G. BOSWELL COMPANY	22,389	0.88	22,581	0.00
SUNNYGEM	20,914	0.91	19,974	0.74
LAS NOGALERAS	10,033	0.85	–	0.00
VIOLICH FARMS INC	8,028	0.90	6,736	0.84
GLOBAL AG PROPERTIES USA LLC	7,729	0.91	5,185	0.61
PACIFIC REALTY ASSOCIATES	7,377	0.78	7,377	0.66
FARMERS INTERNATIONAL INC	6,648	0.92	5,119	0.78
FARMERS COOPERATIVE GIN INC	6,643	0.96	6,672	0.63
TOOR SANTOKH S	6,399	0.90	835	0.76
ARNOLD CA LLC	5,953	0.94	1,022	0.98
AKHAVI LLC	4,976	0.95	1,450	0.87
780 LA BREA LLC	4,570	0.96	4,570	0.16
ORLAND ALMONDS ACQUIS. CO LLC	4,496	0.87	–	0.00
STARRH & STARRH FARMS	4,198	0.90	4,811	0.92
E.W. MERRITT FARMS	4,177	0.95	5,248	0.01
V.A. RODDEN INC	4,032	0.84	3,755	0.46
RAINBOW ORCHARDS LLC	3,855	0.95	4,349	0.34
ERIKSSON LLC	3,813	0.95	3,813	0.93
B & B FAMILY LP	3,795	0.88	3,771	0.59
PREMIERE AGRICULTURAL PROP. LLC	3,723	0.92	5,632	0.78
PACIFIC ORCHARDS LLC	3,400	0.93	3,337	0.37
MFC KERN I LLC	3,349	0.91	3,349	0.00
HUNDAL PARVINDER LIVING TRUST	3,322	0.93	1,958	0.85

Note: This table lists the top 25 owners by acreage of nut cropland in 2023, their total nut acreage in 2013 and 2023, and the share of acreage in their portfolio allocated to nuts in 2013 and 2023.

Table A4: Heterogeneity by Geographic Breadth as a Proxy for Investor Information.

	$\mathbf{1}[NutGrowth_i]$	$\Delta \log(NutAcres_i)$
	(1)	(2)
$LargeOwner_i$	0.099***	-0.104***
	(0.005)	(0.014)
$LargeOwner_i \times NonSpecialist_i$	0.033***	1.002***
	(0.005)	(0.022)
$LargeOwner_i \times ...$	0.008	-0.134***
$... \times MultiCounty_{o(i)}$	(0.010)	(0.047)
$LargeOwner_i \times NonSpecialist_i \times ...$	-0.072***	-0.363***
$... \times MultiCounty_{o(i)}$	(0.012)	(0.056)
$MultiCounty_{o(i)}$	0.003	0.188***
	(0.004)	(0.034)
Zip Code FE	Y	Y
R-squared	0.322	0.173
Number of Observations	329880	69796

Note: This table estimates a variant of equation (7) that assesses whether the differential nut expansion by large nut non-specialists relative to other investors varies by the number of counties in which the owner has farms, a proxy for the investor's information about the behavior of competitors. Subscript i indexes land parcel. The variable $MultiCounty_{o(i)}$ indicates whether in 2013 the owner o of i owned a parcel in the Cropland Data Layer dataset in another county than the county associated with i. The remaining notes are the same as in Table 2.

Table A5: Response to Competitors. Additional Outcome Variables.

	$\mathbf{1}[NutGrowth_i]$	$\Delta NutShare_i$	$\Delta \log(NutAcres_i)$	$SymGrowth(NutAcres_i)$
	(1)	(2)	(3)	(4)
$LargeOwner_i$	0.127***	0.016***	-0.077***	-0.359***
	(0.006)	(0.004)	(0.024)	(0.019)
$LargeOwner_i \times NonSpecialist_i$	-0.012*	0.007*	0.858***	0.570***
	(0.006)	(0.004)	(0.035)	(0.025)
$LargeOwner_i \times ...$	-0.019***	0.006*	-0.028	0.017
$... \times CompetitorNutGrowth_{c(i)}$	(0.005)	(0.003)	(0.018)	(0.014)
$LargeOwner_i \times NonSpecialist_i \times ...$	0.048***	0.012***	0.068***	0.090***
$... \times CompetitorNutGrowth_{c(i)}$	(0.005)	(0.003)	(0.026)	(0.019)
$CompetitorNutGrowth_{c(i)}$	0.043***	-0.009**	-0.059*	-0.103***
	(0.008)	(0.004)	(0.033)	(0.021)
Zip Code FE	Y	Y	Y	Y
R-squared	0.322	0.104	0.171	0.265
Number of Observations	329880	329880	69796	119140

Note: This table replicates column (1) of Table 5 with the other outcome variables shown in Table 5. Subscript i indexes land parcel.