ABSTRACT

Title of dissertation: ESSAYS ON THE ECONOMETRIC ANALYSIS
OF U.S. AGRICULTURE

Shinsuke Uchida, Doctor of Philosophy, 2014

Dissertation directed by: Professor Erik Lichtenberg
Department of Agricultural and Resource Economics

This dissertation consists of three essays empirically investigating three important aspects of the U.S. agriculture: conservation, subsidy, and productivity. Each essay is conducted with the U.S. Census of Agriculture micro file data. Availability of cross-sectional and time variations of detailed individual farm production and demographic characteristics allows for uncovering heterogeneous relationships between farm production decisions and the corresponding aspects of U.S. agriculture.

The first essay examines an adverse effect of a cropland retirement policy. A cropland retirement policy contributes to the reduction of environmental externalities from agricultural production such as soil erosion, nutrient runoff and loss of wildlife habitat. On the other hand, participant's potential adverse behavior could undermine the environmental benefits of the policy. Several sources of such an unintended effect, known as "slippage", have been conceptually identified, but their empirical evidence has been scarce. This article tests one source of slippage caused by in-farm land substitution from noncropland to cropland as a result of farmland retirement in the U.S. Conservation Reserve Program (CRP). The causal relationship of CRP participation and subsequent slippage through in-farm land substitution is identified by employing farm fixed effects, time-varying county fixed effects, and selection-on-observables. These could eliminate effects of unobservables that are potentially correlated with both the program participation and subsequent farmland reallocation decisions. Overall, slippage seems evident and fairly robust among specifications. It is found that an average program participant converts 14% of noncropland to cropping activities after enrollment. Results further show that participants with a larger share of uncropped land contribute more to slippage, indicating that farms with the excess capacity of conversion are more flexible in the land allocation decision and thus likely to give rise to slippage. This suggests that additional restrictions on the rest of land use for participants and/or introduction of penalty points reflecting the share of noncropland in the current auction mechanism can hinder such a backward incentive offsetting the program benefits.

The second essay examines the distortionary effects of agricultural policy on farm productivity by examining the response of U.S. tobacco farmers' productivity to the quota buyout of 2004. We focus on the impact of distortionary policy, i.e., the tobacco quota, by decomposing aggregate productivity growth into the contribution of farm-level productivity growth and the contribution of reallocation of resources among tobacco growers. We find that the aggregate productivity of Kentucky tobacco farms grew 44%

between 2002 and 2007. The elimination of quota rental costs and reallocation of resources, including entry and exit, accounted for most of the post-buyout productivity growth. It is also noted that the aggregate productivity of Kentucky tobacco farms vary across farm characteristics and locations. This highlights the importance of using highly disaggregated data to uncover the sources of aggregate productivity growth.

The third essay examines the relationship between farm size and productivity growth. In the past several decades, crop production in the U.S. has shifted to larger farms. During the same period, crop productivity has fairly improved. While these two events seem clearly associated, no studies have fully uncovered the link between them. Using farm-level longitudinal data from the Censuses of Agriculture from 1987-2007 enables us to decompose the contributions of aggregate productivity growth (APG) by farm size, but also by farm entry/exit and by technology/reallocation. We have three main findings. First, productivity growth is clearly non-uniform among farm sizes. Between 1987 and 2007, virtually all of the aggregate productivity growth of crop farms came from farms with annual sales of more than \$500,000. These farms account for only 8% of U.S. crop farms. A closer look at the APG contributions to productivity growth from surviving farms confirms the findings for all crop farms: the productivity of mid-size farms has barely increased, and the productivity of smaller farms has fallen. Finally, the relative importance of technical efficiency growth and resource reallocation varies over time. Technical efficiency growth seems to be a larger source of APG for large farms between 1987 and 1997, whereas reallocation across all sales classes contributes more to APG between 1997 and 2007. Overall, our finding provides the concrete evidence that farm consolidation has been strongly associated with the productivity growth of U.S. crop farms. Our finding that resource reallocation through farm consolidation is nontrivial for the APG of crop farms highlights the usefulness of farm-level panel data for studying structural changes and APG.

ESSAYS ON THE ECONOMETRIC ANALYSIS OF U.S. AGRICULTURE

by

Shinsuke Uchida

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2014

Advisory Committee:
Professor Erik Lichtenberg, Chair/Advisor
Professor Maureen Cropper
Professor Richard Just
Professor Barrett Kirwan
Professor Charles Towe

Dedication

To Yuka and Yuta.

Acknowledgments

The countless number of people have made me complete this long journey. I am extremely grateful to my advisor, Erik Lichtenberg for his insightful comments and fruitful discussions. His patience and encouraging support helped me overcome many critical situations over an entire period. His philosophy of research and education has influenced my academic career.

I would also like to thank my committee members, Professors Maureen Cropper, Richard Just, Barrett Kirwan and Charles Towe for agreeing to serve on my dissertation committee and for sparing their invaluable time reviewing the manuscript.

I especially acknowledge Barrett Kirwan. Without his extensive knowledge and continuous encouragement, my journey would have been never-ending. He also gave me an invaluable opportunity to work at ERS and accomplish a challenging but extremely interesting project together.

I am also grateful to Kirk White for research collaboration and continuous support. His admirable research agenda and wit have stimulated my motivation for scholarly life.

I would like to acknowledge help and support from some of the staff members in USDA–Jim Burt and Robert Hunt at NASS and Eldon Ball, Vince Breneman, Robert Dubman, Daniel Hellerstein, Sun Ling Wang, and Ryan Williams at ERS who provided me the smooth access to data.

I would also like to express my gratitude to faculty members and colleagues in AREC who have nurtured my academic knowledge and experiences, as well as mentors, friends and family members who have fueled my journey. Special thanks are due to Kayo Aoyama, Toshio Aoyama, Michele Baggio (with distinction), Gregmar Galinato, Chiara Pedrazza Gorlero, Nathaniel Higgins, Higuchi Family, Kaoru Kimura, Jia Li, Megumi Makisaka, Kimiko Miyazaki, Minoru Nakada, Nishimoto Family, Rei Odawara, Taku Otsuki, Dimitrios Reppas, Hiroshi Saeki, Akiko Sagesaka, Nazumi Takeda, Fumiya Togashi, Charles Towe, and Marcella Veronesi for scholarly interactions and the bonds of friendship.

Finally, I owe my deepest thanks to my mother, Ikuyo Uchida, and my wife, Yuka Uchida. They are

essential.

Table of Contents

Essay I

Indirect Land Use Effects of Conservation:

Disaggregate Slippage in the U.S. Conservation Reserve Program

abstract

A cropland retirement policy contributes to the reduction of environmental externalities from agricultural production such as soil erosion, nutrient runoff and loss of wildlife habitat. On the other hand, participant's potential adverse behavior could undermine the environmental benefits of the policy. Several sources of such an unintended effect, known as "slippage", have been conceptually identified, but their empirical evidence has been scarce. This article tests one source of slippage caused by in-farm land substitution from noncropland to cropland as a result of farmland retirement in the U.S. Conservation Reserve Program (CRP). With the farm-level longitudinal data I can utilize cross-sectional and time variation of detailed individual farm characteristics to identify the causal relationship of CRP participation and subsequent slippage through in-farm land substitution. An identified assumption of the slippage estimate is verified by farm fixed effects, time-varying county fixed effects, and selection-on-observables. These could eliminate effects of unobservables that are potentially correlated with both the program participation and subsequent farmland reallocation decisions. Overall, slippage seems evident and fairly robust among specifications. It is found that an average program participant converts 14% of noncropland to cropping activities after enrollment. Results further show that participants with a larger share of uncropped land contribute more to slippage, indicating that farms with the excess capacity of conversion are more flexible in the land allocation decision and thus likely to give rise to slippage. This suggests that additional restrictions on the rest of land use for participants and/or introduction of penalty points reflecting the share of noncropland in the current auction mechanism can hinder such a backward incentive offsetting the program benefits.

JEL Classification Codes: Q15, Q18, Q24, Q58.
Keywords: Conservation Reserve Program, Farmland use, Land conservation, Slippage.

The views expressed are those of the authors and should not be attributed to USDA. The results in this paper have been screened to insure that no confidential information is revealed. I am grateful to Barrett Kirwan, Erik Lichtenberg, Eiichiro Nishizawa, Charles Towe and Kirk White as well as workshop participants at the University of Tokyo and the University of Kyoto for comments and suggestions. I also thank Jim Burt and Robert Hunt for many disclosure avoidance reviews.

Introduction

Programs that pay landowners for reductions in soil erosion, preservation of wildlife habitat, avoided deforestation or afforestation, and the like are seen as an equitable and efficient way to restore ecosystem services. In developed nations like the US and in EU countries, they are also seen as an attractive way of maintaining farm income supports, because such green payments are considered "green box" subsidy under WTO rules. But the effectiveness of the programs is open to question, because participant's potential adverse behavior could undermine the targeted environmental benefits of the policy. Answering this question is of particular importance in conducting the cost and benefit analysis of future policies where absence of the legitimate measure of such adverse effects would overestimate the benefits.

This paper evaluates such an unwanted effect, known as "slippage", as a consequence of participation in a farmland retirement program. Several sources of slippage have been conceptually identified, but their empirical evidence has been scarce. Wu (2000) and Roberts and Bucholtz (2005) analyzed the impacts of the Conservation Reserve Program (CRP), U.S. voluntary farmland setaside program, on farmland conversion from noncropland to cropland using region-level aggregate data. They indicate the possibility that benefits from retired acres in the CRP were partially offset by an increase in cropped land converted from noncropland. While these studies shed light well on the incidence of slippage, their estimation results and policy implications are confronted with methodological problems and practical limitations, respectively. First, their cross-sectional estimates may suffer from a self-selection problem due to the voluntary nature of program participation, as well as from spurious correlation between participation and farmland allocation decisions due to unobserved farm characteristics. Debates between Roberts and Bucholtz (2005, 2006) and Wu (2005) identified these potential econometric problems, yet they have remained unsolved.

Second, even though their slippage estimates were proved consistent, their region-level aggregate results are not able to fully reveal mechanisms through which such slippage occurs.

This article makes three distinct contributions. First, several econometric techniques are used to identify the causal relationship of CRP enrollment and slippage. An identified assumption of the slippage estimate is verified by farm fixed effects, time-varying county fixed effects, and selection-on-observables. These could eliminate effects of unobservables that are potentially correlated with both the CRP participation and subsequent farmland reallocation decisions. With the quinquennial U.S. Census of agriculture micro file data from 1982 to 1992 cross-sectional and time variations of detailed individual farm production and demographic characteristics allow me to employ those techniques. Second, the article contrasts with the previous aggregate studies by isolating one source of slippage from others.[1] Specifically, I test slippage caused by "in-farm" land conversion from noncropland to cropland as a result of CRP enrollment. The mechanism and the testable slippage hypothesis via in-farm land substitution were illustrated by Wu (2000). By using a subsample of data from farms whose size remained constant between Census years, I single out potential effects from purchases and/or rentals of land on the farm's land allocation decision between cropping and non-cropping activities. Finally, the rich farm-level panel data also offers an opportunity to discern farm's heterogeneous responses to the CRP program across region, farm production type, farm operation size, and the timing of CRP enrollment.

Knowledge about the mechanism(s) through which slippage occurs should help policymakers devise programs with features designed to avoid or mitigate slippage incentives. A potential is large in the growing market of carbon sequestration projects where carbon leak-

---

[1] Slippage could occur from the redistribution of resources between farms through farmland trade because CRP enrollment may influence economies of scale of participants. In addition, the large amount of cropland retirement in certain region may influence local farmland market per se. Such a region-level effect may also occur in the commodity market where a sharp decline in crop production raises output prices thereby attracting more production (price feedback effect) in the same region and/or elsewhere. Moreover, program participants may reallocate input resources to increase the intensity of crop production at margin. Identifying these sources of slippage is equivalently important and will be investigated in the future.

age is one of the primary concerns. Voluntary based programs to preserve biodiversity and reduce deforestation may have also experienced similar backward incentives. For instance, the Sloped Land Conversion Program, a Chinese nationwide cropland setaside program implemented in 1999, has a similar objective to the CRP to achieve poverty alleviation and ecological service enhancement.[2] Also, a similar type of payments-for-environmental-services programs has been recently launched in a number of other developing countries in Latin America and Asia to conserve standing forests (Mayrand and Paquin 2004).

To understand the nature of the problem, the CRP mechanism is outlined in the next section. Section 3 revisits the Wu's land substitution model that explains how CRP enrollment affects farm's land allocation behavior. Section 4 presents description of data and estimation issues related to section 5, where identification strategies are demonstrated. Estimation results and discussion are provided in section 6. Section 7 concludes.

The Conservation Reserve Program

The CRP was established in the Food Security Act of 1985 as a long-term federal cropland retirement program that operates on a voluntary basis. In contrast to previous setaside programs with the objective of crop supply control and farm income support, its main aim is to mitigate environmental degradation caused by excessive use of environmentally sensitive agricultural lands. The primary concern was to protect farmland from soil erosion, but after amendments in 1990 and 1996 more targets were added on broader environmental benefits such as improvement of air and water quality and restoration of wildlife habitat. Since it was implemented in 1986, this has been one of the largest land conservation programs

---

[2] See similarities and differences in the two programs in Lohmar, et al. (2007).

worldwide in terms of scale and cost.[3] CRP impacts on regional ecosystems seem to be evident.[4]

This program offers eligible farmers an opportunity to retire part or all of their croplands from production in exchange for an annual rental payment. The contract requires holding land out of production for 10 to 15 years, in contrast with previous setaside farmland programs which were annual. Participants are obligated not to use enrolled land in any agricultural production activities during this period, but instead to maintain them with certain conservation practices such as grass introduction and forestation with cost-sharing payments of up to 50 percent for practice installation and up to $10 per acre for maintenance.

Although CRP participation is voluntary, potential participants must first meet several eligibility conditions and then enter an auction mechanism to compete with other applicants in each general signup period. Producers must have been the owner, operator, or tenant of potentially qualifiable croplands for at least twelve months prior to the closing date of the CRP signup period.[5] An eligible farmer can submit their cropland parcel(s) into the CRP if the offered parcels satisfy physical land criteria. For the first nine CRP signups in 1986-1989, highly erodible cropland and cropland in wetland or near water body were only CRP eligible.[6] In addition to the farm-level land quality condition, regional-level geologi-

---

[3] With about 1.7 billion dollars being allocated to CRP annually, according to the report by the Economic Research Service (ERS), 34 million acres of cropland had been retired as of 1997. This accounts for almost 8 percent of the total U.S. cropland in 1997 (Vesterby, 2003). This is about as large as the size of world annual deforestation rate during the last decade (Food and Agriculture Organization of the United Nations, 2010).

[4] It is estimated that the current amount of retirement mitigates 626 million tons of annual soil erosion from cropland (Anderson and Magleby, 1997). Another report estimates that CRP enrolled lands also contribute considerably to wildlife restoration, generating $428 million of recreational value from wildlife per year (Feather, Hellerstein, and Hansen, 1999).

[5] Tenants are allowed to submit their rented land with certain agreement with their landowners. In fact, a fair amount of CRP acreage is observed from rental land.

[6] Erodibility was initially measured by the Land Capability Classes (LCC) which categorizes soil quality into eight classes (class VIII being most sensitive to erodibility) with sub-classes of (e) erosion, (w) excess wetness, (s) problems in the rooting zone, and (c) climatic limitations. A parcel of land became eligible if it belonged to VI to VIII or II to V with a predicted annual erosion rate greater than certain level. This was altered

cal characteristics were added to the eligibility criteria after 1990. As a result of the Food, Agriculture, Conservation, and Trade (FACT) Act of 1990, the National Conservation Priority Areas (NCPAs) and State Conservation Priority Areas (SCPAs) were established in 1991 to conserve environmentally sensitive areas. Areas that were first designated as NCPAs are the Chesapeake Bay, Long Island Sound, and Great Lakes regions.[7] SCPAs have been established over time to increase CRP enrollment in locations that are sensitive to water, air and wildlife quality within a state. Another physical criterion pertains to cropping history. Eligible lands must have been cropped in two of the five most recent crop years.[8]

Once all the eligibility criteria are met, a qualified farmer submits an offer to the bidding process with a rental payment bid for each offered parcel. Before 1990, the offered rental payment was subject to a confidential maximum acceptable bid cap set by the federal administrating agency. The bid cap was initially determined based on an average cash rent for cropland in the multicounty areas with similar farm production and land characteristics.[9] Bids were accepted if they were at or below the bid cap at multicounty level. The bidding mechanism changed after 1990. The multicounty average bid cap was replaced by a county average soil-specific agricultural rental rate of land. In addition to the bid cap, the confidential ranking system, the so-called environmental benefit index (EBI) was introduced. Each parcel of offered land is scored according to its physical and geological characteristics as well as submitted rental payment. Bids are gathered at national level and accepted in a descending order from the highest EBI score until the targeted enrollment acres in

---

by the Erodible Index (EI) after 1987 that qualified land as highly erodible if the EI was above 8. This was subsequently relaxed in the 1990 and 1996 Farm Bill. Land eligibility conditions for CRP signups are listed in table 1.

[7] The Federal Agriculture Improvement and Reform (FAIR) Act of 1996 added the Prairie Pothole region and the Longleaf Pine region in 1997 and 1998, respectively. The boundary information on the NCPAs is provided by the Farm Service Agency (FSA) upon request. Some of the NCPAs can be also found from the EPA's "Surf Your Watershed" webpage, http://cfpub.epa.gov/surf/locate/index.cfm.

[8] After the amendment in the Farm Security and Rural Investment Act of 2002, eligible land is required to have cropped four of the past six years.

[9] For the first three signups in 1986, bid cap calculation accounted for rents not only for dryland cropland but also for irrigated cropland, so areas with higher share of irrigated acres had a relatively high bid cap.

each signup are filled up (Anderson and Magleby, 1997).[10] Upon acceptance, each county has the uniform cap on total CRP acres no more than 25 percent of total county cropland acres.[11] Thus, offered parcels that could secure the bid are even rejected when the county total CRP acres have already reached the cap.

Accepted lands must be retired from production activities and utilized for conservation practices in return for rental payment for the duration of the CRP contract. A CRP contract generally becomes effective from the following cropping year once an offer is accepted.

A Model of Farmland Allocation

In this study, I investigate one of the slippage mechanisms posited by Wu (2000). Namely, CRP participants would convert some noncropland into crop production following enrollment of some cropland. This land substitution is induced by the law of diminishing marginal returns to cropping (denoted by C) and noncropping (N) activities.[12]

Suppose that the farm has three segments of land: high-quality $\bar{A}_H$, medium-quality $\bar{A}_M$ and low-quality land $\bar{A}_L$, and chooses to allocate each of them between the two activities by the amount of A_{ij} (for $i = H, M, L$, $j = C, N$). Suppose also that all high-quality land is allocated for crop production because the return from crop production is always larger in high-quality land, whereas low-quality land generates higher return from non-cropping activities or the conversion cost of low-quality land into crop production outweighs its return. Allocation of medium-quality land is allocated between cropland A_{MC} and noncropland A_{MN} based on market conditions and farm characteristics.

Let $\pi_C(\bar{A}_H, A_{MC}; \mathbf{p}_C, \mathbf{w}, \phi)$ and $\pi_N(A_{MN}; \bar{A}_L, \mathbf{p}_N, \mathbf{w}, \phi)$ represent the restricted profit functions for the cropping and non-cropping activities, respectively, where $\mathbf{p}$ is a vector of ex-

---

[10] For details of the EBI point system, see the Appendix III in Lehmann (2005).

[11] The maximum allowable county acreage is set in order to avoid potential negative effects on the agriculturally-dependent local economies (US General Accounting Office, 1989). However, this limit can be waived by the FSA admission unless such effects are expected.

[12] I define cropping activities as crop production including rotation activities, while noncropping activities are defined as any other land use such as grazing on pasture and forest.

pected output prices of the cropping and non-cropping activities, **w** is a vector of variable input prices, and ϕ denotes farm characteristics. They are assumed to be concave and twice differentiable in choice variables. The farmer's maximization problem can be given by

$$(1) \quad \max_{A_{MC}, A_{MN}} \{\pi_C(\bar{A}_H, A_{MC}; \mathbf{p}_C, \mathbf{w}, \phi) + \pi_N(A_{MN}; \bar{A}_L, \mathbf{p}_N, \mathbf{w}, \phi); A_{MC} + A_{MN} = \bar{A}_M\}.$$

Optimal allocation of A_{MC} and A_{MN} is then determined by the following equilibrium condition of their corresponding marginal returns,

$$(2) \quad \tilde{r} = \frac{\partial \pi_C(\bar{A}_H, \hat{A}_{MC}; \bullet)}{\partial A_{MC}} = \frac{\partial \pi_N(\hat{A}_{MN}, \bar{A}_L; \bullet)}{\partial A_{MN}},$$

where $\tilde{r}$ is an implicit rental rate of land at equilibrium, and $\hat{A}_{MC}$ and $\hat{A}_{MN}$ denote optimal cropland and noncropland acreage of medium-quality land, respectively. Figure 1 depicts the relationship in equation (2).

Suppose now that a CRP signup begins and medium-quality cropland is eligible for enrollment.[13] An eligible farm then submits a sealed bid of r^{CRP} with acreage of A_{CRP} in the competitive auction if r^{CRP} is above the reservation price of farmland $\tilde{r}$. Conditional on acceptance of the bid, a contract becomes effective and enrolled CRP acres of A_{CRP} are set aside from any production activities in the following crop year. Because A_{CRP} is taken out of medium-quality cropland acreage $\hat{A}_{MC}$, the marginal condition in equation (2) changes as

$$(3) \quad \frac{\partial \pi_C(\bar{A}_H, \hat{A}_{MC} - A_{CRP}; \bullet)}{\partial A_{MC}} > \frac{\partial \pi_N(\hat{A}_{MN}, \bar{A}_L; \bullet)}{\partial A_{MN}}.$$

Bacause the farm has the diminishing marginal return from crop production, this induces reallocation of farmland by converging land from the non-cropping to cropping activities by acreage A_S. This slippage mechanism is explained by the following new equilibrium

---

[13] Recall that only highly erodible cropland is CRP eligible.

condition, as given by

$$(4) \qquad r^* = \frac{\partial \pi_C(\bar{A}_H, \hat{A}_{MC} - A_{CRP} + A_S; \bullet)}{\partial A_{MC}} = \frac{\partial \pi_N(\hat{A}_{MN} - A_S, \bar{A}_L; \bullet)}{\partial A_{MN}},$$

where r^* is an implicit rate of land at re-equilibrium. The mechanism is illustrated in figure 2. As a result, the net impact of CRP enrollment is offset by the ratio of A_S/A_{CRP}.

In this study, the testable hypothesis of slippage identifies a *rate* of slippage, (i.e., $= A_S/A_{CRP}$). It is clear from figure 2 that a slippage rate is affected by the relative curvature of the cropping and non-cropping supply functions. Slippage A_S gets larger if the acreage response for the cropping activities is relatively inelastic. For instance, relatively inelastic cropland supply can be characterized by price and income support programs. Payments of these programs were linked to commodity prices prior to the 1996 FAIR Act, program participants were likely less responsive to market prices. On the other hand, relatively elastic demand for non-cropping activities can stem from the large share of economically marginal land. Marginal land is frequently converted in and out of crop production as commodity prices fluctuate.

Data

Data Description

To test farm-level slippage, I obtain individual farm information on CRP enrollment, production activities and operator demographics from the U.S. Census of Agriculture longitudinal micro files. The Agricultural Censuses are conducted every five years which essentially cover all U.S. farmers.[14] Access to this confidential data is permitted under an agreement with the USDA National Agricultural Statistics Service (NASS). Farm samples in 1982, 1987, and 1992 are connected to create unbalanced panel data. In addition to the

---

[14] U.S. Department of Agriculture defines a "farm" if farm operation produces at least \$1,000 of agricultural products. Each of the Censuses consists of about 1.5 million farm observations out of roughly 2 million U.S. farms.

Censuses, commodity price data are used to account for market influences on the farm production decision. Monthly futures prices of commodities are obtained from the Chicago Board of Trade (CBOT),[15] and state-level price indexes are provided by the ERS.[16] Land quality data and CRP administration data are also obtained, respectively, from the Natural Resources Inventory (NRI) and the ERS.[17]

Sample Selection

The Census longitudinal micro data mainly have three advantages to examine the Wu's land substitution effect. Firstly, the Censuses are available before and after the first implementation of the CRP in 1986, so that I can utilize exogenous variation explaining differences in the change in land use between CRP participants and non-participants. Secondly, both cross-sectional and time variations allow for identifying the causal impact of CRP implementation on farm's land use. For the analysis of CRP enrollment and the associated change in farmland use, the two-year panel of 1982-1987 and 1987-1992, and the long panel of 1982-1992 are used for 48 consecutive states. To examine the change in crop production activities, the analyses focus only on farm observations that exist over the panel periods. Thirdly, detailed farmland ownership information permits one to select farm observations that record no farmland transactions over the periods. I restrict the sample to farms with the fixed operating farmland size over Census years. The restricted sample can thus single out the CRP-induced farmland substitution effect between farms and isolate the slippage effect underlying within-farm land substitution in response to CRP enrollment.

For the purpose of estimating the treatment effect of CRP enrollment, I further limit the sample by eliminating observations located in counties where the share of highly erodible land (HEL) is nearly zero. The county-level HEL distribution is estimated from the NRI

---

[15] Available commodities from the CBOT during the 1982-1992 period include corn, soybeans, wheat, and cattle. For more details about data, refer to http://www.cmegroup.com/market-data/datamine-historical-data/.

[16] I owe special thanks to Eldon Ball and Sun Ling Wang for making this data available.

[17] I am grateful to Daniel Hellerstein for generously providing me with the refined NRI data and corresponding statistical codes.

parcel-level data.[18] The definition of CRP-eligible HEL cropland changes over time. For the 1982-1987 panel sample, the county-level HEL cropland is estimated based on the land eligibility criteria in the first three CRP signups conducted in 1986, because CRP lands enrolled in the 1987 cropping year are determined in the previous year. As documented in table 1, the eligibility criteria in the first three signups follow the LCC. Similar sample adjustment is made for the other panel periods based on the time-varying CRP-eligible land criteria.

The sample selection procedures delineated above may introduce selection bias. First, because only continuous farm observations over two or three consecutive Census years are used, the parameter of interest would be biased if the decision of exit or stay in farm production is correlated with the CRP enrollment and cropland conversion decisions. For instance, using the same Census longitudinal data, Key and Roberts (2007) find some evidence that supports a positive relationship between past (non-CRP) farm subsidy payments and subsequent farm business survival. Although it is unclear whether the farm survival decision is also correlated with the CRP enrollment decision, such a potential bias can be mitigated by conditioning on subsidy payments and farm operator characteristics in the pre-CRP year. The second source of sample selection bias could arise from the fact that the 1987 and 1992 Census of Agriculture did not collect *almost* all of farms that cease agricultural production activities by retiring whole farmland in the CRP.[19] Table 2 suggests

---

[18] The NRI is a panel survey of land use and physical land characteristics on non-Federal lands. It was conducted in the years of the Agricultural Censuses from 1982 to 1997 over 48 contiguous states, but data were collected from land parcels instead of farm operation units. Data include approximately 844,000 land parcels. County total HEL acres are then computed by taking a weighted sum of parcels that are qualified as HEL by definition in footnote 6. It is noted that the county-level estimates from the NRI data may not be accurate because of the nature of the data sampling procedure. Notwithstanding, correlation between the eligibility estimates and the FSA's administrative CRP enrollment data is high about 0.7, implying that the estimates could be a proxy to explain county-level enrollment variation.

[19] Strictly speaking, the definition of the "whole-farm CRP" includes farms with all cropland enrolled in the CRP in which less than $1,000 of agricultural products other than crops are produced and sold. In fact, a few number of such whole-farm CRP observations that have non-crop products such as livestock more than or equal to $1,000 were collected in the 1987 and 1992 Censuses. I drop those farms from estimation in order

that acres retired by these "whole-farm" CRP enrollees are non-negligible.[21] Omission of the whole-farm CRP observations would generate a biased estimate of interest if some underlying factors that determine the farm's decision to retire all or part of farmland in the CRP also affect subsequent cropland conversion. To condition out this retirement effect, I analyze determinants of whole-farm CRP enrollees by using the 1992-1997 Census panel data where the 1997 Census started to collect such farm observations.[22] Logit estimation results reported in table 3 suggest that small-scale and less profitable operators are more likely to retire entire cropland in the CRP. Also, older farmers with longer farm operation as well as operators who report off-farm work as their principal occupation and work more off-farm are likely to become whole-farm enrollees. Assume that these determinants remain constant over time, the potential sample selection bias in the 1982-1992, 1982-1987 and 1987-1992 panel analyses could be avoided by conditioning on these variables. This procedure can allow me to estimate *the slippage effect of partial-farm CRP participants*. Because the sample is further restricted by grain farms due to availability of futures commodity prices, the final sample consists of 12,074 of grain farms. These farms used about 3 million acres of active cropland in 1982. Summary statistics of the Census data are provided in table 4.

Empirical Strategy

Identification

Several econometric techniques are used to identify the causal relationship of CRP enrollment and slippage pertaining to in-farm land substitution. An identified assumption of the

---

to focus on pure slippage from partial-farm CRP participants.[20] Estimation exercise including those whole-farm CRP observations confirms that their slippage contribution is merely zero.

[21] Roughly 20% of the U.S. CRP acres are enrolled by whole-farm CRP enrollees.

[22] Logit regression was conducted by assigning one for whole-farm CRP observations in 1997 and zero for partial-farm CRP observations in 1997 and regressing on the base-year explanatory variables in 1992. Results are similar to findings in the ERS report about CRP farm characteristics (Sullivan, et al., 2004).

slippage estimate is verified by farm fixed effects, time-varying county fixed effects, and selection-on-observables. These could eliminate effects of unobservables that are potentially correlated with both the CRP participation decision and subsequent farmland reallocation. Farm-level cross-sectional and time variations of farm characteristics allow me to employ those techniques.

The parameter of interest is obtained by a regression of cropped acreage on acreage enrolled in the CRP, as given by

$$A_{it}^{C} = \alpha_0 + \alpha_1 A_{it}^{CRP} + \alpha_2 \bar{A}_{it} + \varepsilon_{it}, \tag{5}$$

where, given farm size $\bar{A}_{it}$, farm i allocates A_{it}^{C} acres for cropping activities while A_{it}^{CRP} acres are retired in the CRP at year t, α_0 is an intercept, ε_{it} is an error term, and the parameter of interest α_1 measures a proportional change in cropped acreage in response to acreage enrolled in the CRP. If there is no slippage, then $\alpha_1 = -1$, whereas $\alpha_1 > -1$ indicates the presence of slippage. A key assumption to obtain a consistent estimate of α_1 is $E[A_{it}^{CRP}\varepsilon_{it}|\bar{A}_{it}] = 0$. Because CRP participation is voluntary and thus CRP acres are not randomly assigned, endogeneity of the CRP enrollment and crop production decisions is one of the issues that violate this assumption. Nevertheless, the slippage estimate may not suffer from this endogeneity due to the timing of enrollment. In general, a CRP contract becomes effective in October once an offer is accepted. This implies that enrolled CRP acres for cropping year t are predetermined in the previous year, thereby making the CRP decision recursive unless there exists intertemporal dependence thorough the error term.

However, serial correlation likely exists, because the irreversible CRP decision adheres to the farm's return to future production through farm's underlying parameters such as entrepreneur skill and farm productivity. These farm characteristics, denoted by u_i, are usually unobserved by econometricians, so that we likely fail to satisfy the identifying assumption because $E[A_{it}^{CRP}(u_i)(u_i + \varepsilon_{it})] \neq 0$. For example, Roberts and Bucholtz (2005) indicate positive association between the frequency of CRP enrollment and a rate of noncropland conversion to cropland in areas with relatively low land quality. Land quality distribution is an important factor that determines farmland allocation among different activities. A farm with more high-quality of land is likely to stay in crop production whereas a farm with economically marginal land is sensitive to surrounding environment such as commodity prices and weather. At the same time, land quality may be highly correlated with land erodibility, which is one of the CRP eligibility conditions and therefore increase the likelihood of CRP enrollment. In addition to land quality, likely unobserved operator's management quality and natural risk attitude may also be determinants of both the CRP participation and crop production decisions. A high-skilled operator is more likely to continue crop production, so they may not get incentive for land retirement. On the other hand, they may intend to enroll in the CRP as a source of additional income from high erodible but unproductive unused land. Moreover, a more risk-averse farm may decide to enroll in the CRP to secure a future stream of certain rental payment. But such a farm would operate relatively low-level production activities. As a result, unobserved management skill and risk attitude would cause a bias on the slippage incidence although the direction of confounding effects from these operator characteristics is ambiguous. Influences of such time-invariant unobserved heterogeneity can be controlled by using farm fixed effects.

In addition, I include year fixed effects, time-varying county fixed effects and observable farm-level production characteristics to minimize any other potential confounding effects on the parameter of interest from time-varying unobserved heterogeneity. Year fixed effects capture the macro-economic shocks to farm production at time t, while time-varying county fixed effects can account for any time-varying regional effects influencing the farm's production decision, such as the change in region-specific policies, output and input markets, and weather.

Introducing the fixed effect for farm i, f_i, the fixed effect for year t, θ_t, the county-year fixed effect in county j in year t, C_{jt}, and a vector of covariates of individual farm characteristics, X_{it} in equation (5) yields

$$(6) \quad A^{C}_{it} = \alpha_0 + \alpha_1 A^{CRP}_{it} + \alpha_2 \bar{A}_{it} + \mathbf{X}_{it}\alpha_3 + f_i + C_{jt} + \theta_t + \varepsilon_{it},$$

where the identifying assumption is replaced by $E[A^{CRP}_{it}\varepsilon_{it}|\bar{A}_{it}, \mathbf{X}_{it}, \theta_t, f_i, C_{jt}] = 0$. This proves the OLS estimate of α_1 to be consistent.

Yet, one may wonder whether the CRP decision is truly predetermined as well as whether the aforementioned sets of fixed effects and time-variant observable farm characteristics fully account for confounding effects from unobservables. The identifying assumption may be still invalid if the CRP decision is highly correlated with past crop production activities, which in turn are likely correlated with current crop production activities through ε_{it}. This is likely true because CRP participation is contingent on the cropping history. The summary statistics of the sample in table 4 seems to indicate their association (that is, CRP participants have larger cropped acres in the base year). This potential pre-enrollment heterogeneity bias could be more problematic particularly in presence of other government payment programs affecting the production decision with a similar eligibility condition to the CRP's. A participation level in the price and income support programs in the 1980s and early 1990s is constrained by base acres that are generally determined by the 5-year average of cropping history.

These concerns can be assessed by conditioning on base-year heterogeneity among CRP participants and non-participants. Taking first-difference of equation (6) over the Census panel years enables me to include the pre-enrollment (base-year) farm characteristics, as given by

$$(7) \quad \Delta A^{C}_{it} = \alpha_1 \Delta A^{CRP}_{it} + \Delta \mathbf{X}_{it}\alpha_3 + \mathbf{X}_{ib}\alpha_4 + \Delta C_{jt} + \Delta\ \theta_t + \Delta\varepsilon_{it},$$

where the delta represents the first-difference operator between the period t and t-5 (or t-10 for the 1982-1992 panel analysis), $\Delta\theta_t$ becomes the common intercept for all farms, and $\mathbf{X}_{ib}$ denote a vector of base-year farm characteristics. Note also that given observations with fixed farm size, first-differencing eliminates the impact of the potential farmland transactions decision induced by CRP enrollment. Accordingly, the identifying assumption can be rewritten such that $E[\Delta A_{it}^{CRP}\Delta\varepsilon_{it}|\Delta\mathbf{X}_{it},\mathbf{X}_{ib},\Delta C_{jt},\Delta\theta_t] = 0$.

Finally, for the 1987-1992 panel data, additional source of bias may stem from violation of the strict exogeneity assumption. This is because the cropping history becomes endogenous in the subsequent CRP signups after 1986. For instance, the CRP enrolled acreage in the first CRP signup in 1986 is contingent on cropped acreage prior to the CRP, but the CRP eligibility status in 1990 can be controlled by farmers by increasing crop production in 1986-1989. This future option effect turns out that $E[\Delta A_{it}^{CRP}\varepsilon_{i,1987}] \neq 0$ for t = 1992. But this can be avoided by additionally conditioning on pre-CRP-period variables that can characterize the farm's inherent crop production capacity. Hence, the identifying assumption for the 1987-1992 panel data can be rewritten as $E[\Delta A_{it}^{CRP}\Delta\varepsilon_{it}|\Delta\mathbf{X}_{it},\mathbf{X}_{ib},\mathbf{X}_{i,1982},\Delta C_{jt},\Delta\theta_t] = 0$.

Variable Construction

Dependent variable

A dependent variable is defined as the change in acres in cropping activities net CRP acres. As depicted in figure 3, the Censuses categorize farmland acres into cropland, woodland, pastureland and rangeland, and all other land (land in house lots, roads, ponds, wasteland, etc.). Cropland acres are further decomposed into six subcategories: crop harvested, crop failed, cultivated summer fallow, used for cover crops, idled, and used for pasture and grazing. Among these, acres for cropping activities can be defined as the sum of cropland harvested, crop failed, summer fallowed and used for cover crops, as indicated by orange color in figure 3.[23] From cropping acres, CRP acres are subtracted to create net cropped acres for CRP participants.

Measurement errors in the dependent variable

Data on CRP enrollment acres introduce two measurement errors on the dependent variable. The measurement errors on the dependent variable would not affect the parameter of interest unless the corresponding explanatory variable and the dependent variable are correlated. I explain below why the measurement errors on the dependent variable matter in this exercise. First, the Censuses specify that CRP acres belong to the category of either cropland used for cover crops or idled. However, cropland used for cover crops is also counted as part of cropped acres. Thus, constructing the dependent variable by the simple difference between cropped acres and CRP acres generate the measurement error that is also correlated with CRP-enrolled acres. Second, some observations seem to double-count cropped and CRP-enrolled acres on the same parcel of land. This attributes to the fact that the Census data are collected at the end of the calendar year (and recorded as of December 31), whereas the CRP contract starts at the beginning of crop year (generally October). For instance with the 1982-1992 panel data, CRP acres which are supposed to be binding in the 1993 land use are rather counted as the 1992 land use, because the corresponding CRP contract becomes effective on October 1, 1992. Until the contract date, the contracted land parcels are free from land use restriction, so they can be used for production activities. Therefore, those parcels can be counted twice in the 1992 Census data as both cropped acres and acres enrolled in the CRP. These issues are taken into account in constructing CRP-net cropped acres as follows.

First, I subtract CRP acres from cover-crop acres. If the computed value turns out negative, it is assigned zero. This truncated value is then added to the sum of cropland acres

---

[23] That is, this definition takes crop rotation into consideration.

harvested, crop failed, and cultivated summer fallow. This can be given as

$$
\begin{aligned}
CroppedAcres = {} & Harvested + Failed + SummerFallow + \\
& + Max((CoverCrops - CRP), 0).
\end{aligned}
\tag{8}
$$

Derived acres represent a lower bound of the CRP-net cropped acres because the maximum amount of potential CRP acres is subtracted from the current cover-crop cropland acres. Hence, the slippage estimate with this definition of a dependent variable also indicates a lower bound. Note that, for the 1987-1992 panel, the lower bound estimate is fully justified only for the sub-sample with no base-year CRP enrollment (i.e., the lower bound estimate can be guaranteed only for new participants after 1987).

Next, the measurement error from double-counting the following crop year's CRP enrollment is eliminated by dropping such erroneous observations from estimation. The constructed dependent variable in equation (8) fails to exclude such CRP acres, resulting in the potentially upward bias of a slippage estimate. I build the following criteria to endeavor to minimize this measurement error in the currently available Census data format. First, I calculate the excess acreage of CRP by subtracting acres in the CRP-potential categories of land use from total CRP acres. Although CRP land is defined as part of cropland used for cover crops and idled, it is often observed in the Census data that CRP acres exceed acres used for cover crops and idled. In fact, it appears that the current CRP acres also belong to woodland, pastureland and rangeland, or all other land categories, as indicated by green color in figure 3. This should stem from the CRP eligibility condition of cropping history. Because land is eligible for the CRP after two years of cropping activities in the previous five years, currently CRP-enrolled acres are not confined by currently cropped acres. Therefore, the excess CRP acreage is calculated as

$$
\begin{aligned}
ExcessCRPAcres = {} & CRPAcres - (CoverCrops + Idled + \\
& + Pasture + Woodland + OtherLand).
\end{aligned}
\tag{9}
$$

If this excess CRP acreage is positive, then it indicates the least evidence of double-counting. Such observations are dropped from estimation. Despite that the criteria may still leave some more double-counting observations, I find that a dropping rate for e.g., the 1982-1992 panel data is about 6% of the sample size of CRP participants, which is larger than an actual enrollment rate of 1992 CRP contracts during the 1986-1992 signups (less than 5%). Hence, this procedure reasonably reduces the measurement error from double-counting.

Independent variable

Several time-varying farm production characteristics are added as covariate to minimize the potential impacts of unobservables on the parameter of interest.

First of all, cropland conversion is affected by exogenous market shocks of output and input prices. Time-varying county fixed effects can account for them only if farms within a county have the identical elasticity. Because the farm's production decision is determined inherently to location-specific soil and climatic properties and they could vary even within a county, farms would respond to prices of certain sets of outputs and inputs unique to their farmland capacity. To account for this heterogeneous response by farm production type, I classify farms into a similar type of commodity production by following the six-digit Standard Industrial Classification (SIC) code.[24] The interaction term of the county-year and SIC fixed effects is then included in regression assuming that a similar type of farms in the same region is likely subject to a similar choice set of commodities and input types.

Another variation in farm's response to the output price change may stem from farmland quality as argued by Roberts and Bucholtz (2005). Farms with more economically marginal land endowment may be more sensitive to market conditions. To account for this farmland-specific response pattern to commodity prices, I use futures contract prices of

---

[24] Refer to http://www.osha.gov/pls/imis/sic_manual.html for a list of the SIC. The Agricultural Censuses contain farm's SIC information.

major crops and livestock products at a planting period. Monthly average futures prices in March for corn and September for winter wheat are obtained to represent expected prices at the planting period.[25] They are deflated by state-level output price index to allow for regional variation over time. Then, a variable reflecting farm-specific output price change is created by multiplying the change in the deflated futures prices by the beginning year's sales shares of respective crops and livestock products. Because the historical data of output futures prices are available only for corn, soy beans, and wheat, and cattle, I use for estimation grain farm observations whose major crop sales come from either corn, soy beans, or wheat. The differential price impact among heterogeneous farmland quality can be further explained by proxy by adding the interaction term of the farm-specific output price change and base-year yield of respective crops.

In addition to the market impacts, effects of other government subsidy programs are taken into consideration. Prior to 1996, agricultural production was supported by deficiency payments and commodity loan programs to stabilize crop prices. Program participants thus gained benefits by reducing a production risk. To refrain from excess supply as a result of risk reduction, the programs limited an amount of enrolled acreage and also required payment recipients to annually set-aside a certain proportion of farmland. Also, the program enrollment level was determined based on a five-year planting history, so that program participants were motivated to maintain their production level. As a result, the current production level of the participants are closely tied to the payment level that is also correlated with past production level. But the past production level also affects the CRP enrollment level as one of the eligibility conditions. To control for the association between farm's crop production and production support program participation, annual se-

---

[25] The construction of expected prices follows Holt, (1999). Monthly average futures prices in March for harvest-time futures contracts are taken from the December CBOT contract for corn and spring wheat and the November CBOT contract for soybeans. For winter wheat, monthly average futures prices in the previous September are taken from the July CBOT contract.

taside acreage information under these government programs is used as an indicator of the participation level.[26]

Another time-varying farm variation that affects cropland conversion attributes to technological change through capital accumulation. The change in production technology may also affect the CRP participation decision as it likely changes marginal returns to production. Irrigation is one of the most effective technologies to improve productivity to induce production expansion. I control for the change in irrigated acres to capture the impact of technological change.[27]

Finally, several base-year farm characteristics are added as covariates to mitigate the potential of sample selection bias as discussed in Section 4.2 as well as to account for pre-enrollment farm heterogeneity. Several pre-CRP-period farm characteristics are also controlled for to avoid the violation of the strict exogeneity assumption for the 1987-1992 panel data. Farm size, per-acre sales, acres in cropland, pastureland, woodland and irrigation, and operator's age, operation experience, principal occupation and off-farm working status are included. Summary statistics for grains farms are provided in table 4.

Estimation Results

I estimate the model for three time periods: 1982-1987, which covers the first CRP signup; 1987-1992, which covers subsequent signups; and 1982-1992, the same period used by Wu (2000) and Roberts and Bucholz (2005). The analysis with the 1982-1992 long panel data has advantages. Because the CRP signups started in 1986, farm information in the 1982 Census is exogenous to any CRP-induced changes. Also, the long panel can enable one to observe the farm's long-term adjustment motive in production activities as a result of

---

[26] One might worry about the potential for additional simultaneity bias because program participation and crop production are jointly determined. Nevertheless, inclusion of aforementioned fixed effects and exogenous output price changes can control for time-varying factors that affect the change in a program participation rate.

[27] A potential simultaneity bias between irrigation technology adoption and cropland use can be avoided by conditioning on time-varying county fixed effects, as they control for exogenous weather shocks that influence irrigation technology adoption.

CRP enrollment. Moreover, the same 1982-1992 period is used by the Wu's and Roberts and Bucholtz's analyses, so results can be comparable to their aggregate estimation results. In contrast, the shorter panels allow me to see whether a slippage rate changed as the program expanded its coverage. The 1982-1987 short panel is of particular interest in analyzing instantaneous impact of first CRP implementation. Results from the three panel data analysis are integrated for robustness check.

Due to data limitation on commodity futures prices as mentioned in section 5.2, I use corn, soy, wheat, and other cash grain farms defined by six-digit SIC codes. To better capture the output price effects, I restrict the sample whose base-year sales share of corn, soy, and wheat products cover a majority of total sales. This may be a sensible approach as farm's production activities should be most influenced by the majority of their products. To see how this sample attrition affects the slippage estimate, robustness check will be provided in section by adding non-grain farm observations.[28]

Results from the 1982-1992 Panel Data

First, I show how the parameter estimate of interest varies in absence of farm fixed effects. Table 5 provides regression results from pooled OLS and random effects estimation based on equation (5). Cropped acreage is regressed on CRP acreage with or without additional covariates. A notable difference is observed in the OLS coefficient estimates of CRP acres among specifications. With the random effects model the estimates become relatively stable. Because the parameter of interest is not robust among specifications and also because they are not able to include base-year farm characteristics which would further influence the estimate, those techniques may not yield a reliable estimate of slippage incidence.

Table 6 presents estimation results from the farm fixed effects model based on equation (7). The change in cropped acreage is regressed on the change in CRP acreage with or with-

---

[28] I also exclude CRP participants that break their contracts during the periods (i.e., more CRP acres enrolled in the 1987 Census than in the 1992 Census), because these cases cannot be properly identified. Such observations account for only 10% of participants in the sample.

out additional covariates. Also, for each of the regressions, a set of fixed effects–county-year fixed effects and the interaction of county-year and SIC fixed effects–are included in addition to farm fixed effects. Slippage seems evident in table 6. There is about 14% of land conversion from noncropland to cropland if farm fixed effects are included in column (1) (i.e., -1 - (-0.861)). The slippage estimate is fairly stable even with additional covariates in columns (2) and (3). This indicates that once unobserved farm characteristics are eliminated by farm fixed effects, additional covariates barely affect the slippage estimate.[29] The slippage estimate is also robust with county-year fixed effects and its interaction with SIC fixed effects as in columns (4)-(9). These findings suggest that conditional on farm fixed effects, the slippage estimate is likely orthogonal to unobserved heterogeneity. This also provides a firm support for the supposition that the CRP participation decision is predetermined. This finding is reasonable particularly because the currently used sample only includes grain farms with a similar crop pattern, so that farms within a county or within a county and a production type are likely homogeneous to time-varying shocks.

Besides the slippage estimate, coefficient estimates of the other covariates can validate the specification used for estimation. The three price change variables reasonably capture an economic incentive of the farm's crop production decision when the base-year controls are included. As expected, crop and livestock prices create opposing effects on cropping activities. In addition, farms with low productivity (that is, lower average grain yield) are more sensitive to the change in commodity prices.[30] These estimates become hardly significant with county-year and SIC fixed effects in column (9), suggesting that these fixed effects reasonably account for the farm's heterogeneous response to price shocks.

The other two time-varying observables (i.e., indicators of commodity support program participation and technology adoption) also have the expected signs and notable influence

---

[29] I also conducted the same estimation with acreage share variables that adjust potential heteroskedasticity due to farm operation size, and results are almost identical.

[30] Note that the price change variables are weighted by output values, so the magnitude of their estimates does not reflect the actual price elasticity.

on land allocation. The coefficient of the change in setaside acreage moves significantly when the base-year variables are included. This indicates that commodity support program participation is highly correlated with past production activities. Nevertheless, it rarely affects the slippage estimate. The coefficient of the change in irrigated acreage changes to some extent when county-year fixed effects and its interaction with SIC fixed effects. This indicates that some county-level time-varying factors affect irrigation technology adoption and such an effect varies across farm type. Again, irrigation does not affect the slippage estimate.[31]

In addition to the mean estimate of slippage, the rich farm-level panel data offers an opportunity to further examine farm's heterogeneous response to the CRP program in multiple dimensions: across region, type and size of farm operation, and timing of CRP enrollment. Table 7 provides some evidence that could concrete the incidence of slippage underlying in-farm land substitution . Panel A examines the relationship between slippage and participation in the production support programs. Production support program participants are likely less responsive to market prices and therefore have relatively inelastic cropland demand. It appears that an average slippage rate is larger by about 10 percentage points for CRP enrollees who also participated in the production support programs. This points out the potential ineffectiveness of the land retirement program in conjunction with other market-distorted policies enhancing crop production activities. Panel B presents a marked difference in the slippage estimate by farm groups with different shares of cropped acres in 1982. Slippage is statistically and economically significant for grain farms with a larger share of *uncropped* land, indicating that farms with the excess capacity of conversion are more flexible in the land allocation decision and thus likely to give rise to slippage. This result suggests that additional restrictions on the rest of land use for participants and/or

---

[31] For instance, weather conditions in 1982 and 1992 differ significantly. Rough estimates of U.S. average temperature and precipitation from the data in Schlenker and Roberts (2009) indicate more temperature variation (hotter summer and colder winter) in 1982 than in 1992 and fewer precipitation during the 1982 crop season. Larger uncertainty in the production decision influences irrigation technology adoption.

introduction of penalty points reflecting the share of noncropland in the current auction mechanism can hinder such a backward incentive offsetting the program benefits.

Table 8 reports region-specific slippage estimates. Definition of three regions is identical to the one used in Wu (2000) and Roberts and Bucholtz (2005). Most CRP-concentrated five Midwest regions–Corn Belt, Lake States, Northern and Southern Plains and Mountain–are used to estimate the region-specific slippage incidence relative to the other regions.[32] Results in table 8 present different slippage estimates across the regions. During the 1982-1992 period, largest slippage was present in Southern Plains regions (about 35%), and Corn Belt, Lake Sates, Northern Plains and Mountain regions experienced the less amount of CRP-induced land conversion (10%, 15%, 15%, and 14%, respectively). These estimates in Corn Belt, Lake Sates, and Northern Plains are numerically comparable to the Wu's (30%, 19%, and 11%) and Roberts and Bucholtz's (17%, 11%, and 22%).[33] However, my estimates present the sole evidence of the in-farm land substitution effect, whereas theirs indicate aggregate impacts of CRP enrollment through multiple channels.[34]

Table 9 provides the relationship between the slippage rate and several other farm operation types. Panel A exhibits different slippage rates by operating farmland size. Panel B also shows differences by farm operation type and sales size. These results inform three unique findings. First, combining these two results reveal that small-scale and likely less efficient full-time farms contribute most to slippage incidence. Next, despite that small-scale farm participants give rise to the highest *slippage rate* as seen in panel A, larger farms

---

[32] A Corn Belt region includes Illinois, Indiana, Iowa, Missouri and Ohio, Lake States include Michigan, Minnesota and Wisconsin, Northern Plains include Kansas, Nebraska, North Dakota and South Dakota, South Plains include Oklahoma and Texas, and Mountain region includes Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming. For the other region category, see http://www.ers.usda.gov/briefing/arms/resourceregions/resourceregions.htm.

[33] The slippage estimates of Roberts and Bucholtz presented here are OLS estimates.

[34] Despite the reliability of estimates, their aggregate estimates could account not only for the land substitution effect but for the price feedback effect and the land transactions effect. Also, both whole-farm and partial-farm CRP participants are included in their estimates, while my estimate only takes into account contribution from partial-farm CRP participants.

also contribute to slippage at a steady rate over 10 percentage points, thereby causing more *slippage acres*. In fact, average acres enrolled in the CRP are much larger for larger-scale farms as provided in column (3). In addition, it is interesting to note that part-time farms in small-scale production contribute to negative slippage although statistically not significant. In other words, CRP participation possibly induces recreational farms to retire additional land from crop production. This may be a sign of positive spillover from an environmental conservation policy in presence of altruistic preferences.

Another advantage of the three-year panel data enables one to differentiate the CRP enrollment impact by different signup periods. CRP participants during the 1982-1992 period are categorized by: (i) 1982-1987 enrollees who enrolled in the CRP only prior to 1987; (ii) 1987-1992 enrollees who enrolled in the CRP only after 1987; and (iii) 1982-1992 enrollees who enroll in the CRP in both of the 1982-1987 and 1987-1992 periods (i.e., more than one enrollments). Estimates are reported in table 10. A slippage rate is similar for one-time enrollees in the 1982-1987 period (13.7%) and the 1987-1992 period (12.2%).[35] In contrast, slippage is clearly larger (28.2%) for participants enrolling multiple times. This could suggest that the slippage problem got worse as farmers became more familiar with the program and squeezed more rents from the policy.

Results from the 1982-1987 and 1987-1992 Panel Data

Table 11 reports estimation results from separate estimation of the 1982-1987 and 1987-1992 short panel data. A mean slippage rate for new enrollees decreases by 12% (from 24.5% to 12.5%) from the 1982-1987 to 1987-1992 periods. This implies that the initial CRP signups in 1986 induce more slippage. This could stem from the flawed program design in early signups. That is, in the first three signups in 1986, the maximum allowable

---

[35] A slightly larger slippage rate in the early signup period may indicate two things: long-term adjustment effect and mechanism pitfalls. It could imply that participants could adjust their farmland allocation more flexibly (i.e., more slippage) in the longer time period after enrollment. Or it could result from the flawed program design in early signups as discussed in the nect section.

rental payment was determined based on average cash rents for cropland across collections of counties with homogeneous characteristics. However, farms are likely heterogeneous even within a county, therefore uniform pricing should have given low-productive participants an incentive to overbid. Also, the region-average cash rents included rents for both non-irrigated and irrigated cropland. Since cash rents for irrigated land are clearly higher than dryland, this spurred dryland farms to enroll in the program to enjoy the miss-specified rent. The region-specific slippage rates in column (1)-(2) in table 12 partly support the evidence of this policy misspecification. Areas except the Corn Belt and Lake States regions experienced sizable fluctuation in the slippage incidence before and after the ammendment of the rental payment mechanism. In fact, these areas covered the majority of U.S. irrigated land at that time.

Slippage from All Farm Observations

Although the assessments thus far result from the restricted sample of grain farms, we saw in table 6 that inclusion of time-varying county fixed effects and SIC fixed effects could account for farm's heterogeneous response to market shocks. Provided that this is a legitimate assumption also for non-grain farms, table 13 provides regression results without price covariates for all operating farms (with fixed farmland size) during the 1982-1992 period. It is found that the slippage estimate for non-grain farms (that is, the sum of the estimate of CRP acreage change and its interaction with the non-grain indicator) changes to some degree with different sets of fixed effects and covariates. A marked change in the estimate is observed when the base-year farm characteristics are controlled for. Slippage is significantly larger for non-grain farms by about 25% than grain farms in column (6) in table 13 . In particular, a remarkable rate of slippage (about 47%) attributes to livestock farms as seen in column (7). This may pertain to the excess capacity of conversion as argued above, because farms that primarily produce livestock products likely own/rent larger share of marginal cropland. This also indicates that the non-grain farm's land allocation decision is strongly tied with initial land use constraints.

Conclusion

This article tests one unique source of slippage caused by in-farm land substitution from noncropland to cropland as a result of farmland retirement in the U.S Conservation Reserve Program (CRP). With the farm-level panel data I can utilize cross-sectional and time variation of detailed individual farm characteristics to identify the causal relationship of CRP enrollment and subsequent slippage through in-farm land substitution. An identified assumption of the slippage estimate is verified by farm fixed effects, time-varying county fixed effects, and selection-on-observables. These could eliminate effects of unobservables that are potentially correlated with both the CRP participation and subsequent farmland reallocation decisions.

The in-farm slippage effect is examined for the three different time periods: 1982-1987, 1987-1992, and 1982-1992. Overall, slippage seems evident and fairly robust among specifications when farm fixed effects reasonably account for unobserved heterogeneities. It is found that an average partial-farm CRP participant converts about 14% of noncropland to cropping activities after CRP enrollment. Moreover, the rich farm-level panel data also offers an opportunity to further examine farm's heterogeneous response to the CRP program across regions, farm production and operator types, and the timing of CRP enrollment. Results show that a rate of slippage incidence varies not only across region but also across time. I also find that the slippage rate increases for participants enrolling in the multiple CRP signups, suggesting that the slippage problem got worse as farmers became more familiar with the program and squeezed more rents from the policy. Moreover, participants with a larger share of uncropped land contribute more to slippage, indicating that farms with the excess capacity of conversion are more flexible in the land allocation decision and thus likely to give rise to slippage. This result suggests that additional restrictions on the rest of land use for participants and/or introduction of penalty points reflecting the share of noncropland in the current auction mechanism can hinder such a backward incentive offsetting the program benefits. Finally, the simplest solution to avoid slippage from idle land conversion seems to expand the mechanism that encourages farms to retire whole farmland, as operated by programs like the Wetland Reserve Program and Agricultural Easements. It is important in this regard to carefully reinvestigate both the environmental effectiveness and the cost effectiveness of the CRP.

Results indicate that any program of this kind is likely to generate some offsetting behavior, with farmers shifting crop production to previously uncropped land in response to subsidized land setasides. Attention may be particularly given to developing countries where a number of cropland and forest conservation program have been recently launched. Poorer farmers may have relatively price inelastic demand for crop production activities because no substitutable income activities are available, hence such a program would induce larger incentive to convert noncropland (uncultivated land or non-harvested forest) into cropland. Knowledge about the mechanisms by which and whom slippage occurs should help policymakers devise programs with features designed to avoid or mitigate slippage incentives, especially by taking the heterogeneity of potential participants into account.

Besides the impact of CRP enrollment on cropland conversion during the 1982-1992 period, further research opportunities are available with the Agricultural Census data for the 1992-2002 period. It is interesting to examine whether the trends I observe for 1982-1992 in the constant farm size sample carry over from the 1992-2002 period. Another interesting question departs from the partial equilibrium setting where the land substitution mechanism within a farm causes slippage. That is to look at that possibility to identify the other source of slippage caused by cross-farm land substitution in presence of the local farmland market. This can be conducted by using variation of farm size change over the Census periods. Preliminary results show strong correlation between land transactions and

CRP enrollment, and interestingly the impact of such association on cropland conversion is asymmetric by the type of land transactions (i.e., seller or buyer as well as owner or renter).

Table 1: Conservation Reserve Program Signup Periods and Eligibility Criteria

Signup	Type	Dates	Eligibility Criteria*	Contract Acres
1	General	March 3-14, 1986	A-B	753,668
2	General	May 5-16, 1986	A-B	2,771,660
3	General	August 4-15, 1986	A-C	4,703,379
4	General	February 9-27, 1987	A-D	9,478,599
5	General	July 20-31, 1987	A-D	4,442,719
6	General	February 1-19, 1988	A-F	3,375,364
7	General	July 18-31, 1988	A-F	2,604,901
8	General	February 6-24, 1989	A-H	2,462,382
9	General	July 17 - August 4, 1989	A-H	3,329,893
10	General	March 4-15, 1991	A-C,E,G,I-K	475,175
11	General	July 8-19, 1991	A-C,E,G,I-K	998,211
12	General	June 15-26, 1992	A-C,E,G,I-K	1,027,444

Source: USDA (2008)
* Eligibility Criteria:
A. Land capability classes 6 - 8
B. Land capability classes 2 - 5 with predicted average annual erosion rate greater than 3T
C. Land capability classes 2 - 5 with predicted average annual erosion rate greater than 2T and with gully erosion
D. Land with EI $>$ 8 and predicted average annual erosion rate greater than T
E. Land for filter strips alongside wetlands, streams, or other water bodies
F. Land for tree planting-eligible when 1/3 of field meets criteria A or Class 2-5 soil with predicted average annual erosion rate greater than 2T
G. Land having evidence of scour erosion caused by out-of-bank water flows
H. Wetland as follows:
  Cropped wetland of at least 6 acres
  A field of which 1/3 or more is cropped wetland
  A field of 6 to 9 acres on which wetlands are present
I. Land in designated national conservation priority areas
  Chesapeake Bay Region
  Great Lakes Region
  Long Island Sound Region
 Land in designated State water quality priority areas
 Public wellhead protection area established by EPA
 Hydrologic Unit Areas approved by the Secretary
 Land located in areas designated as Clean Water Act "319" priority areas
J. Lands to be established in specified eligible practices, including filter strips, riparian buffers, windbreaks, grass waterways, and salt tolerant grasses
 Wetland eligibility suspended
K. Land with an EI $>$ 8, regardless of the predicted annual erosion rate relative to T

Table 2: The Number of Omitted Whole-Farm CRP Places and Partial-Farm CRP Observations in the 1992 Census of Agriculture, Selected States

Geographic areas	Agricultural places excluded by farm definition with acres in the CRP (Whole-Farm CRP)			Farms with acres in the CRP (Partial-Farm CRP)		
	Number	Land in places (acres)	Land in CRP (acres)	Number	Land in farms (acres)	Land in CRP (acres)
United States	66,716	11,676,115	6,705,082	166,278	159,830,072	22,792,319
Alabama	2,314	591,878	159,842	2,922	1,886,069	270,179
Colorado	620	296,313	256,408	2,890	7,841,347	1,325,574
Georgia	2,647	608,468	158,060	4,168	2,687,461	304,625
Idaho	503	179,096	136,706	1,919	2,762,605	545,880
Illinois	3,230	297,093	168,075	8,547	4,421,225	465,026
Indiana	3,260	275,385	148,066	4,843	1,869,523	214,051
Iowa	5,978	677,405	475,843	17,703	7,884,008	1,294,635
Kansas	2,359	433,833	361,183	14,786	18,159,808	2,278,157
Kentucky	2,308	264,268	124,302	4,193	1,349,657	270,166
Michigan	2,098	196,336	109,392	2,937	1,097,895	130,652
Minnesota	5,443	811,547	530,605	11,548	5,822,189	907,213
Mississippi	3,396	776,059	257,071	3,435	2,169,800	325,499
Missouri	4,185	561,327	353,119	10,380	5,271,974	1,038,935
Montana	582	376,448	313,288	3,957	14,919,550	2,159,530
Nebraska	1,319	223,148	188,878	8,083	9,133,820	989,126
North Dakota	1,277	384,726	326,623	8,615	13,335,245	2,120,670
Ohio	2,321	216,402	121,644	3,643	1,260,035	162,509
Oklahoma	929	185,398	151,689	4,678	5,371,738	827,597
South Dakota	620	154,938	135,477	6,124	10,442,626	1,300,085
Tennessee	3,140	399,213	159,049	3,393	1,363,890	207,684
Texas	3,970	1,123,267	963,392	9,914	14,761,094	2,473,797
Virginia	874	119,820	27,597	1,617	729,867	61,222
Washington	418	233,193	200,144	1,877	4,863,907	742,155
Wisconsin	5,253	536,515	238,182	8,261	2,308,351	359,072

Source: Appendix B in the U.S. Census of Agriculture 1992
Notes: The data for “whole farm” CRP places are not complete for all States. The census mail list was developed from sources which indicated the farm had agricultural production activity. It was not designed to cover all “whole farm” CRP places. Therefore, the data for these places are limited to what was reported in the census and have not been adjusted to account for nonresponse, incomplete coverage, and reporting errors.

Table 3: Logit Regression Results for Determinants of Whole-Farm CRP Enrollees in 1997

Independent variables	(1)	(2)	(3)	(4)	(5)	(6)
Operator's age	0.055***	0.048***	0.049***	0.048***	0.035***	0.034***
Years of operation	-0.013***	-0.008***	-0.008***	-0.007***	-0.006***	-0.005***
Principal job is farming	-1.170***	-1.107***	-1.109***	-1.087***	-0.936***	-0.922***
Number of off-farm working days		-0.001***	-0.001***	-0.001***	-0.001***	-0.001***
Log of total farmland		-0.249***	-0.260***	-0.310***	-0.108***	-0.159***
Share of land owned		-0.001	-0.001	-0.001	-0.001	-0.001
Per acre return		-0.001***	-0.001***	-0.001***	-0.001***	-0.001***
Total subsidy			0.001***	0.001***	0.001***	0.001***
Log of land rented-in					-0.181***	-0.180***
Log of land rented-out					0.093***	0.085***
Constant	-4.319***	-2.606***	-2.576***	-3.868***	-2.506***	-3.512***
County fixed effects	NO	NO	NO	YES	NO	YES
Observations	99386	96188	96188	96111	96188	96111
Pseudo R2	0.09	0.10	0.10	0.11	0.13	0.14

Note: Logit estimation is conducted with the 1992-1997 Census panel data to examine the determinants of CRP enrollment by retiring either whole farmland or part of farmland. A dependent variable indicates whether CRP participants in 1997 retire whole farmland (= 1) or not. The "whole-farm CRP" farms are defined as farms that enroll all cropland in the CRP and produce less than $1,000 of agricultural products other than crops. Initial year farm characteristics in 1992 are used as explanatory variables. ***, ** and * indicate significant difference from zero at the 99th, 95th and 90th percentiles, respectively.

Table 4: Summary Statistics: All Sample Farms and Grain Farms in the 1982-1992 Panel

Sample farm group	All Operating Farms		Grain Farms	
Number of Observations	N = 80699	N = 3456	N =10823	N = 1251
	Non-CRP	CRP	Non-CRP	CRP
	(1)	(2)	(3)	(4)
Change in net-CRP cropped acres	-0.6	-71.4	-1.6	-94.9
	(47.0)	(161.0)	(49.6)	(186.4)
Change in CRP acres	0.0	87.4	0.0	107.3
	(0.0)	(147.2)	(0.0)	(180.9)
Change in setaside acres in commodity support programs	-0.1	-3.9	-0.4	-5.5
	(7.1)	(20.8)	(14.0)	(26.7)
Change in irrigated acres	-0.4	-2.0	-0.2	-1.9
	(32.4)	(39.9)	(21.3)	(35.0)
Cropped acres	61.3	222.5	161.3	304.1
	(138.7)	(321.2)	(242.1)	(425.3)
Pastureland and rangeland acres	128.8	156.5	32.8	99.8
	(5030.6)	(639.4)	(129.9)	(271.7)
Woodland acres	12.3	19.9	9.1	20.1
	(163.8)	(170.2)	(72.3)	(248.5)
Setaside acres in commodity support programs	0.9	7.2	3.6	10.7
	(7.9)	(23.7)	(15.1)	(31.2)
Irrigated acres	7.5	10.3	8.4	10.5
	(61.4)	(68.0)	(60.5)	(70.6)
Total farmland acres	213.9	424.8	218.7	455.8
	(5096.3)	(843.9)	(349.3)	(706.7)
Years of operation	17.7	22.2	20.2	21.7
	(12.1)	(12.2)	(12.6)	(12.5)
Principal job is farming (= 1) or not	0.4	0.7	0.5	0.6
	(0.5)	(0.5)	(0.5)	(0.5)
Number of off-farm working days	123.5	85.7	116.6	97.2
	(104.6)	(101.5)	(104.9)	(103.1)
Operator's age	51.6	52.4	51.4	51.8
	(11.9)	(11.1)	(12.1)	(11.4)
Per-acre sales of agricultural products	1015.5	169.8	136.5	105.8
	(20832.8)	(380.2)	(90.0)	(77.3)

Note: Data are from confidential U.S. Census of Agriculture microfiles. Mean estimates are reported with the standard deviations in parenthesis, where estimates are weighted by the Census response weight. Variables in bold indicate base-year variables in 1982. The sample consists of farms which: continued to exist during the 1982-1992 Census period; had no land transactions during the panel period; and were located in counties with CRP-eligible acres. Columns 1 and 2 contain summary statistics for all operating farms. Columns 3 and 4 contain summary statistics for sample grain farms used in the analysis.

Table 5: Regression Results for Grain Farms from the 1982-1992 Long Panel Data with Pooled OLS and Random Effects Models

	Pooled OLS model				Random effects model			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CRP acres	-0.870	-0.757 ††	-0.953	-0.890	-0.862 † † †	-0.833 † † †	-0.821 † † †	-0.805 † † †
	(0.120)	(0.111)	(0.090)	(0.083)	(0.049)	(0.055)	(0.055)	(0.056)
Total farmland acres	0.595 ***	0.537 ***	0.615 ***	0.569 ***	0.594 ***	0.583 ***	0.573 ***	0.556 ***
	(0.031)	(0.036)	(0.027)	(0.030)	(0.036)	(0.037)	(0.030)	(0.030)
Setaside acres in commodity support programs		3.502 ***		2.295 ***		0.629 ***		0.735 ***
		(0.530)		(0.393)		(0.187)		(0.155)
Irrigated acres		0.123 ***		0.160 ***		0.224 ***		0.271 ***
		(0.036)		(0.040)		(0.047)		(0.059)
Futures price of grains		-0.013 **		0.012		-0.009		0.019 *
		(0.006)		(0.010)		(0.009)		(0.011)
Futures price of cattle		-2.041 ***		-1.671 ***		-1.806 ***		-1.402 ***
		(0.117)		(0.122)		(0.144)		(0.129)
Futures price of grains X grain yields		0.001 ***		0.001 ***		0.001 ***		0.001 ***
		(0.0001)		(0.0001)		(0.0002)		(0.0001)
County-year fixed effects	NO	NO	YES	YES	NO	NO	YES	YES
SIC fixed effects	NO	NO	YES	YES	NO	NO	YES	YES
Observations	24148	24148	24148	24148	24148	24148	24148	24148
Adjusted R2	0.78	0.82	0.87	0.88	0.78	0.80	0.73	0.75

Note: A dependent variable is cropped acreage. Cropped acreage is computed as the sum of cropland harvested, failed, summer fallowed and used for cover crops, net CRP acres. Heteroskedasticity-robust standard errors are reported in parenthesis. For the coefficient of CRP acreage, † † †, ††, and † indicate significant difference from -1 at the 99th, 95th and 90th percentiles, respectively. For the coefficient of the other covariates, ***, ** and * indicate significant difference from zero at the respective percentiles.

Table 6: Regression Results for Grain Farms from the 1982-1992 Long Panel Data with the Farm Fixed Effects Model

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Change in CRP acres	-0.861 † † †	-0.857 † † †	-0.854 † † †	-0.853 † † †	-0.850 † † †	-0.856 † † †	-0.855 † † †	-0.854 † † †	-0.864 † † †
	(0.046)	(0.047)	(0.055)	(0.047)	(0.047)	(0.042)	(0.052)	(0.053)	(0.048)
Change in setaside acres in commodity support programs		0.083	1.106 ***		0.145	1.209 **		0.083	1.102 ***
		(0.161)	(0.429)		(0.152)	(0.304)		(0.166)	(0.347)
Change in irrigated acres		0.314 ***	0.341 ***		0.389 ***	0.419 ***		0.491 ***	0.532 ***
		(0.103)	(0.102)		(0.111)	(0.108)		(0.128)	(0.130)
Change in the futures price of grains		0.064	0.107 *		0.006	0.091		-0.057	0.007
		(0.052)	(0.064)		(0.051)	(0.048)		(0.099)	(0.091)
Change in the futures price of cattle		0.170	-0.678 *		0.479* *	-0.530 *		0.440	-0.626
		(0.277)	(0.361)		(0.246)	(0.317)		(0.312)	(0.390)
Change in the futures price of grains X grain yields		-0.001	-0.003 ***		-0.0004	-0.003 ***		-0.0003	-0.002 *
		(0.001)	(0.001)		(0.001)	(0.000)		(0.001)	(0.001)
Base-year farm characteristics	NO	NO	YES	NO	NO	YES	NO	NO	YES
Farm fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
County-year fixed effects	NO	NO	NO	YES	YES	YES	YES	YES	YES
SIC fixed effects	NO	NO	NO	NO	NO	NO	YES	YES	YES
Observations	12074	12074	12074	12074	12074	12074	12074	12074	12074
Adjusted R2	0.50	0.51	0.55	0.60	0.61	0.65	0.58	0.59	0.63

Note: A dependent variable is the change in cropped acreage over 1982-1992. See notes to table 5 for the definition of cropped acres. Heteroskedasticity-robust standard errors are reported in parenthesis. For the coefficient of the CRP acreage change, † † †, ††, and † indicate significant difference from -1 at the 99th, 95th and 90th percentiles, respectively. For the coefficient of the other covariates, ***, ** and * indicate significant difference from zero at the respective percentiles.

Table 7: Slippage Estimates from the 1982-1992 Long Panel by Production Support Program Participation and Base-Year Cropped Acreage Share

	Coefficient Estimate (1)	Slippage Rate (2)	Share of CRP Participants out of 1251 Observations (3)
	A. By Production Support Program Participation		
Non-participants	-0.907 ††	9.3% **	21%
	(0.039)		
Participants	0.098	19.1%**	79%
	(0.092)		
	B. By Cropped Acreage Share in 1982		
50% ≤ Share of cropped acres	-0.956 †	4.4% *	82%
	(0.024)		
Share of cropped acres < 50%	0.383 ***	42.7%***	18%
	(0.103)		

Note: In panel A, a slippage rate is estimated by subsidy recipient status in 1992 by including the interaction of the CRP acreage change and the 1992 setaside acreage dummy variable (with non-recipients as a reference). In panel B, a slippage rate is estimated by groups of different cropped acreage shares over total farmland in 1982 by including the interaction of the CRP acreage change and indicator variables of categorical groups. The sample is divided into two groups: (i) cropped acreage share in 1982 is above 50% (as a reference) and (ii) below 50%. Estimation is conducted with full specification, i.e., with all covariates and all sets of fixed effects. A dependent variable is the change in cropped acreage over 1982-1992. See notes to table 5 for the definition of cropped acres. Heteroskedasticity-robust standard errors are reported in parenthesis. Column (1) reports coefficient estimates of CRP acreage change and its interaction terms with respective group indicator variables. Slippage rates in column (2) are computed from those estimated coefficients. † † †, ††, and † indicate significant difference from -1 at the 99th, 95th and 90th percentiles, respectively. Column (3) reports the share of CRP participants in each category out of 1251 observations. ***, ** and * indicate significant difference from zero at the 99th, 95th and 90th percentiles, respectively.

Table 8: Slippage Estimates from the 1982-1992 Long Panel by Region

	Coefficient Estimate (1)	Slippage Rate (2)
Other Regions	-0.976	2.4%
	(0.081)	
Corn Belt	0.072	9.7%***
	(0.082)	
Lake States	0.129	15.4%***
	(0.084)	
Northern Plains	0.128	15.3%***
	(0.087)	
Southern Plains	0.324	34.9%*
	(0.202)	
Mountain	0.119	14.3%
	(0.117)	
Total		13.6%

Note: Region-specific slippage rates are estimated by including the interaction of the CRP acreage change and region indicator variables (with other regions as a reference). The Corn Belt region includes Illinois, Indiana, Iowa, Missouri and Ohio, the Lake States include Michigan, Minnesota and Wisconsin, the Northern Plains include Kansas, Nebraska, North Dakota and South Dakota, the South Plains include Oklahoma and Texas, and the Mountain region includes Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming. Estimation is conducted with full specification, i.e., with all covariates and all sets of fixed effects. A dependent variable is the change in cropped acreage over 1982-1992. See notes to table 5 for the definition of cropped acres. Heteroskedasticity-robust standard errors are reported in parenthesis. Column (2) reports coefficient estimates of CRP acreage change and its interaction terms with respective group indicator variables. Slippage rates in column (3) are computed from those estimated coefficients. † † †, ††, and † indicate significant difference from -1 at the 99th, 95th and 90th percentiles, respectively. ***, ** and * indicate significant difference from zero at the 99th, 95th and 90th percentiles, respectively.

Table 9: Distribution of Slippage Estimates from the 1982-1992 Long Panel by Farm Types

	Coefficient Estimate (1)	Slippage Rate (2)	Mean acres enrolled in the CRP (3)
	A. By Farm Size (Acreage)		
Farmland < 100 acres	-0.734 † † †	26.6% ***	19.1
	(0.093)		
100 acres ≤ Farmland < 250 acres	-0.118	14.8% ***	46.3
	(0.095)		
250 acres ≤ Farmland < 500 acres	-0.136	13.0% ***	97.8
	(0.100)		
500 acres ≤ Farmland	-0.131	13.5% **	260.5
	(0.111)		
	B. By Farm Type and Farm Size (Sales)		
Part-time farm with sales < $10,000	-1.103	-10.3%	33.4
	(0.179)		
Part-time farm with sales ≥ $10,000	0.148	4.5%	77.1
	(0.188)		
Full-time farm with sales < $10,000	0.365 *	26.2% **	56.3
	(0.210)		
Full-time farm with $10,000 ≤ sales < $50,000	0.263	16.0% ***	125.0
	(0.186)		
Part-time farm with sales ≥ $50,000	0.241	13.8% *	194.6
	(0.194)		

Note: Panel A and panel B report slippage estimates by two different farm size definitions. In panel A, the slippage estimate is allowed to vary across farmland size (with the smallest farmland size group as a reference). In panel B, the slippage estimate is allowed to vary across operator's principal occupation and farm sales categories (with smaller non-farm farms as a reference). Estimation is conducted with full specification, i.e., with all covariates and all sets of fixed effects. A dependent variable is the change in cropped acreage over 1982-1992. See notes to table 5 for the definition of cropped acres. Heteroskedasticity-robust standard errors are reported in parenthesis. Column (1) reports coefficient estimates of CRP acreage change and its interaction terms with respective group indicator variables. Slippage rates in column (2) are computed from those estimated coefficients. Column (3) reports mean acreage enrolled in the CRP for each group. † † †, ††, and † indicate significant difference from -1 at the 99th, 95th and 90th percentiles, respectively. ***, ** and * indicate significant difference from zero at the 99th, 95th and 90th percentiles, respectively.

Table 10: Distribution of Slippage Estimates from the 1982-1992 Long Panel by CRP Signup Periods

CRP Enrollment Period	Coefficient Estimate (1)	Slippage Rate (2)	Mean acreage enrolled in the CRP (3)
Enrollment during 1986	-0.873 ††	13.7%**	94.1
	(0.057)		
Enrollment during 1987-91	-0.055	12.2%*	101.9
	(0.069)		
Enrollment during 1986 and 1987-91	0.145	28.2%***	164.5
	(0.091)		

Note: An enrollment-specific slippage rate is estimated by including the interaction of the CRP acreage change and indicator variables of the enrollment status of CRP participants. The enrollment status is classified into three categories: (i) 82-87 enrollees who enrolled in the CRP only prior to 1987 (reference); (ii) 87-92 enrollees who enrolled in the CRP only after 1987; and (iii) 82-92 enrollees who enrolled in the CRP during both of the 1982-1987 and 1987-1992 periods. Estimation is conducted with full specification, i.e., with all covariates and all sets of fixed effects. A dependent variable is the change in cropped acreage over 1982-1992. See notes to table 5 for the definition of cropped acres. Heteroskedasticity-robust standard errors are reported in parenthesis. Column (1) reports coefficient estimates of CRP acreage change and its interaction terms with respective group indicator variables. Slippage rates in column (2) are computed from those estimated coefficients. Column (3) reports mean acreage enrolled in the CRP for each group. † † †, ††, and † indicate significant difference from -1 at the 99th, 95th and 90th percentiles, respectively. ***, ** and * indicate significant difference from zero at the 99th, 95th and 90th percentiles, respectively.

Table 11: Regression Results for Grain Farms from the 1982-1987 and 1987-1992 Panel Data

Panel Period	1982-1987 (1)	1987-1992 with only new CRP (2)	1982-1992 (3)
Change in CRP acres	-0.755 † † †	-0.875 † † †	-0.864 † † †
	(0.093)	(0.043)	(0.048)
Farm characteristics	YES	YES	YES
Base-year farm characteristics	YES	YES	YES
Farm fixed effects	YES	YES	YES
County-year fixed effects	YES	YES	YES
SIC fixed effects	YES	YES	YES
Observations	28286	18504	12074
Adjusted R2	0.33	0.69	0.63

Note: Estimation results from 1982-1987 and 1987-1992 panel data are compared with the 1982-1992 estimation result. Estimation is conducted with full specification, i.e., with all covariates and all sets of fixed effects. A dependent variable for each panel data is the change in cropped acreage over the respective panel period. See notes to table 5 for the definitions of cropping acreage. The 1987-1992 panel data analysis in column (2) uses only participants enrolling after 1987 to avoid the measurement error of the dependent variable as discussed in section 5.2. Heteroskedasticity-robust standard errors are reported in parenthesis. For the coefficient of the CRP acreage change, † † †, ††, and † indicate significant difference from -1 at the 99th, 95th and 90th percentiles, respectively. For the coefficient of the other covariates, ***, ** and * indicate significant difference from zero at the respective percentiles.

Table 12: Trend of Regional Slippage Incidence during the 1982-1992 Period

Panel Period	1982-1987 (1)	1987-1992 with only new CRP (2)	1982-1992 (3)
Corn Belt	16.3%***	15.1%***	9.7% ***
Lake States	19.7%***	23.0%***	15.4%***
Northern Plains	17.5%***	7.8%	15.3%***
Southern Plains	29.6%***	43.8%***	34.9%*
Mountain	28.3%***	14.9%	14.3%
Other regions	37.4%***	1.1%	2.4%
Total	24.5%***	12.5%***	13.6%

Note: Region-specific slippage rates are computed from each of the 1982-1987, 1987-1992, and 1982-1992 panel data estimations by including the interaction of the CRP acreage change and region indicator variables. The Corn Belt region includes Illinois, Indiana, Iowa, Missouri and Ohio, the Lake States include Michigan, Minnesota and Wisconsin, the Northern Plains include Kansas, Nebraska, North Dakota and South Dakota, the South Plains include Oklahoma and Texas, and the Mountain region includes Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming. Estimation is conducted with full specification, i.e., with all covariates and all sets of fixed effects. A dependent variable is the change in cropped acreage over 1982-1992. See notes to table 5 for the definition of cropped acres. The 1987-1992 panel data analysis in column (2) uses only participants enrolling after 1987 to avoid the measurement error of the dependent variable as discussed in section 5.2. ***, ** and * indicate significant difference from zero at the 99th, 95th and 90th percentiles, respectively.

Table 13: Regression Results for All Farms from the 1982-1992 Long Panel Data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Change in CRP acres	-0.863 † † †	-0.856 † † †	-0.854 † † †	-0.859 † † †	-0.856 † † †	-0.865 † † †	-0.859 † † †
	(0.045)	(0.047)	(0.055)	(0.051)	(0.051)	(0.046)	(0.043)
Change in CRP acres X Non-grain farms	0.094	0.113 *	0.267 ***	0.098	0.110	0.247 ***	
	(0.064)	(0.066)	(0.080)	(0.065)	(0.067)	(0.074)	
Change in CRP acres X Non-grain crop farms							0.093
							(0.121)
Change in CRP acres X Livestock farms							0.319 ***
							(0.078)
Farm characteristics	NO	YES	YES	NO	YES	YES	YES
Base-year farm characteristics	NO	NO	YES	NO	NO	YES	YES
Farm fixed effects	YES	YES	YES	YES	YES	YES	YES
County-year fixed effects	NO	NO	NO	YES	YES	YES	YES
SIC fixed effects	NO	NO	NO	YES	YES	YES	YES
Observations	84155	84155	84155	84155	84155	84155	84155
Adjusted R2	0.24	0.25	0.32	0.35	0.35	0.42	0.43

Note: A dependent variable is the change in cropped acreage over 1982-1992. See notes to table 5 for the definition of cropped acres. Heteroskedasticity-robust standard errors are reported in parenthesis. For the coefficient of the CRP acreage change, † † †, ††, and † indicate significant difference from -1 at the 99th, 95th and 90th percentiles, respectively. For the coefficient of the other covariates, ***, ** and * indicate significant difference from zero at the respective percentiles.

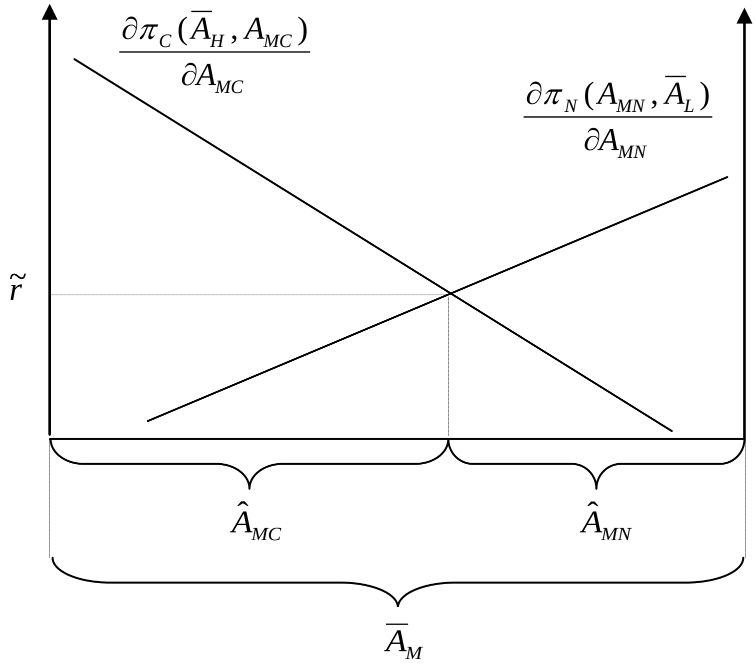

Figure 1: Farmland allocation decision for medium-quality land

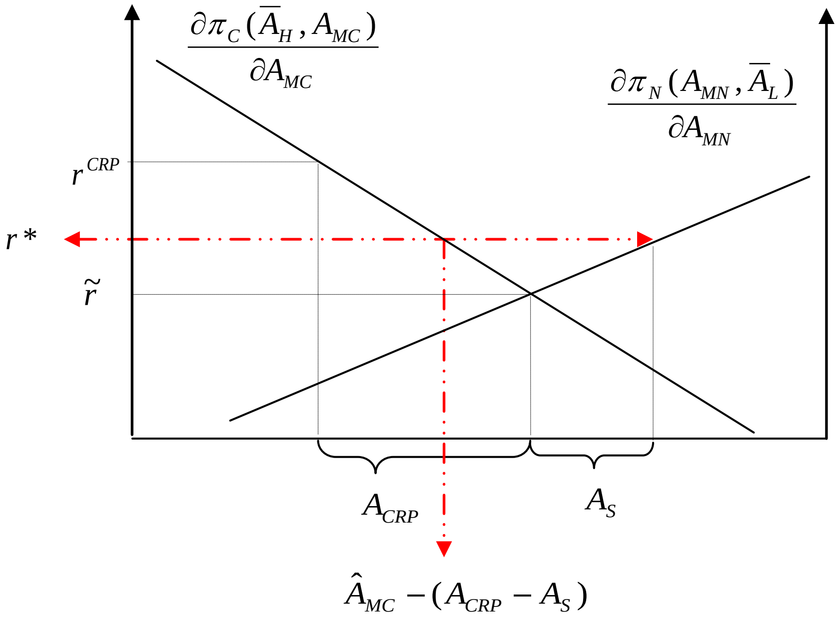

Figure 2: Impact of CRP enrollment on subsequent land allocation for medium-quality land

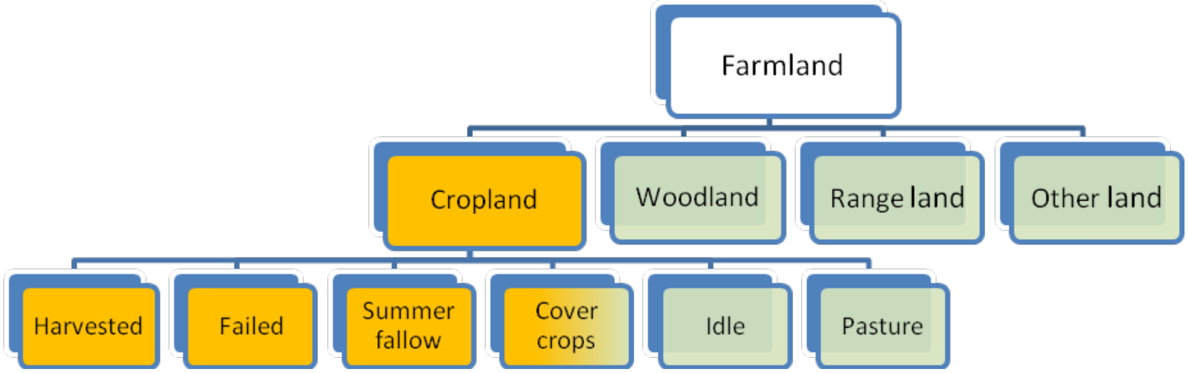

Figure 3: Land use categories in the Census of Agriculture

Essay II

Aggregate and Farm-Level Productivity Growth in Tobacco: Before and After the Quota Buyout

abstract

This study examines the distortionary effects of agricultural policy on farm productivity by examining the response of U.S. tobacco farmers' productivity to the quota buyout of 2004. We focus on the impact of distortionary policy, i.e., the tobacco quota, by decomposing aggregate productivity growth into the contribution of farm-level productivity growth and the contribution of reallocation of resources among tobacco growers. We find that the aggregate productivity of Kentucky tobacco farms grew 44% between 2002 and 2007. The elimination of quota rental costs and reallocation of resources, including entry and exit, accounted for most of the post-buyout productivity growth. It is also noted that the aggregate productivity of Kentucky tobacco farms vary across farm characteristics and locations. This highlight the importance of using highly disaggregated data to uncover the sources of aggregate productivity growth.

JEL Classification Codes: Q18, Q12, O47

Keywords: Tobacco, Quotas, Aggregate Productivity Growth, Reallocation.

This is a co-authored work with Barrett E. Kirwan, assistant professor in the Department of Agricultural and Consumer Economics at the University of Illinois and T. Kirk White, economist at the Center for Economic Studies, Census Bureau, Department of Commerce. The views expressed are those of the authors and should not be attributed to ERS or USDA. The results in this paper have been screened to insure that no confidential information is revealed.The authors wish to thank two anonymous reviewers and David Hennessy, Erik Lichtenberg, and Jim MacDonald for comments and suggestions,and Jim Burt for many disclosure avoidance reviews. This is a pre-copy-editing, author-produced PDF of an article accepted for publication in the American Journal of Agriculture Economics following peer review. The definitive publisher-authenticated version 94(4):838-853 is available online at: http://ajae.oxfordjournals.org/content/early/2012/05/07/ajae.aas019.full.

AGGREGATE AND FARM-LEVEL PRODUCTIVITY GROWTH IN TOBACCO: BEFORE AND AFTER THE QUOTA BUYOUT

BARRETT E. KIRWAN, SHINSUKE UCHIDA, AND T. KIRK WHITE

We examine the distortionary effects of agricultural policy on farm productivity by examining the response of U.S. tobacco farmers' productivity to the quota buyout of 2004. We focus on the impact of distortionary policy, i.e., the tobacco quota, by decomposing aggregate productivity growth into the contribution of farm-level productivity growth and the contribution of reallocation of resources among tobacco growers. We find that the aggregate productivity of Kentucky tobacco farms grew 44% between 2002 and 2007. The elimination of quota rental costs and reallocation of resources, including entry and exit, accounted for most of the post-buyout productivity growth.

Key words: Tobacco; Quotas; Aggregate Productivity Growth; Reallocation.

JEL codes: Q18, Q12, O47.

The Tobacco Transition Act of 2004 ended a 66-year-old federal farm program and replaced it with...nothing. The Transition Act, also known as the tobacco quota buyout, was a rapid and complete market liberalization: from one growing season to the next, U.S. tobacco production went from a policy environment of severe restrictions on production to a free market regime. Such a large and seemingly permanent policy change provides an opportunity to study the full effects of distortionary economic policy. In this article we seize this opportunity by analyzing the effects of the buyout on aggregate productivity growth in tobacco production. We focus on a single major tobacco-producing state: Kentucky.[1]

Under the federal tobacco program, the USDA annually set an aggregate limit on virtually all domestic tobacco production and supported the prices received by U.S. tobacco growers. In addition, in most states, tobacco quota could not be sold or leased across county lines. These and other restrictions of the quota program limited growers' ability to efficiently allocate land and other resources for tobacco production. The quotas were a source of economic rents for quota owners, but they were also a major expense for growers, many of whom leased some if not all of their quota. Economic theory predicts that removing the restrictions imposed by the quota program frees farmers to allocate resources to tobacco production more efficiently. To what extent has reallocation occurred? To what extent did reallocation of resources contribute to productivity growth in tobacco production after the buyout?

Previous economic research has studied the effects of the quota buyout. For example, Brown, Rucker, and Thurman (2007) analyzed the distortionary effects of the quota program and used county-level data and simulations to predict the effects of the quota buyouts on production. They calibrated their simulation models with historical data and predicted that in the medium run tobacco production would increase. In fact, tobacco production decreased. Dohlman, Foreman, and Da Pra (2009) report that after the 2004 buyout harvested acreage for burley leaf and flue-cured leaf fell by 30 and 25-percent, respectively (although flue-cured production subsequently recovered). Brown, Rucker, and Thurman (2007) acknowledge that "the exit of some tobacco growers" was a complicating issue to

---

Barrett E. Kirwan is an assistant professor in the Department of Agricultural and Consumer Economics at the University of Illinois. Shinsuke Uchida is a PhD candidate in the Department of Agricultural and Resource Economics at the University of Maryland. T. Kirk White is an economist with USDA's Economic Research Service (ERS). The views expressed are those of the authors and should not be attributed to ERS or USDA. The results in this paper have been screened to insure that no confidential information is revealed. The authors wish to thank two anonymous reviewers and David Hennessy, Erik Lichtenberg, and Jim MacDonald for comments and suggestions, and Jim Burt for many disclosure avoidance reviews.

[1] Kentucky produces more tobacco than any state other than North Carolina. We focus on Kentucky and not North Carolina because estimates of tobacco quota rental rates are readily available for Kentucky for the period of interest.

Amer. J. Agr. Econ. 94(4): 838–853; doi: 10.1093/ajae/aas019

their analysis. Such a large number of grower exits changed sectoral dynamics so much that a well-calibrated tobacco-sector forecast model provided substantially incorrect forecasts.

In this article we focus on the total factor productivity of tobacco growers in Kentucky before and after the buyout. We use data from the 1997, 2002, and 2007 Censuses of Agriculture, linked longitudinally at the farm level. In contrast to previous research, the panel we construct allows us to decompose the effects of the buyout into the contributions of farms that continued producing tobacco and the contributions of entrants into and exiters from tobacco production.

Methodologically, we combine the aggregate productivity growth decompositions of Diewert and Fox (2010) and Petrin and Levinsohn (2010), adapted to the context of tobacco production in Kentucky before and after the quota buyout. The Petrin and Levinsohn approach allows us to decompose the aggregate productivity growth (APG) of continuing farms into the contributions of farm-level technical efficiency growth and APG due to reallocation of resources among continuing farms. The Diewert and Fox index number approach allows us to separately account for the contributions of continuing farms versus entering and exiting farms.

We find that the aggregate productivity of Kentucky tobacco farms decreased by 7.1% between 1997 and 2002 and increased by 44% between 2002 and 2007. Reallocation of resources played an important role in aggregate productivity growth. About 22 percentage points of the 44% post-buyout increase in aggregate productivity in Kentucky tobacco production was due to reallocation of inputs among continuing farms and entry into and exit from tobacco production among existing farms. The combined contributions of the elimination of quota rental costs and reallocation of resources accounted for most of the post-buyout aggregate productivity growth of Kentucky tobacco farms.

The Tobacco Quota Program, the Quota Buyout, and Trends in Kentucky Tobacco Production

Under the federal tobacco program, growers had to own or lease marketing quota in order to sell tobacco. Allocated by the federal government when the program started in 1938, quota was an asset with its own market, but it was not completely freely tradable. The program applied to the two major types of tobacco, burley and flue-cured. Each crop had unique rules. Here we discuss the burley program because burley makes up the vast majority of the value of tobacco production in Kentucky, where this article focuses.[2] Womach (2003) provides an overview of the program for both burley and flue-cured tobacco.

The quota program placed both geographic and temporal restrictions on the allocation of land and other resources to tobacco production. Starting in 1991, burley growers could buy or lease quota separately from the land on which the tobacco was grown. In most states, including Kentucky, burley quota could not be sold or leased across county lines. Quota could only be sold or leased to active growers. However, it could be inherited, and it could be retained by inactive growers. In the final years of the program, most quota was not owned by active growers (Womach 2004). Quota had to be used by the owner or leased to another grower in 2 out of 3 years or be forfeited.

In Kentucky, the average quota lease rate increased from about 27 cents per pound in 1997 to about 59 cents per pound in 2002. These averages obscure wide variation in quota lease prices across Kentucky counties, reflecting the county-level variation in marginal costs of tobacco production. Quota lease prices ranged from 5 to 48 cents per pound in 1997 and from 25 to 85 cents per pound in 2002.[3] Over the same period, the average (nominal) price of tobacco in Kentucky increased only slightly from $1.90 per pound in 1997 to $2.02 per pound in 2002.[4] Thus quota rental costs were a significant and increasing fraction of the price of tobacco. The large across-county variation in quota lease prices also provides some evidence of the extent to which the quota program distorted tobacco production decisions. In the absence of restrictions on the across-county trade of quota, we would expect tobacco production to be reallocated to counties with lower

---

[2] Prior to the buyout in 1997 and 2002, respectively 96% and 91% of the value of tobacco produced in Kentucky was from burley tobacco, with fire-cured and dark tobacco accounting for the rest. By 2007, fire-cured and dark tobacco accounted for the 24% of the value of Kentucky tobacco production, with burley accounting for the remaining 76%. See the NASS Quickstats website at http://www.nass.usda.gov/QuickStats.

[3] We thank Will Snell of the University of Kentucky for providing us with his unofficial estimates of the quota lease prices for every Kentucky tobacco-producing county over the period 1991–2004.

[4] See the NASS Quickstats website: http://quickstats.nass.usda.gov.

marginal costs until quota lease prices were equalized across counties (Rucker, Thurman, and Sumner 1995).

The design of the quota buyout also likely affected production decisions. Quota owners received \$7 per pound of quota. Importantly, growers who produced tobacco between 2002 and 2004 received an additional \$3 per pound of quota–the so-called "grower benefit." Various proposed versions of the quota buyout were discussed in policy circles and tobacco communities years in advance of the Transition Act. In light of these facts, it seems likely that, in order to capture the grower benefit, some quota owners continued or even entered tobacco production instead of renting out their quota in 2002.

Because of increasing foreign competition and decreasing domestic demand, U.S. tobacco production declined steeply between 1997 and 2002.[5] Kentucky followed the national trend, with the number of Kentucky farms with tobacco sales decreasing from 46,792 in 1997 to 29,253 in 2002.[6] After the buyout, demand for tobacco products in the U.S. continued to decline, and the cost of inputs to production such as hired labor and fuel increased. Net exports of U.S. tobacco leaf increased after the buyout, in part because the price of U.S. leaf declined when the effective price support of the quota program was removed (Dohlman, Foreman, and DaPra 2009). However, after the buyout the number of tobacco farms continued to decline, both nationally and in Kentucky. By 2007, there were only 8,113 tobacco farms in Kentucky.

A Brief Review of Reallocation and Aggregate Productivity Growth Decompositions

Hulten (1978) shows that in a perfectly competitive economy with no distortions, adjustment costs, or other frictions, aggregate productivity growth is equal to the weighted sum of enterprise-level technical efficiency growth rates, i.e., aggregate technical efficiency growth. In a seminal paper, Baily, Hulten, and Campbell (1992, BHC hereafter) define aggregate productivity growth as the weighted sum of plant-level technical efficiencies. Then they decompose this index into the output-share-weighted sum of the growth rates of plant-level technical efficiency (the "within" component), and the technical-efficiency-weighted sum of the changes in plant-level output shares (the "between" component). The between component is usually interpreted as measuring the contribution of reallocation to aggregate productivity growth. Several other authors refine the BHC decomposition to include additional terms in the decomposition (Griliches and Regev 1995; Olley and Pakes 1996; Foster, Haltiwanger, and Krizan 2001). All of these decompositions share the feature that aggregate productivity is defined as the weighted sum of plant-level (or firm-level) productivity.

All of the BHC-like decompositions share a common problem. As emphasized by Petrin and Levinsohn (2010, P-L hereafter), in an economy in competitive equilibrium with no distortions, adjustment costs, or other frictions, further reallocation of resources does not contribute to aggregate productivity growth. In other words, in such an economy, the "between" component in a BHC decomposition does not measure the contribution of reallocation to aggregate productivity growth. Both P-L and Basu and Fernald (2002) point out that when there are adjustment costs or markups over marginal cost or other distortions (such as taxes, subsidies, or quotas), (i) aggregate productivity growth is generally not equal to aggregate technical efficiency growth and (ii) reallocation of resources can contribute to aggregate productivity growth. These theoretical results imply that in an economy in which markups or distortions such as taxes or subsidies or quotas are important, the BHC index misses an important component of aggregate productivity growth. Recent empirical results using manufacturing data from the U.S., Japan, and Chile show that the difference between aggregate productivity growth and the growth rate of a BHC type of index can be quite large (Petrin, White, and Reiter 2011; Kwon, Narita, and Narita 2009; Petrin and Levinsohn 2010).

Growing empirical and theoretical literatures have highlighted the importance of resource reallocation for aggregate productivity growth (Melitz 2003; Bernard et al. 2003; Lentz and Mortensen 2008; Petrin, White, and Reiter 2011). Recent studies by Restuccia and Rogerson (2008) and Hsieh and Klenow (2009) have also found that

---

[5] Domestic demand for tobacco leaf declined for a variety of reasons, including health concerns associated with tobacco products, increasing state and Federal excise taxes on tobacco products, and increased restrictions on smoking in public (Dohlman, Foreman, and DaPra 2009).

[6] These are USDA's published totals. See the NASS Quickstats website: http://quickstats.nass.usda.gov.

within-industry heterogeneity in distortions (e.g., taxes or subsidies) may have important effects on aggregate total factor productivity. Both within-industry heterogeneity in distortions (because of restrictions on leasing quota across counties) and reallocation of resources were clearly important features of Kentucky tobacco production in the years before and after the quota buyout. In light of these facts, we use an aggregate productivity decomposition that accounts for the role of heterogeneous distortions and reallocation in determining the aggregate productivity growth of Kentucky tobacco farms, namely the P-L decomposition.

The Petrin-Levinsohn Decomposition

Petrin and Levinsohn (2010) show how to decompose aggregate productivity growth into the separate contributions of firm-level technical efficiency growth and the reallocation of each factor of production across firms. We apply the P-L methodology, except that we adapt it to U.S. tobacco production before and after the quota buyouts. We follow the discussion of the theory in P-L. For the purpose of explaining the theory, we assume that all tobacco farms only produce tobacco.[7] Each farm i's production technology can be represented as[8]

$$(1) \qquad Q_i = F(X_i, M_i, \omega_i).$$

where $X_i = (X_{i1}, \ldots, X_{iK})$ is a vector of primary input usage (land, labor, buildings and machinery) on farm i and $M_i = (M_{i1}, \ldots, M_{iJ})$ is the vector of intermediate inputs (fertilizer, agricultural chemicals, seeds, fuel, etc.). Finally, ω_i is the level of farm i's technical efficiency.

Here we adapt the P-L framework for the purpose of measuring the aggregate productivity of tobacco farms under the quota program. P-L defines aggregate productivity change as the change in aggregate *final demand* minus the change in aggregate costs, where a firm's final demand Y_i is its output Q_i minus the portion of its output that is used as intermediate input by all other firms: $Y_i = Q_i - \sum_j M_{ji}$, where M_{ji} denotes output from firm i used as intermediate input at firm j. If we sum across all firms, aggregate final demand is equal to aggregate value-added. Since we are focusing on a single industry (tobacco production) and we do not observe the final demand for tobacco farms' output, we can write this industry's aggregate productivity change as the change in the aggregate *output* of the industry minus the change in aggregate costs:

$$(2) \qquad dAP \equiv \sum_i P_i dQ_i - \sum_i \sum_k W_{ik} dX_{ik} - \sum_i \sum_j P_{ij} dM_{ij} - \sum_i R_i dQuota_i,$$

where the summation is over Kentucky tobacco farms. P_i denotes the price of farm i's tobacco, and thus $\sum_i P_i dQ_i$ is equal to the instantaneous change in aggregate output holding prices constant. W_{ik} is the marginal cost of the k^{th} primary input and dX_{ik} is the instantaneous change in the use of that primary input at farm i. P_{ij} is the price of intermediate input j at farm i, and dM_{ij} is the instantaneous change in the use of that input. The last term on the right side of equation (2) captures the direct cost of renting quota, where R_i is the rental rate of quota for farm i, and $dQuota_i$ is i's change in quota usage. For farms that own quota for all of the tobacco that they sell, R_i captures the opportunity cost at the margin of not renting out their quota. Quotas can have an indirect effect on aggregate productivity by driving a wedge between value marginal products and marginal costs. At the level of the entire economy, the quota rents themselves are just a redistribution of wealth from renters to owners, and do not *directly* affect aggregate productivity.[9] However, as noted above, by the end of the tobacco program, most quota was not owned by growers, and quota rental was a significant cost for tobacco growers. Since we are analyzing aggregate productivity at the level of the tobacco production industry, we include changes in these quota rental costs as part of our measure of aggregate productivity.

---

[7] In the data many tobacco farms also produce other crops and/or livestock. We discuss how we deal with multi-output farms in the measurement section below.

[8] Petrin and Levinsohn (2010) allow for fixed costs of production, which are subtracted from output. Here we abstract from fixed costs.

[9] We thank Tom Vukina for pointing this out.

P-L shows that if the farm-level production function F is differentiable, then the change in aggregate productivity in equation (2) can be decomposed as:

$$dAP = \sum_i \sum_k \left(P_i \frac{\partial F}{\partial X_k} - W_{ik} \right) dX_{ik} + \sum_i \sum_j \left(P_i \frac{\partial F}{\partial M_j} - P_j \right) dM_{ij} - \sum_i R_i dQuota_i + \sum_i P_i d\omega_i, \tag{3}$$

Equation (3) decomposes the change in aggregate productivity into the contributions of, respectively, reallocation of primary and intermediate inputs, the reallocation of quota, and farm-level technical efficiency change. The first two double-summation terms on the right side of equation (3) measure the contributions of reallocation of primary (X) and intermediate (M) inputs. Within these terms, the expressions $P_i \frac{\partial F}{\partial X_k} - W_{ik}$ and $P_i \frac{\partial F}{\partial M_j} - P_j$ are gaps or wedges reflecting the difference between the farm's value marginal product and its marginal cost for each input. If the value marginal product is equal to the marginal cost for every input on every farm, then reallocation of inputs will not contribute to aggregate productivity change. In this case, in the absence of quota rental costs, the change in aggregate productivity is just the price-weighted sum of the changes in farm-level technical efficiencies: $dAP = \sum_i P_i d\omega_i$. However, if there are gaps between the value marginal products and the marginal costs for any of the inputs, then reallocation also contributes to aggregate productivity change. Note that the P-L decomposition does not force us to take a stand on what is causing the gaps between marginal products and marginal costs. If there are gaps for any reason, then the first two double summations in equation (3) measure the contribution of reallocation to aggregate productivity change. In the case of Kentucky tobacco production before the buyout, quota lease prices varied widely across counties, suggesting that restrictions on reallocating quota across counties drove wedges been marginal products and marginal costs.

If we divide equation (2) by the aggregate value-added of the industry and do a bit of algebra, we obtain the following equation for aggregate productivity growth (APG):

$$APG = \sum_i D_i dlnQ_i - \sum_k \sum_i D_i c_{ik} dlnX_{ik} - \sum_j \sum_i D_i c_{ij} dlnM_{ij} - \sum_i c_{iq} dlnQuota_i \tag{4}$$

where $D_i = \frac{P_i Q_i}{\sum_{i=1}^{N} P_i Y_i}$ is the Domar (1961) weight, $c_{ik} = \frac{W_{ik} X_{ik}}{P_i Q_i}$ is the revenue share of primary input k, $c_{ij} = \frac{P_{ij} M_{ij}}{P_i Q_i}$ is the revenue share of intermediate input j, and $c_{iq} = \frac{R_i Quota_i}{P_i Q_i}$ is the revenue share of quota rental costs. The Domar weight takes into account the fact that some of farm i's output will contribute to aggregate productivity growth because it will be used as intermediate input in other industries.

If we divide both sides of equation (3) by the aggregate value-added of the industry and do some more algebra, then aggregate productivity growth in equation (4) can be decomposed as:

$$APG = \sum_i D_i \sum_k (\varepsilon_{ik} - c_{ik}) dlnX_{ik} + \sum_i D_i \sum_j (\varepsilon_{ij} - c_{ij}) dlnM_{ij} - \sum_i D_i c_{iq} dlnQuota_i + \sum_i D_i dln\omega_i, \tag{5}$$

where D_i is the Domar weight, ε_{ik} and ε_{ij} are the elasticities of output with respect to primary and intermediate inputs, $c_{ik} = \frac{W_{ik} X_{ik}}{P_i Q_i}$ and $c_{ij} = \frac{P_j M_{ij}}{P_i Q_i}$ are the respective farm-specific revenue shares for primary and intermediate inputs, and $dln\omega_i$ is the growth rate of farm i's technical efficiency, where the base is Q_i: $dln\omega_i \equiv \frac{d\omega_i}{Q_i}$. Equation (5) decomposes aggregate productivity *growth* into the contributions of, respectively, reallocation of primary and intermediate inputs, the reallocation of quota, and farm-level technical efficiency growth. Now the gap expressions $\varepsilon_{ik} - c_{ik}$ and $\varepsilon_{ij} - c_{ij}$ represent differences between the output elasticities and the revenue-shares, but the intuition is the same as for the aggregate productivity change decomposition (equation 3): if markups, subsidies, quotas, or other distortions drive a wedge between an input's value marginal product and its marginal cost, then reallocation will contribute to aggregate productivity growth.

Discrete-Time Approximation and Dealing with Entry and Exit

The Petrin and Levinsohn (2010) theory is developed in continuous time. In the real world, data is collected at discrete intervals. We could approximate equation (4) with a Törnqvist index, which has many desirable properties (Diewert 1976). However, the Törnqvist index cannot be used to calculate the contribution of entering or exiting farms, since it is impossible to compute farm-level growth rates for farms that are observed in only one of the two consecutive periods. Entering and exiting tobacco farms made up a significant portion of the changes in total tobacco production, and so it is important for us to account for those farms when measuring aggregate productivity growth.

Diewert and Fox (2010, D-F hereafter) develop a multilateral index number approach to measuring the contribution of entering and exiting firms to aggregate productivity growth. Since tobacco farms produce multiple outputs and use multiple inputs, we would ideally define farm-level productivity using the farm's entire vector of input and output prices and quantities. Unfortunately we do not observe all these prices and quantities–for most inputs we only observe expenditures. In this situation D-F suggest constructing firm-level "approximate output and input aggregates" using (deflated) revenues and costs. For simplicity of exposition we continue to assume that each farm has only one output. Thus for each farm i, approximate productivity in year t, Π_{it} is:

$$(6)\qquad \Pi_{it} = \frac{P_{it}Q_{it}}{\sum_k W_{ikt}X_{ikt} + \sum_j P_{ijt}M_{jit} + R_{it}Quota_{it}}$$

where all the variables on the right side are defined above.[10]

Using this definition of farm-level productivity, an approximation of aggregate productivity is:

$$(7)\qquad AP_t = \frac{\sum_i P_{it}Q_{it}}{\sum_i \left(\sum_k W_{ikt}X_{ikt} + \sum_j P_{ijt}M_{jit} + R_{it}Quota_{it}\right)}$$

where the outer summations are over all farms active in year t. Intuitively, this measures aggregate productivity as aggregate revenues over aggregate primary and intermediate input costs and quota rental costs.[11]

Let $cost_{it}$ denote farm i's costs in year t: $cost_{it} = \sum_k W_{ikt}X_{ikt} + \sum_j P_{ijt}M_{jit} + R_{it}Quota_{it}$. Aggregate productivity in year t can be decomposed as:

$$(8)\qquad AP_t = \sum_{i\in C} s_{it}\Pi_{it} + \sum_{i\in E} s_{it}\Pi_{it}$$

where $s_{it} = \frac{cost_{it}}{\sum_i cost_{it}}$ is farm i's share of aggregate costs in year t, C denotes the set of farms that continued from $t-5$ to t, and E denotes the set of farms that entered between $t-5$ and t. Similarly, we can decompose aggregate productivity in year $t-5$ as:

$$(9)\qquad AP_{t-5} = \sum_{i\in C} s_{i,t-5}\Pi_{i,t-5} + \sum_{i\in \chi} s_{i,t-5}\Pi_{i,t-5}$$

where again C denotes the set of farms that continue from $t-5$ to t, and χ is the set of farms that exit between $t-5$ and t. Approximate APG is then computed as $(AP_t - AP_{t-5})/AP_{t-5}$. Combining equations (8) and (9) and rearranging terms yields:

$$(10)\qquad APG_t = \left[\sum_{i\in C}(s_{it}\Pi_{it} - s_{i,t-5}\Pi_{i,t-5})\right]/AP_{t-5} + \left[\sum_{i\in E} s_{it}\Pi_{it} - \sum_{i\in\chi} s_{i,t-5}\Pi_{i,t-5}\right]/AP_{t-5}$$

The first line of (10) approximates the contribution of continuing farms to APG, and the

---

[10] In practice we deflate the revenues and expenditures in equation (6) using state-level price indexes. Here we abstract from deflators for simplicity of exposition.

[11] Note that if we use equation (7) to derive the change in aggregate productivity resulting from an infinitesimal change in all of the inputs, holding prices constant, the result is equation (2).

second line approximates the contribution of farms identified as entrants and exits.

For *continuing* farms in the pre-buyout period, the P-L decomposition of APG into reallocation and technical efficiency growth in equation (5) can be approximated by the following Törnqvist index:

$$(11)\quad APG_{Ct} = \sum_{i\in C}\overline{D}_{it}\left[\sum_{k}(\overline{\varepsilon}_{ikt}-\overline{c}_{ikt})\Delta lnX_{ikt} + \sum_{j}(\overline{\varepsilon}_{ijt}-\overline{c}_{ijt})\Delta lnM_{ijt}\right] - \sum_{i\in C}\overline{D}_{it}\overline{c}_{iqt}\Delta lnQuota_{it} + \sum_{i\in C}\overline{D}_{it}\Delta ln\omega_{it}$$

where for any variable z, $\overline{z}_{it} = \frac{z_{it}+z_{i,t-5}}{2}$, Δ is the first difference operator, and C denotes the set of continuing tobacco farms. In the post-buyout period, we drop the quota rental costs in equation (11) for the same reason we exclude entrants and exits. After the buyout, all farms had zero quota, so we cannot measure the (negative) growth rate of quota for these farms. Substituting equation (11) into equation (10), for 1997–2002 we have:

$$(12)\quad APG_t = \sum_{i\in C}\overline{D}_{it}\left[\sum_{k}(\overline{\varepsilon}_{ikt}-\overline{c}_{ikt})\Delta lnX_{ikt} + \sum_{j}(\overline{\varepsilon}_{ijt}-\overline{c}_{ijt})\Delta lnM_{ijt}\right] - \sum_{i\in C}\overline{D}_{it}\overline{c}_{iqt}\Delta lnQuota_{it} + \sum_{i\in C}\overline{D}_{it}\Delta ln\omega_{it} + \sum_{i\in C}U_{it} + \left[\sum_{i\in E}s_{it}\Pi_{it} - \sum_{i\in \chi} \times s_{i,t-5}\Pi_{i,t-5}\right]/AP_{t-5}$$

where the residual term for continuers $\sum_{i\in C}U_{it}$ is the difference between the D-F APG approximation and the P-L APG approximation for continuers:

$$(13)\quad \sum_{i\in C}U_{it} \equiv \left[\sum_{i\in C}(s_{it}\Pi_{it} - s_{i,t-5}\Pi_{i,t-5})\right]/AP_{t-5} - \sum_{i\in C}\overline{D}_{it}\left[\sum_{k}(\overline{\varepsilon}_{ikt}-\overline{c}_{ikt})\Delta lnX_{ikt} + \sum_{j}(\overline{\varepsilon}_{ijt}-\overline{c}_{ijt})\Delta lnM_{ijt}\right] + \sum_{i\in C}\overline{D}_{it}\overline{c}_{iqt}\Delta lnQuota_{it} - \sum_{i\in C}\overline{D}_{it}\Delta ln\omega_{it}$$

Intuitively, the $\sum_{i\in C}U_{it}$ term accounts for the fact that the index of aggregate productivity in equation (10) includes changes in relative prices of inputs and output, whereas the Törnqvist approximation for continuers in equation (11) holds these prices constant. Equations (12) and (13) apply to the pre-buyout period. When we decompose APG for 2002–2007, we drop the quota reallocation term, $\sum_{i\in C}\overline{D}_{it}\overline{c}_{iqt}\Delta lnQuota_{it}$, from equations (12) and (13). As a result, for 2002–2007, the $\sum_{i\in C}U_{it}$ term also accounts for the fact the D-F decomposition in equation (10) includes changes in the costs of quota, but the P-L decomposition for continuers (for 2002–2007) does not.

To measure the contribution of each term to APG in equation (12), we calculate revenue shares, c_{ikt} and c_{ijt}, and cost shares s_{it} separately for each farm in each year. To measure the output elasticities ε_{ikt} and ε_{ijt} and the growth rate of farm-level technical efficiency, we estimate production functions, as described in the next section.

Production Function Estimation

We assume Kentucky tobacco farms' production technology can be approximated by a translog production function. Specifically, we estimate the following by OLS, OLS with county fixed effects, and using the Levinsohn and Petrin (2003, L-P hereafter) estimator, which attempts to address the input endogeneity issues pointed out by Marschak and Andrews (1944):[12]

$$(14)\quad lnQ_{it} = \beta_0 + \sum_{\kappa}\beta_{\kappa} lnZ_{i\kappa t} + \sum_{\kappa}\beta_{\kappa}(lnZ_{i\kappa t})^2 + \frac{1}{2}\sum_{\kappa}\sum_{l\neq\kappa}\beta_{\kappa l} lnZ_{i\kappa t} lnZ_{ilt} + u_{it}$$

where Q is *output* of farm i in year t, $Z_{i\kappa t}$ is primary or intermediate input κ, and u_{it} is an error term. For inputs, we use *land* (acres harvested), *labor* (including hired, contract and operator labor), *capital*, *intermediates*, and *livestock* expenses. The output elasticity for input κ is then derived as:

$$(15)\quad \frac{\partial lnQ}{\partial lnZ_{\kappa}} = \beta_{\kappa} + \sum_{l}\beta_{\kappa l} lnZ_{ilt}$$

Note that this allows the output elasticity to vary across farms and across years. Given a set of production function parameter estimates, our estimate of the log of technical efficiency of farm i in year t is the estimated intercept plus the residual: $ln\omega_{it} = \widehat{\beta}_0 + \widehat{u}_{it}$. We use $ln\omega_{it}$ and the estimated output elasticities in equation (15) to compute the APG decomposition in equation (12).

Tobacco Sector Dynamics

The buyout led to a major restructuring of tobacco production. The total number of Kentucky tobacco farms declined precipitously from 31,082 in 2002 to 8,113 in 2007.[13] At the same time, the average tobacco farm size in Kentucky more than doubled between 2002 and 2007. These dramatic changes indicate the magnitude of the distortion caused by tobacco quotas. We begin to get a sense of the reallocative process and extensive distortions by examining the changes in farm number and size.

We investigate the structural change in tobacco production by selecting Kentucky farms in the 1997, 2002, and 2007 Censuses of Agriculture that harvested tobacco in one or more of these years. For each time period, we classify farms into five categories: farm entrants, tobacco entrants, farm exits, tobacco exits, and continuers. Consider, for example, the dynamics between 1997 and 2002. Tobacco farms which are in the data in 1997 are defined as farm exits if they disappear from the sample in 2002 or "tobacco exits" if they continue farming but do not produce tobacco in 2002. Similarly, tobacco farms which are in our sample in 2002 are defined as farm entrants if they are not in our sample in 1997 or "tobacco entrants" if they were in the data but did not produce tobacco in 1997. Farms in our sample that produced tobacco in both 1997 and 2002 are continuers.

Table 1 shows the dynamics in two periods, 1997–2002 and 2002–2007, for farms in Kentucky that produced tobacco in 1997, 2002, or 2007.[14] Columns 1 and 3 report the dynamics for all farms in the sample over the two time periods, respectively. Columns 2 and 4 report the dynamics for just those farms that produced tobacco during the indicated time period. The farm exit rate was constant at about 40% in both intervals, but the tobacco exit rate jumped from 22% between 1997–2002 to 43% between 2002–2007. The table suggests that the transformation was more subtle than merely a mass exodus. For example, although 25,789 farms stopped producing tobacco between 2002 and 2007, the Censuses of Agriculture indicate that 2,820 farms *began* producing tobacco. Eighty percent of these entrants (2,290 farms) appeared to be new farms, and 20% (530 farms) were active farms that (re)entered tobacco production.[15]

---

[12] In order to take account of differences in weather that might affect productivity, we also estimated specifications in which we included county-level measures of rainfall and degree-days. However, the weather data had little effect on our production function estimates.

[13] Our estimate of the total number of Kentucky tobacco farms in 2007 matches the USDA's published count for farms with harvested tobacco acres. In 1997 and 2002, our totals are slightly different from the published totals for two reasons. First, published Agricultural Census totals reflect adjustments for undercoverage, but the adjustments for undercoverage have changed over time. Continuing farms that appear in two consecutive Censuses may have different weights in the published totals, but we have to choose a single weight for each farm. This also explains why the final numbers for 1997–2002 do not exactly match the initial numbers for 2002–2007. Second, our total tobacco farm counts in 1997 and 2002 are slightly different from the published totals because of difficulty matching longitudinal identifiers between 1997 and 2002, a problem affecting about 1% of our sample.

[14] These include all farms that produced any type of tobacco. Unfortunately the Census of Agriculture does not distinguish between types of tobacco.

[15] Because farm identifiers in the Agricultural Censuses sometimes change due to operator turnover or consolidation, it seems likely that some of the farms we identify as entrants and exits were in fact continuing farms that changed identifiers from one Census to the next. However, this is not the case for the 530 farms that

Table 1. Numbers of Continuing, Entering, and Exiting Kentucky Tobacco Farms, 1997–2002 & 2002–2007

		(1)	(2)	(3)	(4)
		1997–2002		2002–2007	
		Operating Farms	Tobacco Producing Farms	Operating Farms	Tobacco Producing Farms
Initial		53,649	51,309	42,306	31,082
Farm Exits	Number	20,818	20,773	16,790	12,547
	% Initial	(39)	(40)	(40)	(40)
Tobacco Exits	Number		11,512		13,242
	% Initial		(22)		(43)
Continuers	Number	32,831	19,024	25,516	5,293
	% Initial	(61)	(37)	(60)	(17)
	% Final	{80}	{65}	{84}	{65}
Tobacco Entrants	Number		2,179		530
	% Final		{7}		{7}
Farm Entrants	Number	8,229	8,034	4,770	2,290
	% Final	{20}	{27}	{16}	{28}
Final		41,060	29,237	30,286	8,113

Note: Operating farms consist of all KY farms that produced tobacco in any of the years 1997, 2002, or 2007. Data source: U.S. Census of Agriculture. Parenthesis () indicate proportion of initial farm numbers. Curly brackets {} indicate proportion of final farm numbers.

The relative characteristics of surviving tobacco growers, entrants, and exiters illustrate the ways in which the tobacco-sector dynamics changed following the buyout. Table 2 shows our estimates of the average tobacco acreages and farm sizes before and after the quota buyout. Average tobacco acres harvested on farms that produced tobacco in both 1997 and 2002 decreased 36 percent, even though the average size of these farms increased from 82 to 95 acres.[16] Interestingly, average tobacco yields on these continuing farms also decreased slightly. Farms that produced tobacco in both 2002 and 2007 tended to be larger, and their average tobacco acreage increased from 8.7 to 12.2. The average tobacco acreage share of these farms increased somewhat, and their average tobacco yield increased significantly from 2,079 to 2,247 pounds per acre. The third and seventh rows of table 2 show that farms that exited tobacco production between 1997 and 2002 or between 2002 and 2007 tended to be smaller than continuers in the same year, both in terms of farm size and tobacco acreage, and they tended to have lower tobacco yields.

The difference between pre- and post-buyout dynamics may, in part, be due to farmers who started growing tobacco simply to claim the grower's benefit in the buyout. Notably, entrants between 1997 and 2002 had lower yields in 2002 than exiters did in 1997. In contrast, the entrants between 2002 and 2007 were significantly larger, more productive, and harvested more than double the tobacco acreage. Finally, more than 87 percent of the 1997–2002 entrants exited tobacco production after the buyout.

Clearly a significant amount of acreage allocated to tobacco production in Kentucky was reallocated among farms in the years after the quota buyout. Under the tobacco program, growers could not easily shift tobacco production across counties in Kentucky. After the buyout, tobacco acreage shifted from eastern to central and western Kentucky, with every county in the Eastern district decreasing acreage, and some counties in the central and western districts increasing acreage. The Eastern district had the highest average production costs in 2002. However, the relationship between production costs and post-buyout tobacco acreage growth was not

---

were in both the 2002 and 2007 Censuses (with the same identifier in both years), and produced tobacco in 2007 but not in 2002. Some of these "entrants" in 2007 may have been existing tobacco farms that were unable to obtain quota in 2002 because quota owners were using their quota to take advantage of the grower benefit. We also found similar rates of entry and exit using other data sources. We provide a detailed description of our robustness checks in a supplementary appendix online.

[16] In comparison, total U.S. burley acreage fell 47 percent between 1997 and 2002.

Table 2. Tobacco Acreage and Farm Size of Continuers, Entrants, and Exits, Kentucky Tobacco Farms, 1997-2007

Panel Period	Group	Mean (s.d.) of Tobacco Acreage Harvested	Mean (s.d.) of Total Acreage Harvested	Mean (s.d.) of Acreage Share of Tobacco	Mean (s.d.) of Tobacco Yield (lbs./acre)
1997 to 2002	Continuers (1997)	7.2	82.0	0.40	1964.8
		(11.4)	(280.0)	(0.40)	(588.2)
	Continuers (2002)	4.6	94.8	0.31	1909.8
		(8.1)	(317.2)	(0.40)	(656.0)
	Exiters (1997)	4.8	52.7	0.48	1874.0
		(7.4)	(185.6)	(0.44)	(606.6)
	Entrants (2002)	4.1	84.3	0.38	1821.3
		(6.8)	(268.1)	(0.43)	(684.7)
2002 to 2007	Continuers (2002)	8.7	171.9	0.26	2079.1
		(12.9)	(507.6)	(0.36)	(625.4)
	Continuers (2007)	12.2	179.1	0.29	2247.1
		(21.2)	(522.5)	(0.36)	(661.7)
	Exiters (2002)	3.5	74.2	0.35	1837.9
		(5.6)	(232.6)	(0.42)	(668.0)
	Entrants (2007)	11.0	120.0	0.37	2154.4
		(18.3)	(292.6)	(0.40)	(697.2)

Sources: 1997, 2002, and 2007 Censuses of Agriculture (long and short forms). Standard deviations in parentheses.

monotonic.[17] Economic theory predicts that quota rental rates should be higher in counties with lower marginal costs of production (Rucker, Thurman, and Sumner 1995). The pairwise correlations between county-level quota rental rates in 1997, 2002, and 2004 and the 2002–2007 county-level growth of tobacco acreage are, respectively, 0.30, 0.19, and 0.40. Taken together, the evidence on geographic variation in tobacco acreage growth, quota rental prices, and production costs suggests that although costs of production were an important part of the story, they do not explain all of the reallocation of tobacco acreage. To fully understand how the reallocation affected aggregate productivity growth, we also need to take account of the reallocation of inputs other than land. We turn to this growth accounting next.

Estimation Results

Table 3 shows our estimates of the output elasticities for Kentucky tobacco farms. They are evaluated at the sample mean for each of the three aforementioned production function estimators. Robust standard errors are shown in parentheses. The parameter estimates are all statistically significant at standard significance levels, and the estimates are remarkably similar across all three estimators. Kentucky tobacco farms seem to exhibit increasing returns to scale in this period.[18]

Table 3. Mean Output Elasticities, Kentucky Tobacco Farms, 1997–2007

Input	(1) OLS	(2) OLS with County Fixed Effects	(3) Levinsohn & Petrin
Land	0.216	0.229	0.224
	(0.006)	(0.006)	(0.006)
Intermediates	0.531	0.519	0.482
	(0.005)	(0.006)	(0.007)
Capital	0.098	0.090	0.088
	(0.006)	(0.006)	(0.024)
Labor	0.324	0.288	0.306
	(0.012)	(0.012)	(0.011)
Livestock	0.064	0.062	0.063
	(0.001)	(0.001)	(0.002)

Sources: 1997, 2002, and 2007 Censuses of Agriculture
Note: All observations in 1997, 2002, and 2007 are pooled to estimate the production functions. Sample size is 33,827. The table shows output elasticities evaluated at the sample mean. Robust standard errors in parentheses.

---

[17] We provide more detailed analysis of tobacco acreage shifts and production costs by county and district in a supplemental online appendix.

[18] We also estimated a Cobb-Douglas specification of the production function, which constrains the coefficients on the squared

Table 4. Aggregate Productivity Growth Decompositions, Kentucky Tobacco Farms, 1997-2007

	1997–2002			2002–2007		
APG Component	OLS (1)	Fixed Effects (2)	L-P (3)	OLS (4)	Fixed Effects (5)	L-P (6)
Aggregate Productivity Growth	−7.1%	−7.1%	−7.1%	44.4%	44.4%	44.4%
Input Reallocation	3.3%	3.3%	3.5%	7.9%	7.6%	8.3%
Quota Reallocation	6.3%	6.3%	6.3%	na	na	na
Technical Efficiency Growth	−10.1%	−10.2%	−10.5%	−6.3%	−6.0%	−6.7%
Residual	12.7%	12.8%	12.9%	22.7%	22.7%	22.7%
Farm Entry & Exit	−23.2%	−23.2%	−23.2%	6.2%	6.2%	6.2%
Tobacco Entry & Exit	4.1%	4.1%	4.1%	13.9%	13.9%	13.9%

Sources: 1997, 2002, and 2007 Censuses of Agriculture.
Note: Residual for 2002–2007 includes elimination of quota rental costs.
na = not applicable.

Table 4 shows our estimates of aggregate productivity growth and its decomposition for Kentucky tobacco farms for 1997 to 2002 and 2002 to 2007 using equation (12). Columns (1)-(3) report the OLS, fixed effects, and Levinsohn-Petrin estimates, respectively, for 1997–2002 aggregate productivity growth. The D-F APG measure shows that the aggregate productivity of Kentucky tobacco farms decreased by 7.1% between 1997 and 2002.[19] The second row shows the total contribution of input reallocation among continuing tobacco farms. Using the L-P estimator (column 3), we find that this reallocation contributed 3.5 percentage points to aggregate productivity growth. The third row shows the *direct* contribution of the reallocation of quota among continuing farms, *holding quota rental prices constant*. Continuing tobacco farms reduced their tobacco production over this period (see table 2), so they also reduced their usage of quota, directly contributing 6.3 percentage to APG. Aggregate technical efficiency growth of continuing farms contributed −10.5 percentage points. The fifth row shows that the residual term specified in equation (13) accounted for 12.9 percentage points of APG. In the sixth and seventh rows, we disentangle the contributions of farm entrants/exits and tobacco entrants/exits, respectively, as defined in the previous section.[20] From 1997 to 2002 we find that net farm entry contributed −23.2 percentage points to aggregate productivity growth. On the other hand, net tobacco entry contributed 4.1 percentage points to APG. The estimates using OLS and county fixed effects (columns 1 and 2) are essentially the same, except that the L-P estimator attributes slightly more positive growth to input reallocation and slightly more negative growth to technical efficiency decline among continuing tobacco farms.

Negative aggregate productivity growth between 1997 and 2002–especially the large contributions of farm net entry and negative technical efficiency growth among continuers–warrants some explanation. The "grower benefit" in the quota buyout created incentives for farmers to become/remain tobacco growers. The results of these incentives can be seen in the anomalous characteristics of tobacco

---

and interaction terms in equation (14) to equal zero. The estimated output elasticities are similar. However, an F-test strongly rejects the hypothesis that the squared and interaction terms in (14) are jointly zero. We present the Cobb-Douglas estimates in the online supplemental appendix.

[19] According to the USDA Agricultural Productivity Accounts, total factor productivity for *all* Kentucky farms fell by 4.3% from 1997 to 2002.

[20] To the extent that our "farm entry" and "farm exit" measures are capturing changes in farm identifiers, those "entrants" and "exits" are all accounted for by the sixth row of the table.

entrants between 1997 and 2002, as noted in the previous section and in table 2. This may explain the large negative contribution of farm net entry, as quota owners entered tobacco production to take advantage of the grower benefit. The grower benefit also provided an incentive for tobacco growers to continue production when they otherwise might have exited. Since the grower benefit was the same (per pound of tobacco) for all growers, it was more likely to affect the exit decision of less profitable growers. Profitability and productivity tend to be positively correlated, so less productive growers may have continued producing in 2002–2004 so that they could receive the grower benefit. Growers who were planning to exit once the quota program ended also had little incentive to make productivity-enhancing investments in their tobacco enterprise in the years leading up to the buyout. Thus anticipation of the quota buyout may have lowered the aggregate productivity of tobacco growers between 1997 and 2002.

Columns (4)–(6) of table 4 show APG and its decomposition for 2002 to 2007 using equation (12). In stark contrast to the earlier period, we find that the aggregate productivity of Kentucky tobacco farms grew by 44% between 2002 and 2007. As expected, after the quota buyout, input reallocation among continuing tobacco farms contributed positively, adding 8.3 percentage points to aggregate productivity growth according to the L-P estimator. As noted above, we cannot separately measure the *direct* APG contribution of the elimination of quota, because all farms had zero quota after the buyout. Aggregate technical efficiency growth among continuing tobacco growers contributed −6.7 percentage points. The residual term for continuers, which includes the contribution of eliminating quota, was the most important factor, accounting for 22.7 percentage points of our APG measure. Farm net entry contributed 6.2 percentage points to aggregate productivity growth as smaller, less productive farms exited and larger, more productive farms entered. Finally, existing farms that entered or exited tobacco production contributed 13.9 percentage points to APG after the buyout. Once again, the results for the OLS and the county fixed effects estimators (columns 4 and 5) are similar.

Aggregate productivity growth of 44% between 2002 and 2007 implies an average annual productivity growth rate of about 7.6%. Although this is quite high, it is not implausible given the distortions tobacco growers faced before the buyout and the large, rapid consolidation of resources that occurred afterwards. Between 2002 and 2007, the total number of tobacco-producing farms in Kentucky declined by 74%, and the average tobacco acreage per tobacco-producing farm increased 168%–from 4.4 acres per farm in 2002 to 11.8 in 2007. To put this into perspective, the average acreage size of all U.S. farms increased by "only" 96% between 1982 and 2002 (Key and Roberts 2007). Over the same period, according to the USDA Agricultural Productivity Accounts, U.S. agricultural productivity increased by 38%.[21] The production function estimates in table 3 indicate that tobacco farms faced increasing returns to scale. Before the buyout, the restrictions on inter-county transfers of quota prevented some growers from taking advantage of these returns to scale. Furthermore, in the final years of the tobacco program quota rental prices in Kentucky averaged 30% of the price of burley leaf, and in some major tobacco-producing counties the price of quota rental was as much as 40% of the price of burley leaf. As table 4 shows, the residual term including the elimination of quota rental costs accounted for half of total APG between 2002 and 2007.

Negative technical efficiency growth among continuing farms between 2002 and 2007 also deserves an explanation. As noted above, our measure of farm-level technical efficiency growth is the residual from a regression of deflated revenue on similarly deflated inputs. This implies that our measure of farm-level technical efficiency growth includes measurement error due to the differences between the growth rates of the prices of tobacco and other outputs and the growth rate of the output price index. In particular, after the buyout the price of burley tobacco fell faster than the output price index, adding negative measurement error to our estimates of technical efficiency growth.[22]

---

[21] Of course, returns to scale do not explain all of the productivity growth of U.S. farms between 1982 and 2002, but the same is true of Kentucky tobacco farms–other factors also affected aggregate productivity growth. The point of this comparison is that the massive reallocation of resources in Kentucky tobacco production happened very quickly after the buyout. To see a similar reallocation of resources at the more aggregated level, one has to look at a longer time frame.

[22] This type of measurement error does not affect our estimate of overall APG–it only affects the decomposition of APG into technical efficiency growth versus reallocation.

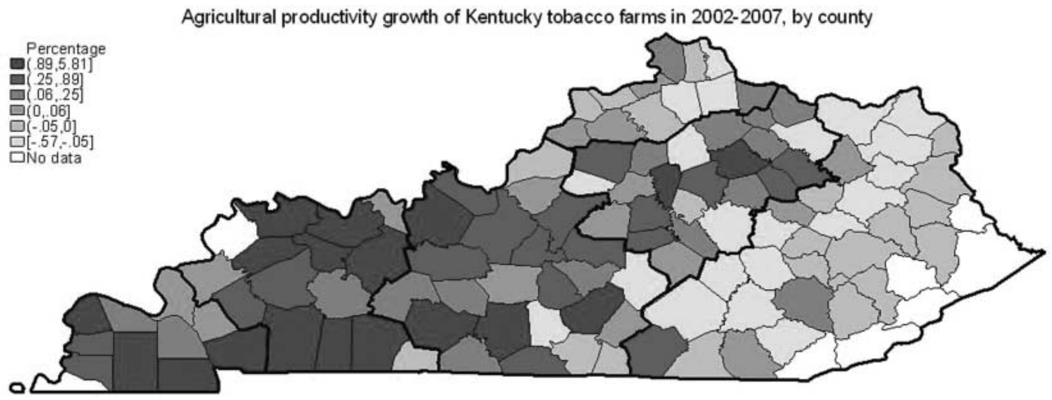

Figure 1. Productivity growth of Kentucky tobacco farms 2002–2007, by county

Sensitivity Analysis

The APG decomposition allows us to account for the contribution of each geographic region to aggregate productivity growth. Figure 1 shows the contribution of each county to the aggregate productivity growth of tobacco farms between 2002 and 2007 using equation (10). Most counties in eastern Kentucky contributed little to aggregate productivity growth, whereas many central and western counties contributed positively. This is consistent with economic intuition–we expect to see more aggregate productivity growth in counties to which resources are being reallocated.

Tobacco Specialization

We have selected farms that produced tobacco between 1997 and 2007. Most Kentucky tobacco farms also produce other products. Although the Agricultural Census data does not allow us to distinguish between inputs (other than land) used for tobacco versus other crops, it does allow us to distinguish between outputs. Farms that were less dependent on tobacco revenue might have responded differently to the quota buyout, or might have affected aggregate productivity growth in different ways. To test this hypothesis, we divided Kentucky tobacco farms into three groups based on the share of their sales coming from tobacco: less than 50%, 50 to 90%, and greater than 90%.[23] Row 1 of table 5 shows the percentages of our sample accounted for by each group in each period. As shown in table 2, after the buyout Kentucky tobacco farms diversified. The least tobacco-dependent group increased from 41 to 47% of the sample, and the most tobacco-specialized group decreased from 31 to 25% of the sample.

For each tobacco sales share group, we computed its contribution to the total APG of tobacco farms and to each component of the P-L decomposition.[24] Between 1997 and 2002, tobacco farms with less than 50% of their sales from tobacco contributed (positive) 6.2 percentage points to APG, counterbalancing the −6.1 percentage points contributed by farms with tobacco sales shares of 90% or more. The least tobacco-dependent farms may have been better able to reduce their tobacco acreage in the face of increasing quota rental costs leading up to the buyout. Our results are consistent with this hypothesis–quota reallocation among highly tobacco-specialized continuing farms contributed less than 1 percentage point to APG, compared to 2.6 and 2.8 percentage points for the less tobacco-dependent groups. After the buyout, tobacco farms with less than 50% of their sales from tobacco accounted for almost all of the APG of tobacco farms over that period. The least-specialized group contributed more to total APG after the buyout in part simply because they accounted for a larger share of both tobacco production and the total production of tobacco farms. For the least tobacco-specialized farms, the direct effect of the elimination of quota rental costs (plus the price change residual) was the most important factor in APG after the buyout, contributing 19.6 percentage points. The

---

[23] For continuing farms, the tobacco sales share is from the base year (e.g., 2002 for farms that continue from 2002 to 2007).

[24] Columns 1-3 of table 5 sum to column 3 of table 4. Columns 4-6 of table 5 sum to column 6 of table 4.

Table 5. Aggregate Productivity Growth Decomposition by Tobacco Sales Share, Kentucky Tobacco Farms, 1997–2007

	1997–2002			2002–2007		
	< 50% (1)	50–90% (2)	> 90% (3)	< 50% (4)	50–90% (5)	> 90% (6)
Proportion of Sample	41%	28%	31%	47%	27%	25%
APG Component						
Aggregate Productivity Growth	6.2%	−7.2%	−6.1%	43.1%	2.6%	−1.2%
Input Reallocation	1.9%	1.6%	0.0%	5.1%	2.2%	1.0%
Quota Reallocation	2.6%	2.8%	0.9%	na	na	na
Technical Efficiency Growth	−4.1%	−3.1%	−3.2%	−3.4%	−2.1%	−1.1%
Residual	7.1%	2.6%	3.1%	19.6%	2.8%	0.3%
Farm Entry & Exit	−5.3%	−10.9%	−7.1%	4.4%	2.6%	−0.8%
Tobacco Entry & Exit	4.1%	−0.3%	0.2%	17.4%	−0.9%	−0.6%

Sources: 1997, 2002, and 2007 Censuses of Agriculture.
na = not applicable.

second most important factor was the contribution of tobacco entry/exit, accounting for 17.4 percentage points.

As noted above, our estimates of farm-level technical efficiency growth include measurement error due to differences between the growth rates of the prices of tobacco and other outputs and the growth rate of the output price index. Since the price of tobacco dropped more than the output price index after the buyout, more specialized tobacco farms are more affected by this negative measurement error. Our results are consistent with this hypothesis. The unweighted average of technical efficiency growth of the most tobacco-specialized farms was more negative than the unweighted average of the least tobacco-dependent farms.[25]

Conclusions

We study the impact of the U.S. tobacco quota program and the 2004 quota buyout on the aggregate productivity growth of tobacco farms in Kentucky. We find that aggregate productivity decreased by 7.1% between 1997 and 2002, but grew by 44.4% between 2002 and 2007. Between 1997 and 2002, technical efficiency growth of continuing tobacco farms contributed about −10.5 percentage points to aggregate productivity growth, while reallocation of resources among continuing tobacco farms contributed 3.5 percentage points; net exit contributed −19.1 percentage points. Reduction and reallocation of the quota rental costs of continuing tobacco farms (holding prices constant) directly contributed 6.3 percentage points. A residual term which accounts for changes in relative prices contributed the remaining 12.9 percentage points. Between 2002 and 2007, technical efficiency growth of continuing tobacco farms contributed −6.7 percentage points. Reallocation among continuing tobacco farms contributed 8.3 percentage points, and net entry between 2002 and 2007 contributed 20.1 percentage points. A residual term, which in this case includes the elimination of quota rental costs, accounted for the remaining 22.7 percentage points. After the buyout, tobacco production shifted from eastern to western Kentucky. Although the number of tobacco farms decreased in every county, total tobacco acreage increased in some western counties.

---

[25] Although less tobacco-dependent farms contributed more to the decline in aggregate technical efficiency after the buyout, this was entirely because these farms accounted for a larger share of the total production of tobacco farms.

Although our empirical results are generally consistent with economic theory, we interpret our measurements of entry and exit with some caution. Although we have conducted several robustness checks using different datasets and alternative definitions of entry and exit, we still find a surprising number of "new farms" entering tobacco production during a period in which the demand for U.S. burley tobacco leaf was in decline. Further research and better data on the entry and exit of tobacco farms (and farm entry and exit more generally) may be needed.

Our finding that resource reallocation (including entry and exit) made a large contribution to aggregate productivity growth contrasts with previous research on aggregate productivity growth in U.S. agriculture. Using aggregate state-level data, Ball et al. (1999) find that resource reallocation across states had little effect on aggregate productivity growth in agriculture. To the extent that resource reallocation is occurring within states more than across states, our results highlight the importance of using highly disaggregated data to study the sources of aggregate productivity growth. Our results also show the importance of using an aggregate productivity decomposition that allows for gaps between marginal revenue products and marginal costs. In tobacco production, these gaps were probably the result of the quota program, which in most states (including Kentucky) did not allow quota to be reallocated across counties. In other industries, these gaps could exist because of markups, adjustment costs, subsidies, or other distortions. To the extent that agricultural production–in the U.S. or anywhere–can be characterized as a sector in which subsidies, quotas, or other distortions are important, reallocation of resources probably plays an important role in aggregate productivity growth in the entire sector.

References

Baily, M., C. Hulten, and D. Campbell. 1992. "Productivity Dynamics in Manufacturing Plants." *Brookings Papers on Economic Activity*, pp. 187–267.

Ball, V.E., F.M. Gollop, A. Kelly-Hawke, and G.P. Swinand. 1999. "Patterns of State Productivity Growth in the U.S. Farm Sector: Linking State and Aggregate Models." *American Journal of Agricultural Economics* 81:164–179.

Basu, S., and J. Fernald. 2002. "Aggregate Productivity and Aggregate Technology." *European Economic Review* 46:963–991.

Bernard, A., J. Eaton, B. Jensen, and S. Kortum. 2003. "Plants and Productivity in International Trade." *American Economic Review* 93:1268–1290.

Brown, A.B., R.R. Rucker, and W.N. Thurman. 2007. "The End of the Federal Tobacco Program: Economic Impacts of the Deregulation of U.S. Tobacco Production." *Review of Agricultural Economics* 29:635–655.

Diewert, E. 1976. "Exact and Superlative Index Numbers." *Journal of Econometrics* 4: 115–145.

Diewert, E., and K. Fox. 2010. "On Measuring the Contribution of Entering and Exiting Firms to Aggregate Productivity Growth." In E. Diewert, B. Balk, D. Fixler, K. Fox, and A. Nakamura, eds. *Price and Productivity Measurement: Volume 6–Index Number Theory*. Vancouver: Trafford Press, pp. 41–66.

Dohlman, E., L. Foreman, and M. Da Pra. 2009. *The Post-buyout Experience: Peanut and Tobacco Sectors Adapt to Policy-reform*. Washington, DC: U.S. Department of Agriculture, ERS Economic Information Bulletin 60, November.

Domar, E.D. 1961. "On the Measurement of Technological Change." *The Economic Journal* 71:709–729.

Foster, L., J. Haltiwanger, and C. Krizan. 2001. "Aggregate Productivity Growth: Lessons from Microeconomic Evidence." In C. R. Hulten, E. R. Dean, and M. J. Harper, eds. *New Developments in Productivity Analysis*. Chicago: University of Chicago Press, pp. 303–372.

Griliches, Z., and H. Regev. 1995. "Firm Productivity in Israeli Industry: 1979–1988." *Journal of Econometrics* 65:175–203.

Hsieh, C.T., and P.J. Klenow. 2009. "Misallocation and manufacturing TFP in China and India." *Quarterly Journal of Economics* 124:1403–1448.

Hulten, C. 1978. "Growth Accounting with Intermediate Inputs." *The Review of Economic Studies* 45:511–518.

Key, N., and M.J. Roberts. 2007. *Commodity Payments, Farm Business Survival, and Farm Size Growth*. Washington, DC: U.S. Department of Agriculture, ERS Economic Research Report 51, November.

Kwon, H.U., F. Narita, and M. Narita. 2009. "New Evidence on Japan's Productivity

Growth in the 1990s." Working Paper, Research Institute of Economy, Trade, and Industry.

Lentz, R., and D. Mortensen. 2008. "An Empirical Model of Growth Through Product Innovation." *Econometrica* 76: 1371–1373.

Levinsohn, and Petrin. 2003. "Estimating Production Functions Using Inputs to Control for Unobservables." *Review of Economic Studies* 70:317–341.

Marschak, J., and W. Andrews. 1944. "Random Simultaneous Equations and the Theory of Production." *Econometrica* 12:143–205.

Melitz, M. 2003. "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity." *Econometrica* 71:1695–1725.

Olley, S., and A. Pakes. 1996. "The Dynamics of Productivity in the Telecommunications Equipment Industry." *Econometrica* 64:1263–1297.

Petrin, A., and J. Levinsohn. 2010. "Measuring Aggregate Productivity Growth Using Plant-Level Data." Working Paper, Dept. of Econ., University of Minnesota, Twin Cities.

Petrin, A., T.K. White, and J.P. Reiter. 2011. "The Impact of Plant-level Resource Reallocations and Technical Progress on U.S. Macroeconomic Growth." *Review of Economic Dynamics* 14:3–26.

Restuccia, D., and R. Rogerson. 2008. "Policy Distortions and Aggregate Productivity with Heterogeneous Plants." *Review of Economic Dynamics* 11:707–720.

Rucker, R.R., W.N. Thurman, and D.A. Sumner. 1995. "Restricting the Market for Quota: An Analysis of Tobacco Production Rights with Corroboration from Congressional Testimony." *Journal of Political Economy* 103:142–175.

Womach, J. 2003. *Tobacco Price Support: An Overview of the Program*. Washington, DC: Congressional Research Service, CRS Report for Congress, November.

——2004. *Tobacco Quota Buyout Proposals in the 108th Congress*. Washington, DC: Congressional Research Service, CRS Report for Congress, November.

AJAE Appendix: “Aggregate and Farm-level Productivity Growth in Tobacco: Before and After the Quota Buyout"

This supplemental appendix provides detailed descriptions of the data that we use in the article. The appendix also includes robustness checks for our measures of entry and exit and estimates of entry, exit, reallocation, and production costs by county and district. Finally, we provide robustness checks for our production function estimates.

We use confidential farm-level data from the Censuses of Agriculture for 1997, 2002, and 2007. We also use county-level estimates of burley tobacco quota rental rates in Kentucky obtained from Will Snell at the University of Kentucky. We use USDA price indexes for farm inputs and output, and capital rental rates for farm machinery from the Bureau of Labor Statistics (BLS). In the Agricultural Censuses, we observe individual farms, and we use a numeric farm-level identifier, the POID, to link these farms longitudinally across censuses. For each farm, in each census year we observe tobacco revenue and pounds and acres of tobacco harvested. We also observe the revenue from other crops and livestock and acres harvested of other crops. On the input side, we observe farm-level total expenditures on chemicals, fertilizer, utilities, fuel, livestock expenses, contract labor, hired labor, seeds/transplants, machinery, the total value of land and buildings, and the number of days the operator(s) worked off the farm.

For the aggregate productivity growth estimates and their decompositions we use farm-level revenues and expenditures and farm-level input and output quantities. Except for land, we substitute real revenues or expenses for quantities. The lack of availability of price indexes for some variables also dictates that we combine some real variables. To be consistent, we combine the corresponding nominal expenditures as well. This gives us a single output and five inputs to production: land, capital, labor, livestock, and other intermediate inputs. We describe how we construct each variable.

Our measure of farm-level revenue is the total value of sales of all commodities on the farm. Although we select farms that grow tobacco, very few Kentucky tobacco farms produce only tobacco. To obtain a measure of farm-level *output* Q_{it}, we deflate farm-level sales of all commodities by USDA's state-level price index for total sales of farm products in Kentucky. The price indexes, used to construct the USDA state-level productivity accounts, were provided by Eldon Ball and Sun Ling Wang of USDA's Economic Research Service. For more information about the construction of these price indexes and the USDA productivity accounts, see http://www.ers.usda.gov/Data/AgProductivity/.

Our measure of land input (*land*) is acres of crops harvested. To obtain a measure of the farm-level cost of land, we multiply the farm's acres of crops harvested by the farm-specific rental rate for land, which we calculate from total acres rented divided by total farmland rental expenditures, both from the Agricultural Census. If the farm does not rent any land, then we multiply the acres of crops harvested by the average rental rate for all tobacco farms in the county.

To compute real labor input (*labor*), we deflate labor expenditures by the region-specific farm labor wage rate available from the USDA's National Agricultural Statistics Service (NASS). We then combine this hired labor input with the operator's own labor. For livestock expenses (*livestock*), we use nominal livestock production expenses (which includes the cost of purchased feed). To obtain a quantity measure, we deflate this by the USDA/ERS state-specific price index.

We combine several detailed input measures into a single measure of intermediate inputs (*intermediates*): fertilizer, agricultural chemicals, seeds/transplants, fuel, and utilities. For fertilizer, we deflated nominal expenditures by the USDA/ERS state-level fertilizer price index for Kentucky. Likewise, for real agricultural chemicals and seeds/transplants, we deflate nominal expenditures by state-specific price indexes for these inputs. For real fuel and utilities expenditures, we deflate nominal expenditures on these inputs by the state-specific prices of gas and electricity, available from NASS and the U.S. Energy Information Administration (EIA), respectively.

Our final measured input to production is farm machinery and equipment. To compute the real input, we divide the total value of farm machinery and equipment (observed in the Agricultural Census) by the state-specific price index for farm machinery and equipment from the USDA productivity accounts. To compute the cost of this type of capital, we multiply the farm-level real value by the Bureau of Labor Statistics' annual rental rates for farm tractors and for agricultural machinery (excluding tractors) for NAICS industries 111 and 112 (crop and animal production).

Although quota is not an input to production, during the tobacco program, leasing quota was a cost of production. To measure farm-level quota rental costs, we multiply the farm's pounds of tobacco harvested by Will Snell's estimates of the county- and year-specific quota rental rates for burley tobacco in Kentucky.

Sample Selection and Sample Weights

To estimate the micro-level productivity of tobacco farms, in 1997 and 2002 we restrict the sample to farms that received the Agricultural Census long-form questionnaire, since only the long form asks about production costs in those years. For 1997, we include in our estimation sample all tobacco farms that responded to the long-form questionnaire. For 2002 and 2007 we take a slightly different approach to sample selection. Tobacco acreage and prices declined substantially over this period (Dohlman, Foreman, and Da Pra 2009). In light of these facts, reallocation of resources *out of* tobacco production was potentially important for aggregate productivity growth. If tobacco farms stop producing tobacco entirely, and the land and other resources formerly used for tobacco production are reallocated for production of other crops, then ignoring these farms would produce a downward biased estimate of their contribution to aggregate productivity growth. In light of this fact, for 2002 we select all farms in the 2002 long-form sample that produced tobacco in that year or in 1997. In the aggregate productivity growth decompositions, farms in our sample that produced tobacco in 1997 but not in 2002 are counted as exits, and farms that produced tobacco in 2002, but not in 1997 are counted as entrants. Likewise, for 2007, we select all farms that produced tobacco in 2007 or in 2002 and entrants and exits are defined in the same way.

Because the long-form sample is randomly chosen within each Census year, some continuing farms will appear in the long-form sample in one Census, but not in the subsequent Census. For these continuing farms, we cannot compute farm-level productivity growth rates. We can only compute farm-level productivity growth for continuing farms that appear in two consecutive long-form samples. When we compute farm-level and aggregate productivity growth, we appropriately modify the Domar weights in equations (11), (12), and (13) in the article to include the long-form sampling weights. This means we represent the population of continuing tobacco farms by weighting the continuing farms by the product of their long-form survey weights in the relevant years. Similarly, when we compute aggregate productivity using the Diewert and Fox index in equations (10) and its decomposition in equations (12) and (13) in the article, we weight the farm-level cost shares s_{it} by their long-form survey weights in the relevant years.

Measuring Entry and Exit

In the Agricultural Census data, we link farms longitudinally using a numeric identifier, the POID. This allows us to identify continuing farms as well as entrants and exits. However, the POID does not allow us to distinguish between a farm that appeared or disappeared in the data versus a farm that changed numerical identifiers. We investigate the magnitude of these possibly spurious entries/exits in several ways.

First, we use Farm Service Agency (FSA) Commodity Credit Corporation payment data to identify all tobacco-producing farms in Kentucky in 2000-2002. We then use these FSA administrative data to compare tobacco farm entry/exit rates with the Census data. In the FSA data, the exit rate of tobacco farms in Kentucky between 2000 and 2002 is 24.9%. Multiplying by 2.5 to get the 5-year change, the rate is 62.2%–basically the same as the

1997-2002 exit rate that we found in the Agricultural Census, which was 62% (including farm exits and tobacco exits). The entry rate in the FSA data between 2000 and 2002 is 14.3%. Multiplied by 2.5, the 5-year entry rate is 35.8%–just slightly higher than the 34% entry rate (including farm entrants and tobacco entrants) from the Agricultural Census.

Second, we calculate the Kentucky tobacco farm entry/exit rates for 2002-2007 using FSA Compliance data, which the FSA uses to ensure that program participants abide by the various program restrictions. The total number of Kentucky tobacco farms in the FSA data is higher than in the Agricultural Census (36,500 in 2002 and 9,342 in 2007), probably because the FSA uses a different definition of a farm than the Agricultural Census does. However, the entry and exit rates are very similar to what we calculated from the Agricultural Censuses. The FSA exit rate from 2002 to 2007 is 85%, and the entry rate is 41%–close to the 83% exit rate and the 35% entry rate that we calculated from the Agricultural Censuses. The FSA data and the Agricultural Census are collected by different agencies and they use different farm identifiers. The fact that we obtain such similar entry and exit rates from these two different data sources increases our confidence in our estimates.

Third, using the 2008 Agricultural Resource Management Survey (ARMS) tobacco-specific sample, we also estimate that 23.7% of Kentucky tobacco operators in 2008 had been producing tobacco less than 7 years (indicating they started after 2002), and 18.8% had been producing less than 5 years (meaning they started after 2004). The ARMS tobacco farm sample was designed to produce a representative sample of tobacco growers, but it was not necessarily designed to produce a representative sample of tobacco *entrants*. The average tobacco acreage of Kentucky burley entrants in the ARMS was 18.4 acres, and for dark tobacco entrants, the average was 25.4 acres. These numbers are much higher than the average tobacco acreage of 11.0 for all Kentucky entrants in the 2007 Agricultural Census and 12.2 for continuers. Therefore we suspect that the 2008 ARMS tobacco farm sample undersamples smaller tobacco entrants. This would explain why the entry rates in the 2008 ARMS are lower than those calculated from the 2007 Agricultural Census.

Entry, Exit, and Reallocation by County and District

As noted in the article, under the tobacco program, growers could not shift tobacco quota across counties in Kentucky. After the quota buyout we would expect production to shift from counties with higher marginal costs to counties with lower marginal costs. Figure 1 shows a map of Kentucky with the changes from 2002 to 2007 in total tobacco acreage harvested in each county, computed from published Agricultural Census data. After the buyout, tobacco acreage shifted from eastern to western Kentucky, with every county in the Eastern region decreasing acreage, and many counties in the two western districts increasing acreage. We also checked the county-level estimates of change in tobacco acreage between 2002 and 2007 against the FSA Compliance data. Figure 2 presents the results from the FSA data. Although the acreage change pattern is not exactly the same as in figure 1, it is remarkably similar.

We also examine geographic variation in net exit after the buyout. Figure 3 plots location within the state against the percentage change in the county's tobacco acres–where we have plotted the districts from west to east (left to right in the graph). The size of each bubble is proportional to the net number of farms that exited tobacco production between 2002 and 2007. The graph shows a greater number of net exits (bigger bubbles) in the eastern districts than in the western, as one would expect from legitimate entries and exits.

In the article we argue that higher costs of production in eastern Kentucky are part of why tobacco acreage was reallocated from eastern Kentucky to the central and western districts of the state. Here we supplement that argument with evidence on per-acre costs of production. The first row of table 1 shows average total costs per acre (excluding quota rental costs) for all Kentucky tobacco farms, by agricultural statistical district in 2002.[1] Comparing figure 3 to table 1, we see that to some extent the post-buyout reallocation of tobacco acreage was associated with costs of production. The Eastern district–which decreased tobacco acreage in every county between 2002 and 2007–had the highest average total costs per acre in 2002. However, the relationship between 2002 costs of production and subsequent tobacco acreage growth is not monotonic. Furthermore, the total per-acre costs in the different districts have not remained constant relative to one another. Between 2002 and 2007, per-acre costs increased much more in the two western districts.[2] By 2007, average per-acre costs in the Purchase district were higher than per-acre costs in the three easternmost districts.

Cobb-Douglas Production Function Estimates

In the main article we estimated a translog production function. We also tried estimating a Cobb-Douglas production function, which constrains the squared terms and interaction terms in the translog to equal zero:

$$lnQ_{it} = \alpha_0 + \tilde{\varepsilon}_a lnA_{it} + \tilde{\varepsilon}_n lnN_{it} + \tilde{\varepsilon}_k lnK_{it} + \tilde{\varepsilon}_m lnM_{it} + \tilde{\varepsilon}_l lnL_{it} + u_{it} \tag{1}$$

where Q is real revenues of farm i in year t, A is acres harvested, N is labor input, including hired, contract and operator labor, K is capital, M is intermediate inputs, L is livestock expenses, and the $\tilde{\varepsilon}_j$'s are the output elasticities of each of the inputs. We estimated equation (1) by OLS, OLS with county fixed effects, and using the Levinsohn and Petrin (2003) estimator. Table 2 presents the results. In general the estimated output elasticities are quite similar to the estimates from the translog production function. The main differences are that the labor coefficient estimates are higher in the Cobb-Douglas specification.

Notes

[1] Our measure of production costs includes the costs of intermediate inputs (fertilizer, other chemicals, seeds/transplants, fuel), land, labor, capital, and livestock expenses from the Census of Agriculture. Labor costs include reported expenses for hired and contract labor, as well as the imputed value of operator labor. The cost of land includes rental expenses as well as the imputed value of operator-owned land.

[2] Note that the figures in table 1 are in nominal dollars, so they do not measure changes in real costs over time. The point of table 1 is to compare relative costs across districts in the same year.

References

Dohlman, E., L. Foreman, and M. Da Pra. 2009. *The Post-buyout Experience: Peanut and Tobacco Sectors Adapt to Policy-reform*. Washington, DC: U.S. Department of Agriculture, ERS Economic Information Bulletin 60, November.

Levinsohn, and Petrin. 2003. "Estimating Production Functions Using Inputs to Control for Unobservables." *Review of Economic Studies* 70:317–341.

Figures

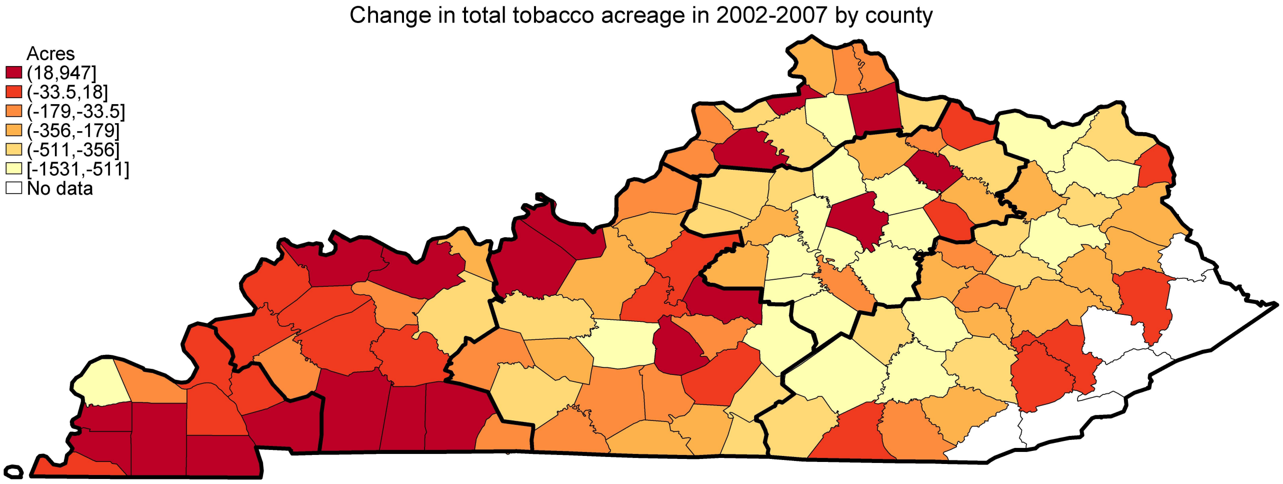

Figure 1. Change in total tobacco acreage in Kentucky, 2002-2007, by county. Source: Censuses of Agriculture. Note: Districts are outlined by bold lines.

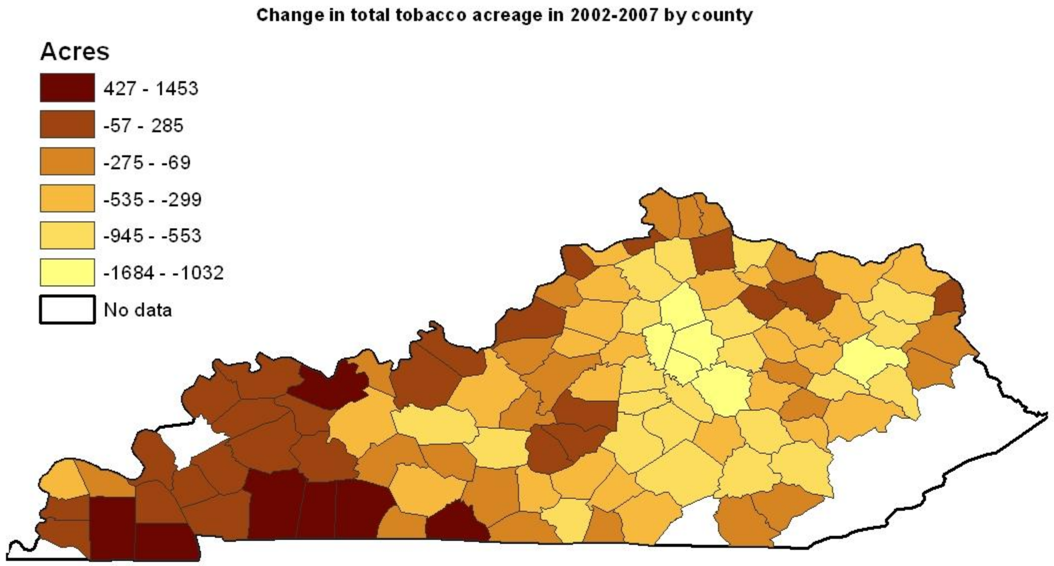

Figure 2. Change in total tobacco acreage in Kentucky, 2002-2007, by county. Source: USDA's Farm Service Agency (FSA) Compliance data.

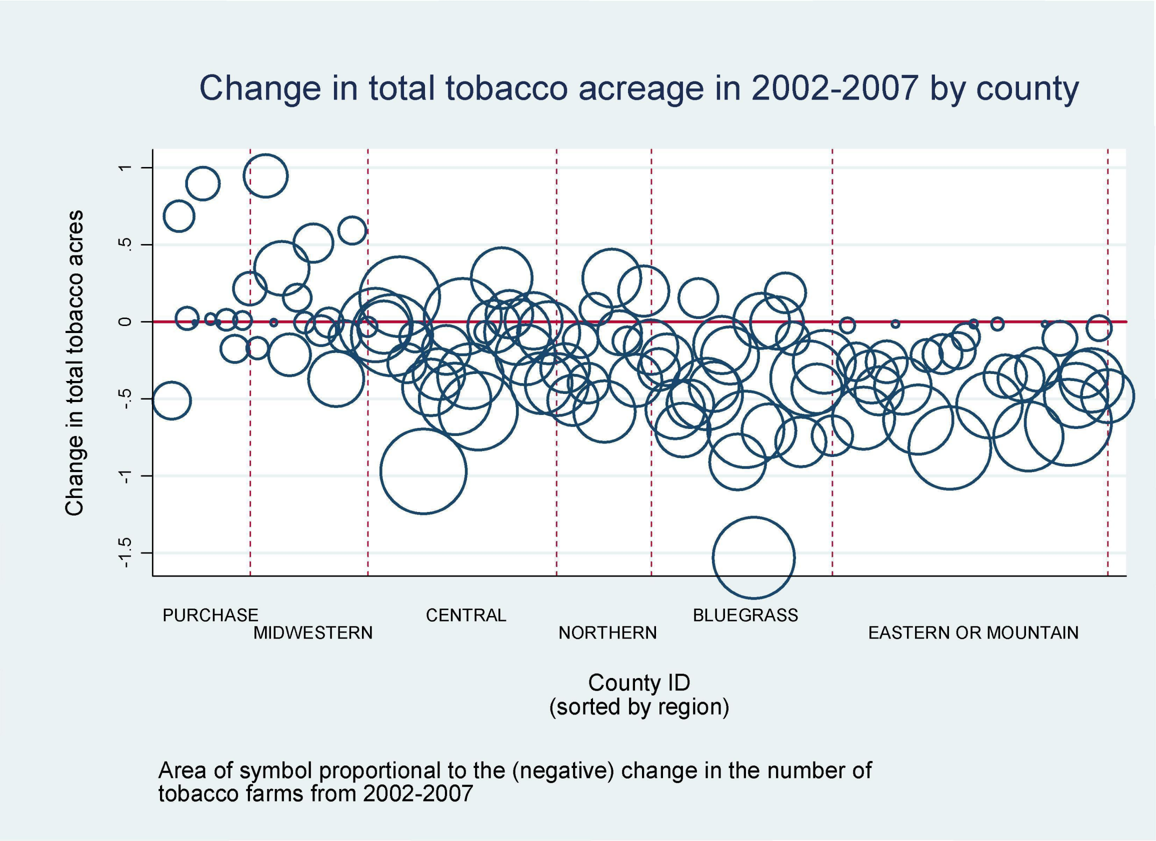

Figure 3. Change in total tobacco acreage and tobacco farms in Kentucky, 2002-2007, by county. Source: Censuses of Agriculture. Note: The change in total tobacco acres in the vertical axis is in thousands of acres.

Tables

Table 1. Average Per Acre Costs of Production, by Agricultural Statistical District, Kentucky Tobacco Farms

	District					
	Purchase	Midwestern	Central	Northern	Bluegrass	Eastern
2002						
Total	748	716	623	941	702	1311
Hired labor	29	22	16	26	24	39
Fertilizer	27	32	21	27	20	14
Fuel	19	22	14	23	18	21
2007						
Total	1473	1102	844	693	770	1233
Hired labor	149	72	30	32	42	42
Fertilizer	89	80	54	40	39	58
Fuel	51	46	33	30	30	35

Sources: 2002 and 2007 Censuses of Agriculture

Note: units are dollars per acre.

Table 2. Production Function Parameter Estimates, Kentucky Tobacco Farms, 1997-2007

Input	(1) OLS	(2) OLS with County Fixed Effects	(3) Levinsohn & Petrin
Land	0.178	0.196	0.174
	(0.006)	(0.006)	(0.008)
Intermediates	0.538	0.510	0.459
	(0.007)	(0.007)	(0.009)
Capital	0.152	0.145	0.125
	(0.006)	(0.006)	(0.015)
Labor	0.504	0.473	0.463
	(0.011)	(0.011)	(0.011)
Livestock	0.041	0.040	0.043
	(0.001)	(0.001)	(0.002)

Sources: 1997, 2002, and 2007 Censuses of Agriculture
Note: All observations in 1997, 2002, and 2007 are pooled.
to estimate the production fucntions. Sample size is 33,827.
Robust standard errors in parentheses.

Essay III

Structural Change and the Aggregate Productivity Growth of U.S. Crop Farms

abstract

This study examines the relationship between farm size and productivity growth. In the past several decades, crop production in the U.S. has shifted to larger farms. During the same period, crop productivity has fairly improved. While these two events seem clearly associated, no studies have fully uncovered the link between them. Using farm-level longitudinal data from the Censuses of Agriculture from 1987-2007 enables us to decompose aggregate productivity growth (APG) by farm size, but also by farm entry/exit and by technology/reallocation. We have three main findings. First, productivity growth is clearly non-uniform among farm sizes. Between 1987 and 2007, virtually all of the aggregate productivity growth of crop farms came from farms with annual sales of more than $500,000. These farms account for only 8% of U.S. crop farms. A closer look at the APG contributions to productivity growth from surviving farms confirms the findings for all crop farms: the productivity of mid-size farms has barely increased, and the productivity of smaller farms has fallen. Finally, the relative importance of technical efficiency growth and resource reallocation varies over time. Technical efficiency growth seems to be a larger source of APG for large farms between 1987 and 1997, whereas reallocation across all sales classes contributes more to APG between 1997 and 2007. Overall, our finding provides the concrete evidence that farm consolidation has been strongly associated with the productivity growth of U.S. crop farms. Our finding that resource reallocation through farm consolidation is nontrivial for the APG of crop farms highlights the usefulness of farm-level panel data for studying structural changes and APG.

JEL Classification Codes: Q18, Q12, O47.
Keywords: Structural Change, Crop Farms, Productivity Growth.

This is a co-authored work with T. Kirk White, economist at the Center for Economic Studies, Census Bureau, Department of Commerce. The views expressed are those of the authors and should not be attributed to ERS or USDA. The results in this paper have been screened to insure that no confidential information is revealed. The authors wish to thank Jim MacDonald for comments and suggestions, and Jim Burt and Robert Hunt for many disclosure avoidance reviews.

Introduction

In recent decades crop production in the U.S. has been shifting to larger crop enterprises and larger crop farms (Hoppe, MacDonald, and Korb 2010; MacDonald 2011; White and Hoppe 2012). Over the same period, U.S. agricultural productivity has increased tremendously.[1] For example, White and Hoppe (2012), show that for several major field crops,[2] between 1992 and 2007 the acre-weighted median enterprise size increased between 52 and 100 percent, depending on the crop. White and Hoppe (2012) also show that for these same crops, the share of the total value of production accounted for by large and very large farms (sales of $500,000 or more in 2009 dollars), increased from 22 percent in 1991 to 54 percent in 2009. These shifts of production to larger farms continue an earlier trend documented by, e.g., Hoppe, MacDonald, and Korb (2010) and MacDonald, Korb, and Hoppe (2013).

While crop farm size increases and the aggregate productivity growth of U.S. crop farms are positively correlated, few empirical studies measure the contribution of shifts in farm size to aggregate productivity growth. Many studies find either that productivity differs among farm sizes or that farm productivity changes over time (e.g., Maietta 2000; Morrison et al. 2004; Mosheim and Lovell 2009), but do not show that the *rate* of productivity growth differs across farm sizes.[3] If shifts in crop farm size contributed to aggregate productivity growth, one may also wonder *how* this structural change contributes to the aggregate productivity growth (APG) of crop farms. Do larger farms use resources more efficiently than smaller farms? Or did the larger farms adopt technologies that caused their productivity to grow faster than that of smaller farms? State-level analyses (e.g., Ball et al. (1999), Huffman and Evenson (2001), Acquaye, Alston, and Pardey (2003) and Ahearn, Yee, and Korb (2005)) do not capture the relationships between farm size and APG through those

---

[1] For example, between 1987 and 2007, total agricultural productivity increased by 33 percent. See the USDA productivity accounts, available on the internet at http://www.ers.usda.gov/Data/AgProductivity/.

[2] The crops are corn, soybeans, barley, oats, rice, sorghum, wheat, peanuts, and cotton.

[3] Moreover, these studies use the fairly small sample sizes, which prevents further disaggregation.

channels. Aggregate data may mask considerable within-state variation in farm production activities over time.

This study uses farm-level longitudinal data from the quinquennial Censuses of Agriculture from 1987 to 2007. These data enable us to disaggregate crop farm APG by farm size class. In sum, the purpose of our study is to offer the quantitative measures of the magnitude, direction, and channels of APG among farm sizes in U.S. crop production.

The rest of the paper is organized as follows. We first review methodologies to compute APG and then explain the methodology applied in this article. Next, we provide a description of Agricultural Census data and U.S. crop farm trends. Then we discuss the estimation results and finally, we conclude.

Literature Review on Aggregate Productivity Growth Decompositions

There are two strands of literature on aggregate productivity decompositions. In the first strand, beginning with the seminal paper by Baily, Hulten, and Campbell (1992, BHC hereafter), aggregate productivity growth is decomposed into the output-share-weighted sum of plant-level technical efficiency growth rates (defined as the “within" term), and the technical-efficiency-weighted sum of the changes in establishment-level output shares, (the “between" term) which is usually interpreted as the contribution of reallocation to aggregate productivity growth (e.g., Griliches and Regev 1995; Olley and Pakes 1996; Foster, Haltiwanger, and Krizan 2001). All of the BHC-like decompositions assume a perfectly competitive economy with no distortions, adjustment costs, or other frictions. However, in the presence of distortions–for example, agricultural subsidies–BHC-like decompositions do not properly measure the contribution of resource reallocation to aggregate productivity growth (Basu and Fernald 2002; Petrin and Levinsohn 2010).

Petrin and Levinsohn (2012, P-L hereafter) proposes an alternative APG decomposition that correctly measures the contribution of reallocation to APG in the presence of distortions, adjustment costs, and other market frictions. P-L and some other recent empirical studies (Petrin, White, and Reiter 2011; Kwon, Narita, and Narita 2009) used plant-level manufacturing data for the U.S., Japan, and Chile and found large differences between APG and the growth rate of a BHC-like index. Studies by Restuccia and Rogerson (2008) and Hsieh and Klenow (2009) also found that within-industry heterogeneity in distortions (e.g., taxes or subsidies) may have important effects on aggregate total factor productivity.

The P-L approach calculates aggregate productivity growth as a weighted average of farm-level growth rates of inputs and technical efficency, and thus requires observations for each farm in two consecutive periods. However, a significant number of farms appear to enter or exit between Censuses of Agriculture, so the impact of these entries and exits on APG is non-negligible (Kirwan, Uchida, and White 2012). Kirwan, Uchida, and White (2012, KUW hereafter) combine the P-L approach and the index number approach developed by Diewert and Fox (2010, D-F hereafter) which accounts for the contributions of entering and exiting farms, to measure the aggregate productivity of tobacco farms in Kentucky between 1997 and 2007. In this paper we apply the KUW method to decompose the APG of all U.S. crop farms. In the following section, we describe the KUW methodology in detail.

The KUW Decomposition

First we describe how the P-L approach decomposes aggregate productivity growth (APG) into the separate contributions of farm-level technical efficiency growth and the reallocation of resources across farms. [4] The production technology for each farm can be described by:

$$Q_i = F(X_i, \omega_i). \tag{1}$$

where Q_i is the output of farm i, $X_i = (X_{i1}, \ldots, X_{iK})$ is a vector of primary input usage (land, labor, buildings and machinery) and intermediate input usage (fertilizer, agricultural chem-

---

[4] In this section we borrow heavily from the exposition in KUW.

icals, seeds, fuel, etc.).[5] Farm i's technical efficiency is indexed by ω_i. In P-L, aggregate productivity change is defined as the change in aggregate *final demand* minus the change in aggregate costs, where firm i's final demand Y_i is Q_i minus the part of Q_i used as intermediate input (M) by all other firms j: $Y_i = Q_i - \sum_j M_{ji}$. For now we assume that crop farm outputs are not used as inputs by other crop farms, so crop farms' aggregate productivity change can be written as the price-weighted change in the aggregate *output* of crop farms minus the marginal cost-weighted change in aggregate inputs:

$$dAP \equiv \sum_i P_i dQ_i - \sum_i \sum_k W_{ik} dX_{ik}, \tag{2}$$

where the summation is over all crop farms. P_i is the price of farm i's output, and $\sum_i P_i dQ_i$ is the instantaneous change in aggregate crop farm output holding prices constant. W_{ik} denotes the marginal cost of the k^{th} input and dX_{ik} is the instantaneous change in the use of that input at farm i. Substituting equation (1) into (2), the change in aggregate productivity can be decomposed as:

$$dAP = \sum_i \sum_k \left(P_i \frac{\partial F}{\partial X_{ik}} - W_{ik}\right) dX_{ik} + \sum_i P_i d\omega_i, \tag{3}$$

where the double-summation on the right side of equation (3) measures the contribution of reallocation, and the second summation, $\sum_i P_i d\omega_i$, measures the contribution of technical efficiency change.[6] The technical efficiency term represents the contribution to APG coming from farms producing more output, holding inputs constant. The reallocation term measures the APG contribution from changes in input reallocation *across* farms (irrespective of within-farm changes in technical efficiency). Within the reallocation term, the expression $P_i \frac{\partial F}{\partial X_{ik}} - W_{ik}$ is the gap between the farm's value marginal product and its marginal cost for

---

[5] Petrin and Levinsohn (2010) distinguish between primary and intermediate inputs. Since this distinction plays no role in our analysis, we simplify the exposition by using the same notation for both types of inputs.

[6] We normalize $\frac{\partial F}{\partial \omega} = 1$.

input k. With perfectly competitive firms facing no adjustment costs or other frictions or distortions, marginal revenue products will equal marginal costs, and thus in equilibrium further reallocation will not contribute to changes in aggregate productivity. In the context of U.S. crop farms, gaps between marginal revenue products and marginal costs might exist because of taxes, farm subsidies, costs of adjusting land, capital or labor inputs, credit constraints, or perhaps other frictions or distortions. If the gap for input k is more positive (or less negative) for farm i than for some other farm j, then a reallocation of input k from farm j to farm i contributes positively to aggregate productivity.

Dividing equation (2) by the aggregate value-added of all crop farms and doing some algebra, we obtain the following expression for the APG of crop farms:

$$APG = \sum_i D_i dlnQ_i - \sum_k \sum_i D_i c_{ik} dlnX_{ik}, \tag{4}$$

where $D_i = \frac{P_i Q_i}{\sum_{i=1}^{N} P_i Q_i}$ is the Domar (1961) weight and $c_{ik} = \frac{W_{ik} X_{ik}}{P_i Q_i}$ the cost of input k as a share of the farm's revenue. Dividing both sides of equation (3) by the aggregate value-added of crop farms, doing a bit more algebra, and substituting the result in equation (4), we obtain the following APG decomposition:

$$APG \;=\; \sum_i D_i \sum_k (\varepsilon_{ik} - c_{ik}) dlnX_{ik} + \sum_i D_i dln\omega_i, \tag{5}$$

where ε_{ik} is the elasticity of output with respect to input k, $dlnX_{ik}$ is the growth rate of input k on farm i, and $dln\omega_i$ is the growth rate of farm i's technical efficiency, with base Q_i: $dln\omega_i \equiv \frac{d\omega_i}{Q_i}$. The double summation gives the APG contribution of reallocation of inputs and the second summation term is the contribution of farm-level technical efficiency growth. The intuition for the reallocation term is the same as for the reallocation term in equation (3): if the gap between the output elasticity and the cost share for input k is more positive (or less negative) for farm i than for farm j, then reallocation of input k from farm i

to farm j will contribute positively to APG. Note that while the variables in the reallocation term may be correlated with the farm's technical efficiency, they are not the same thing. In other words, the APG contribution of reallocation from farm j to farm i does not directly depend on the relative technical efficiencies of those two farms.[7]

As noted by P-L, the decomposition in equation (5) can be approximated by a Törnqvist index. However, we cannot measure the APG contribution of entering or exiting farms with a Törnqvist index, because it requires measurements in two consecutive periods for each farm. As we show below, we find a significant number of entering and exiting crop farms in the Census of Agriculture, so we want to account for these farms in our APG measure. The D-F multilateral index number approach provides a way of measuring the APG contribution of entering and exiting farms. In the ideal case, D-F measures a farm's productivity using its entire vector of inputs and outputs and their prices. However, in the Census of Agriculture, for most inputs we only observe expenditures. In the absence of a complete set of prices and quantities, D-F suggest using deflated revenues and costs to construct farm-level "approximate output and input aggregates." Following KUW, for each farm i, we approximate productivity in year t by:

$$\Pi_{it} = \frac{P_{it}Q_{it}}{\sum_k W_{ikt}X_{ikt}}, \tag{6}$$

where P, Q, W, and X are as defined above.[8] Using equation (6) to approximate farm-level productivity, an approximation of aggregate productivity is:

$$AP_t = \sum_i \frac{\sum_k W_{ikt}X_{ikt}}{\sum_i \sum_k W_{ikt}X_{ikt}} \Pi_{it} = \frac{\sum_i P_{it}Q_{it}}{\sum_i \sum_k W_{ikt}X_{ikt}}, \tag{7}$$

---

[7] This is why the "between" term in BHC-like decompositions does not measure the contribution of reallocation to APG.

[8] For simplicity, here we assume that each farm has only one output and we abstract from inflation. In the empirical analysis we use farm-level revenues, and we deflate revenues and expenditures in equation (6) with state-level price indexes.

where the outer summations are over all crop farms in year t. This approximates aggregate productivity with aggregate revenues divided by aggregate input costs. Note that if we differentiate (7), we get equation (2), the definition of aggregate productivity change. D-F also show that aggregate productivity in year t can be decomposed as:

$$AP_t = \sum_{i \in C} s_{it}\Pi_{it} + \sum_{i \in E} s_{it}\Pi_{it}, \tag{8}$$

where $s_{it} = \frac{\sum_k W_{ikt}X_{ikt}}{\sum_i \sum_k W_{ikt}X_{ikt}}$ is farm i's share of the total costs of all crop farms active in year t; C is the set of farms that remained active from year $t-5$ to year t; and E is the set of farms entering between years $t-5$ and t. Aggregate productivity in year $t-5$ can be decomposed as:

$$AP_{t-5} = \sum_{i \in C} s_{i,t-5}\Pi_{i,t-5} + \sum_{i \in \chi} s_{i,t-5}\Pi_{i,t-5}, \tag{9}$$

where χ is the set of farms exiting between years $t-5$ and t. Approximate APG can be computed as $(AP_t - AP_{t-5})/AP_{t-5}$. Combining equations (8) and (9) we have:

$$\begin{aligned} APG_t &= [\textstyle\sum_{i \in C}(s_{it}\Pi_{it} - s_{i,t-5}\Pi_{i,t-5})]/AP_{t-5} \\ &\quad + [\textstyle\sum_{i \in E} s_{it}\Pi_{it} - \sum_{i \in \chi} s_{i,t-5}\Pi_{i,t-5}]/AP_{t-5}. \end{aligned} \tag{10}$$

The first line of (10) gives continuing farms' approximate APG contribution, and the second line is the APG contribution of net entry/exit. For *continuing* farms in year $t-5$, the P-L decomposition of APG into reallocation and technical efficiency growth in equation (5) can be approximated by the following Törnqvist index:

$$\begin{aligned} APG_{Ct} &= \textstyle\sum_{i \in C} \overline{D}_{it}[\sum_k (\overline{\varepsilon}_{ikt} - \overline{c}_{ikt})\Delta lnX_{ikt} \\ &\quad + \textstyle\sum_{i \in C} \overline{D}_{it}\Delta ln\omega_{it}, \end{aligned} \tag{11}$$

where for any variable z, $\bar{z}_{it} = \frac{z_{it}+z_{i,t-5}}{2}$, Δ denotes the first differences operator, and C is the set of continuing farms. Substituting equation (11) into equation (10) yields:

$$\begin{aligned} APG_t &= \textstyle\sum_{i\in C}\overline{D}_{it}\sum_k(\overline{\varepsilon}_{ikt}-\overline{c}_{ikt})\Delta lnX_{ikt} \\ &\quad +\textstyle\sum_{i\in C}\overline{D}_{it}\Delta ln\omega_{it}+\sum_{i\in C}U_{it} \\ &\quad +[\textstyle\sum_{i\in E}s_{it}\Pi_{it}-\sum_{i\in\chi}s_{i,t-5}\Pi_{i,t-5}]/AP_{t-5}, \end{aligned} \tag{12}$$

where the term $\sum_{i\in C}U_{it}$ is the difference between the D-F APG approximation and the P-L APG approximation for continuers:

$$\begin{aligned} \textstyle\sum_{i\in C}U_{it} &\equiv [\textstyle\sum_{i\in C}(s_{it}\Pi_{it}-s_{i,t-5}\Pi_{i,t-5})]/AP_{t-5} \\ &\quad -\textstyle\sum_{i\in C}\overline{D}_{it}\sum_k(\overline{\varepsilon}_{ikt}-\overline{c}_{ikt})\Delta lnX_{ikt} \\ &\quad -\textstyle\sum_{i\in C}\overline{D}_{it}\Delta ln\omega_{it}. \end{aligned} \tag{13}$$

We call this the "approximation residual" for continuers. The $\sum_{i\in C}U_{it}$ term accounts for the fact that the index of aggregate productivity in equation (10) includes changes in relative prices of inputs and output, whereas the Törnqvist approximation for continuers in equation (11) holds these prices constant. Ideally we would hold these prices constant for all farms, since our goal is to measure the growth in crop farms' aggregate output minus the growth in inputs used to produce those outputs. However, we cannot hold farm-level prices constant for entering or exiting crop farms. Thus the KUW decomposition is a compromise between two conflicting goals: including all crop farms in the sample and holding prices constant across two consecutive periods. To measure the contribution of each term to APG in equation (12), we calculate revenue shares c_{ikt} and cost shares s_{it} separately for each farm in each year. To measure the output elasticities ε_{ikt} and the growth rate of farm-level technical efficiency, we estimate production functions, as described in the next section.

Production Function Estimation

We assume crop farms' technology can be approximated by a translog functional form:

$$lnQ_{it} = \beta_0 + \sum_k \beta_k lnX_{ikt} + \sum_k \beta_k (lnX_{ikt})^2 + \tfrac{1}{2}\sum_k \sum_{l \neq k} \beta_{kl} lnX_{ikt} lnX_{ilt} + u_{it}, \tag{14}$$

where Q is *output* of farm i in year t, X_{ikt} is input k, and u_{it} is an error term. For inputs, we use *land* (acres harvested), *labor* (including hired, contract and operator labor), *capital*, and *intermediates* (including fertilizer, pesticides, fuel, seeds/transplants, and livestock expenses). We derive the output elasticity for input k as:

$$\frac{\partial lnQ}{\partial lnX_{ik}} = \beta_k + \sum_l \beta_{kl} lnX_{ilt}. \tag{15}$$

This allows the output elasticities to vary across farms and over time. We estimate the parameters of the production function using OLS, OLS with county fixed effects, and the Levinsohn and Petrin (2003, L-P hereafter) estimator.[9] Given a set of production function parameter estimates, our estimate of the log of technical efficiency of farm i in year t is the estimated intercept plus the residual: $ln\omega_{it} = \widehat{\beta}_0 + \widehat{u}_{it}$. We use $ln\omega_{it}$ and the estimated output elasticities to calculate the APG decomposition in equation (12).

Data Description

We use confidential farm-level data from the quinquennial Censuses of Agriculture for 1987-2007. By using numeric farm-level identifiers, we link farms longitudinally across censuses. We then select “crop farms", defined as a farm with the positive total value of production (TVP) of any crops. To construct variables for estimation, we follow KUW’s variable construction.[10] For each farm we observe TVP from livestock and crops and acres

---

[9] The L-P estimator is designed to address the well-known input endogeneity problem pointed out by Marschak and Andrews (1944). It corrects for the simultaneous determination of inputs and unobserved productivity shocks by using a proxy variable. In agriculture, input choices are likely correlated with weather shocks after the planting period. We therefore use seed input as a proxy, which is determined at the beginning of production.

[10] The supplemental appendix in KUW provides a more detailed description.

harvested for crops. We also observe farm-level expenditures on chemicals, contract labor, hired labor, fertilizer, fuel, seeds/transplants, utilities, livestock expenses, machinery, and the total value of land and buildings, and the number of days the operator(s) worked off the farm. For the production functions estimated in equation (14) we construct farm-level output and input quantity variables by substituting real revenues and expenses, except for land.[11] To construct the real values of farm output, labor and capital, we deflate the corresponding nominal variables with USDA price indexes for output and labor and capital rental rates for farm machinery from the Bureau of Labor Statistics. The other inputs — chemicals, fertilizer, seeds/transplants, utilities, and livestock expenses — are combined into a single measure of intermediate inputs after deflating by the corresponding USDA state-specific price indexes. This gives us a single output and four inputs to production: land, capital, labor, and intermediate inputs. For the APG estimates and their decompositions in equation (12) we compute the share variables for these four inputs from TVP and expenditures.

U.S. Crop Farm Dynamics in the Census of Agriculture

Table 1 shows the total number of crop farms and the percentage of crop farms by size class in each census year from 1987 to 2007. The total number of crop farms fluctuated between about 820,000 and 907,000. The increase in the number of farms classified as crop farms between 1992 and 1997 is due to the administrative change from the SIC classification system to the NAICS system in 1997.[12] In 2007, NASS expanded the sampling frame for the Census of Agriculture to increase the coverage of small farms. This expansion explains the large increase in the total number of crop farms between 2002 and 2007. In table 1, we classify farms into 5 size classes based on each farm's TVP.[13]

---

[11] The relative prices included in these measures of inputs and outputs may proxy for quality.

[12] In 1997, the Census Bureau collected the data based on the SIC system, but estimates were published under the NAICS system. If we classify farms based on the SIC system, there were only 836,333 crop farms in 1997, instead of 897,572. For consistency, we use the SIC based farm sample for estimation with the 1992-1997 data, while using the NAICS based farm sample with the 1997-2002 data.

[13] All dollar figures are in 1996 dollars.

The percentage of crop farms in the categories with TVP less than \$10,000 and between \$100,000 and \$250,000 remains stable between 1987 and 2007, while the percentage of crop farms in the intermediate category with TVP between \$10,000 and \$100,000 declined steadily, from a total of about 45% of farms to about 34%. Over the same period, the percentage of crop farms in the next largest size class (TVP between \$250,000 and \$500,000) more than doubled from 3% to 8%, and the percentage of farms in our largest size class quadrupled, from 2% to 8%.[14] These patterns are consistent with previous research showing that increasing shares of crop production and the value of crop production shifted to larger farms and larger crop enterprises over the past 2 decades (Hoppe, MacDonald, and Korb 2010; MacDonald 2011; White and Hoppe 2012).

Although the total number of crop farms has been relatively stable in recent decades, this masks a significant amount of turnover at the farm level, at least in the data. Previous research has documented a significant amount of farm entry and exit in U.S. agriculture. Using the longitudinally-linked Censuses of Agriculture from 1978 to 1997, Hoppe and Korb (2006) found that 5-year exit rates for all U.S. farms over this period were between 33 and 40%. Using the same data, Ahearn, Korb, and Yee (2009, AKY hereafter) find that 5-year entry rates for all U.S. farms varied between 32 and 39% over the same period. Table 2 presents our estimates of 5-year crop farm entry and exit rates by size class from the 1987-2007 Censuses of Agriculture. [15] Although we extend the analysis to 2002 and 2007

---

[14] Given that many small farms were added to sampling frame in the 2007 Agricultural Census, the actual increase in the share of these two large farm categories was probably greater than 9 percentage points.

[15] As in AKY and KUW, we create longitudinal linkages and define entry and exit rates in the Census of Agriculture based on farm-level numeric identifiers. For the 1987-1992 and 1992-1997 linkages we use the Census File Number (CFN). After 1997, when USDA's NASS started collecting the Census of Agriculture, the CFN was replaced by the POID. We use the POID for 1997-2002 and 2002-2007 longitudinal linkages. If a crop farm appears in the Census in year t, but that farm's numeric identifier does not appear in the Census in year $t+5$, we define that as a farm exit. Likewise, if a crop farm appears in the Census in year t, but that farm's identifier did not appear in the Census in year $t-5$, we define that as a farm entry. As noted in AKY, the numeric identifiers in the Census can change for a variety of reasons. If a farm's ownership changes, either because the owner dies or sells the farm, the numeric identifier may change or it may stay the same. For example, if an inherited farm is split into two farms, the resulting farms may get two new idenfiers. In this case the split would appear as an exit and two entrants. To take another example, a farm that is sold may be merged with an existing farm. If the resulting larger farm keeps one of the original identifiers, this would appear as an exit with no corresponding entry. Unfortunately the Census of

and focus only on crop farms, our findings are broadly consistent with previous research. The overall crop farm entry and exit rates over this period were relatively stable, ranging from 35 to 40% for entry and 40 to 44% for exit.[16] By sales class, the entry and exit rates range from 20 to 50%. The exit rate is always higher than the entry rate for farms with total value of production between \$10,000 and \$500,000. Until 2002, both the entry and exit rates tend to decline with farm size for farms with TVP less than \$500,000. Between 2002 and 2007, entry and exit rates declined uniformly with farm size. In summary, the data show more turnovers in smaller farm operations. Also, the *net* exit rate declines with farm size, except for the 2002-2007 period. Overall the results in tables 1 and 2 are consistent with previous evidence of U.S. crop farm consolidation over time.

Estimation Results

Table 3 shows our estimates for the elasticities in (15) using the LP estimator, evaluated at the sample mean for each 5-year panel.[17] The output elasticity for land is somewhat higher in 2002-2007 compared to earlier years. Otherwise the estimates are stable over time.

The top row of table 4 shows our estimates of the APG of crop farms (the left side of equation 10) for each 5-year period from 1987 to 2007. We observe that aggregate productivity decreased by 1.1% between 1987 and 1992 and by 3.7% between 1997 and 2002. In contrast, aggregate productivity increased by 3.1% between 1992 and 1997 and by

---

Agriculture does not allow us to distinguish between mergers and splits of existing operations as opposed to farm operations simply going out of business or the entry of entirely new operations. However, we can still measure the aggregate contribution of these types of farms dynamics — entries, exits, merges, and splits — to productivity growth. If entrants and “new" farms resulting from a split are aggregately more (less) productive than farms that exited and the original farms that split, then these farms will contribute positively (negatively) to our measure of APG.

[16] We calculate entry and exit rates within each 5-year panel using a consistent definition of crop farms. As noted above, in 1997 the Census of Agriculture was collected under the SIC system but published under the NAICS system, so in 1997 farms were given and SIC code as well as a NAICS code. For the 1992-1997 entry and exit rates in table 2 we included farms classified as crop farms under the SIC system. For the 1997-2002 panel, we used farms classified as crop farms under the NAICS system.

[17] Estimations are conducted by pooling observations for each of the four panels. We also estimated the production function in (14) by OLS, OLS with county fixed effects, and LP with state fixed effects, and all of these with weather variables (temperature and rainfall) to account for unobservable shocks which may influence input choices. The output elasticity for land tends to be slightly higher when we include state or county fixed effects, but the other estimates are remarkably robust across estimators.

10.1% between 2002 and 2007. Whether these findings are surprising or not remains open to discussion. The USDA/ERS aggregate total factor productivity estimates for all U.S. farms show positive growth during the corresponding four periods.[18] However, our sample includes only crop farms, while the USDA productivity accounts represent all farms, including livestock farms. More importantly, these aggregate estimates mask a great deal of heterogeneity at the farm level. The last 6 rows of table 4 show our estimates of the APG contribution of the farms in each of 6 size classes.[19] Small and intermediate size crop farms — those with TVP less than $500,000 — contributed negatively to APG in every 5-year period between 1987 and 2007. In contrast, large farms with TVP between $500,000 and $1 million contributed positively except between 1997 and 2002. Farms with TVP over $1 million accounted for most of the APG between 1987 and 2007.

These findings highlight an important limitation of previous research on the aggregate productivity growth of U.S. farms. Productivity growth is not uniform across farm size classes. Crop productivity growth between 1987 and 2007 has come primarily from farms with TVP more than $500,000, which account for less than 8% of U.S. crop farms. On the other hand, farms with TVP less than $500,000 have contributed negatively to productivity growth over this period.

Next, we show the relative contributions of continuing farms (farms that continue from one census to the next) and entering/exiting farms to APG as defined in equation (12). Column 1 in table 5 shows the contributions of farms continuing crop production from one census to the next. This column represents the first two rows of equation (12). Column 2 shows the APG contribution of entering and exiting crop farms in the last row of equation (12). Column 3 reproduces the total APG estimates from table 4. Each of the 4 panels of the table present the APG contributions from crop farms by size class. Within each panel

---

[18] See the USDA productivity accounts at http://www.ers.usda.gov/Data/AgProductivity/.

[19] Since larger farms account for a large sales share of crop production (over 50% in 1997, 2002 and 2007), we have further divided the largest size class into farms with TVP between $500,000 and $1 million and farms with TVP greater than $1 million.

we have collapsed the bottom 3 size classes in table 4 into one category — farms with total value of production less than $250,000. Note also that the first 4 rows within each 5-year panel add up to the “All crop farms" row for the same 5-year period. For continuing farms, we classify the farm based on its total value of production in the ending year of the panel. So a farm with TVP of $249,000 in 1987 and $251,000 in 1992 (all in 1996 dollars) would be classified in the higher size class.

The disaggregated results in table 5 are similar to the more aggregated results in table 4. That is, larger farms contributed positively to aggregate productivity growth in every period, whether we look at continuing large farms or net entry of large farms. In addition, we find in most cases that, within the same sales class, continuing farms contribute more to productivity growth than the net entries do. This seems reasonable given that in all but the smallest size class, most farms are continuers (see table 2).

Finally, we discuss the relative importance of technical efficiency growth and resource reallocation for APG. Table 6 shows our results for the APG decomposition for continuing crop farms into the contributions of technical efficiency growth and resource reallocation, as defined in the first two rows of equation (12). We provide the lower and upper bounds of the contributions of technical efficiency growth and reallocation in columns 1 and 2, respectively, because we cannot measure price change effects in the P-L APG estimates represented by the residual term (i.e., the U term in equation (12)). Column 3 reproduces the total APG estimates for continuing farms from column 1 of table 5. For example, column (1) in the first row of the table 6, [-9.9%, -1.6%], shows the possible range of the technical efficiency growth contribution of the smallest class of farms between 1987 and 1992.

In most cases the bounds for the APG contributions of both technical efficiency growth and reallocation both cross zero. Nevertheless, two contrasting findings are worth noting. First, the relative importance of each source of aggregate productivity growth varies over time. Technical efficiency growth seems a more important source of APG between

1992 and 1997, while reallocation seems more important between 1997 and 2007. Second, technical efficiency growth seems to be a larger source of APG for larger farms between 1987 and 1997, while resource reallocation across all sales classes contribute more to APG between 1997 and 2007.

The importance of resource reallocation within and between farms is further observed by separately looking at ΔlnX_{ikt} in equation (12). Table 7 shows the average growth rate of the four inputs by sales class in 1987-2007. Overall, the use of intermediate and capital inputs has increased steadily, whereas farmland size has remained stable and labor input has decreased. This is consistent with the conventional wisdom that crop production has changed from labor-intensive farming to the farming with the heavier use of machinery, chemical materials and fertilizer. Input use by sales class provides the additional finding that farmland has been concentrated to larger farms. This finding with the results in table 4, 5 and 6 indicates that farm consolidation has been strongly associated with the productivity growth of U.S. crop farms. In contrast, the smallest farms seem to have attempted to introduce capital and material intensive production activities on shrinking acreage. These findings are one of our major contributions to the literature because either the methodology of aggregate productivity estimation with BHC-like decompositions or the state-level data analysis is not able to reveal such reallocation behaviors within and between farms.

Conclusions

In the past several decades, crop production in the U.S. has shifted to larger farms. During the same period, the aggregate productivity of crop farms has also grown significantly. While these two events seem clearly associated, no studies have fully uncovered the link between them. Using farm-level longitudinal data from the Censuses of Agriculture from 1987-2007 enables us to decompose the aggregate productivity growth (APG) of crop farms into the separate contributions from net entry/exit, technical efficiency growth, and reallocation for each of several farm size classes.

We have three main findings. First, productivity growth is clearly non-uniform among farm sizes. Between 1987 and 2007, virtually all of the aggregate productivity growth of crop farms came from farms with annual sales of more than \$500,000. These farms account for only 8% of U.S. crop farms. In contrast, the overall APG contributions of farms with sales less than \$500,000 to crop productivity growth are negative. A closer look at the APG contributions to productivity growth from surviving farms confirms the findings for all crop farms: the productivity of mid-size farms (annual sales between \$250,000 and \$500,000) has barely increased, and the productivity of smaller farms has fallen. Finally, the relative importance of technical efficiency growth and resource reallocation varies over time. Technical efficiency growth seems to be a larger source of APG for large farms between 1987 and 1997, whereas reallocation across all sales classes contributes more to APG between 1997 and 2007. Overall, our finding provides the concrete evidence that farm consolidation has been strongly associated with the productivity growth of U.S. crop farms.

Our finding that resource reallocation through farm consolidation is nontrivial for the APG of crop farms highlights the usefulness of farm-level panel data for studying structural changes and APG. Since farm-level productivity is positively correlated with farm-level profitability through resource reallocation, our findings also suggest one of the proximate causes of structural change in U.S. crop production: larger farms tend to be more profitable.

Tables

Table 1. Percentage of U.S. Crop Farms by Size Class, 1987-2007

	1987	1992	1997	2002	2007
Total Number of Crop Farms	904,490	858,396	897,572	819,684	907,205
Total Value of Production (TVP)					
0 < TVP <=$10,000	38%	35%	33%	33%	38%
$10,000 < TVP <= $100,000	45%	43%	41%	40%	34%
$100,000 < TVP <=$250,000	12%	14%	14%	14%	13%
$250,000 < TVP <= $500,000	3%	5%	7%	8%	8%
TVP > $500,000	2%	3%	4%	5%	8%

Notes: Crop farms were farms classified as such based on the SIC system until 1992 and based on the NAICS system for 1997-2007.

Table 2. Entry and Exit Rates of U.S. Crop Farms by Size Class, 1987-2007

		1987-92	1992-97	1997-02	2002-07
Overall	Entry	35%	37%	38%	40%
	Exit	41%	39%	44%	40%
Total Value of Production (TVP)					
0 < TVP <=$10,000	Entry	42%	47%	40%	51%
	Exit	49%	46%	51%	46%
$10,000 < TVP <=$100,000	Entry	32%	34%	30%	34%
	Exit	38%	37%	43%	39%
$100,000 < TVP <=$250,000	Entry	25%	26%	24%	23%
	Exit	28%	30%	36%	32%
$250,000 < TVP <= $500,000	Entry	23%	24%	23%	21%
	Exit	26%	26%	33%	27%
TVP > $500,000	Entry	28%	28%	26%	20%
	Exit	30%	29%	32%	20%

Notes: The entry rate for each 5-year panel is the percentage of crop farms in the size class in the final year of a panel which could not be linked to a farm in the previous Census. The exit rate is the percentage of crop farms in a size class in the initial year of a panel that could not be linked to a farm in the subsequent Census. See footnote 13 for calculation of entry/exit rates under different industry classification systems of SIC and NAICS.

Sources: 1987-2007 Censuses of Agriculture.

Table 3. Mean Output Elasticities, U.S. Crop Farms, 1987-2007

Input	1987-92	1992-97	1997-02	2002-07
Land	0.041	0.054	0.068	0.134
	(0.001)	(0.001)	(0.001)	(0.001)
Intermediates	0.676	0.640	0.648	0.657
	(0.001)	(0.002)	(0.002)	(0.002)
Capital	0.107	0.082	0.096	0.079
	(0.003)	(0.004)	(0.004)	(0.003)
Labor	0.231	0.261	0.268	0.223
	(0.001)	(0.001)	(0.001)	(0.001)

The table shows output elasticities evaluated at the sample mean for each 5-year panel. Robust standard errors in parentheses.

Sources: 1987-2007 Censuses of Agriculture.

Table 4. Aggregate Productivity Growth Contributions by Size Class, U.S. Crop Farms, 1987-2007

	1987-92	1992-97	1997-02	2002-07
Total	-1.1%	3.1%	-3.7%	10.1%
Total Value of Production (TVP)				
0 < TVP <=$10,000	-0.7%	-0.4%	-0.4%	-0.6%
$10,000 < TVP <=$100,000	-2.7%	-1.6%	-2.3%	-2.5%
$100,000 < TVP <=$250,000	-1.5%	-0.5%	-2.1%	-2.3%
$250,000 < TVP <= $500,000	-0.01%	-0.1%	-1.4%	-0.3%
$500,000 < TVP <= $1 million	1.1%	1.2%	-0.6%	3.7%
TVP > $1 million	2.7%	4.5%	3.0%	12.2%

Sources: 1987-2007 Censuses of Agriculture.

Table 5. Aggregate Productivity Growth Contributions from Continuing and Net Entry Farms by Size Class, U.S. Crop Farms, 1987-2007

Years	Size Class	Continuous Farms (1)	Entry & Exit (2)	Total APG (3)
1987-92	TVP <= $250,000	-2.5%	-2.4%	-4.9%
	$250,000 < TVP <= $500,000	-0.04%	0.03%	-0.01%
	$500,000 < TVP <= $1 million	0.6%	0.6%	1.1%
	TVP > $1 million	1.5%	1.2%	2.7%
	All crop farms	-0.5%	-0.7%	-1.1%
1992-97	TVP <= $250,000	-0.1%	-2.4%	-2.5%
	$250,000 < TVP <= $500,000	0.2%	-0.3%	-0.1%
	$500,000 < TVP <= $1 million	0.7%	0.5%	1.2%
	TVP > $1 million	2.4%	2.1%	4.5%
	All crop farms	3.2%	-0.2%	3.1%
1997-02	TVP <= $250,000	-0.5%	-4.2%	-4.8%
	$250,000 < TVP <= $500,000	-0.1%	-1.3%	-1.4%
	$500,000 < TVP <= $1 million	0.02%	-0.6%	-0.6%
	TVP > $1 million	2.7%	0.4%	3.0%
	All crop farms	2.0%	-5.8%	-3.7%
2002-07	TVP <= $250,000	-3.8%	-1.6%	-5.5%
	$250,000 < TVP <= $500,000	-0.8%	0.5%	-0.3%
	$500,000 < TVP <= $1 million	2.3%	1.5%	3.7%
	TVP > $1 million	9.0%	3.1%	12.2%
	All crop farms	6.7%	3.5%	10.1%

Sources: 1987-2007 Censuses of Agriculture.

Table 6. Aggregate Productivity Growth Decomposition by Size Class, U.S. Crop Farms, 1987-2007

Years	Size Class	Technical Efficiency Growth (1)	APG from Reallocation (2)	Continuous Farms APG (3)
1987-92	TVP <= $250,000	[-9.9%, -1.6%]	[-0.9%, 7.4%]	-2.5%
	$250,000 < TVP <= $500,000	[-0.5%, 2.1%]	[-2.1%, 0.4%]	-0.04%
	$500,000 < TVP <= $1 million	[-0.3%, 2.1%]	[-1.5%, 0.9%]	0.6%
	TVP > $1 million	[0.7%, 3.7%]	[-2.2%, 0.8%]	1.5%
	All crop farms	[-10.0%, 6.3%]	[-6.7%, 9.5%]	-0.5%
1992-97	TVP <= $250,000	[-1.7%, -1.3%]	[1.2%, 1.6%]	-0.1%
	$250,000 < TVP <= $500,000	[0.7%, 1.1%]	[-0.9%, -0.5%]	0.2%
	$500,000 < TVP <= $1 million	[-0.02%, 2.4%]	[-1.7%, 0.7%]	0.7%
	TVP > $1 million	[5.7%, 6.7%]	[-4.3%, -3.3%]	2.4%
	All crop farms	[5.1%, 8.5%]	[-5.3%, -1.9%]	3.2%
1997-02	TVP <= $250,000	[-9.3%, -4.2%]	[3.6%, 8.7%]	-0.5%
	$250,000 < TVP <= $500,000	[-1.8%, -1.4%]	[1.3%, 1.7%]	-0.1%
	$500,000 < TVP <= $1 million	[-0.6%, -0.4%]	[0.5%, 0.6%]	0.02%
	TVP > $1 million	[-0.7%, 3.5%]	[-0.8%, 3.4%]	2.7%
	All crop farms	[-8.0%, -6.8%]	[8.9%, 10.1%]	2.0%
2002-07	TVP <= $250,000	[-15.4%, -5.9%]	[2.0%, 11.5%]	-3.8%
	$250,000 < TVP <= $500,000	[-3.3%, -1.5%]	[0.7%, 2.5%]	-0.8%
	$500,000 < TVP <= $1 million	[-0.6%, -0.2%]	[2.4%, 2.9%]	2.3%
	TVP > $1 million	[-2.4%, 8.7%]	[0.3%, 11.4%]	9.0%
	All crop farms	[-10.5%, -9.9%]	[16.6%, 17.2%]	6.7%

Sources: 1987-2007 Censuses of Agriculture.

Table 7. The Average Growth Rate of Inputs by Size Class, U.S. Crop Farms, 1987-2007

Years	Size Class	Farmland (1)	Inter-mediates (2)	Capital (3)	Labor (4)
1987-92	TVP <= $250,000	-7.2%	-4.5%	-4.1%	-23.7%
	$250,000 < TVP <= $500,000	13.3%	27.5%	19.3%	-4.3%
	$500,000 < TVP <= $1 million	18.6%	37.9%	24.5%	8.3%
	TVP > $1 million	19.9%	40.5%	32.8%	23.5%
	All crop farms	1.6%	9.7%	6.2%	-13.5%
1992-97	TVP <= $250,000	-9.8%	-12.3%	-8.8%	-22.4%
	$250,000 < TVP <= $500,000	9.8%	18.5%	16.6%	3.1%
	$500,000 < TVP <= $1 million	17.4%	29.2%	20.5%	14.3%
	TVP > $1 million	20.5%	35.2%	17.0%	16.5%
	All crop farms	2.4%	6.7%	5.0%	-6.3%
1997-02	TVP <= $250,000	-7.8%	-1.9%	-1.6%	-22.4%
	$250,000 < TVP <= $500,000	6.3%	18.4%	18.0%	-22.6%
	$500,000 < TVP <= $1 million	15.0%	36.6%	29.3%	-7.4%
	TVP > $1 million	19.1%	55.7%	37.0%	11.2%
	All crop farms	4.0%	18.9%	14.8%	-14.7%
2002-07	TVP <= $250,000	-8.1%	16.6%	8.4%	-9.0%
	$250,000 < TVP <= $500,000	0.2%	35.1%	13.9%	-8.6%
	$500,000 < TVP <= $1 million	6.1%	41.9%	20.0%	-0.6%
	TVP > $1 million	14.0%	46.7%	25.7%	14.6%
	All crop farms	-1.4%	27.9%	13.6%	-4.4%

Sources: 1987-2007 Censuses of Agriculture.

References

Ackerberg, D., K. Caves, and G. Frazer. 2008. "Structural Identification of Production Functions." Unpublished, Working Paper.

Acquaye, A.K., J.M. Alston, and P.G. Pardey. 2003. "Agricultural Influences of Aggregation Procedures in a State-Level Analysis." *American Journal of Agricultural Economics* 85:59–80.

Ahearn, M., P. Korb, and J. Yee. 2009. *Producer Dynamics in Agriculture: Empirical Evidence*, Chicago and London: University of Chicago Press, chap. 10.

Ahearn, M., J. Yee, and P. Korb. 2005. "Effects of Differing Farm Policies on Farm Structure and Dynamics." *American Journal of Agricultural Economics* 87:1182–1189.

Anderson, M., and R. Magleby. 1997. "Agricultural Resources and Environmental Indicators, 1996-97." Agricultural Handbook No. 712, U.S. Department of Agriculture, Economic Research Service.

Baily, M., C. Hulten, and D. Campbell. 1992. "Productivity Dynamics in Manufacturing Plants." *Brookings Papers on Economic Activity*, pp. 187–267.

Ball, V.E., F.M. Gollop, A. Kelly-Hawke, and G.P. Swinand. 1999. "Patterns of State Productivity Growth in the U.S. Farm Sector: Linking State and Aggregate Models." *American Journal of Agricultural Economics* 81:164–179.

Basu, S., and J. Fernald. 2002. "Aggregate Productivity and Aggregate Technology." *European Economic Review* 46:963–991.

Bernard, A., J. Eaton, B. Jensen, and S. Kortum. 2003. "Plants and Productivity in International Trade." *American Economic Review* 93:1268–1290.

Brown, A.B., R.R. Rucker, and W.N. Thurman. 2007. "The End of the Federal Tobacco Program: Economic Impacts of the Deregulation of U.S. Tobacco Production." *Review of Agricultural Economics* 29:635–655.

Diewert, E. 1976. "Exact and Superlative Index Numbers." *Journal of Econometrics* 4:115–145.

Diewert, E., and K. Fox. 2010. "On Measuring the Contribution of Entering and Exiting Firms to Aggregate Productivity Growth." In E. Diewert, B. Balk, D. Fixler, K. Fox, and A. Nakamura, eds. *Price and Productivity Measurement: Volume 6–Index Number Theory*. Vancouver: Trafford

Press, pp. 41–66.

Dohlman, E., L. Foreman, and M. Da Pra. 2009. “The Post-buyout Experience: Peanut and Tobacco Sectors Adapt to Policy-reform.” Economic Information Bulletin 60, Economic Research Service, USDA, November.

Domar, E.D. 1961. “On the Measurement of Technological Change.” *The Economic Journal* 71:709–729.

Feather, P., D. Hellerstein, and L.R. Hansen. 1999. “Economic Valuation of Environmental Benefits and the Targeting of Conservation Programs: The Case of the CRP.” Agricultural Economic Report No. 778, U.S. Department of Agriculture, Economic Research Service.

Food and Agriculture Organization of the United Nations. 2010. “Global Forest Resources Assessment.” FAO, Rome.

Foster, L., J. Haltiwanger, and C. Krizan. 2001. “Aggregate Productivity Growth: Lessons from Microeconomic Evidence.” In C. R. Hulten, E. R. Dean, and M. J. Harper, eds. *New Developments in Productivity Analysis*. Chicago: University of Chicago Press, pp. 303–372.

Griliches, Z., and H. Regev. 1995. “Firm Productivity in Israeli Industry: 1979–1988.” *Journal of Econometrics* 65:175–203.

Holt, M.T. 1999. “A Linear Approximate Acreage Allocation Model.” *Journal of Agricultural and Resource Economics* 24:383–397.

Hoppe, R.A., and P. Korb. 2006. *Understanding U.S. Farm Exits*. Washington, DC: U.S. Department of Agriculture, ERS Economic Research Report 21, June.

Hoppe, R.A., J.M. MacDonald, and P. Korb. 2010. *Small Farms in the United States: Persistence Under Pressure*. Washington, DC: U.S. Department of Agriculture, ERS Economic Information Bulletin 63, February.

Hsieh, C.T., and P.J. Klenow. 2009. “Misallocation and manufacturing TFP in China and India.” *Quarterly Journal of Economics* 124:1403–1448.

Huffman, W.E., and R.E. Evenson. 2001. “Structural and productivity change in US agriculture, 1950-1982.” *Agricultural Economics* 24:127–147.

Hulten, C. 1978. “Growth Accounting with Intermediate Inputs.” *The Review of Economic Studies* 45:511–518.

Key, N., and M.J. Roberts. 2007. *Commodity Payments, Farm Business Survival, and Farm Size Growth*. Washington, DC: U.S. Department of Agriculture, ERS Economic Research Report 51, November.

Kirwan, B.E., R.N. Lubowski, and M.J. Roberts. 2005. “How Cost-Effective Are Land Retirement Auctions? Estimating the Difference between Payments and Willingness to Accept in the Conservation Reserve Program.” *American Journal of Agricultural Economics* 87:1239–1247.

Kirwan, B.E., S. Uchida, and T.K. White. 2012. “Aggregate and Farm-level Productivity Growth in Tobacco: Before and After the Quota Buyout.” *American Journal of Agricultural Economics* 94:164–179.

Kwon, H.U., F. Narita, and M. Narita. 2009. “New Evidence on Japan’s Productivity Growth in the 1990s.” Working Paper, Research Institute of Economy, Trade, and Industry.

Lehmann, P. 2005. “An Economic Evaluation of the U.S. Conservation Reserve Program.” UFZ-Discussion Papers, UFZ, Leipzig, Germany, http://www.ufz.de/data/Disk_Papiere_2005-012519.pdf. Accessed November 15, 2009.

Lentz, R., and D. Mortensen. 2008. “An Empirical Model of Growth Through Product Innovation.” *Econometrica* 76:1371–1373.

Levinsohn, J., and A. Petrin. 2003. “Estimating Production Functions Using Inputs to Control for Unobservables.” *Review of Economic Studies* 70:317–341.

Lohmar, B., C. Nickerson, E. Uchida, and X. Jintao. 2007. “Land Conservation in the United States and China: A Comparison of Practices, Policies, and Data Implications for Assessment and Evaluation.” Paper prepared for presentation at the Fourth International Conference on Agricultural Statistics, Beijing, China, October 22–24, 2007.

Lubowski, R.N., S. Bucholtz, R. Claassen, M. Roberts, J. Cooper, A. Gueorguieva, and R. Johansson. 2006. “Environmental Effects of Agricultural Land-Use Change: The Role of Economics and Policy.” Economic Research Report 25, U.S. Department of Agriculture, Economic Research Service.

MacDonald, J.M. 2011. “Why Are Farms Getting Larger? The Case of the U.S.” Conference Paper, German Association of Agricultural Economists (GeWiSoLa).

MacDonald, J.M., P. Korb, and R.A. Hoppe. 2013. *Farm Size and the Organization of U.S. Crop Farming*. Washington, DC: U.S. Department of Agriculture, ERS Economic Information Bulletin 152, August.

Maietta, O.W. 2000. "The Decomposition of Cost Inefficiency into Technical and Allocative Components with Panel Data of Italian Dairy Farms." *European Review of Agricultural Economics* 27:473–495.

Marschak, J., and W. Andrews. 1944. "Random Simultaneous Equations and the Theory of Production." *Econometrica* 12:143–205.

Mayrand, K., and M. Paquin. 2004. "Payments for Environmental Services: A Survey and Assessment of Current Schemes." Unisfera montreal, http://www.cec.org/files/PDF/ECONOMY/PES-Unisfera_en.pdf. Accessed March 1, 2011.

Melitz, M. 2003. "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity." *Econometrica* 71:1695–1725.

Morrison, C.P., R. Nehring, D. Banker, and A. Somwaru. 2004. "Scale Economies and Efficiency in U.S. Agriculture: Are Traditional Farms History?" *Journal of Productivity Analysis* 22:185–205.

Mosheim, R., and C.K. Lovell. 2009. "Scale Economies and Inefficiency of U.S. Dairy Farms." *American Journal of Agricultural Economics* 91:777–794.

Olley, S., and A. Pakes. 1996. "The Dynamics of Productivity in the Telecommunications Equipment Industry." *Econometrica* 64:1263–1297.

Osborn, C.T., F. Llacuna, and M. Linsenbigler. 1995. "The Conservation Reserve Program: Enrollment Statistics for Signup Periods 1–12 and Fiscal Years 1986-93." Statistical Bulletin No. 925, U.S. Department of Agriculture, Economic Research Service, http://www.ers.usda.gov/publications/sb925/. Accessed May 15, 2009.

Petrin, A., and J. Levinsohn. 2010. "Measuring Aggregate Productivity Growth Using Plant-Level Data." Working Paper, Dept. of Econ., University of Minnesota, Twin Cities.

—. 2012. "Measuring Aggregate Productivity Growth Using Plant-Level Data." *RAND Journal of Economics* 43:705–725.

Petrin, A., T.K. White, and J.P. Reiter. 2011. "The Impact of Plant-level Resource Reallocations and Technical Progress on U.S. Macroeconomic Growth." *Review of Economic Dynamics* 14:3–26.

Restuccia, D., and R. Rogerson. 2008. "Policy Distortions and Aggregate Productivity with Heterogeneous Plants." *Review of Economic Dynamics* 11:707–720.

Roberts, M., and S. Bucholtz. 2005. “Slippage in the Conservation Reserve Program or Spurious Correlation? A Comment.” *American Journal of Agricultural Economics* 87:244–250.

—. 2006. “Slippage in the Conservation Reserve Program or Spurious Correlation? A Rejoinder.” *American Journal of Agricultural Economics* 88:512–514.

Rucker, R.R., W.N. Thurman, and D.A. Sumner. 1995. “Restricting the Market for Quota: An Analysis of Tobacco Production Rights with Corroboration from Congressional Testimony.” *Journal of Political Economy* 103:142–175.

Schlenker, W., and M. Roberts. 2009. “Nonlinear Temperature Effects indicate Severe Damages to U.S. Crop Yields under Climate Change.” *Proceedings of the National Academy of Sciences* 106:15594–15598.

Shoemaker, R. 1989. “Agricultural land values and rents under the conservation reserve program.” *Land Economics* 65:131–137.

Sullivan, P., D. Hellerstein, L. Hansen, R. Johansson, S. Koenig, R. Lubowski, W. McBride, D. McGranahan, S. Vogel, M. Roberts, and S. Bucholtz. 2004. “The Conservation Reserve Program: Economic Implications for Rural America.” Agricultural Economic Report No. 834, U.S. Department of Agriculture, Economic Research Service.

The White House. 2006. “Economic Report of the President.” U.S. Government Printing Office, Washington D.C.

U.S. Department of Agriculture, Farm Service Agency. 2008. “Conservation Reserve Program: Summary and Enrollment Statistics, FY2008.” USDA, Washington DC.

Vesterby, M. 2003. “Land Use.” In Heimlich, R. Agricultural Resources and Environmental Indicators, Agriculture Handbook No.722, U.S. Department of Agriculture, Economic Research Service.

Weber, J., and N. Key. 2012. “How much Do Decoupled Payments Affect Production? An Instrumental Variable Approach with Panel Data.” *American Journal of Agricultural Economics* 94:52–66.

White, T.K., and R.A. Hoppe. 2012. *Changing Farm Structure and the Distribution of Farm Payments and Federal Crop Insurance*. Washington, DC: U.S. Department of Agriculture, ERS Economic Information Bulletin 91, February.

Womach, J. 2003. "Tobacco Price Support: An Overview of the Program." CRS Report for Congress, Congressional Research Service, November.

—. 2004. "Tobacco Quota Buyout Proposals in the 108th Congress." CRS Report for Congress, Congressional Research Service, November.

Wu, J.J. 2000. "Slippage Effects of the Conservation Reserve Program." *American Journal of Agricultural Economics* 82:979–992.

—. 2005. "Slippage in the Conservation Reserve Program or Spurious Correlation? A Reply." *American Journal of Agricultural Economics* 87:251–254.

Young, C.E., and C.T. Osborn. 1990. "The Conservation Reserve Program: An Economic Assessment." Agricultural Economic Report No. 626, U.S. Department of Agriculture, Economic Research Service.