The Economics of Glyphosate Resistance Management*

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Public and Private Sector Policy Implications of Research on the Economics of Herbicide Resistance Management

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*The views expressed in this presentation are the authors and not necessarily those of ERS or USDA.

Presentation outline

- Background
- Study objectives
- Methods and results
- Policy implications

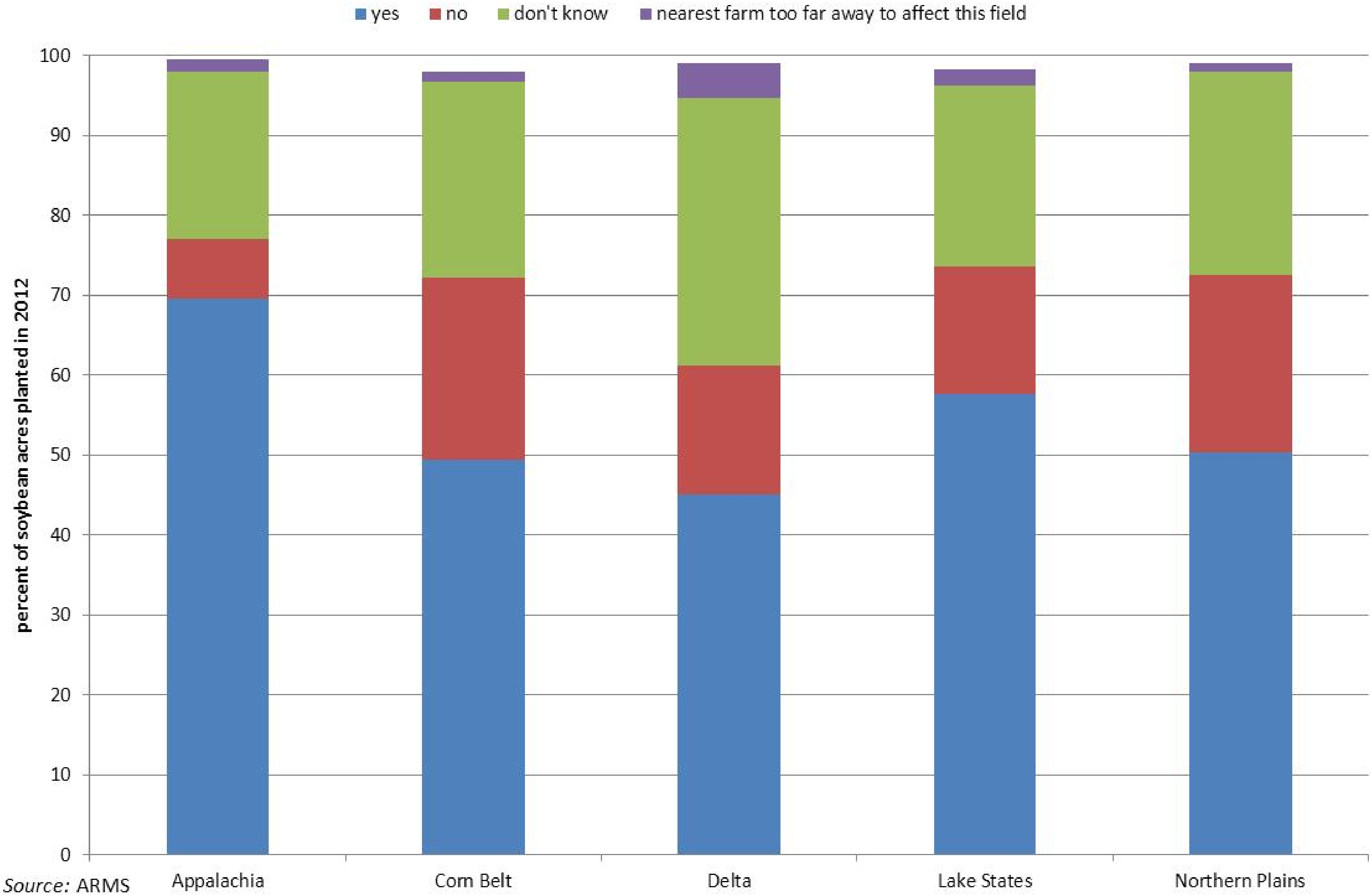
Glyphosate has been the most widely used pesticide in the United States since 2001

- Economic and environmental benefits of glyphosate and glyphosate-tolerant (GT) crops
  - improved farmer safety, flexibility and labor savings in managing weeds
  - ease of using conservation tillage
  - inexpensive generic herbicides due to glyphosate patent expiration in 2000

The ability of weed seeds to disperse between farms reduces incentives to adopt weed best management practices (BMPs)

- Long-run effectiveness of BMPs can depend on the level of adoption by nearby farmers, but short-run costs are borne solely by BMP adopters.
- Therefore, market-based, economic incentives are insufficient to promote an efficient level of BMP adoption.

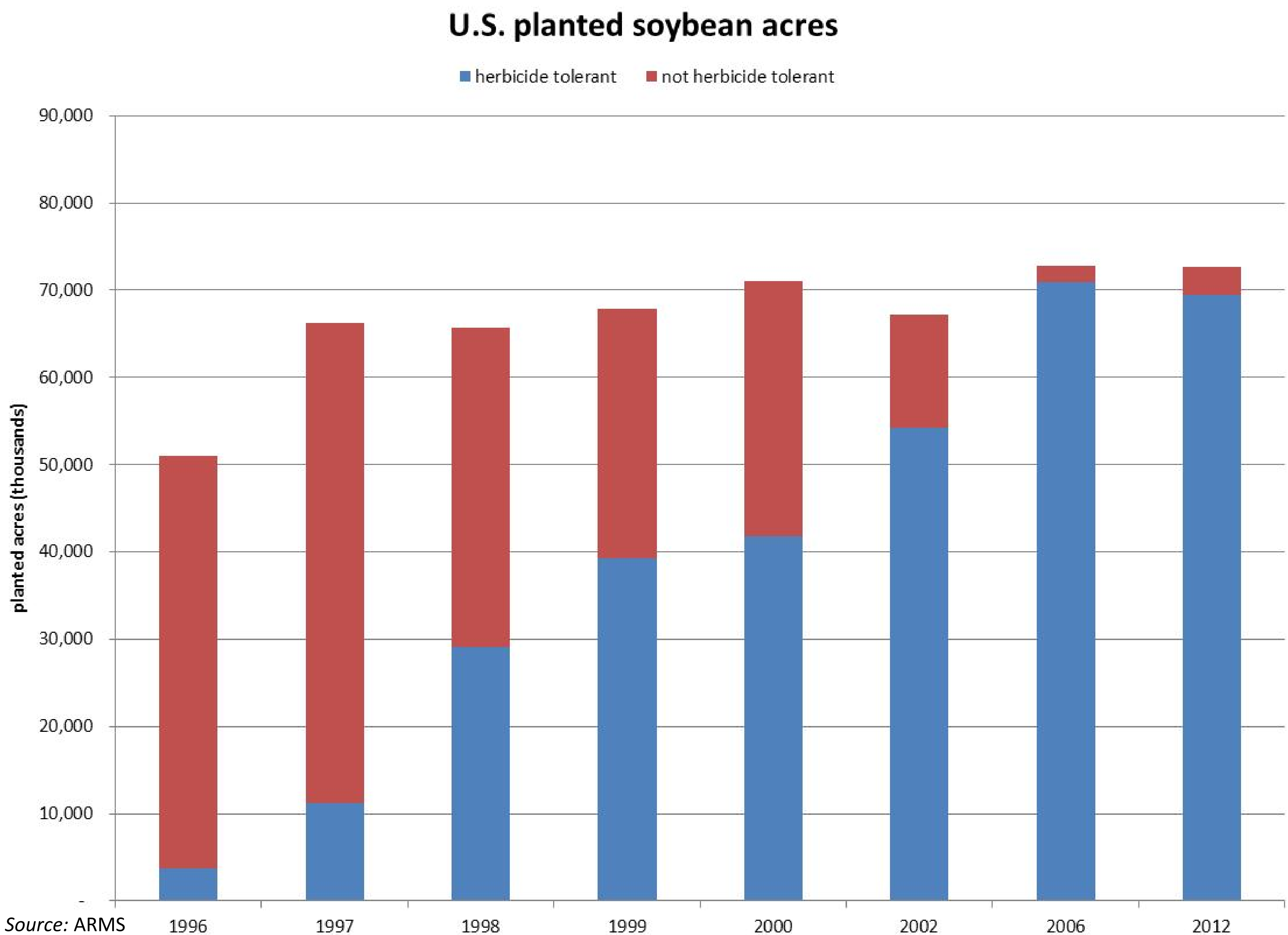
Do you believe the glyphosate resistance management practices you used would be more effective if operators of nearby farms also used them (2012 soybean)?



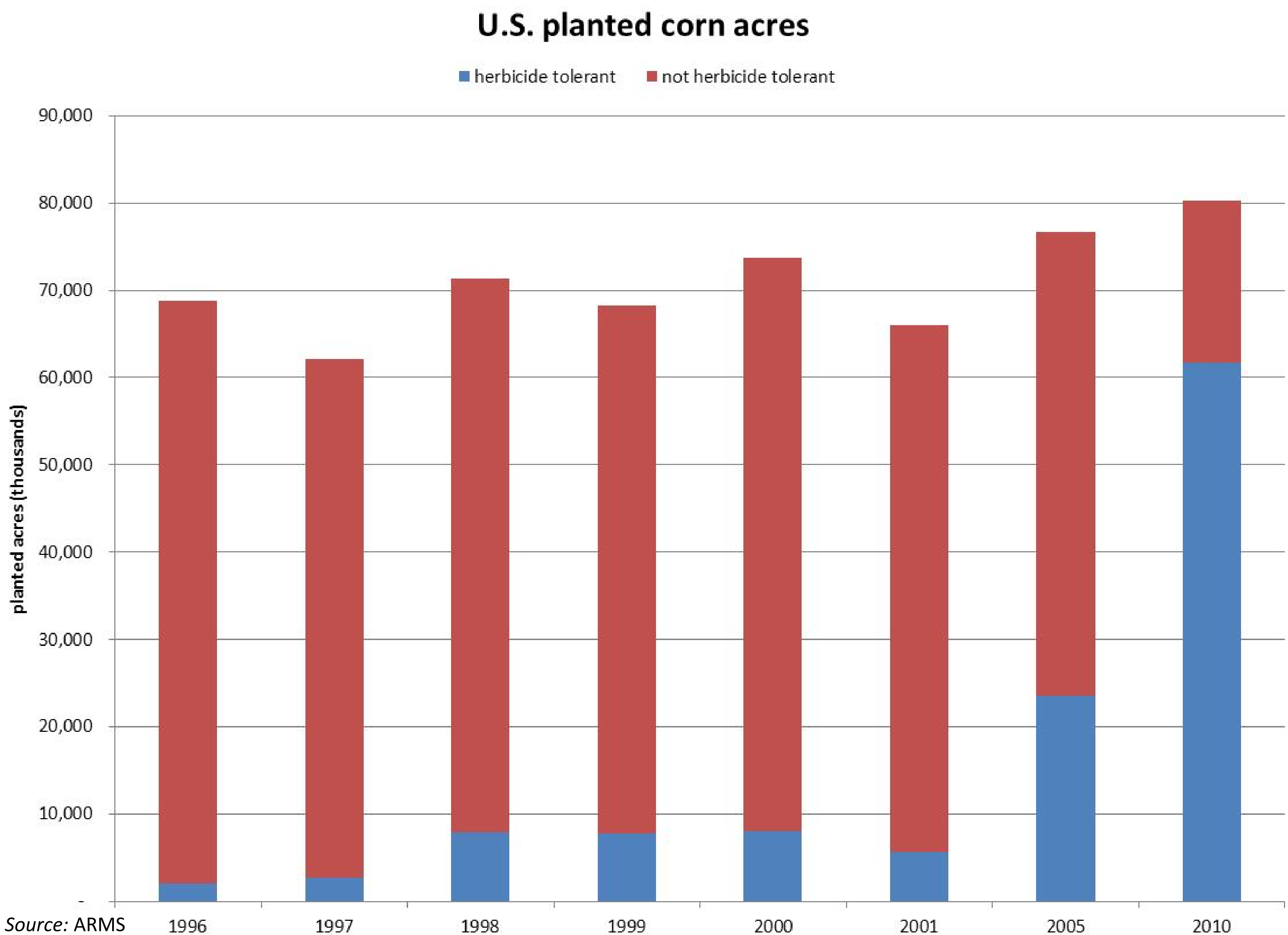
Source: ARMS

Glyphosate resistant (GR) weeds

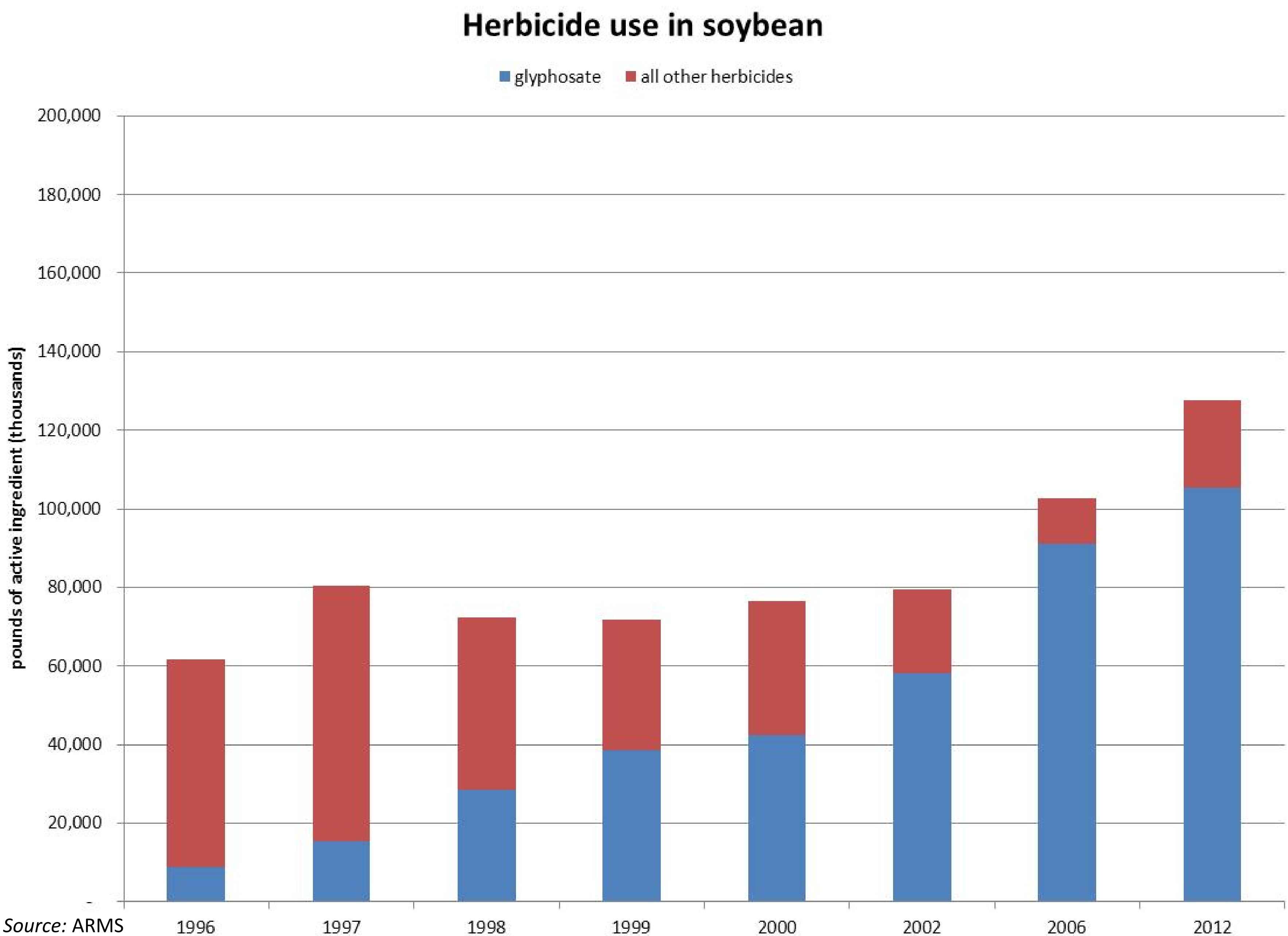
- Reduced incentives to adopt BMPs, the benefits of GT crops and glyphosate, and potential information gaps have led to overreliance on glyphosate and a reduction in the diversity of herbicide use practices, **particularly in soybean**.
  - Glyphosate resistance is currently documented in 14 weed species and biotypes in the U.S.
  - The potential exists for more acreage to be affected.


U.S. planted soybean acres
herbicide tolerant
not herbicide tolerant
planted acres (thousands)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
-
1996
1997
1998
1999
2000
2002
2006
2012

Source: ARMS

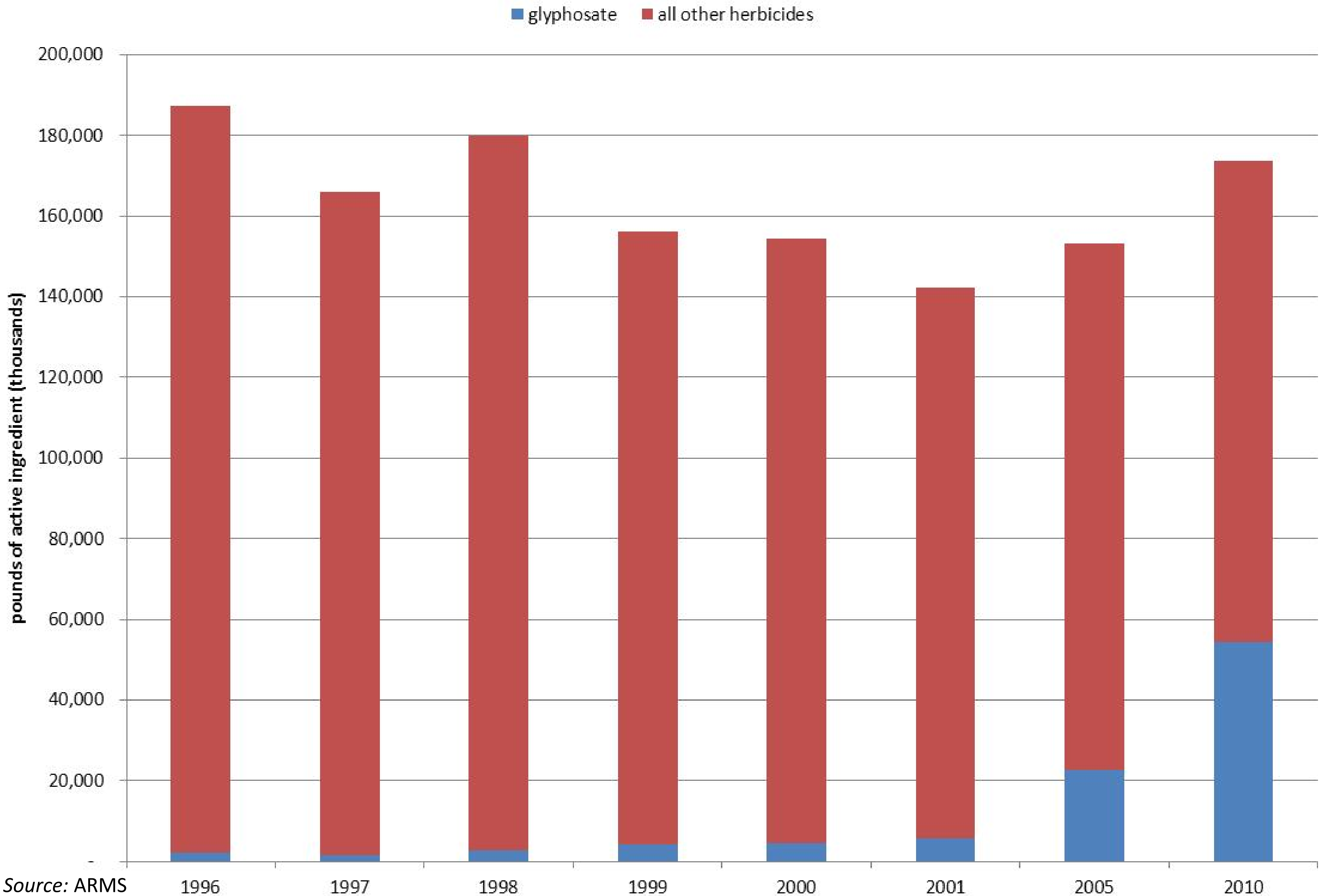

U.S. planted corn acres
herbicide tolerant
not herbicide tolerant
planted acres (thousands)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
-
1996
1997
1998
1999
2000
2001
2005
2010

Source: ARMS

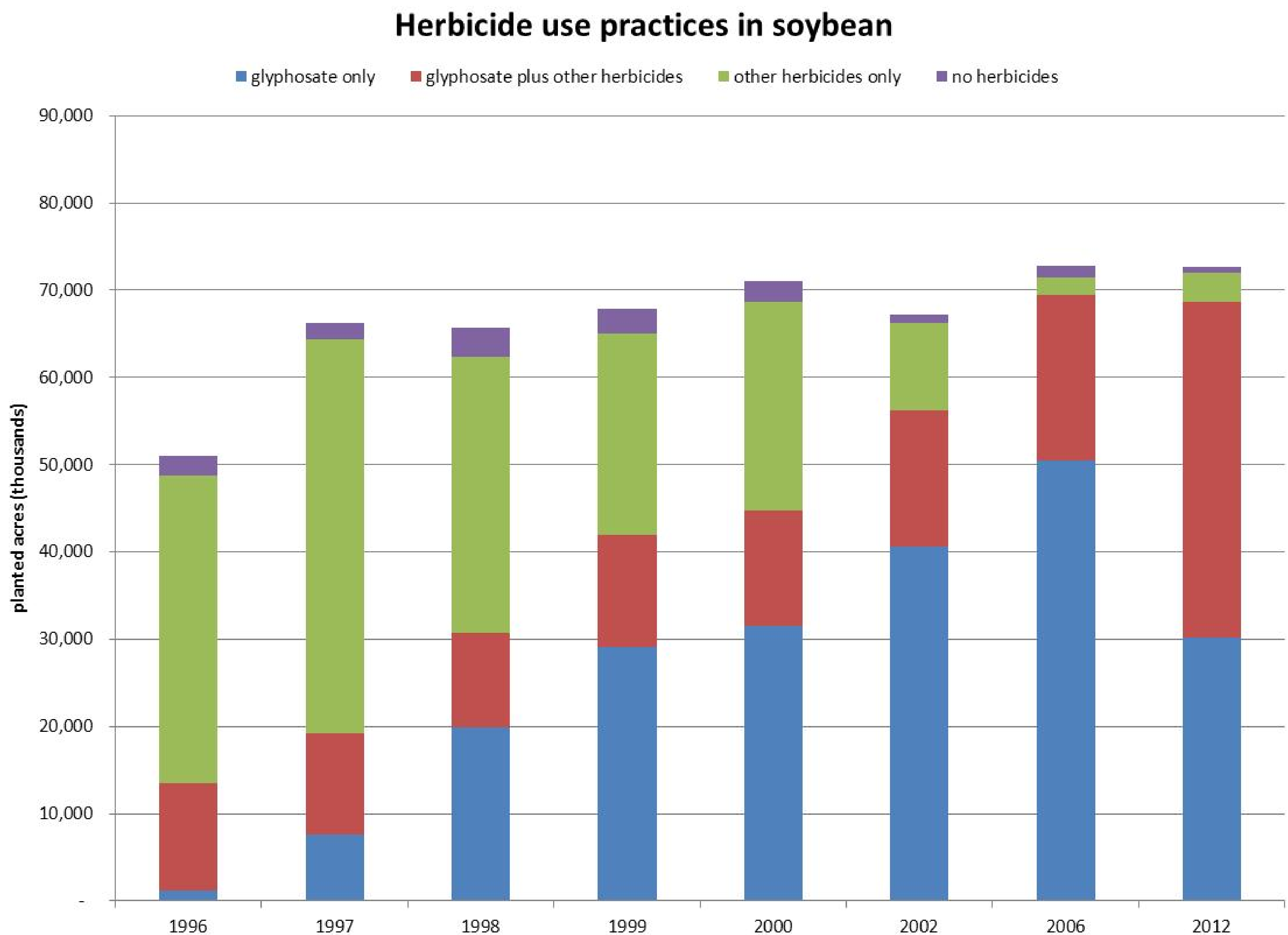

Herbicide use in soybean
glyphosate
all other herbicides
pounds of active ingredient (thousands)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
-
1996
1997
1998
1999
2000
2002
2006
2012

Source: ARMS

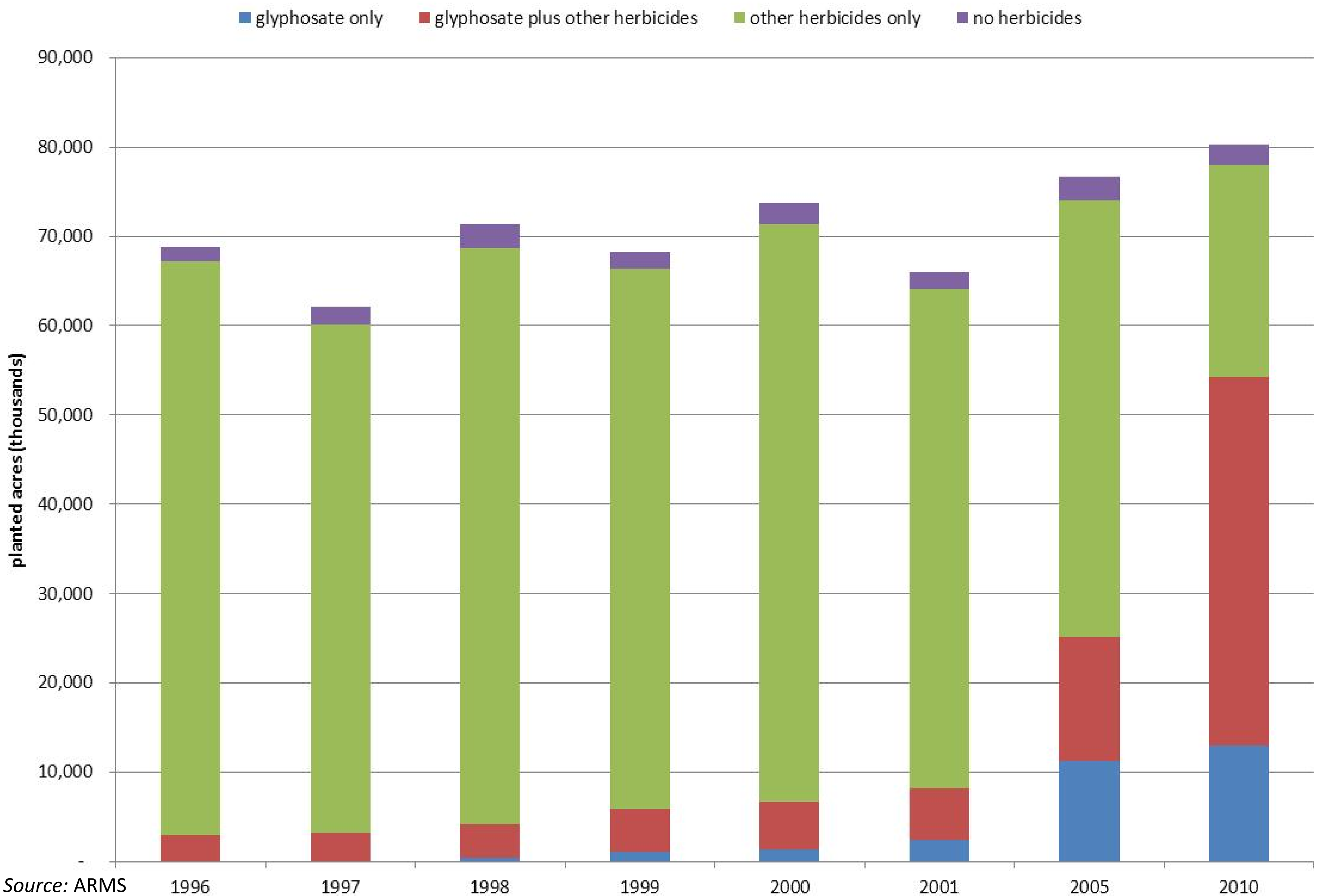
Herbicide use in corn



Source: ARMS


Herbicide use practices in soybean
glyphosate only
glyphosate plus other herbicides
other herbicides only
no herbicides
planted acres (thousands)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
-
1996
1997
1998
1999
2000
2002
2006
2012

Herbicide use practices in corn



Source: ARMS

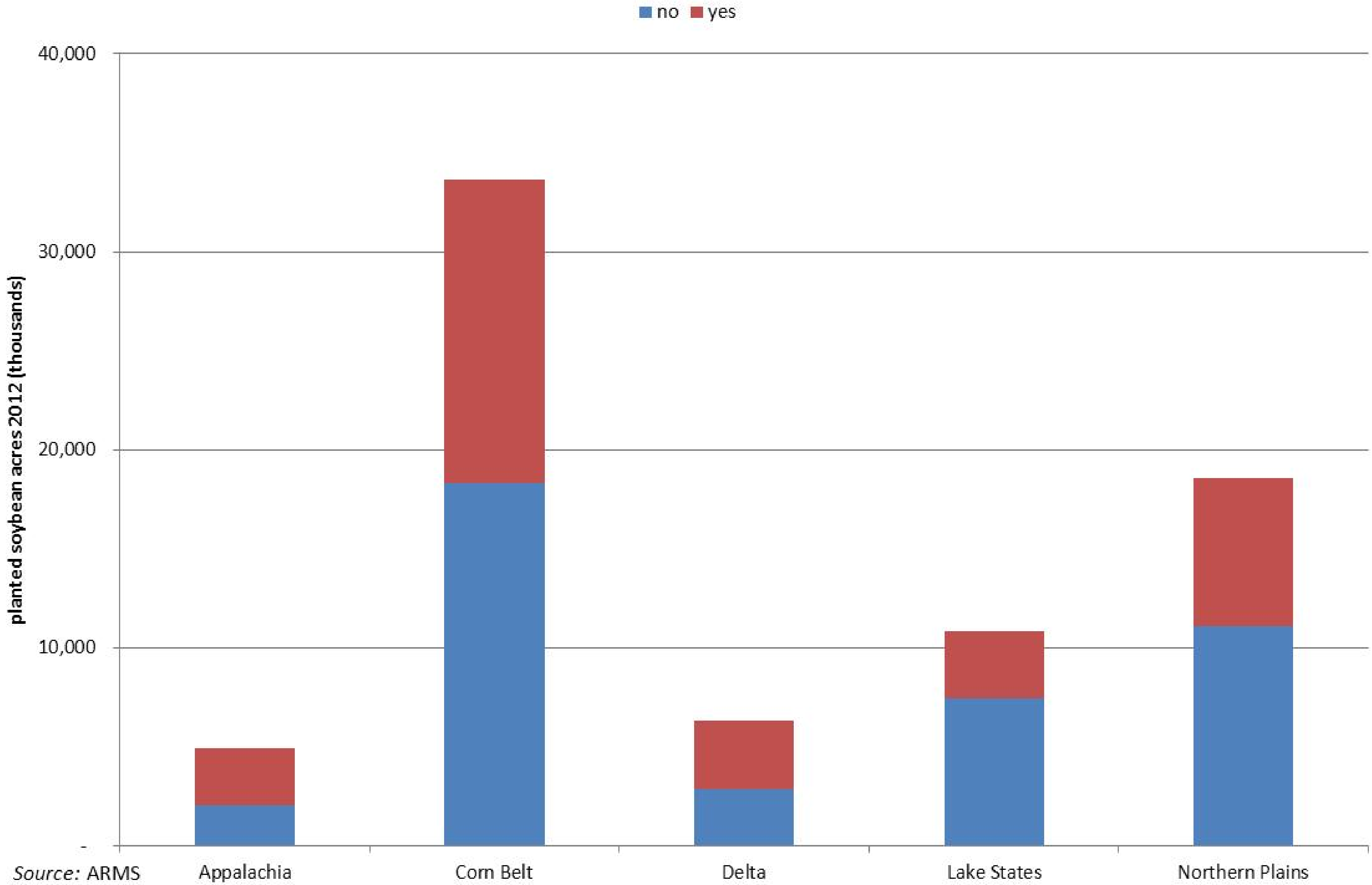
Average percentages of planted HT and non-HT soybean and corn acres by tillage category, 1996-2012

- More non-HT than HT soybean (25 vs. 18%) and corn (34 vs. 33%) acres were conventional till.
- More non-HT than HT soybean (21 vs. 15%) and corn (24 vs. 20%) acres were reduced till.
- Similar HT and non-HT soybean (25%) and corn (23%) acres were mulch till.
- More HT than non-HT soybean (41 vs. 29%) and corn (23 vs. 17%) acres were no till.

Average percentages of HT and non-HT soybean and corn acres by management practice, 1996-2012

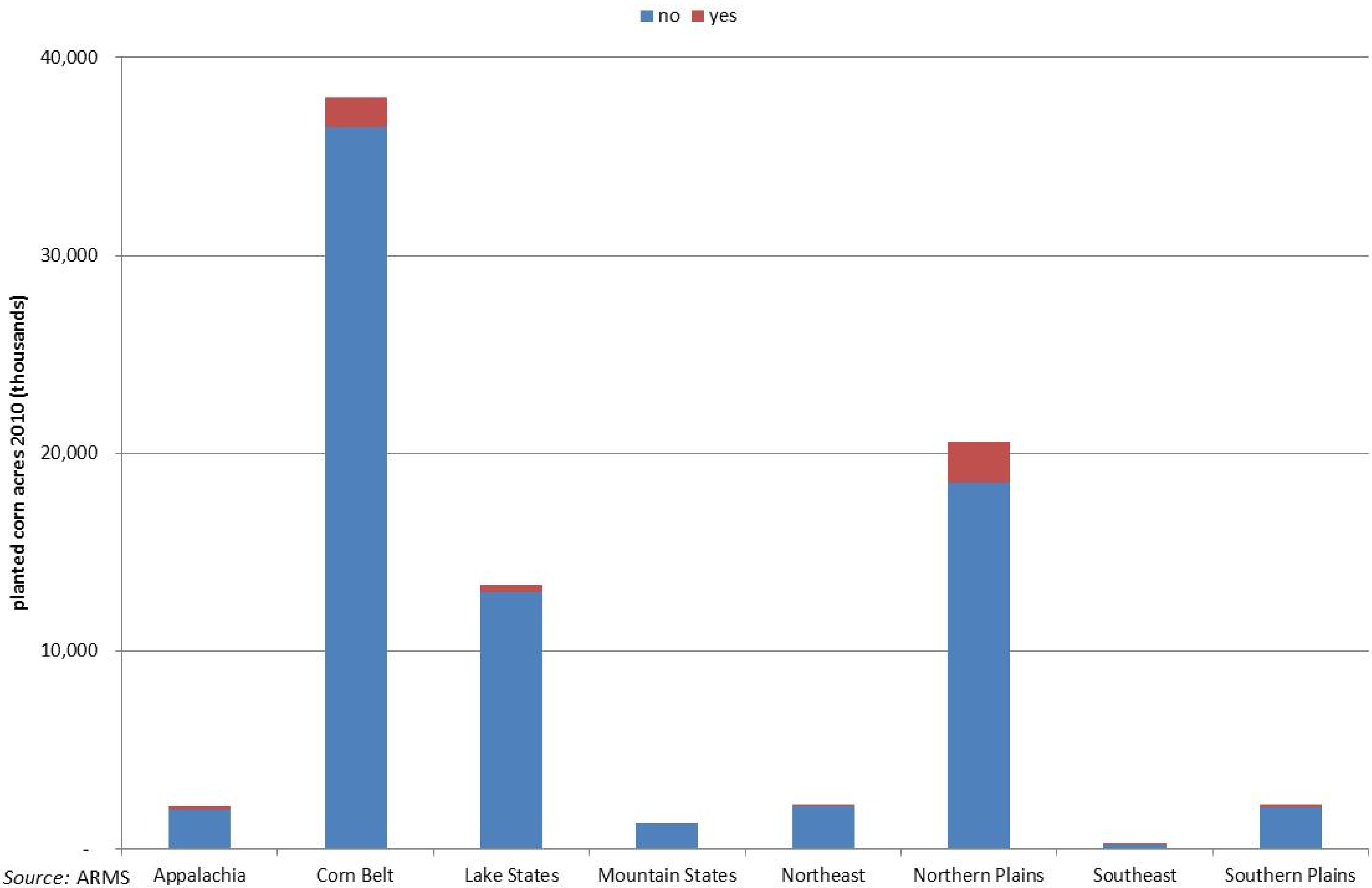
- The majority of HT and non-HT soybean and corn acres were scouted (>80%) for weeds and rotated (>70%).
- More HT than non-HT soybean (60 vs. 33%) and corn (39 vs. 24%) acres received only post-emergence herbicide applications.
- Fewer HT than non-HT soybean (14 vs. 30%) and corn (35 vs. 36%) acres were cultivated for weed control.
- Equipment was cleaned between fields on less than a third of HT and non-HT soybean (30 vs. 31%) and corn (32 vs. 28%) acres.
- **Between 1998-2006, the percent of HT soybean acres in which pesticides were rotated declined from 47 to 12%, increasing to 24% in 2012.**
- **Between 1998-2005, the percent of HT corn acres in which pesticides were rotated declined from 53 to 19%, increasing to 28% in 2010.**

Have you noticed a decline in the effectiveness of glyphosate in controlling weeds in this field (2012 soybean)?



Source: ARMS

Has this field ever been infested with weeds resistant to glyphosate (2010 corn)?



Source: ARMS

Study objectives

- We use econometric models to examine
  - the cost of glyphosate resistance in U.S. cornfields in 2010
  - potential barriers impeding the adoption of 3 BMPs
    - using at least 1 herbicide MOA that is not glyphosate
    - cleaning equipment between fields
    - using tillage when needed
- We use bio-economic optimization models to examine
  - optimal and suboptimal herbicide use decisions
  - economic and biological impacts of those decisions
  - potential barriers impeding adoption of optimal decisions

Estimating the cost of glyphosate-resistant weed infestations

- Not accounting for the influence of farm size and location (sample-selection), differences in production practices (endogeneity) and other factors related to profit and the likelihood GR weed infestations occurred can lead to incorrect estimates of economic impacts and standard errors.

- We use endogenous, regime-switching models to examine impacts on profit, yield, and input use and cost of
  - GR weed infestations, and
  - the use of 3 BMPs.

We use a four-stage estimation procedure

- Estimate expected, cost-minimizing level of damage abatement for each respondent
- Estimate likelihood of GR-weed infestations for each respondent
- Estimate profit functions for different farmers who did and did not observe infestations simultaneously
- Economic impacts are based on profit-function differences evaluated at sample means

First stage – cost-minimizing level of damage abatement

- Each farmer is assigned to one of seven herbicide categories to account for different herbicide combinations and resistance on yield loss
  - glyphosate only
  - glyphosate + 1 different* MOA
  - glyphosate + 2 different MOAs
  - glyphosate + 3 different MOAs
  - 1 different MOA
  - 2 different MOAs
  - 3 different MOAs

*Different from glyphosate

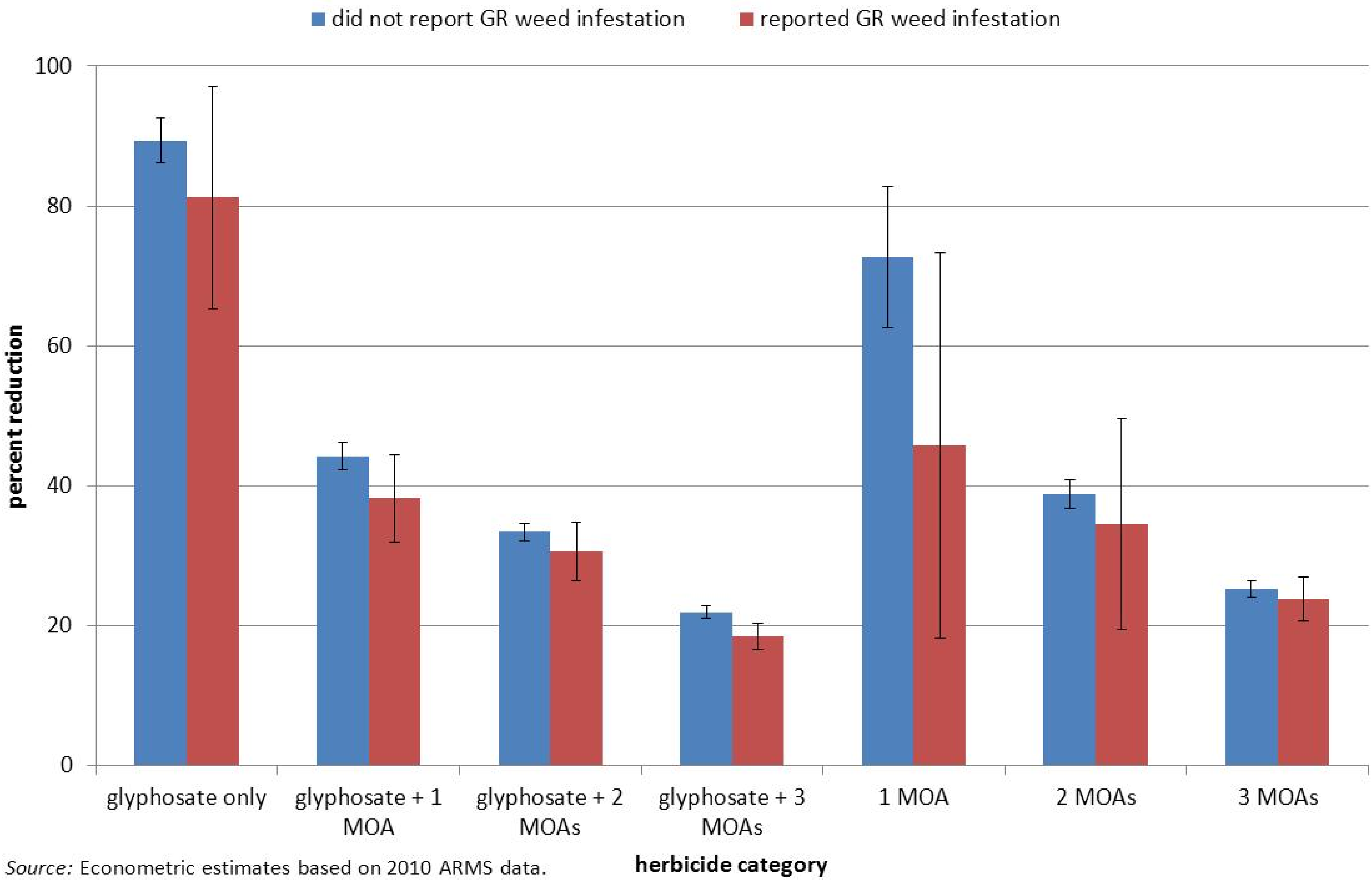
First stage – cost-minimizing level of damage abatement

- The exponential cumulative distribution function is used to relate expected yield-loss reduced (damage abatement) to herbicide use.
- This specification implies a cost function for damage abatement and an associated herbicide demand function.
- The herbicide demand function is estimated to recover the parameter in the damage-abatement function.
- This parameter is used to estimate abatement for each respondent, which is then used to estimate restricted profit functions.
  - We use an herbicide-application index = the sum of the amounts of herbicide a.i.'s applied, each divided by its national, average application rate
  - **It's a continuous measure of herbicide applications that accounts for 1) the amounts of each herbicide a.i. used and 2) the wide variation in average application rates for each a.i.**

First stage – results

- Expected yield loss due to weeds per rate-adjusted herbicide application varied by herbicide category and was generally more volatile for respondents who reported GR weed infestations.
- Corn producers without GR weeds who relied solely on glyphosate expected to eliminate almost 90% of yield loss with only one glyphosate application.
- **Because herbicide categories 2-4 include glyphosate, the estimates suggest that corn producers who relied solely on glyphosate experienced weed infestations that were relatively less severe than those experienced by corn producers in categories 2-4.**

Reduction in yield loss due to weeds per rate-adjusted herbicide application



Source: Econometric estimates based on 2010 ARMS data.

Second stage – likelihood of GR weed infestations

- GR weed infestations were
  - more likely in GA, IN, KS, KY, NE, NC, PA and TX than in IA
  - less likely on larger corn operations
  - more likely the earlier GT crops were adopted
  - more likely the more often soybeans were planted on the surveyed field during the previous four growing seasons

Economic impacts of GR-weed infestations

- There were statistically significant differences in the profit functions for respondents who observed and did not observe GR-weed infestations.
  - The former group of corn producers experienced lower yields but also spent less on nutrients, fuel, and seeds than corn producers in the latter group.
  - **As a result, profits were not statistically lower for producers who experienced GR-weed infestations.**

Economic impacts of using BMPs

- Farmers who relied solely on glyphosate spent $27 less on herbicides, had lower yield losses, received 1.6 more bushels, and earned >$52 more per acre.
  - **It might be difficult to incentivize use of an additional MOA for farmers who experience minor weed infestations.**

- Neither cleaning equipment between fields to prevent the spread of weeds nor using reduced or conventional tillage reduced profits.
  - **There do not appear to be profit incentives impeding the adoption of these practices.**

Optimization model

- We examine optimal herbicide decisions that maximize the present value of profit/acre received over an infinite horizon **and account for resistance**.
- We also examine suboptimal herbicide decisions that maximize annual profit/acre **and ignore resistance**.
- We examine 3 scenarios (corn-soybean and continuous corn and soybean) and 1 target weed (horseweed).

Optimization model

- The seed density and glyphosate resistance allele frequency are observed at the beginning of each year.
- Then one of the following 6 herbicide choices is selected:
    1. residual+glyphosate
    2. residual+glyphosate+alternative
    3. residual+alternative
    4. glyphosate
    5. glyphosate+alternative
    6. alternative

Optimization model

- A biological model relates seed density, allele frequency, and the herbicide choice to this year's cumulative weed density and next year's seed density and allele frequency.
- The biological model is linked to the economic model using GMM estimates of a two-equation system relating 1) weed density to exogenous (year, state dummies) and endogenous factors (tillage intensity, herbicide applications), and 2) ln(crop yield) to exogenous and endogenous (weed density) factors using data from farmers in six states for 2006-2009.
  - Corn and soybean yields declined with weed density.
  - Exogeneity of weed density, tillage, and herbicide applications can be rejected in each model.
  - Overidentifying restrictions tests indicate that the instruments (constant, year and state dummies, whether the field was irrigated, whether the field was "treated," and the field's latitude) are not correlated with the error term in each model, *except for the continuous soybean model*.
    - Because the overidentifying restrictions test suggests the instruments are correlated with the error term in the 2SLS model also, and because the GMM estimates are more reasonable than the 2SLS and OLS estimates, the GMM estimates are used.

Optimization model

- The annual, discount rate used to calculate present values is fixed at slightly over 5%.
- Corn and soybean prices are fixed at 2010 levels, as are all corn and soybean production costs, except herbicide costs.
- The only production cost that varies over time is the herbicide cost.
- No changes in the types of crop seed and available herbicides are allowed.

Simulation results

- Optimal herbicide decisions relative to suboptimal herbicide decisions
  - reduce the number of years during which glyphosate is used,
  - combine glyphosate with more herbicides when glyphosate is used,
  - dramatically lower the horseweed seed density, and
  - reduce the rate of resistance evolutions.

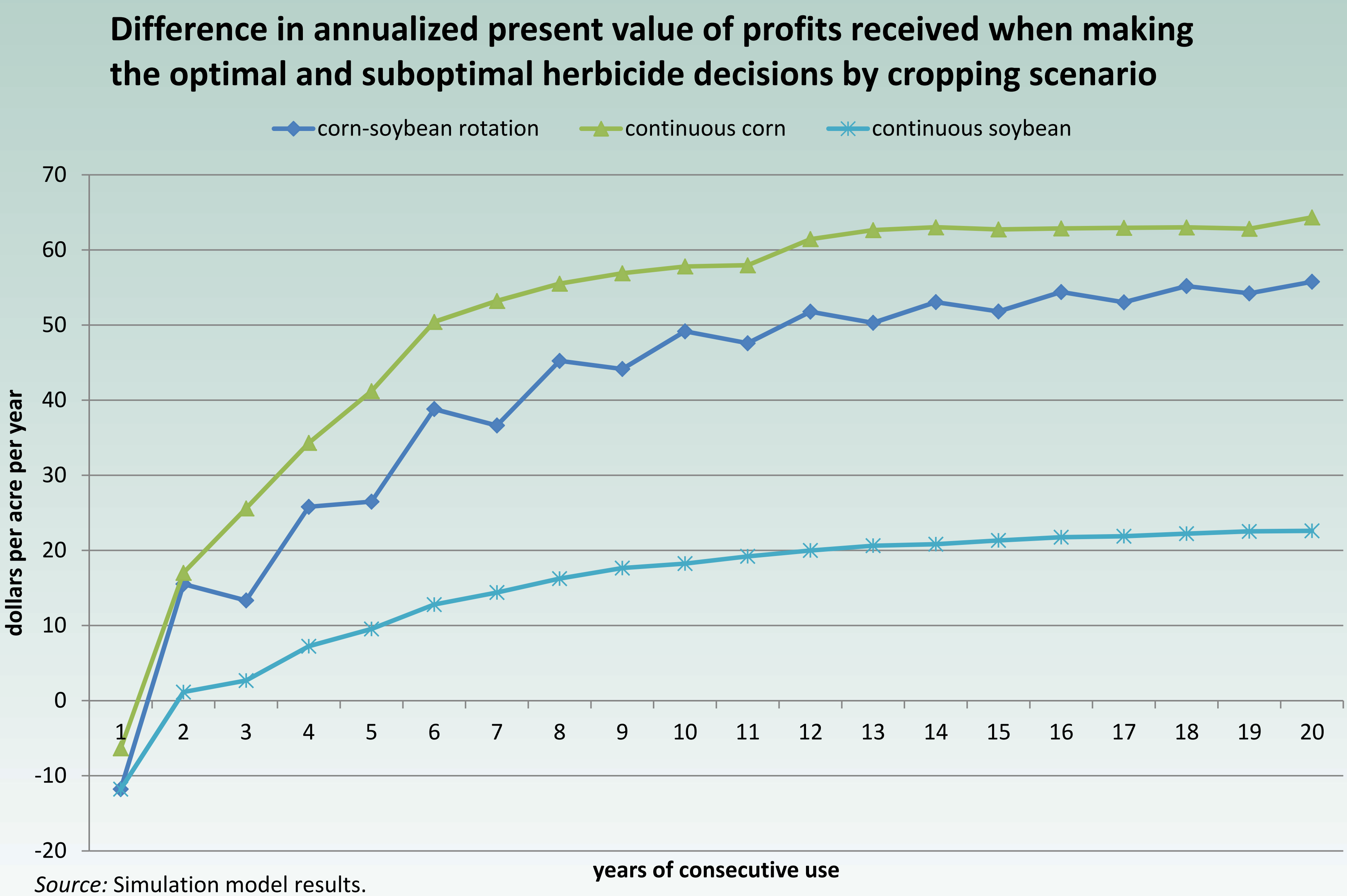
Economic return, herbicide cost, crop yield and characteristics of herbicide choices by decision rule and cropping scenario for a 20-year period

item	corn-soybean optimal	corn-soybean suboptimal	corn-soybean difference	continuous corn optimal	continuous corn suboptimal	continuous corn difference	continuous soybean optimal	continuous soybean suboptimal	continuous soybean difference
	annualized present value (2010 US$)								
profit	378.7	322.9	55.8	431.4	367.0	64.3	183.3	160.7	22.6
herbicide cost	25.0	20.4	4.5	22.7	20.5	2.2	27.4	20.3	7.1
	mean yield (bushels)								
corn	202.0	182.2	19.9	189.8	176.2	13.5			
soybean	58.2	55.8	2.4				50.8	47.9	2.8
	years								
herbicide choice selected									
glyphosate + residual or alternative	2	12		0	7		2	20	
glyphosate + residual + alternative	7	0		6	0		7	0	
residual + alternative	11	8		14	13		11	0	

Source: Simulation model results.

Simulation results

- The difference in economic returns received when making optimal versus suboptimal herbicide decisions
  - is positive after between two and three years of consecutive use, and
  - increases with years of consecutive use.



Source: Simulation model results.

USDA United States Department of Agriculture, Economic Research Service

Simulation results

- Much more weed seed is produced when making the suboptimal rather than the optimal herbicide decisions.

- This has two important policy implications.

First implication

- Suboptimal management on one farm could lead to resistance evolution and lower returns received on nearby farms, even when herbicides are used optimally on nearby farms.
  - This creates a disincentive to account for resistance when making herbicide decisions, **especially in continuous soybean**.
  - **Counteracting this disincentive represents a key policy challenge.**

Second implication

- Optimal management on one farm might not affect resistance evolution on nearby farms, which are using suboptimal herbicide decisions.
  - **The benefit of free riding on the efforts of nearby farmers is likely to be either inconsequential (continuous corn) or nonexistent (corn-soybean, continuous soybean).**
- However, optimal management on one farm could reduce the number and frequency of GR weed seeds migrating to nearby farms.
  - Because this benefit is difficult to observe, it's easy to ignore.
  - **Improving the lines of communication between farmers could help incentivize BMP adoption.**

Percent changes in economic return, herbicide cost and crop yield due to seed immigration from a suboptimally and an optimally managed field relative to the base model

item	corn-soybean			continuous corn			continuous soybean		
	optimal	suboptimal	difference	optimal	suboptimal	difference	optimal	suboptimal	difference
	seed immigration from a suboptimally managed field								
economic return	-11.2	-3.4	-56.2	-4.9	-1.8	-22.9	-15.5	-3.7	-99.8
herbicide cost	18.3	0.3	99.3	18.2	0.6	185.8	-21.1	0.0	-81.0
corn yield	-5.5	-1.2	-45.4	-1.9	-0.6	-18.6			
soybean yield	-3.2	-0.8	-59.2				-6.1	-0.8	-97.1
	seed immigration from an optimally managed field								
economic return	-0.1	-1.1	5.7	0.1	0.3	-1.2	-0.3	-1.2	5.8
herbicide cost	1.6	0.2	8.2	-2.8	0.1	-30.3	2.7	0.0	10.3
corn yield	0.0	-0.5	4.6	0.0	0.2	-2.8			
soybean yield	0.0	0.0	1.5				0.0	-0.3	4.8

Notes: These are simulation results using the base model. A 20-year period is simulated. For each scenario, the immigration rate is five percent of average annual horseweed seed production, and the immigrant-seed resistance allele frequency is the average annual resistance allele frequency. Year one is not included in mean seed production, because the initial seed density is not based on data. Immigration rates are 84.7, 22.8 and 218.9 seeds per square meter, and immigrant-seed resistance allele frequencies are 0.573, 0.273 and 0.680 for the rotation, continuous corn and continuous soybean scenarios, respectively, for seed immigration from a suboptimally managed field. Immigration rates are 0.3, 0.3 and 0.3 seeds per square meter, and immigrant-seed resistance allele frequencies are 0.132, 0.001 and 0.140 for the rotation, continuous corn and continuous soybean cropping scenarios, respectively, for seed immigration from an optimally managed field.

Policy implications

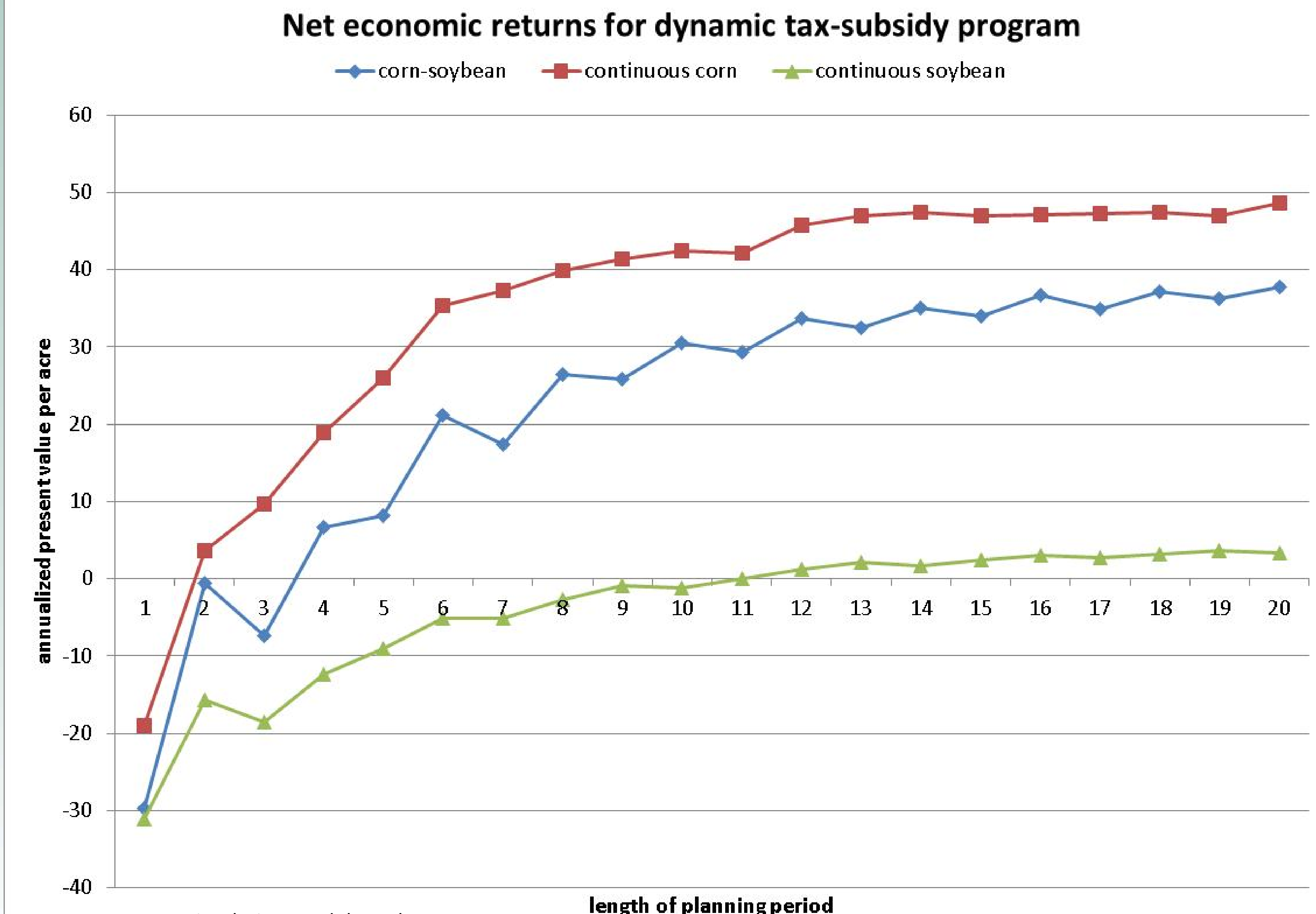
- The benefits of making optimal herbicide decisions could increase with:
  - incentives encouraging the use of optimal decisions (**taxes/subsidies**, **regulations**),
  - improved farmer communication and teamwork (**area-wide management programs, noxious weed compacts, farmer cooperative agreements**),
  - outreach activities communicating the benefits of choosing management practices that satisfy long-run instead of short-run economic goals, and
  - improved cooperation between farmers, industry, and government.

Dynamic tax-subsidy program

- The return increases with program years and becomes positive at the end of 4 (rotation), 2 (continuous corn) and 11 (continuous soybean) years.

- For the 20-year simulation, the return is $38 (=$56-$18, rotation), $48 (=$64-$16, continuous corn) and $4 (=$23-$19, continuous soybean) per acre per year.

- Taxes and subsidies vary as resistance evolves and depend on the crop rotation and could vary regionally according to prevalent weeds, crops, and practices.
  - It's necessary to tax glyphosate in some years and subsidize glyphosate in others.
  - It's necessary to account for the entire range of possible herbicide choices available to crop producers when designing pricing schemes to satisfy resistance management goals.

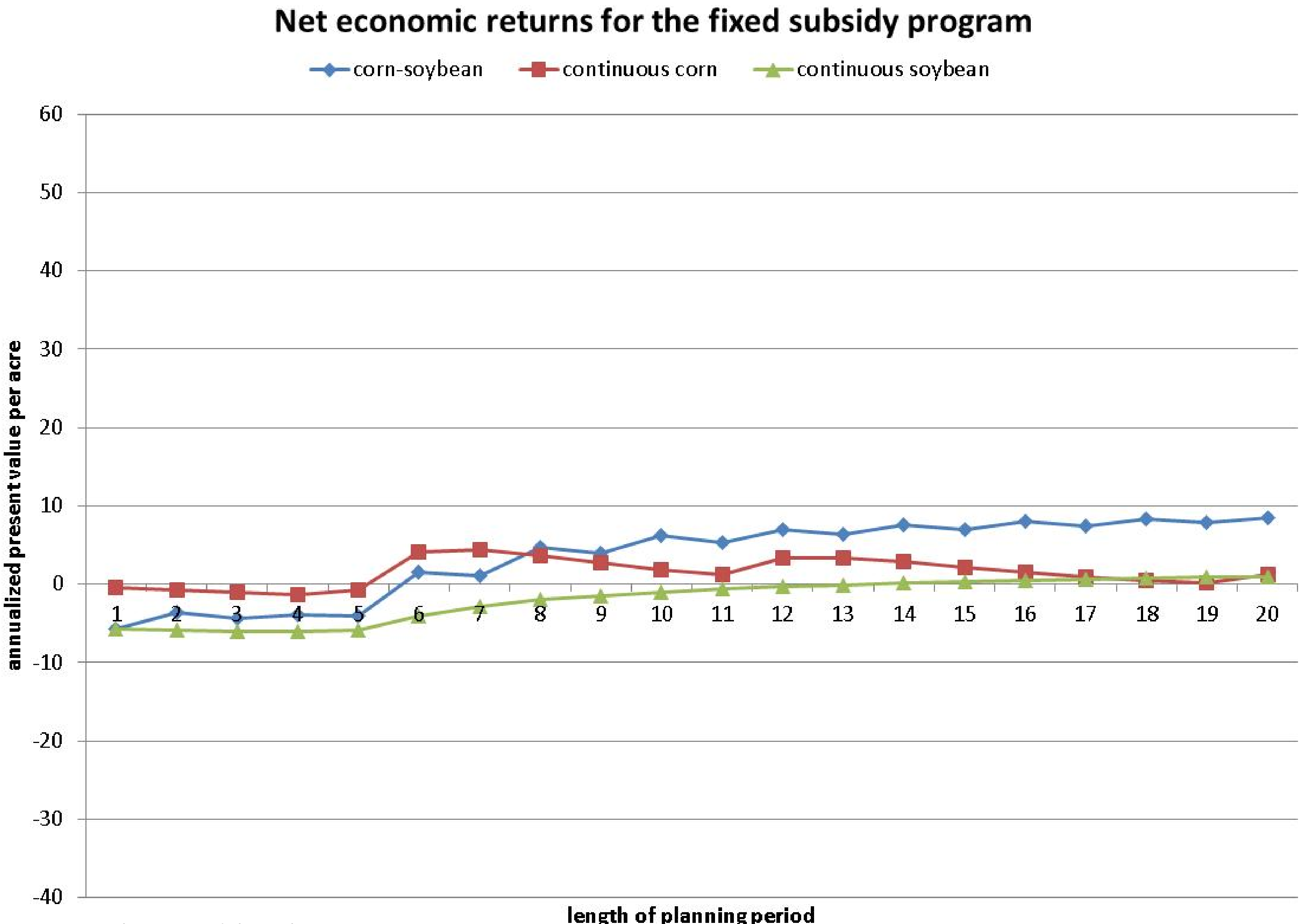


Source: Simulation model results.

United States Department of Agriculture, Economic Research Service

Fixed subsidy program

- 100% subsidies for the residual and alternative maximize returns received when making suboptimal herbicide decisions for each planning period and cropping scenario.
- The suboptimal herbicide choice is residual+alternative each year.
  - **Glyphosate resistance does not evolve, but resistance to the residual and the alternative herbicide would.**
- Program returns generally increase with program years and becomes positive at the end of 6 (rotation, continuous corn) and 14 (continuous soybean) years.
- For the 20-year simulation, the returns are $9 (=$32-$23, rotation), $1 (=$22-$21, continuous corn) and $1 (=$27-$26, continuous soybean) per acre per year.



Source: Simulation model results.