Designing Contracts for Multitasking Groups: A Structural Model of Accountable Care Organizations

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Abstract

Contract and incentive design is used by firms, policymakers, and many others to encourage desired behavior in a variety of settings. In this paper, I estimate a model to design contracts for an incentive program where agents face a tradeoff between multiple tasks, free-ride on each other, and have the option to drop out if payment is not sufficiently generous. The setting, which involves 11 million people and \$100 billion in healthcare expenditure each year, is Medicare's Accountable Care Organizations (ACOs). ACOs are groups of healthcare providers that receive incentive pay from Medicare for spending below a cost target on shared patients. In order to find the contracts between Medicare and ACOs that maximize the money saved by the incentive program while accounting for free-riding, the tradeoff between reducing expenditure and quality of care, and voluntary participation, I build and estimate a two-stage structural model of ACOs. Healthcare providers first choose which, if any, ACO to join based on the income they expect to earn. Next, given participation in an ACO, providers strategically choose effort to put towards quality of care and reducing expenditure in order to maximize their own payoff. The model is estimated with public ACO-level performance and participation data. I find that free-riding within ACOs and the tradeoff between decreasing expenditure and improving quality has a large impact on the contract Medicare should implement to maximize the monetary savings of the incentive program. Counterfactual analysis shows existing contracts between Medicare and ACOs are too generous, and when the savings-maximizing contract is used, Medicare saves \$100 million more per year. If Medicare also imposes financial penalties on ACOs that spend too much, cost-savings increases by \$730 million per year, without a significant change in participation, though ACO quality of care decreases by two standard deviations. The final counterfactual shows free-riding within ACOs decreases program savings by \$1 billion per year.

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1 Introduction

Designing incentive pay to influence the decisions of others is a powerful strategy used by individuals and organizations in all sectors of the economy. Though common, this strategy is challenging: to achieve desired outcomes and limit unintended consequences, incentive pay should be tailored to the institutional environment and take already existing incentives into account. In this paper, I build and estimate a structural model to design contracts for an incentive program with a complicated institutional environment. Agents trade off quality of work for quantity of output, incentive pay is determined by group performance, so members of the group can free-ride on each other, and agents can choose to not participate all together if incentives are underwhelming or too penalizing.

The setting is the Medicare Shared Savings Program (MSSP), an incentive program that involves 11 million Medicare beneficiaries and $100 billion in healthcare expenditure each year. The MSSP gives incentive pay to Accountable Care Organizations (ACOs), which are joint ventures of physicians, group practices, and hospitals that form to coordinate care of their shared patients. An ACO earns incentive pay through the MSSP if its members collectively reduce expenditure on health services. Because the earnings of a provider in an ACO depend heavily on the decisions of other providers, free-riding may severely limit performance. Providers can trade off quality of care for cost-savings, forcing performance pay tied to both tasks. Finally, providers join ACOs voluntarily, so if anticipated earnings from the program are underwhelming, providers will not participate.

Taking voluntary participation, free-riding, and multitasking providers into consideration, how should contracts between ACOs and Medicare be designed in order to maximize the money saved, less payment to ACOs? In this paper, I answer this question by building and estimating a structural model of Medicare providers in ACOs. I model providers' decisions regarding ACOs in two stages: participation and performance. In the first stage, Medicare providers choose which, if any, ACO to join, taking into account the income they expect to earn from joining each ACO. In the second stage, providers participating in an ACO act strategically and choose efforts to put towards cost-saving and quality of care in order to maximize their own payoff. The choices of efforts of each member in an ACO form a Nash equilibrium that describes the ACO's overall performance and the income of providers.

My research design exploits well-defined and observed contracts between Medicare and ACOs in the MSSP to identify structural parameters. The MSSP works by giving an ACO an expected expenditure for healthcare services provided to its members' patients. If a year's Medicare expenditure on those beneficiaries is less than the expected amount, an ACO earns a portion of the difference, adjusted by a quality score, as incentive pay (hence "sharing savings" with Medicare). This structure means that variation in marginal subsidy pay for savings and quality across ACOs is observed, so I'm able to identify a function describing the marginal cost (i.e. a supply curve) of reducing expenditure and improving quality. Importantly, this method yields an empirical estimate of the magnitude of the trade-off between cost-savings and quality—a crucial component to computing contracts that make a combination of monetary savings and quality of care the objective. I use techniques from Berry (1994) to estimate parameters describing provider utility from participating in an ACO using aggregate participation data and accounting for unobserved heterogeneity.

I find that increasing an ACO's income by 1% increases participation in that ACO by 0.5%. There is a strong trade-off between Medicare savings and quality of care: a one standard deviation increase in an ACO's savings rate increases the cost of increasing quality of care by one standard deviation by $6,700 per participating provider. Currently, contracts between ACOs and Medicare allow ACOs to earn up to 75% of the money they save as incentive pay. By simulating equilibrium outcomes under alternative contracts, I compute that the optimal amount of savings to share with an ACO is 44%, where Medicare increases the savings of the program by more than $70 million per year. Under two-sided contracts, where ACOs must pay money back to Medicare if they spend too much, savings rates are four times higher, implying a 352% increase in savings to Medicare. Quality scores decrease under two-sided contracts, since ACOs incur significantly higher costs of increasing quality when saving more. When a combination of program savings and ACO quality scores is the objective, neither contract (one-sided or two-sided) strictly dominates the other. Finally, I find that program savings would increase by over $1 billion per year without free-riding within ACOs. Because of free-riding, Medicare must pay more to ACOs: if every ACO perfectly coordinated, the program would maximize its monetary savings by sharing 35% of savings with ACOs.

This paper is the first to estimate a structural model of ACOs and conduct predictive counterfactual policy analysis of the Medicare Shared Savings Program. I contribute to economics literature concerning health care provider payment systems and provider behavior in organizations (Gaynor et al., 2004; Encinosa et al., 2007; Rebitzer & Votruba, 2011; Ho & Pakes, 2014; Frandsen & Rebitzer, 2015; Frandsen et al., 2017). More generally, this paper aligns with the literature that studies the supply-side of health care, and examines the incentives faced and decisions made by physicians, hospitals, and insurers (Gaynor, 2006; Chandra et al., 2011; Gaynor et al., 2015; Ho & Lee, 2017; Foo et al., 2017; Einav et al., 2018; Eliason et al., 2018).

Frandsen & Rebitzer (2015) calibrate a simple model of ACO performance to examine the size-variance trade-off in group payment mechanisms like the MSSP, and they argue that ACOs will be unable to self-finance. That is, there is no contract with strong enough incentives to overcome the incentive to free-ride among a group of physicians. The authors conclude with a skeptical look at the MSSP, and mention the untenability of integrated organizations in the now very fractured US health care market.[1] Frech et al. (2015) studies county-level entry of private and public ACOs. The authors find small markets generally discourage ACO entry, and that public ACO entry is largely predicted by higher Medicare spending, higher population, and lower physician site concentration. Frandsen et al. (2017) discusses the MSSP's impact on health care in the United States in the context of common agency, where several payers motivate the same agent to improve care delivery and integration. The authors find that unique equilibrium contracts from payers are lower powered in the presence of shared savings payments, and ACO entry can possibly inspire other shared savings contracts in the private sector if they don't already exist.

Early evidence of the performance of ACOs is discussed in McWilliams et al. (2016, 2018)

[1]The predictions of Frandsen & Rebitzer (2015) have had mixed accuracy through the first few years of the MSSP. Each year, roughly one third of all ACOs actually earn shared savings. My simulations indicate free-riding results in program savings that are just 8% of first-best. However, several ACOs still manage to earn shared savings, including ACOs with hundreds of physicians. The results of Frandsen & Rebitzer (2015) indicate that a maximum team size of less than 20 is required to achieve 8% of first best—a team size far smaller than the mean of 38 participants and 603 individual providers across all ACOs. Predictions deviate from observed performance for a few potential reasons. First, the authors model ACOs as providers in a closed group: the sum of expenditure across all providers in the ACO is compared to benchmark expenditure. In MSSP ACOs, beneficiaries are assigned to a group of providers. The sum of Medicare expenditure on those beneficiaries, regardless of the provider making the expenditure, is compared to benchmark expenditure. For this reason, physician efforts may have a stronger overall effect on performance than allowed in the model. Another reason predictions differ may come from the authors' estimates of uncertainty in quality of care and physician expenditure. If these values are too large, then the impact of size on reducing free-riding is understated.[2]

and Markovitz et al. (2019). McWilliams and authors find a reduction of \$36 to \$302 in per-physician spending upon participation in an ACO. Markovitz and authors argue that this decrease is overstated and is primarily driven from high-cost physicians and beneficiaries exiting ACOs.

This paper continues as follows: Section 2 gives a brief overview of the MSSP and ACOs, including descriptive ACO statistics and motivating regression analysis. I outline my model of participation and performance in ACOs in Section 3. I describe identification and estimation of model primitives in Section 4, and estimation results are in Section 5. I present counterfactual analysis, including evaluation of contracts between ACOs and Medicare, in Section 6, and Section 7 concludes.

2 Background and Data

The MSSP, a part of the Patient Protection and Affordable Care Act of 2010 (ACA), is a policy response to increasing healthcare costs in the United States. The premise of the program is that the United States is inefficient at providing healthcare because care delivery is *fragmented*. That is, unique to the United States, patients tend to see several distinct providers that belong to separate businesses with little incentive to coordinate care. Patients therefore receive haphazard and often redundant care, implying increased utilization, cost, and risk of adverse health outcomes.

The MSSP gives providers financial motivation to integrate care delivery. To overcome institutional boundaries to care integration, the program explicitly evaluates and pays Medicare providers based on *group* performance. First, providers join Accountable Care Organizations, or ACOs, which are joint ventures of Medicare providers created to earn payment through the MSSP. Nearly any Medicare provider, including individual physicians, group practices, and large hospital systems, can start or participate in an ACO.[3] Medicare fee-for-service (FFS) beneficiaries are then assigned to ACOs by CMS according to their primary care provider.[4]

Table 1 displays statistics describing ACO participants and beneficiaries assigned to ACOs.[5] There's substantial heterogeneity in the number of providers that join an ACO—some large hospitals are able to form an ACO independently by employing enough PCPs to be assigned 5000 beneficiaries, and others are joint ventures of hundreds of providers. "Hospital led," "physician led," and "mixed leadership," are variables indicating the predominant type of participant in an ACO. Every state has beneficiaries assigned to an ACO, though most ACOs concentrate on beneficiaries in just one state. "Average risk score" is the average Hierarchical Condition Category (HCC) risk score of non-dual eligible beneficiaries assigned to an ACO. A beneficiary's risk score increases as predicted healthcare costs of that beneficiary increase.

[3] A participant can be nearly any health care provider that accepts and bills Medicare. Participants are legally defined by their Tax ID Number (TIN) or CMS Certification number (CCN). Once an ACO shows they have established a governing board that oversees clinical and administrative aspects of operation and shows the presence of formal contracts between itself and its member participants (including the distribution of any earned incentive pay), it then enters into a five year agreement with the Centers for Medicare and Medicaid Services (CMS). (Before July 2019, agreements lasted three years.)

[4] If a given Medicare beneficiary receives the plurality of primary care services from a primary care provider who is (or is employed by) an ACO participant, that beneficiary is assigned to that participant's ACO. When a Medicare beneficiary receives the plurality of primary care services from a primary care provider not associated with an ACO, they are not assigned to an ACO. This assignment methodology results in roughly one fifth to one third of all FFS beneficiaries assigned to ACOs each year. An ACO must be assigned at least 5000 beneficiaries to operate and earn shared savings payments.

[5] The data for this table, and all analysis in this section, is from MSSP ACO Public Use Files, MSSP Participant Lists, MSSP ACO Performance Year Results, and Number of ACO Assigned Beneficiaries by County Public Use Files. In short, the data consists of ACO expenditures, benchmark expenditures, quality scores (along with every quality sub-measure), various assigned beneficiary demographics, and various participant and provider statistics. Little information is available on the characteristics of specific ACO participants or providers.

Table 1: **Summary ACO Statistics: Providers and Beneficiaries**

Variable	Mean	S.D.	Min.	Med.	Max.
Number of participants[a]	37.79	58.03	1.00	20.00	840.00
Hospital led[a]	0.40	0.49	0.00	0.00	1.00
Physician led[a]	0.20	0.40	0.00	0.00	1.00
Mixed leadership[a]	0.41	0.49	0.00	0.00	1.00
Total number of individual providers (1000s)	0.59	0.84	0.00	0.28	7.28
Proportion of providers PCP	0.41	0.18	0.03	0.36	1.00
Proportion of providers specialist	0.41	0.21	0.00	0.44	0.88
Number of states where beneficiaries reside	1.52	0.97	1.00	1.00	10.00
Number of assigned beneficiaries (1000s)	17.78	17.49	0.15	11.87	149.63
Average risk score	1.06	0.11	0.81	1.04	2.09
Percent of beneficiaries over age 75	39.10	6.04	13.20	39.18	66.25
Percent of beneficiaries male	42.66	2.06	34.57	42.69	57.50
Percent of beneficarries nonwhite	16.88	15.34	1.49	12.45	94.98

$N = 1849$. This table shows summary statistics for ACOs for years 2013-2017. The superscript [a] indicates statistics are for 2014-2017 (due to data availability).

Payment of an ACO depends on a calendar year's Medicare expenditure on beneficiaries assigned to the ACO, a quality of care score, and the contract the ACO has with Medicare. Upon formation of an ACO, Medicare assigns a "benchmark expenditure" by forecasting Medicare expenditure for beneficiaries assigned to the ACO.[6] After operating for a year, the ACO's payment is determined by the difference between the benchmark expenditure and realized expenditure on assigned beneficiaries and a composite quality score between 0 and 1.[7] If the ACO's savings rate, defined as $\frac{\text{Benchmark Expenditure}-\text{Expenditure}}{\text{Benchmark Expenditure}}$, exceeds a

[6]For performance years after the first, the benchmark is updated based on projected national growth of per-beneficiary Medicare expenditure, and regional adjustments to benchmarks were introduced in 2017.

[7]An ACO's overall quality score is determined by the combination of 30-40 sub-measures of care quality. These sub-measures fall into the domains of "Patient/Caregiver Experience," "Care Coordination/Patient Safety," "Preventative Health," and "At-Risk Population." Some sub-measures are survey responses (e.g. "ACO2: How Well Your Doctors Communicate"), while others are computed from Medicare Claims and aggregated to the ACO-level (e.g. "ACO21: Proportion of Adults who had blood pressure screened in past 2 years"). See `https://go.cms.gov/2xHy7Uo` for a full list of ACO quality scores for every performance year.

predetermined minimum, it earns and distributes to its members the amount

$$\text{Sharing Rate} \cdot \text{Quality Score} \cdot (\text{Benchmark Expenditure} - \text{Expenditure}) \tag{1}$$

where "Sharing Rate," a number between 0 and 1, is determined by the type of contract the ACO has with Medicare. While uncommon in the first few years of the MSSP, some contracts also penalize ACOs for having expenditure *larger* than benchmark expenditure. These are called "two-sided" contracts.

The overwhelming contract choice of ACOs, "Track 1," has a sharing rate of 50%. Under this contract, if a hypothetical ACO with a benchmark expenditure of \$186 million and minimum savings rate 0.02 had an expenditure of \$180 million with a quality score of 0.90, it would earn

$$0.5 \cdot 0.9 \cdot (\$186 \text{ million} - \$180 \text{ million}) = \$2.7 \text{ million} \tag{2}$$

in shared savings. Its savings rate is $(186 - 180)/186 = 0.03$, so the minimum savings rate is exceeded. Though paying a subsidy, Medicare saves money as well: on net, program savings for this ACO is \$3.3 million, as it paid \$2.7 million to save \$6 million.

Table 2 contains statistics on ACO performance. The first three variables indicate the type of contract an ACO has with Medicare. The second block of variables describe ACO performance. ACO benchmark expenditures and realized expenditures are large: the mean is \$190 million, with several ACOs having expenditure over \$1 billion. From 2013 to 2017, ACOs saved money on average. However, less than one third of ACOs had a savings rate

Table 2: **Summary ACO Statistics: Savings and Quality**

Variable	Mean	S.D.	Min.	Med.	Max.
Sharing rate 50%, one-sided	0.96	0.19	0.00	1.00	1.00
Sharing rate 60%, two-sided	0.01	0.11	0.00	0.00	1.00
Sharing rate 75%, two-sided	0.03	0.16	0.00	0.00	1.00
Benchmark Expenditure ($ billions)	0.19	0.18	0.00	0.13	1.97
Expenditure ($ billions)	0.19	0.18	0.00	0.12	1.97
Benchmark Expenditure - Expenditure ($ millions)	1.46	10.18	-72.49	0.67	89.13
Savings Rate	0.01	0.05	-0.44	0.01	0.30
Quality Score	0.87	0.12	0.07	0.90	1.00
$\mathbf{1}\{\text{Savings Rate} \geq \text{Min. Savings Rate}\}$	0.31	0.46	0.00	0.00	1.00
Earned shared savings or losses	1.50	3.64	-4.66	0.00	41.91
Earned shared savings, given qualified	4.95	5.11	0.00	3.48	41.91
Proportion of expenditure on inpatient services^a	0.31	0.03	0.22	0.31	0.43
Proportion of expenditure on outpatient services^a	0.20	0.06	0.08	0.19	0.49
Number of primary care services (1000s)	10.29	1.76	5.39	9.98	26.16
Number of inpatient admissions (1000s)	0.33	0.09	0.17	0.32	1.86

$N = 1849$. This table shows summary statistics for ACOs for years 2013-2017. The superscript ^{a} indicates statistics are for 2014-2017 (due to data availability). “Quality Score” is computed by the author from ACO quality sub-measures (public data codes Quality Score as 1 or “P4R” in an ACO’s first performance year.)

at least as large as their minimum savings rate, meaning most ACOs don't actually earn incentive pay. Average earned incentive pay is \$1.5 million per ACO, and given an ACO earns incentive pay, incentive pay is nearly \$5 million. Per participant, average earned incentive pay is \$189,108 unconditionally and \$609,654 among ACOs that qualify.

2.1 Motivating Regressions

Recall the example above: this hypothetical ACO had a benchmark of \$186 million, an actual expenditure of \$180 million, a quality score of 0.9, and a sharing rate of 0.5. The bottom line was the ACO earned \$2.7 in incentive pay, and Medicare saved \$3.3 million after paying the ACO. How would the bottom line change if the sharing rate increased to 0.75? ACO participants would have a larger incentive to improve efficiency of care, causing more savings and higher quality of care. However, Medicare would need to pay the ACO 50% more per dollar of savings.

Suppose quality score increases to 0.95 and expenditure decreases to \$170 million under this more generous contract. The ACO would earn \$11.4 million in incentive pay, and Medicare would save \$4.6 million after paying this ACO. Compared to the other contract, Medicare, ACO participants, and Medicare beneficiaries are better off. However, if quality of care was unchanged and expenditure decreased only slightly to \$178 million, the ACO would earn \$5.4 million leaving Medicare with \$2.6 million.

When we consider voluntary participation in ACOs, the problem becomes more complicated. In this example, the less generous contract is better for Medicare as long as the original \$2.7 million earned by the ACO is enough for the ACO to remain in the program.

If this is not the case, Medicare may be better off offering 75% of savings to the ACO.

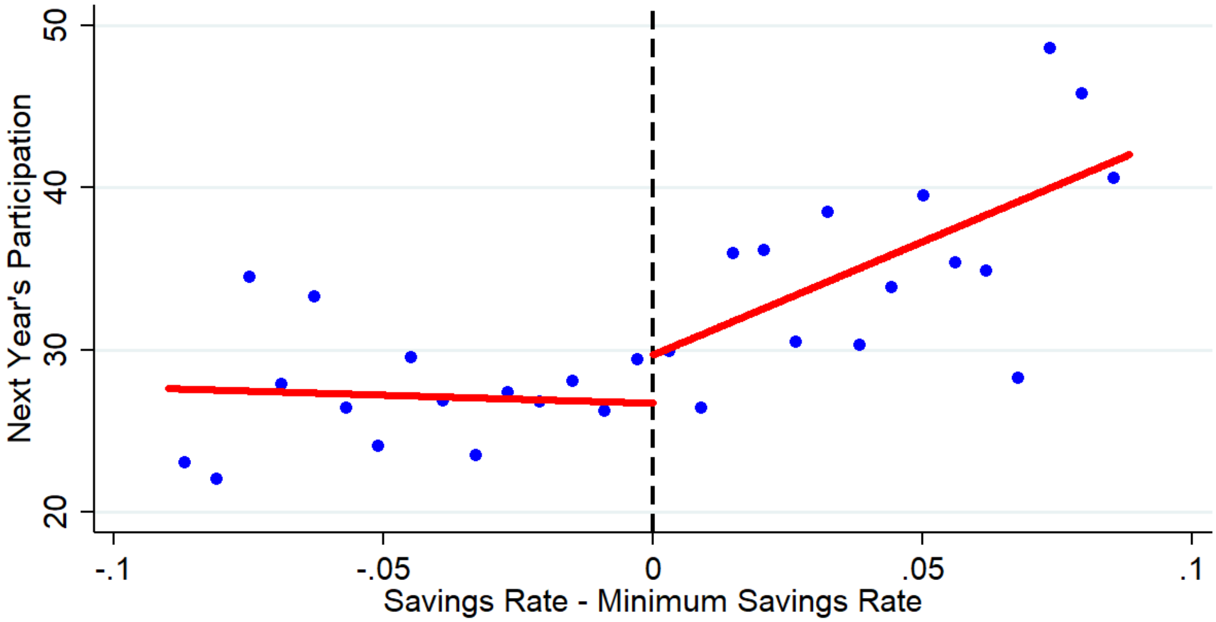
The exact contract that maximizes the money providers save, less the payment to those providers, depends on the implicit and explicit costs incurred by ACO participants when saving money and increasing care quality, as well as the amount of free-riding within the ACO. Savings-maximizing contracts share a larger proportion of ACO savings when ACO participants have larger marginal costs for spending reductions and improvements in quality. Free-riding in ACOs effectively increases the marginal cost of savings and quality; this means savings-maximizing contracts that take free-riding into account are more generous than those that don't. In the following sections of this paper, I build and estimate a model of provider participation and performance in ACOs. This yields empirical estimates of the cost of reducing expenditure and increasing quality incurred by ACO participants, and facilitates counterfactual simulations of contracts that maximize ACO savings, less payment to ACOs, while taking quality of care into account.

To write a model of ACOs, I make the assumption that ACO participants make decisions according to the incentives imposed by the program. I present evidence for this assumption by conducting two reduced form empirical exercises. In the first exercise, I use a Regression Discontinuity Design (RDD) to examine how an ACO's success in earning shared savings causes changes in participation in the following year. Specifically, I estimate the model

$$n_{jt+1} = \alpha_0 + \alpha_1 \left(S_{jt} - \underline{S}_{jt}\right) + \beta_0 \mathbf{1}\{S_{jt} \geq \underline{S}_{jt}\} + \beta_1 \mathbf{1}\{S_{jt} \geq \underline{S}_{jt}\} \left(S_{jt} - \underline{S}_{jt}\right) + \varepsilon_{jt+1} \qquad (3)$$

where n_{jt+1} is the number of Medicare providers participating in ACO j in year $t+1$, S_{jt} is the savings rate of ACO j in year t, and $\underline{S}_{jt}$ is the minimum savings rate of ACO j in year

Figure 1: **Participation vs. Qualifying**



t. When ACO's don't earn incentive pay, α_1 is change in participation with respect to how close the ACO is to the threshold savings level. When ACO's qualify, $\alpha_1 + \beta_1$ is change in participation. Similarly, α_0 and β_0 determine the level of participation.

Figure 1 plots a binned scatter plot of n_{jt+1} vs. $S_{jt} - \underline{S}_{jt}$ along with a line fitted using estimated values of α_0, α_1, β_0, and β_1.[8] When an ACO does not qualify for shared savings in year t, there is no relationship between the distance between savings rate and minimum savings rate in year t and ACO participation in year $t+1$. When an ACO qualifies, there is initially a small jump in participation, and the change in participation in year $t+1$ increases as the difference between savings rate and minimum savings rate grows. The results of this exercise indicate that providers are more likely to join ACOs that earn incentive pay. Moreover, as incentive pay grows, providers are more likely to join.

[8]Estimation is done with domain $|S_{jt} - \underline{S}_{jt}| < 0.09$. The parameter β_0 has p-value 0.33, and the parameter β_1 has p-value 0.051. Models with higher order polynomials of $S_{jt} - \underline{S}_{jt}$ have smaller F-statistics, so linear RDD is the preferred specification.

An essential part of designing incentives for physicians is accounting for quality of care. Medicare achieves this in the MSSP by assigning a quality of care score to ACOs and making it a determinant of incentive pay (see Equation 1). In this exercise, I study the empirical relationship between ACO savings rates and quality scores to show trade-offs between spending reduction and quality scores. There are two unobserved factors correlated positively both S_{jt} and Q_{jt} that impede estimating a trade-off: 1) when an ACO has a high savings rate, the marginal benefit of quality score is larger, so quality scores are higher; 2) latent ACO efficiency drives both savings rates and quality scores higher. For these reasons, I estimate the regression

$$S_{jt} = \alpha_0 + \alpha_1 Q_{jt} + \beta_0 \left(S_{jt} - \underline{S}_{jt}\right) + \beta_1 Q_{jt} \left(S_{jt} - \underline{S}_{jt}\right) + \gamma_j + \delta_t + \varepsilon_{jt} \tag{4}$$

where Q_{jt} is ACO j's overall quality score in year t, S_{jt} is savings rate, $\underline{S}_{jt}$ is the minimum savings rate, γ_j is an ACO fixed effect, and δ_t is a year fixed effect. This specification controls for the increasing marginal benefit of quality with respect to savings by including $S_{jt} - \underline{S}_{jt}$: when the difference between savings rate and minimum savings rate grows, marginal benefit of quality grows. By including ACO fixed effects, any ACO-specific and time invariant characteristics determining ACO efficiency are controlled for. The year fixed effects control for nationwide factors impacting ACO efficiency.

Table 3 shows results from estimating this regression. Column 1 estimates a univariate regression of ACO savings on quality score, and the results show confounding by the incentives imposed by the program and by latent ACO efficiency yield a positive raw relationship. When including ACO and year fixed effects (column 2) or controlling for marginal benefit

Table 3: **Empirical Relationship between ACO Savings Rates and Quality Scores**

	Dependent Variable: S_{jt} (Savings Rate)			
	(1)	(2)	(3)	(4)
Q_{jt} (Quality Score)	0.0268*	0.0216	-0.0119***	-0.00805**
	(0.0107)	(0.0147)	(0.00190)	(0.00292)
$S_{jt} - \underline{S}_{jt}$ (Savings Rate – Min. Savings Rate)			0.838***	0.781***
			(0.0248)	(0.0291)
$Q_{jt}\left(S_{jt} - \underline{S}_{jt}\right)$			0.167***	0.226***
			(0.0285)	(0.0333)
Constant	-0.0147	-0.0102	0.0388***	0.0353***
	(0.00933)	(0.0127)	(0.00167)	(0.00255)
ACO and Year FE?	No	Yes	No	Yes
N	1849	1849	1849	1849

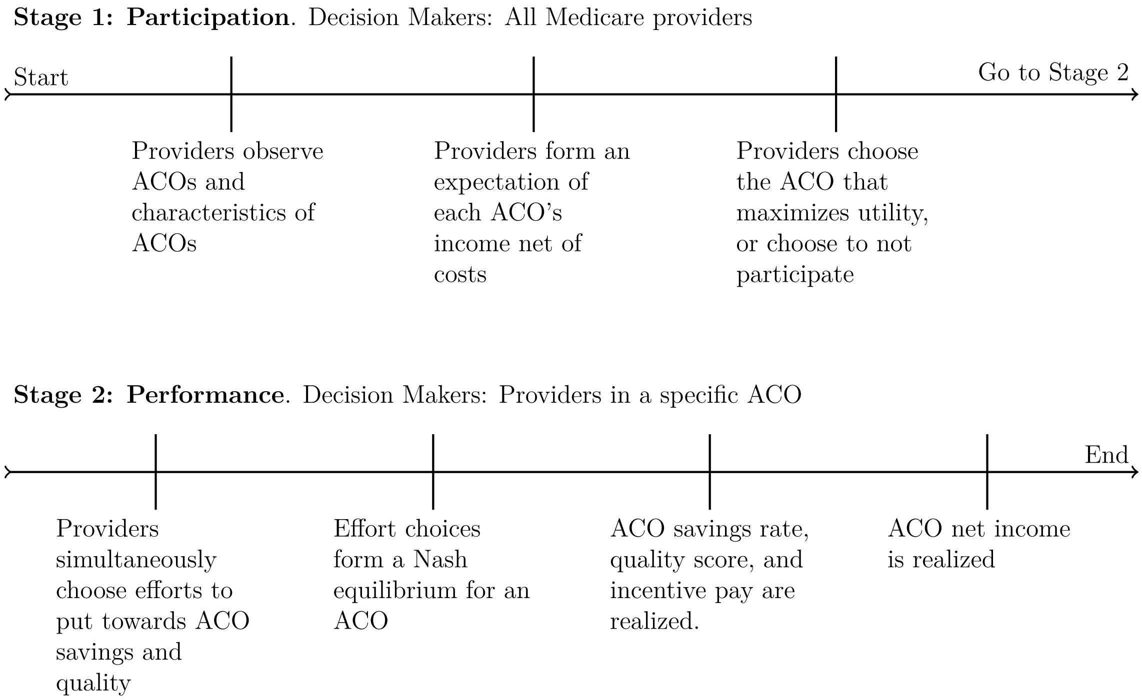
Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

of quality (column 3), the relationship between ACO savings and quality becomes smaller. Results of the full specification are in column 4. The estimates imply that when ACOs don't earn shared savings and $S_{jt} < \underline{S}_{jt}$, the relationship between ACO savings rates and quality scores is negative. For ACO's with sufficiently large values of $S_{jt} - \underline{S}_{jt}$, the relationship between ACO savings rates and quality scores is positive. Because $S_{jt} - \underline{S}_{jt}$ proxies for the marginal benefit of quality score, we can see evidence of the savings and quality trade off in the data.

3 Model of Participation and Performance in ACOs

I model participation and performance in ACOs as a two-stage decision process. All decisions are made by participants (i.e. Medicare providers), and occur in a static environment. I intentionally avoid modeling an ACO's management-level decisions—while ACO management does have influence over their members, it's ultimately the participants that see and treat

Figure 2: **Model Timing**



its assigned beneficiaries, so I assume participants are the relevant decision-makers. Any influence of management is modeled as unobserved heterogeneity, and I identify underlying structural parameters accordingly.

Timing of decisions the model is pictured in Figure 2. In the first stage, a potential participant chooses which ACO to join. The decision is in two steps: first, they choose between joining a hospital led ACO, a physician led ACO, an ACO with mixed leadership, or no ACO at all.[9] If the ACO chooses a type, they then choose an ACO to join among that type. With this structure, I allow for correlation of utilities of participants in ACOs in the same type, accounting for when providers are ex-ante more likely to join an ACO of a given type, and are, in other words, selected into participating. A Medicare provider chooses to join the ACO that offers the highest utility, which is a function of their expected income

[9] ACO leadership types are described in Table 1.

from participating (net of costs) and observed characteristics of the ACO.

In the second stage, participation is taken as given, and each member chooses efforts to put towards savings and quality in order to maximize their own payoff. Formally, each member in an ACO is playing a simultaneous move game, and an ACO's savings rate and quality score is the outcome of the Nash equilibrium strategies chosen by its participants. Though this model is written in a way such that decisions are made by individual participants, underlying structural parameters can be identified and estimated with aggregate, ACO level data. Section 4 details this process.

In the model's first stage, the decision makers in this model are Medicare providers that qualify as a participant in the MSSP. Medicare providers that are participants in an ACO are the decision makers in the model's second stage. These are heterogeneous groups, each including individual providers, group practices, and hospitals. The set of potential participants $\mathcal{I}$ and set of all ACOs $\mathcal{J}$ are exogenous.

3.1 Participation

The model starts with providers simultaneously choosing which, if any, ACO to join. Providers have preferences for ACO income, net of costs, and for specific ACO characteristics. Let $j \in \{1, \ldots, J\} = \mathcal{J}$ index ACOs, and $j = 0$ denote the outside option to not join any ACO. The potential participant $i \in \mathcal{I}$ gets the following utility from joining ACO $j \neq 0$ in nest d:

$$u_{ij} = \alpha_i y_j + \boldsymbol{\beta}' X_j^{part} + \xi_j + \zeta_{id}(\rho) + (1 - \rho)\epsilon_{ij} \, . \tag{5}$$

The variable y_j is the net income of an ACO, and X_j^{part} is a vector of ACO characteristics that observed at the time of participation, including assigned beneficiary demographics and provider characteristics. The variable ξ_j is unobserved ACO heterogeneity that is possibly correlated with y_j and X_j^{part}. The term $\zeta_{id}(\rho)$ is i's specific preference for participating in an ACO in the nest d, where nests are the leadership type of an ACO (and the outside option): $d \in \{hosp, phys, mix, 0\}$. The variable ϵ_{ij} is an idiosyncratic utility shock. Note that ξ_j, $\zeta_{id}(\rho)$, and ϵ_{ij} are observed by providers i, but all are unobserved by the econometrician. Following Berry (1994) and Cardell (1997), I assume ϵ_{ij} is distributed Type I Extreme Value, and $\zeta_{id}(\rho)$ has the unique distribution such that $\zeta_{id}(\rho)+(1-\rho)\epsilon_{ij}$ is distributed Type I Extreme Value. I normalize the utility of the outside option, $j = 0$, to $u_{i0} = \zeta_{i0}(\rho)+(1-\rho)\epsilon_{i0}$.

Net income y_j captures the expected pecuniary benefit to a provider for participating in ACO j. I use the net income of ACO j, and not the earned shared savings of ACO j, to account for the implicit and explicit effort cost incurred by spending less on Medicare beneficiaries and providing higher quality of care. If earned shared savings payments were used instead of net income, pecuniary benefit for participation would be overstated. In order to measure net income, I subtract the estimated increase in cost incurred by providers while operating in an ACO from the earned shared savings of an ACO. I discuss net income in detail in Section 3.3.

The parameters in the first stage of this model are α_i, individual i's marginal utility of net income; $\boldsymbol{\beta}$, a vector describing mean preferences over ACO characteristics; and the nesting parameter $\rho \in [0, 1]$, which measures the correlation of utilities of members in the same nest. As ρ increases, the influence an ACO's nest has over a participant's decision increases. The set of parameters in the first stage of this model is denoted $\boldsymbol{\theta}_1 = \{\alpha_i, \boldsymbol{\beta}, \rho\}$.

The parameter of paramount interest in this first stage is α_i. If positive, then Medicare providers are more likely to join ACOs with higher net income. Though plausible, this fact has not been established in health or economics literature. For reference, Ryan et al. (2015), Yasaitis et al. (2016), and Mansour et al. (2017) discuss physician income and ACO participation, though participation in response to income is inconclusive.

Let I_j be the set of $i \in \mathcal{I}$ that choose to join ACO j. Formally:

$$I_j = \left\{ i \in \mathcal{I} : j = \arg\max_{j' \geq 0} u_{ij'} \right\} \tag{6}$$

Because ϵ_{ij} and $\zeta_{id}(\rho) + (1-\rho)\epsilon_{ij}$ are distributed Type I Extreme Value, the probability of observing $i \in I_j$ where j is in nest d is

$$a_{ij} = \frac{\exp\left(\frac{\alpha_i y_j + \beta' X_j^{part} + \xi_j}{1-\rho}\right)}{\left[\sum_{j' \in d} \exp\left(\frac{\alpha_i y_{j'} + \beta' X_{j'}^{part} + \xi_{j'}}{1-\rho}\right)\right]^{\rho} \cdot \sum_d \left[\sum_{j'' \in d} \left(\frac{\alpha_i y_{j''} + \beta' X_{j''}^{part} + \xi_{j''}}{1-\rho}\right)\right]^{1-\rho}}. \tag{7}$$

The total number of providers in ACO j is $n_j \equiv M a_{ij}$, where $M = |\mathcal{I}|$.

3.2 Performance

In the second stage of this model, participating Medicare providers in ACOs choose their own savings and quality efforts, which in turn determines each ACO's overall savings rate and quality score.[10] Participant savings and quality efforts are chosen strategically to maximize a participant's profit from participating in an ACO.

[10]These participant-level efforts are *theoretical* quantities—that is, ACO participants aren't assigned a benchmark expenditure, and aren't given quality scores, and so actual, observable values don't exist. However, participants act *as if* they chose these values, and these values map to ACO performance measures that are observed.

Recall, n_j participants decide to join ACO j, and the set of all Medicare providers in ACO j is denoted I_j. All participants $i \in I_j$ simultaneously choose savings and quality efforts $s_{ij} \in [-1, 1]$ and $q_{ij} \in [0, 1]$.[11] These choices determine ACO savings rate S_j and overall quality score Q_j through the weighted sums

$$S_j = \sum_{i \in I_j} w_{ij} s_{ij} \qquad\qquad Q_j = \sum_{i \in I_j} w_{ij} q_{ij} \, . \tag{8}$$

Here, $\{w_{ij}\}_{i \in I_j}$ are exogenous influence weights such that $w_{ij} \geq 0$ for all $i \in I_j$ and $\sum_{i \in I_j} w_{ij} \equiv 1$. These weights account for heterogeneous influence of participants efforts on ACO performance.[12]

Each participant $i \in I_j$ solves the profit maximization problem

$$\max_{s_{ij}, q_{ij}} R_{ij}(S_j, Q_j) - c_{ij}\left(s_{ij}, q_{ij}\right) \tag{9}$$

where $R_{ij}(S_j, Q_j)$ is provider i's portion of shared savings earned by an ACO with savings S_j and quality score Q_j, and c_{ij} is the strictly convex and twice-continuously differentiable participant effort cost function. Specifically, $c_{ij}\left(s_{ij}, q_{ij}\right)$ is the explicit and implicit costs incurred by $i \in I_j$ when choosing s_{ij} and q_{ij}. For example, a physician that chooses very large values of s_{ij} and q_{ij} would incur significant cost—both in operational expenses as well as opportunity cost from forgone services to reduce expenditure on assigned beneficiaries.

[11]Savings effort s_{ij} is restricted to the domain $[-1, 1]$—this implicitly restricts an ACO's total expenditure to be between zero and twice its benchmark expenditure. The lower bound of s_{ij} is arbitrary, and the upper bound is predetermined because an ACO can't spend less than zero. Quality effort q_{ij} is restricted to $[0, 1]$ so that overall quality score also falls between $[0, 1]$ (which is always the case in the MSSP).

[12]For example, consider an ACO with $n_j = 2$ participants: a hospital with savings effort analogous to saving 2%, and an individual provider with savings effort analogous to saving 4%. This means $s_{1j} = 0.02$, $s_{2j} = 0.04$, and $\bar{s}_j = 0.03$. The ACO's savings rate, however, would be far closer to $S_j \approx 0.02$ since the hospital has a larger share of overall expenditure. See Appendix B for more details.

Ultimately, c_{ij} places a natural restriction on how well participants, and hence ACOs, can perform.

The shared savings earned by ACO j takes the known and exogenous form

$$R_j(S_j, Q_j) = \begin{cases} 0.5 \cdot B_j S_j Q_j & \text{if } S_j \geq \underline{S}_j \text{ and } Q_j \geq \underline{Q} \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

where B_j is the benchmark expenditure of ACO j, $\underline{S}_j$ is the minimum savings rate for ACO j, and $\underline{Q}$ is the quality reporting standard.[13] Shared savings is distributed to participants according to influence weights w_{ij}, so $R_{ij}(S_j, Q_j) = w_{ij} R_j(S_j, Q_j)$, and the two first order conditions for participant i are then

$$\frac{\partial c_{ij}}{\partial s_{ij}}(s_{ij}, q_{ij}) = \begin{cases} 0.5 \cdot B_j w_{ij}^2 Q_j & \text{if } S_j \geq \underline{S}_j \text{ and } Q_j \geq \underline{Q} \\ 0 & \text{otherwise} \end{cases} \tag{12}$$

$$\frac{\partial c_{ij}}{\partial q_{ij}}(s_{ij}, q_{ij}) = \begin{cases} 0.5 \cdot B_j w_{ij}^2 S_j & \text{if } S_j \geq \underline{S}_j \text{ and } Q_j \geq \underline{Q} \\ 0 & \text{otherwise} \end{cases} . \tag{13}$$

I've assumed with the specification of R_{ij} that ACOs split their earned shared savings with their participants according to influence weights w_{ij}, and not evenly between participants. Actual contracts between ACOs and ACO participants (known as "ACO Participant Agreements") are generally not publicly available. However, splitting shared savings according to

[13] ACOs in their first performance year are "paid to report", and so shared savings takes the form

$$R_j(S_j, Q_j) = \begin{cases} 0.5 \cdot B_j S_j & \text{if } S_j \geq \underline{S}_j \text{ and } Q_j \geq \underline{Q} \\ 0 & \text{otherwise} \end{cases} \tag{11}$$

—in other words, Q_j is equivalently 1 when an ACO meets quality reporting standards in the first performance year.

influence on ACO outcomes is a good approximation of how ACOs actually split earnings.[14] Gaynor et al. (2004) make the similar assumption that HMO group incentive pay is allocated among the group according to physician patient shares.

The shared savings function R_j is written in a way such that it *may* generate a simultaneous move game with strategic complementarity. These games have the property that the best response function of a player is increasing in the strategies of the other players (Bulow et al., 1985; Milgrom & Roberts, 1990). In the context of ACOs, this means that the optimal savings and quality effort choices of a physician are larger when a different physician chooses higher savings and quality efforts. The game played by ACO participants is supermodular if the following holds: 1) $\frac{\partial^2 c_{ij}}{\partial s_{ij} \partial q_{ij}} \leq \frac{w_{ij}^3}{2} B_j$, 2) $S_j \gg \underline{S}_j$, and 3) $Q_j \gg \underline{Q}$.[15]

While strategic complementarity does not hold in general, the concept is useful to guide one's understanding of the game that's played within ACOs. Specifically, because savings and quality enter multiplicatively into the ACO's pay, if there is a small enough trade-off between savings and quality for a given physician, then an increase in effort of one member has the response of higher effort of another member. When one member decreases their effort, others decrease theirs as well. The game will tend to have two equilibria: one with coordination where the ACO earns shared savings, and one without coordination where providers minimize cost and the ACO fails to earn shared savings.

Conditions 1), 2), and 3) above are not usually satisfied, so I prove existence of equilibrium in this game without relying on the presence of a supermodular game. Let $\mathbf{s}_j = \left[s_{1j}, \ldots, s_{n_j j}\right]'$

[14]See `https://go.cms.gov/2HiHgus` for more detail.
[15]I prove that the game is supermodular under these conditions in Appendix A.

and $\mathbf{q}_j = \left[q_{1j}, \ldots, q_{n_j j}\right]'$ and define participant i's profit as

$$\pi_{ij}\left(\mathbf{s}_j, \mathbf{q}_j\right) = R_{ij}(S_j, Q_j) - c_{ij}\left(s_{ij}, q_{ij}\right) \tag{14}$$

and its profit when qualifying as

$$\pi_{ij}^{Q}\left(\mathbf{s}_j, \mathbf{q}_j\right) = 0.5 \cdot w_{ij} B_j S_j Q_j - c_{ij}\left(s_{ij}, q_{ij}\right) \,. \tag{15}$$

Proposition 3.1. *Let* $\frac{\partial c_{ij}}{\partial s_{ij}} \cdot \frac{\partial c_{ij}}{\partial q_{ij}} \geq \left(\frac{\partial^2 c_{ij}}{\partial s_{ij} \partial q_{ij}} - \frac{w_{ij}^3}{2} B_j\right)^2$. *Then, there is a Nash equilibrium in pure strategies.*

Proof. See Appendix A. □

Denote a Nash equilibrium strategy of participant i in ACO j as $\left(s_{ij}^*, q_{ij}^*\right)$ and a Nash equilibrium of the game as $\left(\mathbf{s}_j^*, \mathbf{q}_j^*\right)$. Accordingly, the ACO's saving rate and overall quality score resulting from the set of Nash equilibrium strategies are denoted S_j^* and Q_j^*. Generally, there is not a unique equilibrium. In the proof of Proposition 3.1, I show that there can be up to two equilibria—one where the ACO qualifies or shared savings, and one where it does not. In any case, this is not an issue for estimation, since the equilibrium being played is observed in data.

3.3 Net Income

An ACO's net income is the realized increase in earnings by all members of an ACO in a given performance year by participating in the MSSP. If the ACO does not qualify for shared savings, net income is defined as zero—participants choose savings and quality efforts in the same way they would were they not participating in an ACO. If an ACO does qualify for shared savings, then net income is the total earned subsidy of the ACO, minus the increase in cost incurred by participants for having savings and quality efforts higher than they would otherwise be. By joining an ACO and earning shared savings, a participant acts differently than they otherwise would, which carries explicit and implicit costs.

Let y_j be net income. Define

$$\left(\tilde{s}_{ij}, \tilde{q}_{ij}\right) = \arg\min_{s_{ij}, q_{ij}} c_{ij}\left(s_{ij}, q_{ij}\right) . \tag{16}$$

Then,

$$y_j = \sum_{i \in I_j} \{ R_{ij}\left(S_j^*, Q_j^*\right) - \overbrace{\left[c_{ij}\left(s_{ij}^*, q_{ij}^*\right) - c_{ij}\left(\tilde{s}_{ij}, \tilde{q}_{ij}\right)\right]}^{\text{Increase in cost from earning shared savings}} \} = \sum_{i \in I_j} \left[\pi_{ij}\left(\mathbf{s}_j^*, \mathbf{q}_j^*\right) + c_{ij}\left(\tilde{s}_{ij}, \tilde{q}_{ij}\right)\right] \tag{17}$$

When the equilibrium profile of ACO j is such that ACO participants minimize cost, net income is equivalently zero. I discuss the computation of y_j from data in Section 4.

4 Identification and Estimation

To estimate model primitives, I use ACO-level data on Track 1 ACOs from 2014 to 2017.[16] The first year of the program, 2013, is omitted because participation information is not available. Track 2 and 3 ACOs are omitted because these ACO's *choose* to face downside risk when in the MSSP, so selection may bias estimates if these ACOs were included. Identification and estimation of this model is complicated by the limited data available on ACO

[16] Summary statistics for the data are presented in Tables 1 and 2 in Section 2.

Table 4: **Summary of Model and Data used for Estimation**

Model Stage	Primitives	Data
1 - Participation	Parameters $\boldsymbol{\theta}_1$ in utility from participation u_{ij}.	Share of participation: a_j Computed net income: $y_j(\hat{\boldsymbol{\theta}}_2)$ ACO characteristics determined during participation: X_j^{part}
2 - Performance	Parameters $\boldsymbol{\theta}_2$ in parameterized cost functions c_{ij}.	ACO savings rate: S_j ACO quality score: Q_j ACO benchmark exp.: B_j Summed-cubed share of expenditures: $W_j^{(3)}$ ACO characteristics determined during performance: X_j^{perf}

participants. Only aggregate data is observed: decisions in both stages of the model are made by Medicare providers, and available data describes the outcome of these agents' decisions aggregated to the ACO level. To overcome the challenge imposed by data availability, I use methods from empirical industrial organization (for example, Berry (1994), Berry et al. (1995), and Nevo (2000)) to map ACO characteristics and performance to model primitives.

Table 4 gives an overview of the model primitives and data used for estimation of the primitives. Computing ACO net income y_j requires subtracting effort cost from earned shared savings, so I estimate the model backwards. First, I parametrically estimate average participant cost functions, $c_{ij}(\cdot)$, up to fixed costs. These parameters are denoted by $\boldsymbol{\theta}_2$. Using cost function parameters, I compute an estimate of net income $y_j\left(\hat{\boldsymbol{\theta}}_2\right) \equiv \hat{y}_j$, and finally I use the estimate of net income $\hat{y}_j$ to estimate parameters describing utility from participation, $\boldsymbol{\theta}_1$. I assume that observed ACO savings rates and quality scores are savings rates S_j^* and quality scores Q_j^* from a Nash equilibrium. Equilibrium selection is not required for estimation since the equilibrium played (qualifying or not qualifying for shared savings) is observed. I also assume provider have rational expectations over the net income of an

ACO, so variation computed net income $\hat{y}_j$ identifies and can be used to estimate the

4.1 Identification and Estimation of Participant Cost Functions

4.1.1 Overview

The key estimates in this paper are identified from variation in savings rates and overall quality scores across ACOs *given the observed marginal incentive pay for each measure of performance.* For example, a large positive correlation of savings rates and quality scores across ACOs is not evidence of complementarity of savings and quality. If ACOs with large quality scores also tend to have large marginal incentive pay with respect to savings, then this positive correlation could exist in the presence of no complementarity or a trade-off.[17] Incorporating the structure of ACO participants' incentives is essential to obtain the results in this paper.

Identification begins by using observed ACO performance data and characteristics to construct the influence-weighted average marginal benefit to participants for savings and quality effort, MB_j^S and MB_j^Q, for each ACO j. Recall participant first order conditions in Equations 12 and 13. Pre-multiplying by w_{ij} and summing over $i \in I_j$ yields

$$MB_j^S = \begin{cases} 0.5 \cdot W_j^{(3)} B_j Q_j^* & \text{if } S_j^* \geq \underline{S}_j \text{ and } Q_j^* \geq \underline{Q} \\ 0 & \text{otherwise} \end{cases}, \tag{18}$$

$$MB_j^Q = \begin{cases} 0.5 \cdot W_j^{(3)} B_j S_j^* & \text{if } S_j^* \geq \underline{S}_j \text{ and } Q_j^* \geq \underline{Q} \\ 0 & \text{otherwise} \end{cases}, \tag{19}$$

[17] Indeed, this seems to be the case: see the discussion of Table 3 Section 2.

where $W_j^{(3)} \equiv \sum_{i \in I_j} w_{ij}^3$. The variable $W_j^{(3)}$, which is a measure of influence concentration within an ACO (similar to a Herfindahl-Hirschman index [HHI]), is computed from data as the sum of cubed shares of expenditure for each type of provider within an ACO. The computation of $W_j^{(3)}$ from data is discussed in detail in Appendix B.

Since the marginal benefit of savings and quality effort is equal the marginal cost of savings and quality effort for every participant in equilibrium, it must be the case that the weighted average marginal benefit of savings and quality effort is equal to the weighted average marginal cost of savings and quality effort in equilibrium. Hence, weighted average marginal costs are identified for each ACO j. Let them be MC_j^S and MC_j^Q.

Here, data limitations become evident. Since within-ACO variation across participants is unavailable, its impossible to identify a specific marginal cost for each participant in each ACO. Weighted average marginal costs MC_j^S and MC_j^Q are the fullest description of marginal cost available. These values are still informative, however: because each is weighted by participant influence on ACO outcomes, they can be interpreted as the marginal costs of savings effort and quality effort for the representative participant in a given ACO.

Next, I assume that weighted average marginal benefit is observed with exogenous and mean zero errors ν_j^S and ν_j^Q:

$$MB_j^S = MC_j^S + \nu_j^S \tag{20}$$

$$MB_j^Q = MC_j^Q + \nu_j^Q \, . \tag{21}$$

To estimate, I parameterize MC_j^S and MC_j^Q as linear functions of ACO savings rate S_j^*, quality score Q_j^*, and a vector of characteristics $X_j^{perf} \in \mathbb{R}^k$:

$$MC_j^S = MC^S\left(S_j^*, Q_j^*, X_j^{perf}; \boldsymbol{\theta}_2\right) = \delta_S S_j^* + \boldsymbol{\gamma}_S' X_j^{perf} + \kappa Q_j^* \tag{22}$$

$$MC_j^Q = MC^Q\left(S_j^*, Q_j^*, X_j^{perf}; \boldsymbol{\theta}_2\right) = \delta_Q Q_j^* + \boldsymbol{\gamma}_Q' X_j^{perf} + \kappa S_j^* \tag{23}$$

where the set of parameters to be estimated is $\boldsymbol{\theta}_2 = \{\delta_S, \delta_Q, \boldsymbol{\gamma}_S, \boldsymbol{\gamma}_Q, \kappa\}$. Finally, I use the moment conditions

$$\mathbb{E}\left[\begin{array}{c|c} \nu_j^S & \\ & S_j^*, Q_j^*, X_j^{perf} \\ \nu_j^Q & \end{array}\right] = 0 \tag{24}$$

and the Generalized Method of Moments (GMM) estimator (Hansen, 1982) to obtain estimates of parameters, $\hat{\boldsymbol{\theta}}_2$. Note that GMM is the necessary technique (and not a linear estimator like ordinary least squares) since κ appears in both ν_j^S and ν_j^Q.

4.1.2 Structural Interpretation of Parameters

The linear parameterization in Equations 22 and 23 has the key advantage that average weighted marginal costs as a function of ACO savings rate S_j^* and quality score Q_j^* are the same as participant marginal costs as a function of efforts s_{ij}^* and q_{ij}^*, holding other characteristics constant. Specifically, I am specifying the participant cost function

$$c_{ij}\left(s_{ij}, q_{ij}\right) = c\left(s_{ij}, q_{ij}; x_{ij}^{perf}, \boldsymbol{\theta}_2\right) = \frac{\delta_S}{2} s_{ij}^2 + \frac{\delta_Q}{2} q_{ij}^2 + \left(\boldsymbol{\gamma}_S' x_{ij}^{perf}\right) s_{ij} + \left(\boldsymbol{\gamma}_Q' x_{ij}^{perf}\right) q_{ij} + \kappa s_{ij} q_{ij} \tag{25}$$

where $x_{ij}^{perf} \in \mathbb{R}^k$ is a vector of participant-specific characteristics and $X_j^{perf} \equiv \sum_{i \in I_j} w_{ij} x_{ij}^{perf}$.[18] In other words, if c_{ij} is quadratic in s_{ij} and q_{ij}, then the marginal cost functions of participants are parametrically identified as a function of their savings and quality efforts. This is the cost function I assume for each counterfactual simulation. However, several results remain without a functional form assumption on cost. For example, an empirical estimate of the savings-quality trade-off is by definition the change in marginal cost of savings with respect to quality, or $\frac{\partial \hat{MC}_j^S}{\partial Q_j^*}$.

4.1.3 Illustrative Example

To gain intuition for identifying the shape of ACO participants' cost functions (including a savings-quality trade-off), let's consider a simple example. This example is written without assuming an explicit functional form for c_{ij} so that it's clear that results regarding the shape of participant's cost functions stem from variation in ACO outcomes and not an specific functional form assumption.

First suppose there are two ACOs with weighted average marginal benefit of savings such that $MB_1^S < MB_2^S$, where $S_1^* < S_2^*$ and $Q_1^* = Q_2^*$. Since marginal benefit is (on average) equal to marginal cost in equilibrium, we have $S_1^* < S_2^*$ and $MC^S(S_1^*, Q_1^*) < MC^S(S_2^*, Q_2^*)$. Marginal cost is of savings increasing in savings, so cost is convex in savings. The average

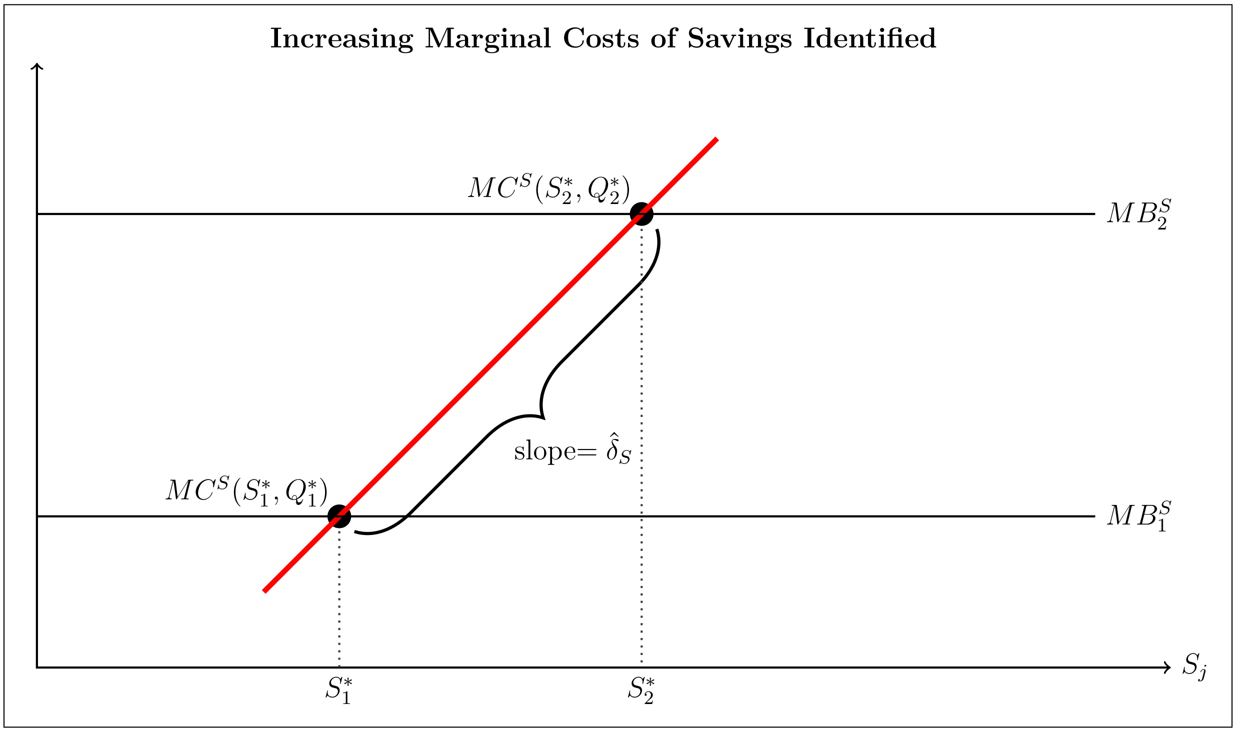
[18] To see this note that $\frac{\partial c_{ij}}{\partial s_{ij}}\left(s_{ij}^*, q_{ij}^*\right) = \delta_S s_{ij}^* + \gamma_S' x_{ij}^{perf} \kappa q_{ij}^*$, so average weighted marginal cost of savings is

$$\sum_{i \in I_j} w_{ij} \frac{\partial c_{ij}}{\partial s_{ij}}\left(s_{ij}^*, q_{ij}^*\right) = \delta_S \left(\sum_{i \in I_j} w_{ij} s_{ij}^*\right) + \gamma_S' \left(\sum_{i \in I_j} w_{ij} x_{ij}^{perf}\right) \kappa \left(\sum_{i \in I_j} w_{ij} q_{ij}^*\right) \tag{26}$$

$$\sum_{i \in I_j} w_{ij} \frac{\partial c_{ij}}{\partial s_{ij}}\left(s_{ij}^*, q_{ij}^*\right) = \delta_S S_j^* + \gamma_S' X_j^{perf} + \kappa Q_j^* \tag{27}$$

since $S_j^* = \sum_{i \in I_j} w_{ij} s_{ij}^*$ and $Q_j^* = \sum_{i \in I_j} w_{ij} q_{ij}^*$.

Figure 3: **Identification of Marginal Cost (1)**



increase in this case would then be equal to

$$\frac{\partial^2 c_{ij}}{\partial s_{ij}^2} = \frac{MC^S(S_2^*, Q_2^*) - MC^S(S_1^*, Q_1^*)}{S_2^* - S_1^*} \equiv \hat{\delta}_S \, . \tag{28}$$

The argument is pictured in Figure 3. Dollars are on the y-axis, and ACO savings rate is on the x-axis. The slope of the line connecting points at $\left(S_1^*, MC^S(S_1^*, Q_1^*)\right)$ and $\left(S_2^*, MC^S(S_2^*, Q_2^*)\right)$ is $\hat{\delta}_S$. The variation in weighted average marginal benefit identifies the slope (with respect to ACO savings rate) of the marginal cost of savings.

In this example, there isn't variation in quality scores, so variation across just these two hypothetical ACOs doesn't identify a savings-quality trade-off. To show variation that identifies a savings-quality trade-off, suppose there's another ACO with the same marginal benefit as ACO 2, but a different savings rate and quality score. Specifically, suppose ACO

3 is observed such that $MB_1^S < MB_2^S = MB_3^S$, $S_1^* < S_2^* < S_3^*$, and $Q_1^* = Q_2^* > Q_3^*$. In the same way I did above, define $\hat{\delta}_S$. The change in marginal cost of savings with respect to quality (the savings-quality trade-off) is equal to

$$\frac{\partial^2 c_{ij}}{\partial s_{ij} \partial q_{ij}} = \frac{MC^S(S_2^*, Q_2^*) - MC^S(S_2^*, Q_3^*)}{Q_2^* - Q_3^*} \,. \tag{29}$$

Then, applying the defintion of $\hat{\delta}_S$, we have

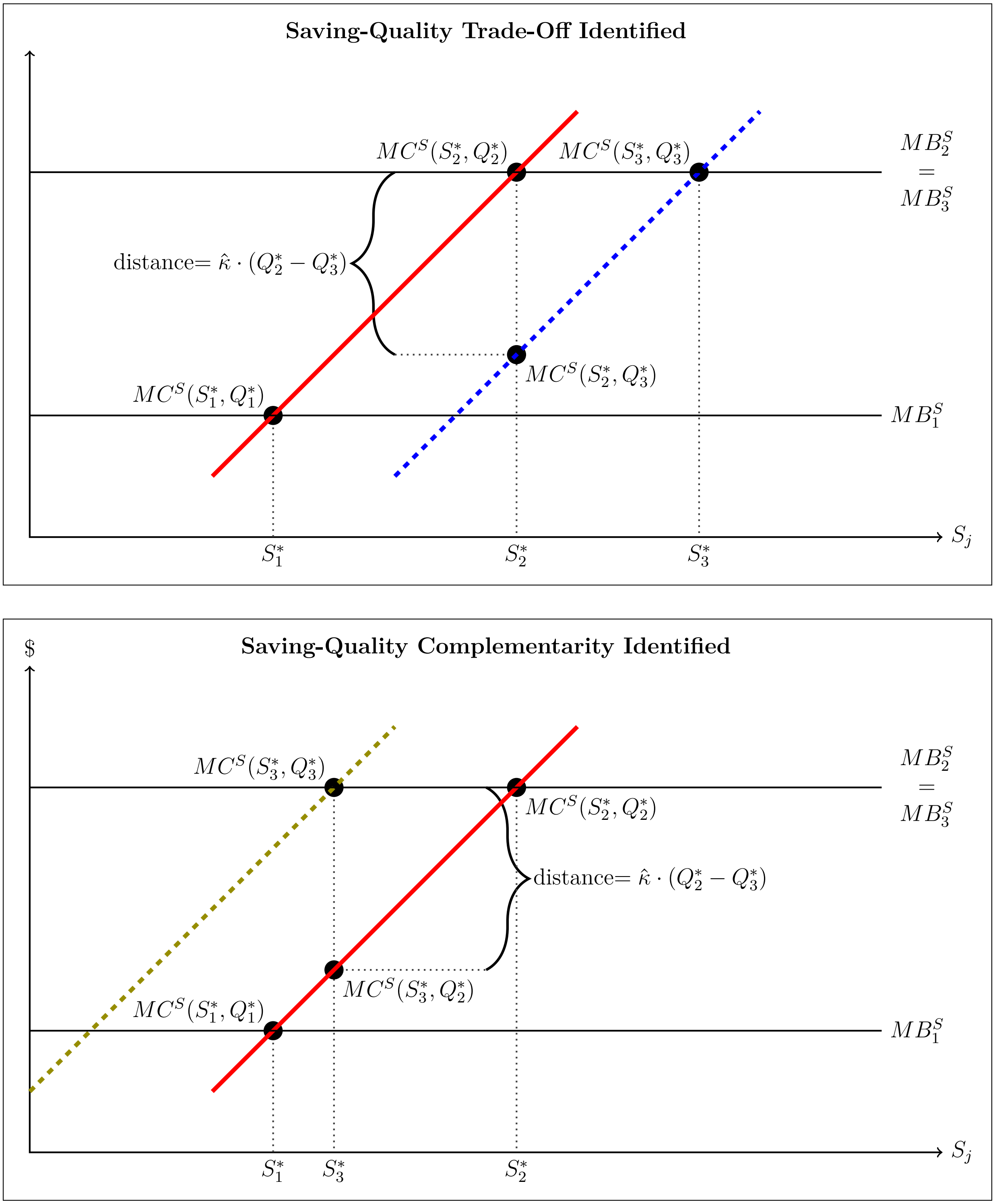
$$\begin{aligned}
\frac{\partial^2 c_{ij}}{\partial s_{ij} \partial q_{ij}} &= \frac{MC^S(S_2^*, Q_2^*) - MC^S(S_2^*, Q_3^*)}{Q_2^* - Q_3^*} && (30)\\
&= \frac{MC^S(S_2^*, Q_2^*) - \left[MC^S(S_3^*, Q_3^*) - \hat{\delta}_S(S_3^* - S_2^*)\right]}{Q_2^* - Q_3^*} && (31)\\
&= \frac{MC^S(S_2^*, Q_2^*) - \left[MC^S(S_2^*, Q_2^*) - \hat{\delta}_S(S_3^* - S_2^*)\right]}{Q_2^* - Q_3^*} && (32)\\
&= \hat{\delta}_S \frac{S_3^* - S_2^*}{Q_2^* - Q_3^*} \equiv \hat{\kappa} \,. && (33)
\end{aligned}$$

Since $Q_2^* > Q_3^*$ and $S_3^* > S_2^*$, this means marginal costs of savings are increasing in quality.

Figure 4 shows this process for identifying a trade-off in the top panel. The solid red line is the same that was found in Figure 3. Since ACOs 2 and 3 have the same marginal revenue of savings (and thus marginal cost), I can compute the marginal cost of savings for an ACO with the savings rate of ACO 2 and quality score of ACO 3, $MC^S(S_2^*, Q_3^*)$. Then, the difference between $MC^S(S_2^*, Q_2^*)$ and $MC^S(S_2^*, Q_3^*)$ (the vertical difference between the red solid line and blue dashed line) is the increase in marginal cost of savings for and increase in quality from Q_3^* to Q_2^*.

The bottom panel of Figure 4 shows how complementarity of savings and quality can be

Figure 4: **Identification of Marginal Cost (2)**



identified. The set up remains the same, except the savings rate of ACO 2 is now greater than the quality score of ACO 3: $MB_1^S < MB_2^S = MB_3^S$, $S_1^* < S_2^* > S_3^*$, and $Q_1^* = Q_2^* > Q_3^*$. Note that $\hat{\kappa}$ is negative in this case, since increasing quality score from Q_3^* to Q_2^* decreases marginal cost by $\hat{\kappa} \cdot (Q_2^* - Q_3^*)$.

4.2 Computation of Net Income

Using $\hat{\boldsymbol{\theta}}_2$, I compute an estimate of net income y_j called $\hat{y}_j$. Recall Equations 16 and 17. Net income has the equivalent expression:

$$y_j = \text{Earned Shared Savings of ACO } j - \sum_{i \in I_j} \left[c\left(s_{ij}^*, q_{ij}^*; x_{ij}^{perf}, \boldsymbol{\theta}_2\right) - c\left(\tilde{s}_{ij}, \tilde{q}_{ij}; x_{ij}^{perf}, \boldsymbol{\theta}_2\right)\right]. \tag{34}$$

The first term in Equation 34 is observed directly in data. The summation over $i \in I_j$ requires computing values of $\left(\mathbf{s}_j^*, \mathbf{q}_j^*\right)$ and $\left(\tilde{\mathbf{s}}_j, \tilde{\mathbf{q}}_j\right)$. This is not directly possible since only X_j^{perf} and not x_{ij}^{perf} is observed. In the results that follow, I approximate the second term in Equation 34 using participant choices coming from a symmetric equilibrium. See Appendix C for more details.

4.3 Identification and Estimation of Utility from Participation

Recall the utility specification for participating in ACO j:

$$u_{ij} = \alpha_i y_j + \boldsymbol{\beta}' X_j^{part} + \xi_j + \zeta_{id}(\rho) + (1-\rho)\epsilon_{ij} \tag{35}$$

Since participant level data on participating providers is unavailable, I follow Berry (1994) and Cardell (1997) to estimate α_i, $\boldsymbol{\beta}$, and ρ with aggregate data and accounting for unobserved heterogeneity ξ_j. For the nested logit specification, I divide ACOs $j \in \mathcal{J}$ into four nests d: the outside option, ACOs that are physician led, ACOs that are hospital led, and ACOs with mixed leadership. Leadership derived from the MSSP ACO Participant List datasets.

Provider preference for net income y_j is represented by the parameter α_i. To estimate dispersion in this preference without individual data, I let α_i be a normally distributed random variable with mean and standard deviation to be estimated. Formally, I specify $\alpha_i = \alpha_0 + \alpha_\eta \eta_i$ with $\eta_i \sim N(0, 1)$.

To understand the variation in data that drives estimates of parameters in Equation 35, let's examine the estimating equation for *mean* participant utility, where variation in taste for net income $\alpha_\eta \equiv 0$. Let a_j be the share of potential ACO participants joining ACO j, let a_0 be the share not joining any ACO, and let a_d be the share of participants choosing any ACO in nest d. Under the nested logit assumptions on ϵ_{ij} and on $\zeta_{id}(\rho)$ we have the estimating equation

$$\ln(a_j/a_0) = \alpha_0 y_j + \boldsymbol{\beta}' X_j^{part} + \rho \ln(a_j/a_d) + \xi_j. \tag{36}$$

Variation in net income y_j across ACOs for given characteristics X_j^{part} identifies α_0. Conceptually, controlling for ACO characteristics in X_j^{part} adjusts the estimate of α_0 so that it represents tastes for net income only, and isn't biased by ACO characteristics that are correlated with (but don't determine) net income. This is particularly important for counterfactual analysis, where I will examine the change in participation in ACOs in response to changes in net income stemming from alternate payment mechanisms.

The unobserved heterogeneity term ξ_j is likely correlated with net income y_j. In particular, "demand" for ACO participants may confound estimates of α_0. ACOs with high net income y_j may become more selective of the providers they welcome into their ACO, amounting to a negative relationship between y_j and ξ_j. This manifests as a downward biased estimate of α_0. I use an instrumental variables approach to recover unbiased estimates of the preference for net income α_0.[19]

The parameter ρ acts as a weight on ACO-type specific shocks relative to ACO specific shocks for a given provider. When ρ is high, the utility shock $\zeta_{id}(\rho)$, which influences all choices in nest d, is high relative to the utility shock $(1 - \rho)\epsilon_{ij}$, which influences choices independently. The parameter is identified by variation in shares of participation between ACO type: the correlation of utilities within groups would have a small estimate if there's significant substitution in the share of participation between groups in response to changes in other variables. There's an endogeneity problem here too: increases in the value of ξ_j cause increases in the share of participating providers a_j. If the additional providers participating in ACO j came primarily from not participating in an ACO, then $\ln(a_j/a_d)$ would be low, causing a downward bias of ρ. On the other hand, if ACO j gains share from a different group (such that $j \in d'$ with $d' \neq d$ initially), $\ln(a_j/a_d)$ would be high, causing a upward bias of ρ. I instrument for $\ln(a_j/a_d)$ to get an unbiased estimate of ρ.

Finally, some control variables X_j^{part} may be equilibrium objects, and hence endogenous.

[19]An instrument-free solution to this problem is to explicitly model the demand side for participants. Along with the already present model of the supply of participants, one could solve for equilibrium conditions and use those for estimation. I forgo this option in favor of instruments to avoid imposing additional structure on ACO formation.

While recovering unbiased estimates of $\boldsymbol{\beta}'$ isn't of particular concern in this analysis (X_j^{part} is held constant in the counterfactuals), they will also be instrumented for so that estimates and standard errors of the parameters of interest α_0, α_η, and ρ aren't impacted.[20]

Denote the instruments and exogenous variables in X_j^{part} as the vector Z_j^{part}. The moment condition for estimation is

$$\mathbb{E}\left[\hat{\xi}_j \middle| Z_j^{part}\right] = 0 \tag{37}$$

where $\hat{\xi}_j$ is the same as Equation 36, but with $\hat{y}_j$ instead of y_j.[21] I follow the contraction mapping approach from Berry (1994) to estimate $\boldsymbol{\theta}_1 = \{\alpha_0, \alpha_\eta, \boldsymbol{\beta}, \rho\}$.

4.4 Control Variables and Instruments

The elements of X_j^{perf} and X_j^{part} along with their descriptions are included in Table 5. Six variables in X_j^{perf} are omitted from X_j^{part} since they are not determined at the time participation decisions are made.

GMM with the moment conditions described in Equation 24 gives the estimate $\hat{\boldsymbol{\theta}}_2$. In a separate estimation, I allow κ to differ in each equation when I estimate the second stage parameters. The resulting parameter estimates are not significantly different, which is consistent with the structural interpretation of κ that requires $\frac{\partial^2 c_{ij}}{\partial s_{ij} \partial q_{ij}} \equiv \frac{\partial^2 c_{ij}}{\partial q_{ij} \partial s_{ij}}$.

I use GMM with the moment condition described by Equation 37 to estimate α_0, α_η, $\boldsymbol{\beta}$,

[20] Estimates presented in Table 8 ultimately indicate that this isn't an issue.

[21] In order to account for uncertainty introduced by using estimates from the second stage, the standard errors of the parameters estimated in the first stage must be adjusted. I achieve this via bootstrapping. Nonetheless, this issue is small when the estimated component of $\hat{y}_j$ is small and the parameter estimates in $\hat{\boldsymbol{\theta}}_2$ are precise.

Table 5: **Elements of X_j^{perf} and X_j^{part}**

Abbreviated Variable Name	Description
# states	Number of states where beneficiaries assigned to the ACO reside
# beneficiaries	Number of beneficiaries assigned to the ACO in thousands
average risk score	Average CMS HCC risk score of aged, non-dual beneficiaries assigned to the ACO.
% over 75	Percent of assigned beneficiaries over age 75
% male	Percent of assigned beneficiaries that are male
% nonwhite	Percent of assigned beneficaries that are non-white
# providers	Total number of individual providers in an ACO in thousands.
fraction PCP	Proportion of individual providers that are primary care physicians
fraction inpatient^a	Proportion of expenditures that are inpatient expenditures (includes short term, long term, rehabilitation, and psychiatric)
fraction outpatient^a	Proportion of expenditures that are outpatient expenditures
# PC services^a	Total number of primary care services in thousands
# admissions^a	Total number of inpatient hospital discharges in thousands
fraction PC served by PCP^a	Proportion of primary care services provided by primary care physician
all group^a	Indicates every participant in ACO is a group practice or hospital

Not listed: Constant term, year and census division fixed effects. The superscript ^{a} denotes the variable is in X_j^{perf} but not X_j^{part}.

Table 6: **Endogenous Variables and Instruments**

Parameter	Endogenous Variable	Instrument
α_0	$\hat{y}_j$ (net income)	Element in X_j^{perf}
	# states	Total Medicare beneficiary person-years in ACO area
	average risk score	Average risk score of non-dual beneficiaries in ACO area
$\boldsymbol{\beta}$	% over 75	Percent of population over 75 in ACO area
	% male	Percent of male population with Medicare in ACO area
	% nonwhite	Percent of population black in ACO area
	# providers	Element in X_j^{perf}
	fraction PCP	Element in X_j^{perf}
ρ	$\ln(a_j/a_d)$ (nesting term)	Relative HMO enrollment in ACO area

and ρ. Table 6 gives an outline of the identification strategy for these parameters. I assume the number of states occupied by an ACO's assigned beneficiaries is uncorrelated with unobserved heterogeneity ξ_j, and so it doesn't need an instrument. I obtain exogenous variation correlated with controls describing ACO assigned beneficiaries (number, average risk score, percent older than 75, percent male, and percent nonwhite) from Medicare county-level public use files. Each of these instruments require the assumption that the characteristics of Medicare beneficiaries in an ACOs area don't impact participation in a particular ACO, except through the ACO's assigned beneficiaries.

To obtain instruments for net income $\hat{y}_j$, the total number of individual providers in an ACO, and the fraction of providers that are primary care providers, I take advantage of the timing in the model. Since services provided to ACO participants don't occur until after the decision to join is made, I can use the characteristics omitted from X_j^{perf} to instrument for characteristics in X_j^{part}. These omitted characteristics are correlated with net income by shifting effort cost, but there is otherwise no explicit preference for these characteristics.

Specifically, I use the fractions of expenditures on inpatient and outpatient services, number of primary care services, and fraction of primary care services served by a PCP as instruments for net income, the total number of individual providers in an ACO, and the fraction of individual providers that are PCPs.

Finally, to instrument for an ACO's share of participation *relative to ACOs in a specific nest*, I use h_j/h_d, where h_j is the share of HMO enrolled physicians in an ACO's area, and h_d is similarly defined. These objects are correlated through providers' latent preferences for joining group payment systems, though relative shares of HMO enrollment alone are otherwise unlikely to contribute directly to participation in ACOs.

5 Estimation Results

The estimated cost function parameters, $\hat{\boldsymbol{\theta}}_2$, are presented in Table 7. The three parameters controlling the shape of the cost function are estimated precisely, and the resulting cost function satisfies the properties required for an equilibrium to exist in the game played by ACO participants in every ACO. The parameter κ, which is the cross partial derivative of cost with respect to savings rate and quality, has a considerably high estimate. Increasing savings effort by one standard deviation makes a one standard deviation increase in quality effort nearly \$6,700 more costly per participant. Increasing quality effort by one standard deviation increases the cost of increaing savings effort by one standard deviation by more than \$7,500 per participant. This means there is a significant trade-off between producing ACO savings and increasing quality of care. Figure 5 plots the marginal cost of savings as a function of savings. Like the top panel in Figure 4, it shows that as quality score increases,

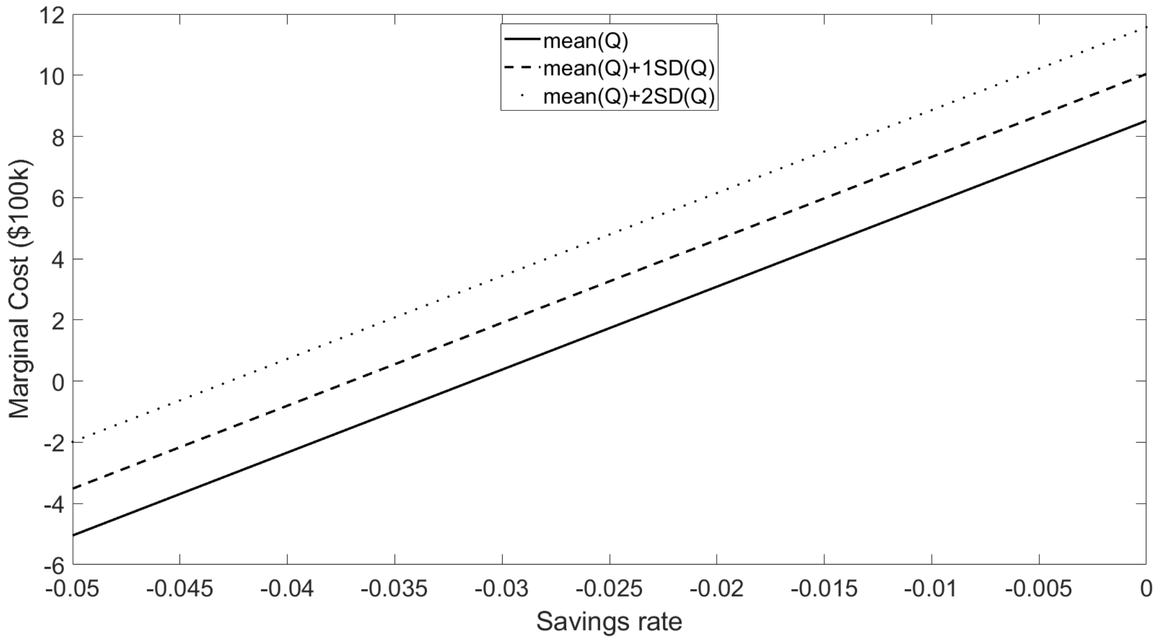
Table 7: **Cost Function Parameter Estimates**

$$c(s,q) = (\delta_S/2)s^2 + (\delta_Q/2)q^2 + \boldsymbol{\gamma}_S s + \boldsymbol{\gamma}_Q q + \kappa sq$$

Coef.	Variable	Estimate	Std. Err.	P-value	95% CI	
	δ_S	271.130	37.115	0.000	216.230	337.640
	δ_Q	1.693	0.417	0.000	0.997	2.373
	κ	15.533	6.049	0.010	3.620	23.680
$\boldsymbol{\gamma}_S$	# states	4.460	2.067	0.031	0.811	7.545
	# beneficiaries	0.210	0.143	0.142	0.000	0.462
	average risk score	116.170	38.847	0.003	36.326	166.970
	% over 75	0.131	0.242	0.587	-0.283	0.505
	% nonwhite	-0.124	0.061	0.041	-0.225	-0.021
	% male	1.097	1.082	0.310	-0.573	2.850
	# providers	-2.195	2.017	0.276	-5.512	0.780
	fraction PCP	5.292	7.131	0.458	-6.010	16.738
	fraction inpatient	-134.000	60.540	0.027	-232.780	-30.566
	fraction outpatient	-113.930	30.472	0.000	-163.880	-62.070
	# PC services	-4.279	1.335	0.001	-6.241	-1.816
	# admissions	-60.862	27.000	0.024	-101.780	-11.279
	fraction PC served by PCP	6.711	10.569	0.525	-11.044	23.293
	all group	29.339	5.204	0.000	21.085	38.347
$\boldsymbol{\gamma}_Q$	# states	-5.031	3.003	0.094	-9.541	0.024
	# beneficiaries	0.327	0.198	0.099	-0.021	0.641
	average risk score	0.011	0.011	0.318	-0.004	0.032
	% over 75	8.352	3.910	0.033	1.985	14.895
	% nonwhite	0.009	0.017	0.594	-0.020	0.037
	% male	-0.004	0.004	0.294	-0.010	0.003
	# providers	0.055	0.081	0.497	-0.067	0.192
	fraction PCP	-0.152	0.153	0.320	-0.429	0.057
	fraction inpatient	0.403	0.475	0.396	-0.345	1.190
	fraction outpatient	-10.024	4.461	0.025	-17.659	-3.337
	# PC services	-6.613	2.015	0.001	-9.979	-3.533
	# admissions	-0.298	0.104	0.004	-0.465	-0.123
	fraction PC served by PCP	-4.148	2.426	0.087	-8.299	-0.201
	all group	0.598	0.680	0.380	-0.477	1.751
	N	1486				

Standard errors, p-values, and CIs are from bootstrapping with 1000 rep. Estimates include year and Census Division FE. δ_S, δ_Q, and κ are scaled estimates.

Figure 5: **Marginal Cost vs. Savings Rate**

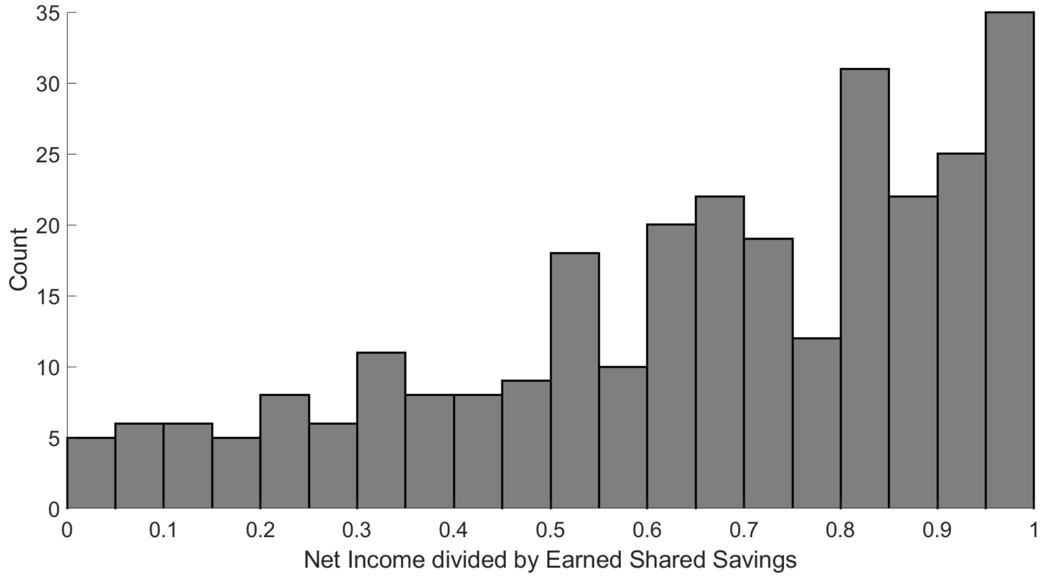


in this case by one and two standard deviations, marginal cost of savings increases.

Other parameter estimates in Table 7 indicate several determinants of the marginal cost of savings and quality. Participants in ACOs with beneficiaries in many states and with high risk scores face larger marginal costs of savings. This coincides with research (referenced in Liu et al. (2016) and McWilliams et al. (2019)) finding ACO benchmarks do not properly account for regional variation in Medicare expenditure growth.

Participants in ACOs comprised entirely of group practices or hospitals have a harder time producing savings, following the results of McWilliams et al. (2013) and Rahman et al. (2016), which discuss the scale of health care providers and margins to improve savings and quality for large providers. Savings is far less costly when the number of inpatient admissions of ACO participants is larger, all else constant. At first, this seems contrary to current literature (for example, Einav et al. (2018) argues reducing the length of stay of beneficiaries

Figure 6: **Histogram of Net Income divided by Earned Shared Savings**



could provide savings without decreasing quality), which contends the current strategy of ACOs is to minimize services per patient and keep beneficiaries out of hospital beds. These are not opposing results, however: the parameter estimates in this paper imply increasing inpatient admissions decreases the marginal cost of savings, holding all else constant. Since other cost-increasing determinants positively correlated with inpatient admissions are held constant, this result is likely capturing economies of scale in reducing expenditure. Table 7 also shows providers with older beneficiaries have a higher marginal cost of quality, and that marginal cost of quality is lower when inpatient admissions and number of primary care services offered to ACO beneficiaries is large.

Using the estimated cost function, I compute net income $\hat{y}_j$. In Figure 6, I show net income $\hat{y}_j$ as a fraction of earned shared savings. The figure shows substantial variation in the margins of ACOs. The average ACO looses 34% of their earned shared savings to increases in effort cost, with some ACOs barely breaking even.

Finally, I present the results to estimation of the participation equation in Table 8. The first column of estimates is of the OLS logistic regression without IVs. The Random Coefficients (non-nested) Logit with IVs is in the second column (RC) and the Random Coefficients Nested Logit with IV is in the third column (RCNL). After accounting for endogeneity, both models estimate a significant response of ACO participants to ACO net income. A $100,000 increase in ACO net income increases the amount of participants in an ACO by over 7%, all else constant. This is an increase in two to three participants for the average ACO. The elasticity of participation with respect to net income is 0.5.

The parameter α_η, which describes the dispersion of taste for net income, has a precise estimate of 0.012 in the RC model and an imprecise estimate of 0.014 in the RCNL model. These estimates imply that the proportion of providers in $\mathcal{I}$ without utility increasing in net income is $1 - \Phi(\alpha_0/\alpha_\eta) \approx 0$, where Φ is the standard normal CDF. In the RCNL estimation, the nesting parameter ρ is estimated with some precision at 0.544. Given the definition of nests d as leadership types of ACOs (hospital, physician, or mixed), this means the correlation of utilities of participants in ACOs under similar leadership is fairly high. Management structure of an ACO plays an important role in a participant's utility. In a related study, McWilliams et al. (2016) discusses the role ACO leadership with regards to ACO performance.

6 Counterfactuals

In this section, I use the estimated model of participation and performance to evaluate the available contracts between ACOs and CMS. Each counterfactual follows the following steps:

Table 8: **Participation Equation Estimates**

$$u_{ij} = (\alpha_0 + \alpha_\eta \eta_i)\hat{y}_j + \boldsymbol{\beta}' X_j^{part} + \xi_j + \zeta_{id}(\rho) + (1-\rho)\epsilon_{ij}$$

Coefficient	Variable	OLS	RC	RCNL
α_0	$\hat{y}_j$ (net income)	-0.007*	0.076**	0.072**
		(0.003)	(0.028)	(0.022)
α_η	$\eta_i \hat{y}_j$ (net income×pref. shock)		0.012***	0.014
			(0.002)	(0.009)
ρ	$\ln(a_j/a_d)$ (nesting term)			0.544*
				(0.227)
$\boldsymbol{\beta}$	# states	-0.045	0.021	-0.014
		(0.039)	(0.071)	(0.073)
	# beneficiaries	0.026***	0.026+	0.023+
		(0.003)	(0.014)	(0.013)
	average risk score	2.137***	-0.306	-0.850
		(0.567)	(0.866)	(0.723)
	% over 75	0.027***	0.135***	0.113***
		(0.007)	(0.028)	(0.028)
	% nonwhite	0.028***	0.045***	0.034***
		(0.002)	(0.009)	(0.008)
	% male	0.100***	0.275**	0.160***
		(0.017)	(0.095)	(0.039)
	# providers	0.134*	-0.457	-0.791*
		(0.060)	(0.414)	(0.366)
	fraction PCP	0.249	-2.494	-3.268*
		(0.201)	(1.771)	(1.439)
N		1486		

+ $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Bootstrapped standard errors (1,000 rep.) in parentheses. Estimates include year and Census Division FE. $\hat{y}_j$ is in units of $100k.

1. Predict ACO outcomes S_j^{CF} and Q_j^{CF} using the shared savings function $R_j^{CF}(S_j, Q_j)$, where CF denotes the counterfactual policy or behavioral assumptions.

2. With S_j^{CF} and Q_j^{CF}, compute net income $\hat{y}_j^{CF}$ under the counterfactual policy, and use that compute changes in participation.

3. To account for ACO exit under the the counterfactual, I estimate a logit with dependent variable equal to one if an ACO exits in performance year $t+1$. I use estimates from this model to predict ACO exit under counterfactual scenarios. Formally, I estimate ν_0, ν_1, ν_2, ν_3, and $\boldsymbol{\psi}$ in

$$exit_{jt+1} = \mathbf{1}\left\{\nu_0 + \nu_1 \hat{y}_{jt} + \nu_2 \mathbf{1}\left\{\hat{y}_{jt} > 0\right\} + \nu_3 age3_{jt} + \boldsymbol{\psi}' X_{jt}^{perf} + \varepsilon_{jt+1}\right\} \tag{38}$$

where $age3_{jt}$ indicates the ACO is three years old and would start a new agreement with CMS in year $t+1$, and $\varepsilon_{jt+1} \sim \text{Logistic}(0,1)$. Results for this is in Table 13 in Appendix D.[22]

4. In the event that two equilibria exist in the second stage counterfactual, I choose the utilitarian equilibrium (where net income is larger).

While participation change in ACOs and ACO exit are predicted, I do not predict which or how many ACOs would *not enter* (as opposed to exit) in the face of the counterfactual changes. Nonetheless, if several ACOs exit under counterfactual changes, it's likely a portion of those exiting ACOs would have never entered in the first place, so the predictions are still informative.

[22]In short, estimates of Equation 38 indicate ACOs with non-negative net income are 15 percentage points less likely to exit. No element in X_{jt}^{perf} is a significant predictor of ACO exit.

To put counterfactual changes in ACO overall quality score into meaningful terms, I use regularized regressions from Machine Learning. As discussed in Section 2, an ACO's overall quality score is a composite measure of 30 to 40 sub-measures. The actual method of computing overall quality score from these sub-measures is discontinuous, unintuitive, and presents no method to find the marginal effect of a sub-measure on overall quality score. For this reason I'll instead estimate a very simple model of overall quality score, where it is merely a linear combination of quality sub-measures. Techniques known as the Least Absolute Shrinkage and Selection Operator (LASSO) and Elastic Net automatically select a subset of sub-measures that explain the most variation in overall quality score. While a simplification, this model still explains over 80% of the variation in overall quality score. Appendix E details the process and results.

6.1 Evaluating Existing Contracts between Medicare and ACOs

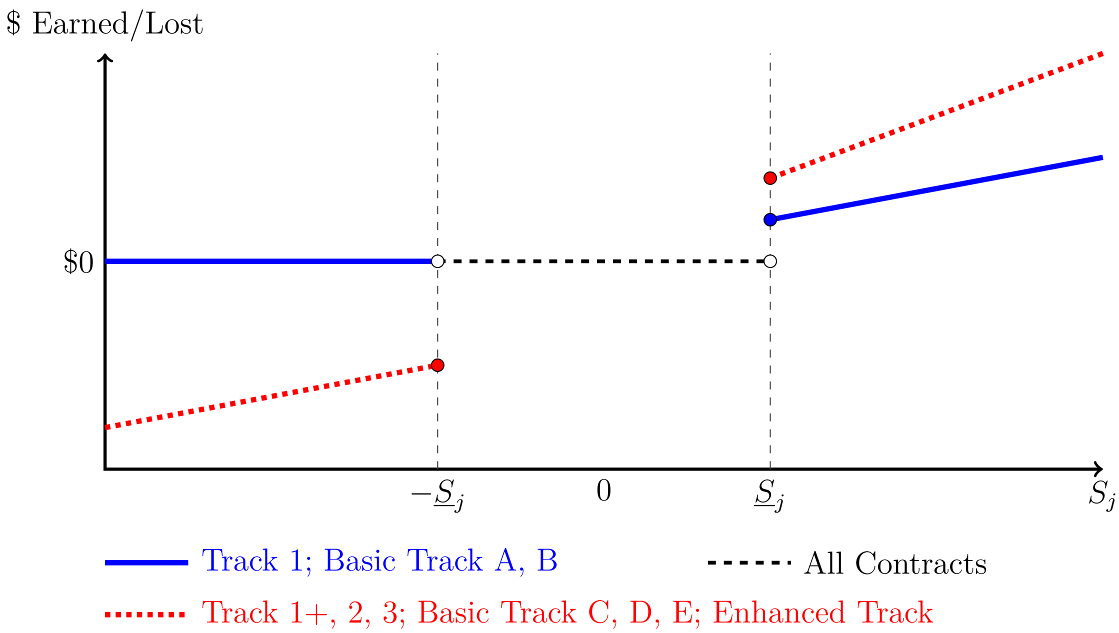
From the beginning of the Medicare Shared Savings Program in 2012 and until June 2019, ACOs had four contract options: Track 1, Track 1+, Track 2, and Track 3. Starting July 2019, these four contracts were replaced with the Basic Track (and its five levels A, B, C, D, and E) and the Enhanced Track. These contracts vary along two general dimensions: the proportion of savings that's shared with an ACO, and the requirement to pay shared losses to Medicare if savings is too low.

Table 9 shows where each contract falls. ACOs under Track 1 and levels A and B of the Basic track do not face downside risk. This contract structure, faced by over 90% of ACOs between 2012 and 2017, offers shared savings when the savings rate of the ACO is above the

Table 9: **ACO Contract Options**

Proportion of Savings Shared	Only Earns Shared Savings	Also Pays Shared Losses
0.40	Basic Track A, B	
0.50	Track 1	Track 1+, Basic Track C, D, E
0.60		Track 2
0.75		Track 3, Enhanced Track

Figure 7: **Risk Models**



minimum savings rate. In the model's notation, this is when $S_j^* \geq \underline{S}_j$. Under every other contract option, there is two-sided risk, and ACOs are required to repay Medicare if their savings rate is below the symmetric minimum loss rate: $S_j^* \leq -\underline{S}_j$.

Figure 7 shows how the various contracts differ in power by graphing an ACO's earned shared savings or losses as a function of its savings rate, S_j. Under any risk model, an ACO earns shared savings when $S_j \geq \underline{S}_j$ and earns nothing when $S_j \in \left(-\underline{S}_j, \underline{S}_j\right)$. Two-sided ACOs (dotted line) typically earn a higher proportion of savings to encourage exposure to downside risk.

The estimation of the cost function and utility from participation uses only Track 1 ACOs, where the shared savings earned by ACO j is

$$R_j(S_j, Q_j) = \begin{cases} F \cdot B_j S_j Q_j & \text{if } S_j \geq \underline{S}_j \text{ and } Q_j \geq \underline{Q} \\ 0 & \text{otherwise} \end{cases} \tag{39}$$

where $F = 0.5$. Other contract types are omitted from the estimation sample, but I can predict their behavior by altering the revenue function and using same cost function (which is invariant to contract changes). For the following predictions, two-sided ACOs have the shared savings formula

$$R_j^{TS}(S_j, Q_j) = \begin{cases} FQ_j \cdot B_j S_j & \text{if } S_j \geq \underline{S}_j \text{ and } Q_j \geq \underline{Q} \\ (1 - FQ_j) \cdot B_j S_j & \text{if } S_j \leq -\underline{S}_j \\ 0 & \text{otherwise} \end{cases} \tag{40}$$

where $F = 0.5$ for Track 1+ and Basic Track C, D, and E ACOs, $F = 0.6$ for Track 2 ACOs and $F = 0.75$ for Track 3 and Enhanced Track ACOs.[23]

Table 10 displays the simulation results. The table contains predictions of average ACO performance for one-sided and two-sided incentive structures and for varying proportions of savings shared with an ACO. The model's prediction for the estimation sample is in the middle-left cells, where $F = 0.50$ and payment is one-sided (italicized font). The row with $F = 0.50^d$ contains statistics from data. The model fits data very well for average ACO savings rate, quality score, and total program savings. Predictions of the proportion of

[23]For two-sided ACOs, the so-called "final loss rate" is defined as $1 - FQ_j$. It is bounded below at 0.4. for Track 3/Enhanced Track ACOs. For Track 2 ACOs, it's bounded above by 0.6; on Track 3/Enhanced Track, its bounded above by 0.75.

Table 10: **ACO Performance Predictions**

F	One-Sided Risk Model S_j^*	Q_j^*	PQ	PF	PS	Two-Sided Risk Model S_j^*	Q_j^*	PQ	PF	PS	SL
0.25	-0.0088	0.8843	0.3351	0.3950	-0.1432	0.0117	0.7167	0.3338	0.0168	0.3971	0.0919
0.30	-0.0048	0.8867	0.3526	0.3869	-0.0301	0.0150	0.7211	0.3546	0.0168	0.4883	0.0919
0.40	0.0023	0.8920	0.3863	0.3769	0.1096	0.0213	0.7293	0.3937	0.0168	0.5837	0.0919
0.50	*0.0078*	*0.8953*	*0.4118*	*0.3668*	*0.1182*	0.0317	0.7660	0.4468	0.0249	0.7408	0.1385
0.50^d	*0.0084*	*0.8840*	*0.3201*	*0.2011*	*0.0919*	N/A	N/A	N/A	N/A	N/A	N/A
0.60	0.0137	0.8998	0.4388	0.3580	0.0354	0.0360	0.7987	0.4704	0.0511	0.5340	0.1911
0.75	0.0202	0.9046	0.4623	0.3520	-0.2984	**0.0375**	**0.7620**	**0.4643**	**0.0289**	**0.0403**	**0.1136**

This table shows model simulations for various ACO contract options. F is the proportion of savings shared with an ACO, S_j^* is average ACO savings rate, Q_j^* is average ACO quality score, PQ is the proportion of ACOs that qualify for shared savings ($S_j^* \geq \underline{S}_j$), and PF is the proportion of ACOs with savings rare below minimum loss rate ($S_j^* \leq -\underline{S}_j$). PS is total program savings in \$ billions, defined in Equation 41. SL is total shared losses paid to CMS in \$ billions. The superscript d indicates values observed in data. Italicized numbers are performance statistics under estimation sample. Bold numbers are the model's predictions for Track 3/Enhanced Track ACOs.

ACOs that save above or below the minimum savings and loss rates are less accurate: this occurs because some ACOs in data save just below $\underline{S}_j$, but the model predicts savings just above $\underline{S}_j$.

The model predicts very large increases in average savings rates of ACOs under the two-sided model. For example, under Track 1, the equilibrium for some ACOs is to minimize cost at a savings rate below $-\underline{S}_j$. This is not optimal under Track 3 because they are penalized for doing so. Looking at columns PQ and PF in Table 10, we can see that out of 1486 observations, 609 (41%) qualify for shared savings under Track 1, and 684 (46%) under Track 3. Moreover, under Track 3, just 45 (3%) pay shared losses to CMS, compared to 550 (37%) Track 1 ACOs with a savings fraction less than the minimum loss rate.

Under both one-sided and two-sided incentives, quality scores almost always increase as F increases.[24] For a fixed F, however, ACOs facing one-sided incentives have a significantly

[24] The lone exception to this is when F changes from 0.6 to 0.75 under two-sided risk. Quality score decreases here because of the cap on the final loss rate $(1 - FQ_j)$. This is also the reason that the proportion of ACOs with $S_j^* \leq -\underline{S}_j$ becomes smaller over the same increment.

higher quality score than ACOs facing two-sided incentives. Since there is a large trade-off between savings and quality (i.e. $\hat{\kappa}$ is very large), ACOs must choose a lower quality score to avoid paying shared losses to CMS. According to the Elastic Net results described in Appendix E, these changes in average overall quality score from 0.90 under one-sided risk to between 0.70 and 0.80 under two sided risk amount to one of the following:

1. The percentile of all ACO providers COPD/Asthma emergency admissions increasing by four to eight percentage points (e.g. from 5th percentile to 9th percentile).

2. The percentile of all ACO providers Heart Failure emergency admissions increasing by 6.5 to 13 percentage points.

3. The percentile of all ACO providers score on Health Promotion and Education portion of CAHPS decreasing by 25 to 50 percentage points.

The contract faced by ACOs plays a large impact on total savings to CMS. Their savings from the program changes since 1) ACOs have different savings rates, 2) the amount of subsidy paid for a given savings rate is different, and 3) CMS may recoup excess payment when ACOs perform poorly. Column SL in Table 10 is the amount paid to CMS by ACOs that fail to save above the minimum loss rate. Column PS is the total money saved (or lost) over the benchmark expenditure, less the amount shared with ACOs. The values indicate we should expect the total savings to CMS to increase significantly were all ACOs under the contract design of Track 1+ or Basic Tracks C, D, and E, from \$118 million to \$740 million. Incentives are too strong, however, for Track 3 and the Enhanced Track. In spite of a much larger average savings rate, since so much of savings is paid to ACOs, overall program savings decreases by 66%.

Table 11: **Two-Sided ACO Net Income and Participation**

	One-Sided Risk Model			Two-Sided Risk Model		
F	Net Income	# of Participants	# of Exiting ACOs	Net Income	# of Participants	# of Exiting ACOs
0.25	1.891	21.017	37.152	1.003	19.644	45.208
0.30	2.579	22.146	34.995	1.685	20.691	41.213
0.40	4.204	25.059	28.817	3.326	23.440	35.004
0.50	*6.117*	*28.982*	*25.818*	5.815	28.323	25.933
0.50^d	*N/A*	*34.077*	*25.355*	N/A	N/A	N/A
0.60	8.313	34.248	17.913	8.067	33.614	21.178
0.75	11.892	44.962	12.564	**10.895**	**41.679**	**21.105**

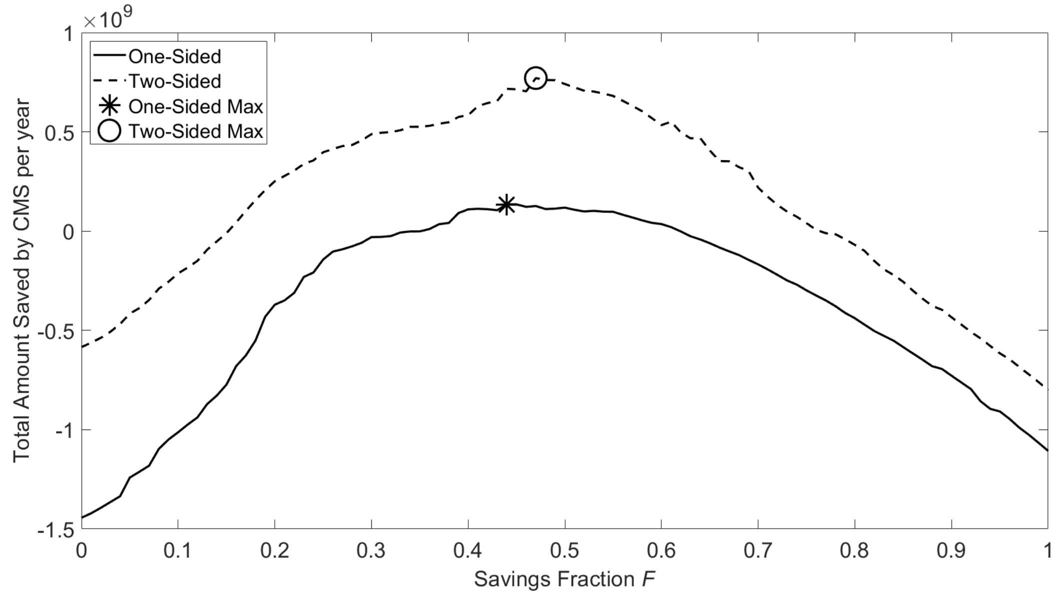
This table shows model simulations for various ACO contract options. F is the proportion of savings shared with an ACO. Net income is in units of \$100k. The superscript d indicates values observed in data. Italicized numbers are performance statistics under estimation sample. Bold numbers are the models predictions for Track 3/Enhanced Track ACOs.

Table 11 shows changes in ACO net income, participation, and exit under different contracts. When switching from one-sided to two-sided incentives and holding the savings fraction fixed, mean net income decreases by less than \$100,000 on average, and mean participation decreases between 3% and 10%. When the savings fraction increases along with the change to a two-sided risk structure (from Track 1 to Track 3, for example), the effect on participation is a net positive.

6.2 Computing the Optimal Contract between ACOs and Medicare

The results in the previous section indicate that the proportion of savings shared with an ACO and the presence of downside risk both play a large role in determining the success of the Medicare Shared Savings Program. To find the contract that maximizes savings of the

Figure 8: **Savings-Optimal Savings Fraction**



MSSP, I compute the *savings-optimal* savings fraction F by solving the problem

$$\max_{F\in[0,1]} \sum_{j\in\mathcal{J}} \left\{ \overbrace{B_j S_j^*(F)}^{\text{\$ saved by ACO } j} - \overbrace{F \cdot B_j S_j^*(F) Q_j^*(F) \mathbf{1}\left\{S_j^*(F) \geq \underline{S}_j\right\} \mathbf{1}\left\{Q_j^*(F) \geq \underline{Q}\right\}}^{\text{\$ paid to ACO } j} \right\} \tag{41}$$

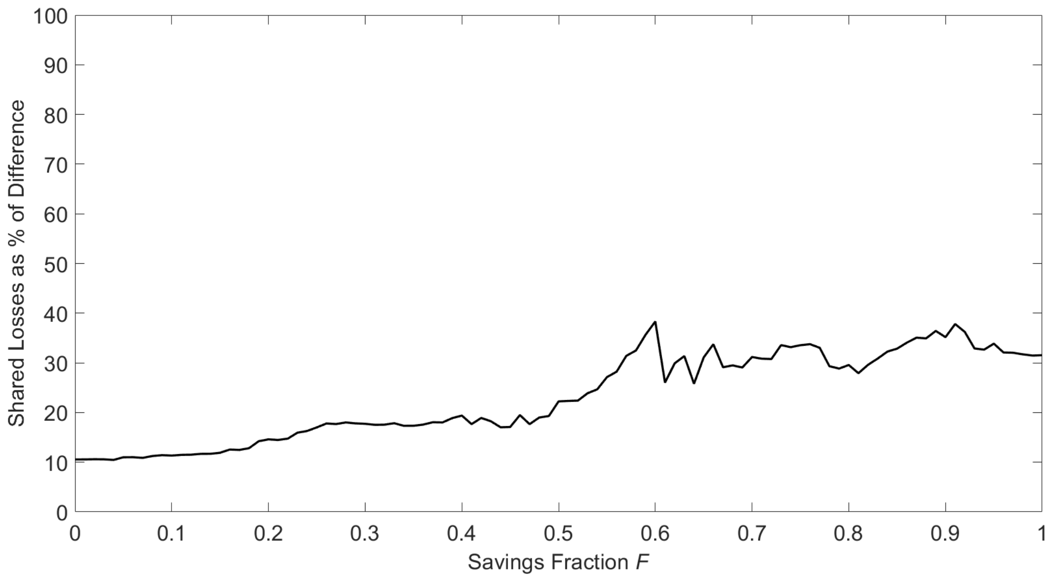
$$\text{s.t.} \quad \left(s_{ij}^*(F), q_{ij}^*(F)\right) = \arg\max_{s_{ij}, q_{ij}} \pi_{ij}\left(s_{ij}, q_{ij}\right) \text{ for all } i \in I_j \text{ and } j \in \mathcal{J}.$$

The objective function is the total amount of money saved by the Medicare Shared Savings Program. Note that an ACO's savings rate S_j^* and quality score Q_j^* are written as a function of the savings fraction F, since ACOs save more when F is higher. The trade-off, of course, is that CMS only receives a fraction of what's saved from the benchmark.

The solid line of Figure 8 plots the objective function of CMS when maximizing total savings with one-sided ACOs (Equation 41), and the dashed line plots the objective function of CMS with two-sided ACOs.[25] CMS saves the most money under a one-sided incentive

[25]CMS's objective for two-sided ACOs is slightly different than Equation 41 and includes an extra term for shared losses paid back to CMS.

Figure 9: **Shared Losses**



scheme at $F^* = 0.44$. The amount saved is just \$16.6 million higher than under the estimation sample, where $F = 0.5$. If payment is two-sided, the optimal saving fraction is nearly the same at $F^* = 0.47$. This again implies incentives are too powerful under Track 3 and the Enhanced Track, where F is 0.75. Compared to these higher power incentives, the amount saved at $F^* = 0.47$ is \$730 million larger.[26]

Figure 9 plots the shared losses paid by ACOs as a percent of the difference in program savings between one-sided and two-sided incentives. As F increases, shared losses increase in its share of the difference between one-sided and two-sided program savings. Shared losses comprise 40% of the difference between one-sided and two-sided incentives at most.

The objective function in Equation 41 is written such that the solution maximizes total program savings, so the solution is *savings-optimal*. Importantly, that objective is *decreasing* in the quality score of ACOs, since a higher quality score increases the amount paid to ACOs.

[26]The savings fraction is higher for two-sided ACOs under current law in order to encourage ACOs to choose those Tracks—my analysis does not account for this choice.

To examine how this impacts the optimal savings fraction, I also compute the *savings-quality-optimal* savings fraction, where the objective is to maximize savings weighted by quality score. Formally, the problem is

$$\max_{F\in[0,1]} \sum_{j\in\mathcal{J}} \left\{ \left[B_j S_j^*(F) - F \cdot B_j S_j^*(F) Q_j^*(F) \mathbf{1}\left\{ S_j^*(F) \geq \underline{S}_j \right\} \mathbf{1}\left\{ Q_j^*(F) \geq \underline{Q} \right\} \right] Q_j^*(F) \right\} \tag{42}$$
$$\text{s.t. } \left(s_{ij}^*(F), q_{ij}^*(F) \right) = \arg\max_{s_{ij}, q_{ij}} \pi_{ij}\left(s_{ij}, q_{ij} \right) \text{ for all } i \in I_j \text{ and } j \in \mathcal{J}.$$

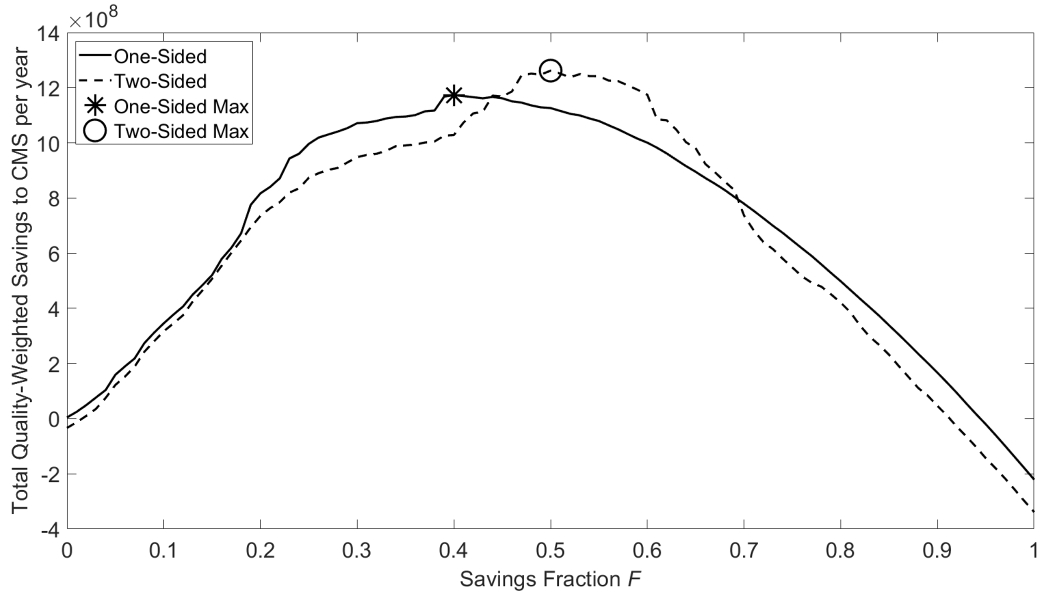
when $S_j^* \geq 0$ and

$$\max_{F\in[0,1]} \sum_{j\in\mathcal{J}} \left\{ \left[B_j S_j^*(F) - F \cdot B_j S_j^*(F) Q_j^*(F) \mathbf{1}\left\{ S_j^*(F) \geq \underline{S}_j \right\} \mathbf{1}\left\{ Q_j^*(F) \geq \underline{Q} \right\} \right] \left[1 - Q_j^*(F) \right] \right\} \tag{43}$$
$$\text{s.t. } \left(s_{ij}^*(F), q_{ij}^*(F) \right) = \arg\max_{s_{ij}, q_{ij}} \pi_{ij}\left(s_{ij}, q_{ij} \right) \text{ for all } i \in I_j \text{ and } j \in \mathcal{J}.$$

when $S_j^* < 0$. The objective is weighted by $(1 - Q_j^*)$ when savings is negative.

Figure 10 plots the objective function of CMS when maximizing total savings weighted by quality score with one-sided ACOs (Equations 42 and 43) and the objective function of CMS with two-sided ACOs. The apparent dominance of the two-sided risk model disappears once we weight program savings by quality scores. In fact, outside of the interval $[0.44, 0.70]$, the one-sided risk model has higher quality-weighted savings than the two-sided risk model. The maximum value occurs at $F = 0.40$ for the one-sided risk model and $F = 0.50$ for the two-sided risk model. The two-sided risk model has an objective value just 7.6% higher at its maximum.

Figure 10: **Savings-Quality-Optimal Savings Fraction**



These counterfactual exercises offer strong evidence that the optimal savings fraction for the MSSP is between 0.4 and 0.5—very close to some current contract options. The push to two-sided incentive structures is well-founded if maximizing program savings is the objective, however, these savings come at the cost of quality of care. The model predicts that program savings will not increase as ACOs shift to higher powered incentives, because the increase in savings is wiped out by the additional incentive pay given to ACOs.

6.3 Performance Loss due to Free-Riding within ACOs

In this section, I consider the problem where a governing body with complete control over ACO participant behavior chooses participant savings and quality in order to maximize the total profit of all participants in an ACO. The maximization problem is

$$\max_{\mathbf{s}_j, \mathbf{q}_j} R_j \left(S_j, Q_j\right) - \sum_{i \in I_j} c_{ij} \left(s_{ij}, q_{ij}\right). \tag{44}$$

Table 12: **Performance Loss from Non-Cooperative Behavior**

F	One-Sided Risk Model w/ Strategic Behavior S_j^*	Q_j^*	PS	Net Income	# Part.	One-Sided Risk Model w/Perfect Coordination S_j^*	Q_j^*	PS	Net Income	# Part.
0.25	-0.0088	0.8843	-0.1432	1.891	21.017	-0.0088	0.8843	-0.1432	2.216	21.542
0.30	-0.0048	0.8867	-0.0301	2.579	22.146	0.0299	0.9098	1.6643	3.117	23.070
0.40	0.0023	0.8920	0.1096	4.204	25.059	0.0392	0.9168	1.6687	5.208	27.047
0.50	0.0078	0.8953	0.1182	6.117	28.982	0.0466	0.9239	1.4698	7.605	32.454
0.60	0.0137	0.8998	0.0354	8.313	34.248	0.0540	0.9286	1.2576	10.200	39.533
0.75	0.0202	0.9046	-0.2984	11.892	44.962	0.0623	0.9360	0.6744	14.583	55.172

This table shows model simulations for various ACO contract options. F is the proportion of savings shared with an ACO, S_j^* is average ACO savings rate, and Q_j^* is average ACO quality score. PS is total program savings in $ billions, defined in Equation 41. Net Income is in $100k.

The difference between this problem and the game played by participants is that cost is now shared between participants: agents with low margins may operate at a loss be compensated by those with high margins. I solve this for every ACO, and present the means in Table 12. Under perfect cooperation, average ACO savings rate increases by nearly four percentage points, or about one standard deviation. Quality scores increase by just 0.02, or 0.22 standard deviations. This amounts to more than $1 billion per year in additional program savings to CMS.

Table 12 also indicates that as coordination increases, the incentives imposed by Medicare should be weakened. While 44% of savings is the optimal amount to share with free-riding, under perfect coordination the optimal amount is 35%.

7 Conclusion

The quality of life and mortality of individuals in an industry of $3.5 trillion is at stake when designing physician incentive programs. In this paper, I take a close look at the incentives faced by participants in the Medicare Shared Savings Program and Accountable Care Organizations. I estimate a two-stage structural model of participation and performance in ACOs which yields several results. First, I find Medicare providers respond to the income they expect to earn from an ACO, and participation is increasing in the amount an ACO earns. Second, I find that provider face a large trade-off between increasing savings and increasing quality of care. Counterfactual policy analysis shows that if ACOs are required to pay penalties to Medicare for spending too much, savings increases drastically, though quality falls. The optimal proportion of savings to share with an ACO (both when and when not weighting by quality score) falls between 0.4 and 0.5. Another counterfactual shows performance improves significantly were ACOs able to perfectly coordinate. Over $1 billion per year is lost to free-riding.

This paper is the first structural applied microeconomics paper on MSSP ACOs, though there promises to be several more. The first step in future work is to use more granular data. For example, ACO provider-level data paired with information on ACO assigned beneficiary claims would permit a far more complicated model of decision making within an ACO, and help answer questions outside the scope of this paper. For example, variation of expenditure by providers within ACOs could address the nature of care coordination within ACOs and the effects thereof. Medicare claims data would also help identify the MSSP's impact on Medicare as a whole, answering questions about common agency, Accountable Care Organizations' relationships with market power and industry concentration, and, over a long enough time span, lasting effects of the program.

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A Strategic Complementarity and Existence of Equilibrium

Usual definitions of supermodular games (e.g. Bulow et al. (1985); Milgrom & Roberts (1990)) require that 1) the strategy space of every agent is compact, 2) the payoff function of every agent is upper semicontinuous in their own actions, 3) the payoff function of every agent is continuous in other agent's actions, and 4) the payoff function of every agent has increasing differences. Conditions 1) and 2) of this definition are easy to confirm for the game played by ACO participants. The strategy space of each participant is $[-1, 1] \times [0, 1]$, which is compact. Upper semicontinuity in own savings effort s_{ij} is established because ACOs qualify for shared savings when the savings rate S_j is greater than *or equal to* the minimum savings rate $\underline{S}_j$ (and similarly for quality score). Condition 3) fails since participant payoff in other's efforts is only upper semicontinuous, but not fully continuous, due to the minimum savings rate. Finally, condition 4) does not typically hold: increasing differences requires the assumption that $\frac{w_{ij}^3 B_j}{2} \geq \frac{\partial^2 c_{ij}}{\partial s_{ij} \partial q_{ij}}$. I estimate the parameter $\kappa \equiv \frac{\partial^2 c_{ij}}{\partial s_{ij} \partial q_{ij}}$, which measures the savings-quality trade-off, in Section 4. The value is very large (Table 7). Since several ACO participants have very small influences weights w_{ij}, it's impossible for this condition to be satisfied for all ACOs.[27]

In the following two propositions, I show that when these conditions hold, the game played by ACO participants exhibits strategic complementarity.

Proposition A.1. *Consider the simultaneous move game played by participants in ACO j,*

[27] With data on individual providers, a parameter κ_j specific to ACOs could be estimated. With this parameter, I could confirm exactly how many ACOs are playing in a supermodular game.

and let $i, i' \in j$ with $i \neq i'$.

1. $\frac{\partial R_{ij}}{\partial s_{ij}}$ *is weakly increasing in $q_{i'j}$ and constant in $s_{i'j}$.*

2. $\frac{\partial R_{ij}}{\partial q_{ij}}$ *is weakly increasing in $s_{i'j}$ and constant in $q_{i'j}$.*

Proof. Note that if $S_j < \underline{S}_j$ or $Q_j < \underline{Q}$, $\frac{\partial R}{\partial s_{ij}}$ is identically zero, so the proof is trivial. Otherwise, we have

$$\frac{\partial^2 R_{ij}}{\partial s_{ij} \partial s_{i'j}} = 0 \tag{45}$$

$$\frac{\partial^2 R_{ij}}{\partial s_{ij} \partial q_{i'j}} = 0.5 \cdot B_j w_{ij}^2 w_{i'j} \geq 0 \tag{46}$$

which proves item 1 of the proposition. Item 2 has a nearly identical proof. □

Proposition A.2. *Consider the simultaneous game played by participants in ACO j, and let $i, i' \in j$ with $i \neq i'$. Let BR_s^i and BR_q^i be the best response functions of the savings and quality efforts, respectively, of participant i. Then, for all $i \in I_j$,*

1. *BR_s^i and BR_q^i are weakly increasing in $q_{i'j}$ and $s_{i'j}$, respectively, for all $i' \neq i$.*

2. *If $\frac{\partial^2 c_{ij}}{\partial s_{ij} \partial q_{ij}} \leq \frac{w_{ij}^3}{2} B_j$, then BR_s^i and BR_q^i are also increasing in $s_{i'j}$ and $q_{i'j}$, respectively, for all $i' \neq i$.*

Proof. Item 1 of Proposition A.2 follows trivially from Items 1 and 2 of Proposition A.2.

To prove Item 2, let $\frac{\partial^2 c}{\partial s_{ij} q_{ij}} \leq \frac{w_{ij}^3}{2} B_j$. Suppose $s_{i'j}$ increases to $s'_{i'j}$. From Item 1, q_{ij} increases to $q'_{ij} = BR_q(s'_{-ij}, q_{-ij})$ as well. The first order condition for s_{ij} maintains

$$\frac{\partial R}{\partial s_{ij}}(q'_{ij}) = \frac{\partial c}{\partial s_{ij}} \left(s'_{ij}, q'_{ij}\right) \tag{47}$$

The left hand side of the above is marginal revenue, which is increasing under Proposition A.1. Thus, either $s'_{ij} \geq s_{ij}$ or $s'_{ij} < s_{ij}$ and $\frac{\partial^2 R}{\partial s_{ij} q_{ij}} < \frac{\partial^2 c}{\partial s_{ij} q_{ij}}$. The latter violates the assumption of this proposition, and so $s'_{ij} > s_{ij}$. An similar argument applies when increasing $q_{i'j}$. $\square$

The intuition behind Proposition A.2 is as follows. First, since i's marginal revenue of savings (quality) is increasing in the quality (savings) effort of i', i will always choose a higher savings (quality) effort when i' chooses a higher quality (savings) effort. Second, since i chooses a higher savings (quality) effort in response to a higher quality (savings) effort of i', i's marginal revenue of quality (savings) *also* increases, since $\frac{\partial R_{ij}}{\partial q_{ij}}$ $(\frac{\partial R_{ij}}{\partial s_{ij}})$ is increasing in s_{ij} (q_{ij}). Since i's marginal revenue of quality (savings) is higher, i chooses a higher quality (savings) effort.

The presence of strict strategic complementarity comes only when the ACO's savings rate and overall quality score meet or exceed the minimum savings rate and quality reporting standard. Otherwise, all participants have best response functions that are constant in the strategies of their peers. In essence, ACOs benefit from strategic complementarity when participants are all operating at a high-level of savings and quality, and when there is a relatively small trade-off between savings and quality for the individual provider. Ultimately, the shared savings formula (defined by law) has the property that ACOs with underachieving participants obtain no advantage from strategic complementarity, but those with participants with high efforts do.

The following proposition (which also appears in the body of the paper) establishes existence of equilibrium.

Proposition A.3. *Let* $\frac{\partial c_{ij}}{\partial s_{ij}} \cdot \frac{\partial c_{ij}}{\partial q_{ij}} \geq \left(\frac{\partial^2 c_{ij}}{\partial s_{ij} \partial q_{ij}} - \frac{w_{ij}^3}{2} B_j \right)^2$. *Then, there is a Nash equilibrium in* *pure strategies.*

Proof. First, the assumption that $\frac{\partial c_{ij}}{\partial s_{ij}} \cdot \frac{\partial c_{ij}}{\partial q_{ij}} \geq \left(\frac{\partial^2 c_{ij}}{\partial s_{ij} \partial q_{ij}} - \frac{w_{ij}^3}{2} B_j \right)^2$ and that c_{ij} is strictly convex guarantees that there's a unique solution to both of the problems (fixing $\mathbf{s}_{-ij}$ and $\mathbf{q}_{-ij}$)

$$\underbrace{\begin{array}{ll} \max & \pi_{ij}^{Q}(\mathbf{s}_j, \mathbf{q}_j) \\ s_{ij} \in [-1,1] & \\ q_{ij} \in [0,1] & \end{array}}_{\text{Problem A}} \qquad \underbrace{\begin{array}{ll} \min & c_{ij}\left(s_{ij}, q_{ij}\right) \\ s_{ij} \in [-1,1] & \\ q_{ij} \in [0,1] & \end{array}}_{\text{Problem B}}$$

for all $i \in I_j$. In any equilibrium, every participant is solving Problem A, or every participant is solving Problem B. Otherwise, there would be at least one participant not maximizing π_{ij}. Let $\left(\mathbf{s}_j^B, \mathbf{q}_j^B\right)$ be the a tuple of vectors such that the elements of the vectors solve Problem B for all $i \in I_j$, and similarly define $\left(\mathbf{s}_j^A, \mathbf{q}_j^A\right)$. I will show that equilibrium exists, and it is always one of these tuples.

$\left(\mathbf{s}_j^B, \mathbf{q}_j^B\right)$ is an equilibrium when there is no $i \in I_j$ such that i is better off choosing $\left(s_{ij}^A, q_{ij}^A\right)$ while others choose $\left(\mathbf{s}_{-ij}^B, \mathbf{q}_{-ij}^B\right)$. In other words, the cost-minimizing equilibrium exists when no participant is so influential (high w_{ij}) with low enough marginal costs such that it's still optimal for that participant to push the entire ACO to earn shared savings.

Suppose there is a participant with such characteristics, and $\left(\mathbf{s}_j^B, \mathbf{q}_j^B\right)$ is not an equilibrium. What's left to establish is that there is at least one such $\left(\mathbf{s}_j^A, \mathbf{q}_j^A\right)$ that is an equilibrium.

To see this, consider the first order conditions to Problem A for all agents:

$$\frac{w_{ij}^2 B_j Q_j^A}{2} = c_{ij,1}\left(s_{ij}^A, q_{ij}^A\right) \tag{48}$$
$$\frac{w_{ij}^2 B_j S_j^A}{2} = c_{ij,2}\left(s_{ij}^A, q_{ij}^A\right) \tag{49}$$

where $c_{ij,1}$ reflects differentiation with respect to the first element. Note that since c_{ij} is strictly convex, $c_{ij,1}$ and $c_{ij,2}$ are strictly increasing and so inverse functions in a given argument exist:

$$c_{ij,1}^{-1}\left(\frac{w_{ij}^2 B_j Q_j^A}{2}, q_{ij}^A\right) = s_{ij}^A \tag{50}$$
$$c_{ij,2}^{-1}\left(\frac{w_{ij}^2 B_j S_j^A}{2}, s_{ij}^A\right) = q_{ij}^A \tag{51}$$

First, note that if c_{ij} is quadratic, $c_{ij,1}^{-1}$ and $c_{ij,2}^{-1}$ are linear, and so a unique equilibrium exists. If $c_{ij,1}^{-1}$ and $c_{ij,2}^{-1}$ are otherwise non-linear, consider the mapping $\Psi_j : [-1,1]^{n_j} \times [0,1]^{n_j} \to \mathbb{R}^{2n_j}$

$$\Psi_j\left(\mathbf{s}_j^A, \mathbf{q}_j^A\right) = \begin{bmatrix} c_{ij,1}^{-1}\left(\frac{w_{ij}^2 B_j Q_j^A}{2}, q_{ij}^A\right) - s_{ij}^A \\ c_{ij,2}^{-1}\left(\frac{w_{ij}^2 B_j S_j^A}{2}, s_{ij}^A\right) - q_{ij}^A \end{bmatrix}_{i \in I_j} \tag{52}$$

Clearly, zeros to the function Ψ_j are equilibria. To show that a unique zero exists, I'll use the inverse function theorem and show the Jacobian of Ψ_j has full rank at $\left(\mathbf{s}_j^A, \mathbf{q}_j^A\right)$. First, note in the diagonal entires of $D\Psi_j$ are all -1. Next, if the ith row of $D\Psi_j$ is odd, then any odd column's element in that row is zero. If the ith row is even, then any even column's element in that row is zero. Therefore, no row is a linear combination of the others, and $D\Psi_j$ has full rank. $\square$

B Influence weights w_{ij}

I've defined influence weights $\{w_{ij}\}_{i \in I_j}$ such that

$$\sum_{i \in I_j} w_{ij} s_{ij} = S_j \qquad \sum_{i \in I_j} w_{ij} q_{ij} = Q_j \tag{53}$$

where $\sum_{i \in I_j} w_{ij} = 1$. Note that for participant savings efforts s_{ij} have to have a definition analogous to that of S_j, we would have

$$S_j = \frac{BE_j - E_j}{BE_j} = \frac{\sum_{i \in I_j} BE_{ij} - \sum_{i \in I_j} E_{ij}}{\sum_{i \in I_j} BE_{ij}} = \sum_{i \in I_j} w_{ij} \frac{BE_{ij} - E_{ij}}{BE_{ij}} = \sum_{i \in I_j} w_{ij} s_{ij} \tag{54}$$

where BE_j and E_j are the benchmark expenditure and expenditure of ACO j (both real quantities observed in data) and BE_{ij} and E_{ij} are the benchmark expenditure and expenditure of participant i in ACO j (both theoretical quantities). Thus, a definition of w_{ij} consistent with the above is $w_{ij} = \frac{BE_{ij}}{BE_j}$, or simply participant i's share of ACO benchmark expenditure. Intuitively, this means that a very influential participant i in ACO j will have a relatively large share of expected expenditure on assigned beneficiaries.

In data, I measure w_{ij} as shares of expenditure for each *type* of provider within an ACO. To be specific, suppose provider i has type k. Then,

$$w_{ij} = \frac{\text{Total Spending by type } k}{(\text{Total \# of } i \text{ with type } k) \times (\sum_{\ell} \text{Total Spending by type } \ell)} \tag{55}$$

The numerator and both terms in the denominator are observed for the general types k.

This measure of w_{ij} has two important requirements. First, it requires that providers of the same type have similar shares of overall expenditure within an ACO. This is likely the case, since ACOs tend to be predominantly hospital based or group practice based. Second, this measure requires that the *ratio* BE_{ij}/BE_j is close to the ratio E_{ij}/E_j, since w_{ij} as defined in Equation 55 is the latter ratio.

C Computation of ACO Savings Rates, Quality Scores, and Net Income

To compute predicted values of S_j^* and Q_j^*, I solve the system of equations implied by participants' first order conditions given an estimate of cost function parameters $\hat{\boldsymbol{\theta}}_2$. Imposing quadratic cost and equating influence-weighted average marginal cost with marginal benefit, we get two systems of two equations each:

$$F \cdot W_j^{(3)} B_j Q_j^* = \hat{\delta}_S S_j^* + \hat{\boldsymbol{\gamma}}_S' X_j^{perf} + \hat{\kappa} Q_j^* \tag{56}$$

$$F \cdot W_j^{(3)} B_j S_j^* = \hat{\delta}_Q Q_j^* + \hat{\boldsymbol{\gamma}}_Q' X_j^{perf} + \hat{\kappa} S_j^* \tag{57}$$

where F is the proportion of savings shared with an ACO, and

$$0 = \hat{\delta}_S S_j^* + \hat{\boldsymbol{\gamma}}_S' X_j^{perf} + \hat{\kappa} Q_j^* \tag{58}$$

$$0 = \hat{\delta}_Q Q_j^* + \hat{\boldsymbol{\gamma}}_Q' X_j^{perf} + \hat{\kappa} S_j^* \,. \tag{59}$$

These systems both have guaranteed solutions given assumptions on π_{ij}^Q and c_{ij}. For each ACO, I check if the first solution offers $S_j^* \geq \underline{S}_j$ and $Q^* \geq \underline{Q}$, and if passed, qualifying for shared savings is a predicted equilibrium outcome for that ACO. If not, only the cost-minimizing equilibrium outcome exists.

Since equilibrium is symmetric, this means $s^*_{ij} \equiv S^*_j$ and $q^*_{ij} \equiv Q^*_j$ for all $i \in I_j$. In the event two equilibria exist, I assume the equilibria played is one where the sum of profit across participants is greater. There are no cases where profit is equal for two equilibria (though it's theoretically possible).

My estimate of net income is then

$$\hat{y}_j = \text{Earned Shared Savings of ACO } j - n_j \left[c\left(s^*_{ij}, q^*_{ij}; X^{perf}_j, \hat{\boldsymbol{\theta}}_2\right) - c\left(\tilde{s}_{ij}, \tilde{q}_{ij}; X^{perf}_j, \hat{\boldsymbol{\theta}}_2\right)\right]. \tag{60}$$

D Exit Logit

Columns (3) and (4) of Table 13 show raw coefficient estimates and marginal effects for the logit model

$$exit_{jt+1} = \mathbf{1}\left\{\nu_0 + \nu_1 \hat{y}_{jt} + \nu_2 \mathbf{1}\left\{\hat{y}_{jt} > 0\right\} + \nu_3 age3_{jt} + \boldsymbol{\psi}' X^{perf}_{jt} + \varepsilon_{jt+1}\right\} \tag{61}$$

None of the elements in $\boldsymbol{\psi}$ are significant, so they are suppressed from output. I also show the result when net income $\hat{y}_j$ is replaced with an ACO's Earned Shared Savings, which is just income as opposed to net income. Note that when ACOs fail to earn shared savings, they have a 0.15 higher probability of exiting. Otherwise, dollar increases in earnings don't significantly impact exiting decisions. ACOs in there final agreement period have a 0.13 higher probability of exiting.

Table 13: **Logit of ACO Exit**

	(1) Raw	(2) M.E.	(3) Raw	(4) M.E.
Earned Shared Savings	-0.00334	-0.000288		
	(0.0115)	(0.000986)		
$\mathbf{1}\{\text{Earned Shared Savings} > 0\}$	-1.430**	-0.123**		
	(0.501)	(0.0441)		
$\hat{y}_{jt}$			-0.00703	-0.000614
			(0.0141)	(0.00123)
$\mathbf{1}\{\hat{y}_{jt} > 0\}$			-1.712**	-0.150**
			(0.565)	(0.0498)
$age3$	1.557***	0.134***	1.475***	0.129***
	(0.215)	(0.0181)	(0.214)	(0.0182)
N	1063	1063	1063	1063

Robust standard errors in parentheses

$\hat{y}_j$ and Earned Shared Savings are in units of \$100,000.

$^+$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

E LASSO and Elastic Net for Overall Quality Score

I use both the Least Absolute Shrinkage and Selection Operator (LASSO) and Elastic Net method to compute which sub-measures of the overall quality score explain changes in the overall quality score. Formally, this takes the following steps:

1. Let ACO quality score take the form: $Q_j = \chi_0 + \sum_{m=1}^{M} \chi_m Q_{jm}$, where Q_{jm} is the mth sub-measure and $\{\chi_m\}_{m=0}^{M}$ are parameters to be estimated.

2. Elastic Net coefficients are given by

$$\{\hat{\chi}_m\}_{m=0}^{M} = \arg \min_{\{\chi_m\}_{m=0}^{M}} \sum_{j=1}^{J} \left(Q_j - \chi_0 - \sum_{m=1}^{M} \chi_m Q_{jm} \right)^2 + \lambda \left[\frac{1-\alpha}{2} \cdot \sum_{m=0}^{M} \chi_m^2 + \alpha \sum_{m=0}^{M} |\chi_m| \right] \tag{62}$$

where $\lambda > 0$ is a regularization parameter and $\alpha \in [0, 1]$ weights regularization on the L^1-norm of coefficients (relative to the L^2-norm). LASSO coefficients are given in the special case when this problem is solved with $\alpha = 1$. Selection of α and λ are done by *cross-validation*. This is a method where for a given λ (or α), coefficients are computed for a subsample of the data, and then out-of-sample fit is computed for the complement of the subsample. See Abadie & Kasy (2017) and Burlig et al. (2019) for more details. Elastic Net is favorable to LASSO when regressors are highly correlated. Since this is clearly the case here, Elastic Net will be my specification of choice, but I present the results to both.

Table 14 presents the results of both specifications.

F Robustness Checks

F.1 Uncertainty in Savings and Quality

In the second stage of this model, participating Medicare providers in ACOs choose their own savings and quality efforts to overall ACO performance, though the mapping from participant choices to overall performance is deterministic. To check the robustness of this paper's results with respect to the assumption of certainty, this section briefly discusses a model and estimation where uncertainty is included. This model is a slight generalization of Frandsen & Rebitzer (2015), since I allow for heterogeneous participants and payment functions that depend on quality score.

Define s_{ij}, q_{ij}, S_j, and Q_j as before, except that *realized* efforts of participants are i.i.d.

Table 14: **Regularized Regressions of Overall Quality Score on Quality Sub-Measures**

Sub-measure (Percentile 0-100)	(1) Elastic Net	(2) LASSO
ACO-2. CAHPS: How Well Your Providers Communicate	0.0310	
ACO-5. CAHPS: Health Promotion and Education	0.314	0.337
ACO-6. CAHPS: Shared Decision Making	0.391	0.382
ACO-9. Ambulatory Sensitive Conditions Admissions: Chronic Obstructive Pulmonary Disease or Asthma in Older Adults (AHRQ Prevention Quality Indicator (PQI) #5)	-1.259	-1.142
ACO-10. Ambulatory Sensitive Conditions Admissions: Heart Failure (AHRQ Prevention Quality Indicator (PQI) #8)	-2.422	-2.560
ACO-11. Percent of PCPs who Successfully Meet Meaningful Use Requirements 0.134	0.141	
ACO-13. Falls: Screening for Future Fall Risk	0.0256	0.0243
ACO-14. Preventative Care and Screening: Influenza Immunization	0.0312	0.0288
ACO-15. Pneumonia Vaccination Status for Older Adults	0.0280	0.0244
ACO-16. Preventive Care and Screening: Body Mass Index (BMI) Screening and Follow Up	0.0852	0.0883
ACO-17. Preventive Care and Screening: Tobacco Use: Screening and Cessation Intervention	0.0236	0.0195
ACO-18. Preventive Care and Screening: Screening for Clinical Depression and Follow-up Plan	0.0476	0.0487
ACO-27. Diabetes Mellitus: Hemoglobin A1c Poor Control	-0.171	-0.184
ACO-30. Ischemic Vascular Disease (IVD): Use of Aspirin or Another Antithrombotic	0.103	0.113
ACO-33. Angiotensin-Converting Enzyme (ACE) Inhibitor or Angiotensin Receptor Blocker (ARB) Therapy – for patients with CAD and Diabetes or Left Ventricular Systolic Dysfunction (LVEF<40[1em] ACO-12. Medication Reconciliation Post-Discharge	0.0401	0.0409
Constant	6.160	8.456
R^2	0.840	0.841
α	0.6842	1
λ	0.1517	0.1159

The parameter λ is found via cross validation in (1) and (2).

The parameter α is found via cross validation in (1) and set equal to 1 in (2).

random variables

$$\hat{s}_{ij} \sim N\left(s_{ij}, \sigma_S^2\right) \qquad \hat{q}_{ij} \sim N\left(q_j, \sigma_Q^2\right) \tag{63}$$

where $N(\cdot)$ is the normal distribution. Defining $\hat{S}_j = \sum_{i \in I_j} w_{ij} \hat{s}_{ij}$ and $\hat{Q}_j = \sum_{i \in I_j} w_{ij} \hat{q}_{ij}$, each participant $i \in I_j$ solves the expected profit maximization problem

$$\max_{s_{ij}, q_{ij}} \mathbb{E}\left[R_{ij}\left(\hat{S}_j, \hat{Q}_j\right)\right] - c\left(s_{ij}, q_{ij}; x_{ij}, \boldsymbol{\theta}_2\right) \tag{64}$$

where $R_{ij}(\hat{S}_j, \hat{Q}_j)$ is the per-participant shared savings earned by an ACO with savings $\hat{S}_j$ and quality score $\hat{Q}_j$ (defined in Section 3.2). The objective function in Equation 64 becomes

$$E_{\Pi}^{j}(s_{ij}, q_{ij}, S_j, Q_j) = 0.5 \cdot w_{ij} B_j \cdot E_S(S_j) \cdot E_Q(Q_j) - c_{ij}\left(s_{ij}, q_{ij}\right) \tag{65}$$

where

$$E_S(S_j) = \mathbb{E}\left[\hat{S}_j \mathbf{1}\left\{\hat{S}_j \geq \underline{S}_j\right\}\right] = S_j \Phi\left(\frac{S_j - \underline{S}_j}{\sqrt{W_j^{(2)}}\sigma_S}\right) + \sqrt{W_j^{(2)}}\sigma_S \phi\left(\frac{S_j - \underline{S}_j}{\sqrt{W_j^{(2)}}\sigma_S}\right) \tag{66}$$

$$E_Q(Q_j) = \mathbb{E}\left[\hat{Q}_j \mathbf{1}\left\{\hat{Q}_j \geq \underline{Q}\right\}\right] = Q_j \Phi\left(\frac{Q_j - \underline{Q}}{\sqrt{W_j^{(2)}}\sigma_Q}\right) + \sqrt{W_j^{(2)}}\sigma_Q \phi\left(\frac{Q_j - \underline{Q}}{\sqrt{W_j^{(2)}}\sigma_Q}\right). \tag{67}$$

and $W_j^{(2)} = \sum_{i \in I_j} w_{ij}^2$ (see Appendix B). The functions ϕ and Φ are the standard normal probability and cumulative density functions, respectively, and $\mathbf{1}\{\cdot\}$ is the indicator function that takes a value of one if the statement in the brackets is true and zero otherwise.

F.1.1 Strategic Complementarity and Existence of Equilibrium

First define the expected revenue function.

$$E_R^j(S_j, Q_j) = 0.5 \cdot B_j \cdot E_S(S_j) \cdot E_Q(Q_j)\ . \tag{68}$$

Proposition F.1. *Let $i' \neq i$. Marginal expected revenue $\frac{\partial E_R^j}{\partial s_{ij}}(S_j, Q_j)$ is increasing in s_{ij} and $s_{i'j}$ when $\underline{S}_j \left(S_j - \underline{S}_j\right) < \sigma_S \sqrt{W_j^{(2)}}$ and is always increasing in $q_{i'j}$. Marginal expected revenue $\frac{\partial E_R^j}{\partial q_{ij}}(S_j, Q_j)$ is increasing in q_{ij} and $q_{i'j}$ when $\underline{Q}_j \left(Q_j - \underline{Q}_j\right) < \sigma_Q \sqrt{W_j^{(2)}}$ and is always increasing in $s_{i'j}$.*

Proof. First, consider the second order derivative of E_R,

$$\frac{\partial^2 E_R}{\partial s_{ij} s_{i'j}}(S_j, Q_j) = -w_{ij}^2 w_{i'j} B_j E_Q(Q_j) \left[\frac{1}{\sqrt{W_j^{(2)}}\sigma_S} + \frac{\underline{S}_j \left(S_j - \underline{S}_j\right)}{W_j^{(2)} \sigma_S^2} \right] \cdot \phi \left(\frac{S_j - \underline{S}_j}{\sqrt{W_j^{(2)}}\sigma_S} \right)\ . \tag{69}$$

The sign of this equation depends entirely on the term in the square brackets. Rearranging terms, we have

$$\underline{S}_j \left(S_j - \underline{S}_j\right) < \sigma_S \sqrt{W_j^{(2)}} \implies \frac{\partial^2 E_R}{\partial s_{ij} s_{i'j}}(S_j, Q_j) > 0$$

Since $\underline{S}_j > 0$, this condition implies that expected revenue has increasing differences in savings efforts always when average savings effort is less than the benchmark. When average savings effort is larger than the benchmark, there is still increasing differences when the difference is less than $\sigma_S \sqrt{W_j^{(2)}} / \underline{S}_j$. A similar argument applies for Q_j. □

Proposition F.1 states that the marginal payoff to a participant in an ACO is strictly increasing in the savings and quality of other participants for large regions of the domains of savings and quality.

Note that satisfying these properties alone do not imply that the game played by ACO participants is necessarily supermodular. That requires the additional condition

$$\frac{\partial E_R^j}{\partial s_{ij} q_{ij}}(S_j, Q_j) > \frac{\partial c_{ij}}{\partial s_{ij} q_{ij}}(s_{ij}, q_{ij}) \tag{70}$$

so that the best response of savings is increasing in own quality and visa versa.

As in Section 3, since the game played by ACO participants is generally not supermodular, I cannot use that property to prove existence of a pure strategy Nash equilibrium. Instead, I impose a restriction on the expected profit function E_Π^j to achieve existence in the following proposition.

Proposition F.2. *Consider the simultaneous move game played by participants i in ACO j. If $D^2 E_\Pi^j$ is negative semidefinite, then there exists a Nash equilibrium in pure strategies. This equilibrium is unique.*

Proof. If the Hessian matrix $D^2 E_\Pi$ is negative semidefinite, then each participant i has a unique pair $\left(s_{ij}^*, q_{ij}^*\right)$ that maximizes $E_\Pi(\cdot)$ given values of s_{-ij} and q_{-ij}. Note it is possible that $\left|\frac{\partial c}{\partial q_{ij}}\right|$ is large enough that a corner solution for q_{ij}^* occurs.

What's left to determine is if the values $\left\{\left(s_{ij}^*, q_{ij}^*\right)\right\}_{i \in I_j}$ constitute a Nash equilibrium. This is obvious—any choice of participants must satisfy their FOCs (or corner solution). Given s_{ij}^* and q_{ij}^* are the best responses to S_j^* and Q_j^*, any deviation would suboptimal. Hence, equilibrium exists, and it is unique. □

Table 15: **Cost Function Parameter Estimates (Uncertainty Model)**

$c(s,q) = \frac{\delta_S}{2}s^2 + \frac{\delta_Q}{2}q^2 + \gamma_S s + \gamma_Q q + \kappa sq$

Model	Coef.	Estimate	Std. Err.	P-value	95% CI	
Baseline	δ_S	271.130	37.115	0.000	216.230	337.640
	δ_Q	1.693	0.417	0.000	0.997	2.373
	κ	15.533	6.049	0.010	3.620	23.680
w/ Uncertainty	δ_S	353.940	47.718	0.000	260.910	418.170
	δ_Q	1.591	0.565	0.005	0.970	2.324
	κ	21.489	6.248	0.001	3.693	24.086
	σ_S	0.011	0.013	0.370	0.000	0.021
	σ_Q	0.010	0.004	0.023	0.002	0.014
N	1486					

Standard errors, p-values, and CIs are from bootstrapping with 1000 rep. Estimates include year and Census Division FE. δ_S, δ_Q, and κ are scaled estimates.

F.1.2 Identification and Estimation

Identification and estimation of $\boldsymbol{\theta}_2$ and $\boldsymbol{\theta}_1$ in this model (with uncertainty) is nearly identical to their identification and estimation outlined in Section 4 for the model without uncertainty. There are two additional parameters to estimate, σ_S and σ_Q. These parameters are identified by variation in $W_j^{(2)}$ *or* if c has linear marginal cost in savings and quality.

F.1.3 Results

Table 15 shows the estimates of parameters in $\boldsymbol{\theta}_2$ that describe the shape of the cost function as well as $\hat{\sigma}_S$ and $\hat{\sigma}_Q$. The parameters estimated from the model with uncertainty are well within a reasonable range of the parameters estimated from the model without uncertainty, albeit some with less precision. The estimate of σ_S is very imprecise, while $\sigma_Q$is estimated with some precision.