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A Model of Hierarchical Professionals:

Cooperation and Conflict between Anesthesiologists and CRNAs

by

Jee-Hyeong Park, Stephen J. Spurr, and Sheng-Kai Chang[1]

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ABSTRACT

This paper examines a labor market with two professional groups both cooperating and directly competing with each other: certified registered nurse anesthetists (CRNAs) and anesthesiologists (MDAs). We develop a model where the supply of MDAs endogenously determines (1) the earnings of CRNAs and MDAs, and (2) the extent of supervision of CRNAs by MDAs. We also analyze how MDAs may lobby to limit the scope of practice of CRNAs, and the resulting market equilibrium. Our theoretical model can be applied to the analysis of relationships between other hierarchical professionals with overlapping responsibilities, such as nurse practitioners and primary care physicians.

JEL classifications: **I11, J31, J44.**

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1. Introduction

An area of economics that is relatively unexplored involves the economic relationships between professions with responsibilities that overlap, but that differ substantially in terms of training: for example, the relations between opticians and ophthalmologists, or between nurse practitioners and primary care physicians, or certified nurse midwives and obstetrician-gynecologists. While workers in different professions compete with each other because of the overlap of services that they provide, they also often work together as a team, usually with the person with the higher level of training supervising the other. This multifaceted economic relationship of hierarchical professional groups in their overlapping markets makes the analysis of their work challenging, because it requires one to answer several questions simultaneously: how do they compete with each other; what determines whether they work together or separately; and if they do work together, how are the fees divided?

This paper analyzes the economic relationships between certified registered nurse anesthetists (CRNAs) and anesthesiologists (MDAs) in the anesthesia service market. The scope of practice of these two anesthesia providers is so similar that researchers find it difficult to identify anything done by MDAs that is not also done by CRNAs.[2] There are, however, substantial differences in the educational requirements for each profession. The training of MDAs includes four years of medical school and four years of medical residency. CRNAs complete a four-year baccalaureate program in nursing; then, after completing a minimum of one year of nursing experience in an acute care setting, they must have an additional two years of training in the delivery of anesthesia. Thus it takes a minimum of twelve years of

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[2] There is, however, some evidence that, other things equal, MDAs are more likely than CRNAs to evaluate patient risk factors, discuss the anesthesia care plan with the patient or the patient's family, or to discharge the patient from post-operative care. It appears that MDAs are also more likely to insert invasive monitoring devices, such as central venous pressure lines or Swan-Ganz catheters. However, invasive monitoring is not done often by either group. Rosenbach and Cromwell (1988).

higher education to become an anesthesiologist, compared to seven to eight years of education for a CRNA.

There is a great disparity in earnings between these groups, which is striking, notwithstanding the difference in educational requirements, given the substantial overlap in the scope of practice of these two providers. In 2005, the median income of MDAs with more than one year of practice in their specialty was $321,686, more than twice the average earnings of CRNAs of $149,147.[3] There is also remarkable variation in the relative numbers of anesthesia providers, i.e., the ratio of MDAs to CRNAs, across different areas. In 2004 this ratio varied from 4.94 in California and 3.95 in New York, to 0.60 in North Carolina and 0.62 in Michigan.[4] One explanation that has been offered for this variation is that the two types of anesthesia providers are excellent substitutes for each other.[5]

These two groups frequently work together, providing anesthesia as a team (an MDA supervising a CRNA). Anesthesia may also be provided by a CRNA working alone, or by an anesthesiologist working alone or with a resident. While the scope of practice of these two providers is essentially identical as discussed above, it is important to note that the practice of CRNAs working alone is generally limited to anesthesia involving less risk. According to Rosenbach and Cromwell (1988),

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[3] Source: for the median income of MDAs, Bureau of Labor Statistics (2008-09); for the average income of CRNAs, the web site of LocumTenens.com (2009). It should, however, be noted that the differential has declined recently. In 1994, the median earnings of anesthesiologists were $244,600, about three times the median earnings of CRNAs of $82,000 (Klein (1997)).

[4] Source: for the number of MDAs, American Medical Association (2005); for the number of active CRNAs, American Association of Nurse Anesthetists (2004).

[5] Klein (1997) notes that “in most States, a supply of CRNAs per capita in excess of the national median coincides with a supply of anesthesiologists below the median, and conversely,” and cites a government report stating that this pattern of geographical distribution demonstrates the substitutability of CRNAs and MDAs. HHS (1990), Tables 2-4 and 2-5, at 20.

"CRNAs working alone were involved in few complex cases, with only 1 percent over *ten* (*procedure complexity*) *units* and none over *sixteen units*," demonstrating the market's preference toward either an anesthesiologist working alone or team practice for anesthesia involving significant risk.[6]

This paper provides a theoretical analysis of cooperation and competition between CRNAs and MDAs. We can summarize the basic structure of our theoretical model as follows. We model competition in the anesthesia market as competition between vertically differentiated services, with MDAs providing anesthesia service of higher quality than CRNAs.[7] As is well known in the industrial organization literature on the competition between vertically differentiated products, a lower price enables a lower quality good (service in our model) to coexist with a high quality one in the market.[8] A distinct feature of a vertically differentiated service market (compared with product markets) is the possibility that service providers in different professions may choose to cooperate with each other in providing the service. In our model a team service (an MDA supervising a CRNA) improves the quality of the CRNA's service by reducing the risk associated with anesthesia. Because an MDA can supervise multiple CRNAs simultaneously, providing a team service can be a mutually beneficial arrangement for both professions. As to how fees are divided for team work, the demand for CRNA services together

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[6] Rosenbach and Cromwell (1988) make this statement based on Center for Health Economics Research Anesthesia Practice Survey, 1986, "a survey of 500 CRNAs and 500 anesthesiologists national wide." According to their article, "*procedure complexity* (*units*) reflects the number of base units assigned to a procedure plus modifiers that take into account extremes of age (below age one, above age seventy) and poor physical status (ASA status of 3, 4 or 5). 3 is least complex and 23 is most complex."

[7] As discussed in Section 2, we assume that an MDA's service reduces the risk associated with anesthesia at a higher rate than a CRNA's service.

[8] Beginning with papers by Gabszewicz and Thisse (1979) and Shaked and Sutton (1982), the industrial organization literature has examined various issues involving vertically differentiated product markets. More recently, Park (2001) analyzed strategic R&D policy in a vertically differentiated international oligopoly market.

with the supply of CRNAs determines the price of a CRNA's services in our model, while an MDA receives the difference between this CRNA price and a price for team service obtained from supervising a CRNA. Then, our theoretical model endogenously determines the earnings of CRNAs and MDAs, and the extent to which CRNAs and MDAs either work together, or practice alone.

There are studies related to ours. With regard to one MDA supervising several CRNAs concurrently, Garicano's (2000) analysis of knowledge-based hierarchies is useful in understanding the division of tasks between two types of service providers in a team practice: using his terminology, CRNAs are assigned the "most common and easiest problem confronted" and MDAs, as "specialized problem solvers, deal with the more exceptional or harder problem" that may arise in the provision of anesthesia.[9] In a similar hierarchy based on relative knowledge, Garicano and Rossi-Hansberg (2004) explain the process of sorting "agents" into self-employed and team practitioners (each team composed of a "manager" and several "workers") and the endogenous inequality in their earnings. While these studies provide micro-foundations for the analysis of hierarchies and associated inequality issues, they largely ignore potential conflicts among hierarchical groups by focusing on pure division of labor reason for hierarchies.

The professional associations representing MDAs and CRNAs take very different positions on the scope of independent practice that CRNAs should have, and engage in intense lobbying activities to change rules and practices in their favor. Leland (1979) shows that given consumers' imperfect information on the quality of services, setting minimum quality standards can be socially desirable, but also emphasizes that the licensed profession has an incentive to set standards too high. Once there are multiple professional groups (with multiple occupational licensing) performing the same types of

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[9] As explained earlier, CRNAs are also professionals with special trainings for problem solving in providing anesthesia service. Given the longer period of training of MDAs and the complexity-based division of tasks between solo-practicing CRNAs and MDAs (or teams) described above, one may classify MDAs as harder problem solvers compared with CRNAs.

services, with one group having better credentials than others, then such groups may have conflicting interests over the appropriate scope of practices of a group with lesser credentials, an issue that has not been fully explored by the literature on occupational licensing.[10] This paper is the first attempt to develop a theoretical model of the complex economic relationships between hierarchical professionals with overlapping responsibilities, cooperating as individuals but collectively in conflict over the scope of practice issues.

In solving our model, we first assume that the anesthesia market is competitive, with neither CRNAs nor MDAs taking any collective action to influence the market outcome in favor of their profession. Under this competitive market assumption, an increase in the number of MDAs in any given market (which we assume to be exogenously determined) will *not* reduce the demand for CRNA services as long as MDAs find supervising CRNAs more profitable than practicing alone: whenever an additional MDA takes away some demand for CRNA-only services by providing team-based services in the market, the decline in demand will be exactly offset, since the same amount of demand will be created for CRNAs' services through the MDA's demand to supervise CRNAs. This implies that adding more MDAs to the market does not necessarily cause downward pressure on CRNAs' earnings. Once the demand for CRNA-only services is entirely eliminated by an ample supply of team-based services, a further increase in MDAs can even increase the demand for CRNA services, creating upward pressure on CRNAs' earnings. When the price for team-based services gets too low (possibly together with a higher price for CRNAs) on account of a large number of MDAs providing team-based services, supervising CRNAs may no longer be more profitable than practicing alone for MDAs. At this juncture, adding MDAs can be bad news for CRNAs because MDAs would begin to practice alone, reducing the demand for CRNAs. Thus, the competitive model predicts that an increase in MDAs will not reduce CRNA earnings as long as the supply of MDAs is not large enough to eliminate CRNA-only services from the market.

[10] See Kleiner an Krueger (2009) for recent studies on the issue of occupational licensing.

While the competitive market assumption is important for establishing the basic features of our model, it ignores the reality that there is intensive lobbying by CRNAs and MDAs to influence the anesthesia market in their favor. Therefore, we incorporate lobbying activities into our model to analyze how such activities will affect market outcomes. Our model focuses specifically on lobbying by MDAs to limit the professional independence of CRNAs by requiring them to work under MDA supervision. MDAs can gain from such lobbying because a successful lobbying effort will increase the price of team-based services and reduce the price that a MDA must pay to a CRNA under supervision, by eliminating (or at least significantly reducing) the demand for CRNA-only services. Our model endogenously determines the MDAs' lobbying activity, which in turn affects the extent to which CRNAs practice under MDA supervision and the earnings of CRNAs and MDAs. The analysis shows that the incentive of MDAs to lobby (measured by the potential gains from successful lobbying) will first increase, and then decrease, as the supply of MDAs increases. An initial increase in the number of MDAs strengthens their incentive to lobby because more MDAs will benefit from elimination of CRNA-only services, through a resulting increase in the price of team-based services and reduction in the price of supervised CRNAs; however, when MDAs already supervise most of the CRNAs in the market such benefits decline and finally disappear. In particular, if the number of MDAs is large enough to eliminate CRNA-only services from the anesthesia market, there will be NO gain to MDAs from requiring CRNAs to work under their supervision!

Our model with lobbying activities reflects the paradoxical relationship between the two groups. On the one hand, the vast majority of CRNAs practice, at least part of the time, in a team arrangement with MDAs. On the other hand, there is fierce competition between these groups in lobbying at the federal and state level and perhaps more importantly, at the level of the hospital, managed care organization or health insurer. Various methods may be used by MDAs to exclude or limit competition by CRNAs – e.g., exclusive care agreements with hospitals or managed care organizations, causing hospitals to adopt restrictive medical staff bylaws, or limiting student nurse anesthetists' access to clinical cases for training purposes. One study notes that "[Accredited nurse anesthesia] programs have closed because of the withdrawal of support from anesthesiologists, particularly in academic medical centers with coexisting residency programs."[11] Broadston (2001) states that "Other MCOs [managed care organizations] . . . . may allow CRNAs into their network, but only a specific number of providers for a given population will be allowed in a particular region. Furthermore, some MCOs may attempt to limit the providers to only physician providers." MDAs concerned about the independence of CRNAs may also seek to replace them with anesthesiology assistants (AAs).[12] Our model of MDA lobbying reflects activities of this kind that undermine the independent practice of CRNAs.

To examine the welfare implications of our model, we compare the total surplus attainable under alternative ways that the market can provide anesthesia: CRNAs practicing with full autonomy and the option of being supervised by MDAs, CRNAs practicing with full autonomy but no option of supervision, and CRNAs who can practice only under supervision. The case where CRNAs practice with full autonomy and the supervision option attains the highest level of total surplus regardless of the supply condition of MDAs. When the supply of MDAs is very limited, the case where CRNAs practice with full autonomy but no supervision option yields a higher total surplus than the case where CRNAs can practice only under supervision, but the reverse is true when the supply of MDAs is abundant enough.

The basic structure of our theoretical model applies not only to the economic relationship between CRNAs and MDAs, but also to relationships between other professions that differ substantially in terms of training, but have overlapping responsibilities. To analyze the economic relationship between nurse

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[11] Rosenbach and Cromwell (1988).

[12] The American Society of Anesthesiologists (ASA) recently adopted resolutions in favor of efforts to obtain licensure and rights to reimbursement for AAs. AANA (2003). There are two educational programs for AAs: one at Emory University in Atlanta, Georgia, and the other at Case Western Reserve University in Cleveland, Ohio. In these programs AAs receive approximately two years of specialized training in anesthesia, divided equally between classroom and clinical instruction.

practitioners and primary care physicians in the medical diagnosis/prescription market, for example, we can model their inter-professional competition as competition between vertically differentiated services, with primary care physicians providing a higher quality of diagnosis/prescription service (possibly having a higher accuracy rate) than nurse practitioners. One can also model cooperation between these two professions in a way that reflects common practices in this market. Once again, such a model can be useful in understanding the economic relationship between nurse practitioners and primary care physicians, including potential lobbying activities by these groups.

The rest of the paper proceeds as follows. Section 2 provides the competitive-market model of the anesthesia market. Section 3 analyzes how lobbying by MDAs affects the anesthesia market. Section 4 concludes with a brief discussion of welfare implications of our model.

2. The Basic Model: Competitive Market

In this section, we develop a theoretical model of the anesthesia market, in which the earnings of CRNAs and MDAs and the extent of supervision of CRNAs by MDAs are endogenously determined. As a benchmark, we first develop a competitive model of the anesthesia market in this section. We will see that MDAs as a group have an incentive to lobby to limit the scope of independent practice of CRNAs. Section 3 analyzes the effects of MDAs' lobbying activity on the anesthesia market.

The Demand for Anesthesia

The demand for anesthesia is derived from patients undergoing medical, surgical or dental procedures. For convenience of exposition, let us assume that the patient has perfect information, and makes all the decisions concerning the purchase of anesthesia, understanding that in fact this decision may be delegated by the patient to an agent such as a surgeon, hospital or managed care organization.[13]

[13] One can develop a model in which hospitals or anesthesia-provider groups make all the decisions concerning the provision of anesthesia services: whether to employ a CRNA-only, an MDA-only, or CRNAs under MDA

In deriving the demand for anesthesia services, we assume that the reservation price that each patient is willing to pay for one unit of a professional anesthesia service depends on two factors. One factor is the risk involved in the anesthesia, which will increase with the complexity or difficulty involved in performing the anesthesia, or because of the patient's physical condition (e.g. a patient who is very young or very old, or who is otherwise in poor health). We denote different types of surgeries by $t \in [0,1]$, with a higher t indicating a higher anesthesia risk.

The other factor that determines the patient's willingness to pay is who provides the anesthesia. We assume that, in the view of patients, there are two levels of quality of anesthesia service: anesthesia provided either by an MDA acting alone, or by a CRNA acting under the supervision of an MDA, is service of higher quality, denoted by M, while anesthesia performed by a CRNA acting alone is service of lower quality, denoted by C.[14] For a type t surgery, we denote the reservation price for one unit of M and for one unit of C, respectively, by $V^M(t)$ and by $V^C(t)$, and that

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supervision, for any surgery that requires anesthesia. We can show that the market outcome under such a model is exactly the same as the one we obtain in this section, as long as the anesthesia-provider groups or hospitals have reservation prices for anesthesia services that are identical to those defined in (1) and are trying to maximize their payoffs as price takers in the market. We will provide the proof of this equivalence upon request.

[14] One might model the anesthesia provided by a CRNA acting under the supervision of an MDA as service of intermediate quality (lower than the service quality of an MDA acting alone but higher than a CRNA acting alone). Such modeling would lead to the division of anesthesia among three types of providers: having an MDA work on the high risk anesthesia, a supervised CRNA on the intermediate risk anesthesia and a solo CRNA on the low risk anesthesia. As discussed by Rosenbach and Cromwell (1988), however, "when CRNAs collaborated with an anesthesiologist, they were as likely as anesthesiologists working alone to be involved in the more complex cases… In fact, the case-mix distribution was identical for anesthesiologists working alone or in a team with CRNAs." Given this practice pattern, it is reasonable to assume that patients (or their agents such as hospitals) perceive the anesthesia of a supervised CRNA to be identical in quality to that of an MDA acting alone.

(1) $V^M(t) = q \cdot t$ and $V^C(t) = t$,

where $q > 1$ represents the perceived quality of *M* relative to *C*.[15]

Figure 1 illustrates how these reservation prices change in response to an increase in the anesthesia risk, *t*. Patients are willing to pay a higher price for anesthesia when the risk is greater ($\partial V^M/\partial t > 0$ and $\partial V^C/\partial t > 0$) and are willing to pay a higher price for *M* than for *C* on any given type of surgery ($V^M(t) > V^C(t)$ for all $t > 0$). In addition, (1) implies that the differential that patients are willing to pay for *M* compared to *C* increases when the anesthesia risk increases ($\partial[V^M(t) - V^C(t)]/\partial t = q - 1 > 0$). These assumptions about patients' willingness to pay for *M* and *C* could be justified, for example, if patients were willing to pay a certain amount for a reduction of anesthesia risk by one unit and they believed that a MDA could reduce the risk by a higher proportion than a CRNA acting alone could.[16]

Given patients' willingness to pay for *C* and *M* specified above, we can now analyze the choice made by patients between *M*, *C*, and no professional anesthesia service.[17] Let p^C and p^M denote the unit price of *C* and *M*, respectively. Because the highest price patients are willing to pay is *q* for *M* and 1 for *C*, we will hereafter confine our attention to $p^M \in (0, q]$ and $p^C \in (0, 1]$ without loss of generality. For the patient who will have a type *t* surgery, buying *M* yields a consumer's surplus of $V^M(t) - p^M$, buying *C*

[15] This specification of demand for vertically differentiated services comes directly from Park (2001).

[16] For example, assume that the health risk associated with one unit of anesthesia on a type *t* surgery is given by $2t$, for which patients are willing to pay $1 for one unit reduction of such a risk. If a CRNA service can reduce 50% of the anesthesia-related risk for any given type of a surgery, then the patients' willingness to pay for one unit of *C* on a type *t* surgery will be *t*, as defined in (1). If patients believe that an MDA service or an MDA-supervised CRNA service can reduce ($q\times 50$)% of the anesthesia-related risk, then $V^M(t) = q \cdot t$, as defined in (1).

[17] A decision not to buy professional anesthesia service does not necessarily mean that no anesthesia will be provided for the patients' surgical procedure. A surgeon or other practitioner in charge of the procedure may still

yields a surplus of $V^C(t) - p^C$, and not hiring any anesthesia provider yields a zero surplus. We define two critical types of surgeries: t^M is the type of surgery for which patients would be indifferent between buying *M* and buying *C* with $t^M \equiv (p^M - p^C)/(q - 1)$ from $V^M(t^M) - p^M = V^C(t^M) - p^C$, and t^C is the type of surgery for which patients are indifferent between buying *C* and not buying any professional anesthesia service, with $t^C \equiv p^C$ from $V^C(t^C) - p^C = 0$.

If $t^C < t^M < 1$, or equivalently $p^C < (p^M - p^C)/(\mathrm{q} - 1) < 1$ as shown in Figure 1, then the demand for *M* and the demand for *C* will co-exist in the market. Because the extra amount patients are willing to pay for *M* rather than *C* increases as the anesthesia risk rises, patients will choose *M* for high risk surgeries ($t > t^M$) despite its higher price, choose *C* for surgeries with intermediate risk ($t^C < t < t^M$), and choose no anesthesia service for surgeries with low risk ($t < t^C$) as long as the difference between the prices of *M* and *C* is neither too small nor too large with $p^C < (p^M - p^C)/(\mathrm{q} - 1) < 1$.

On the one hand, if p^M gets too high relative to p^C so that $(p^M - p^C) > (q - 1)$, thus $t^M \equiv (p^M - p^C)/(q - 1) > 1$, then patients would never choose *M* and all the patients with *t* being higher than t^C $(= p^C)$ will choose *C*. On the other hand, if p^C gets too high relative to p^M so that $(p^M - p^C) < p^C(q - 1)$, thus, $t^M \equiv (p^M - p^C)/(q - 1) < t^C \equiv p^C$, then patient would never choose *C* and all the patients with *t* being higher than p^M/q ($\Leftrightarrow V^M(t) - p^M = qt - p^M > 0$) will choose *M*. *Lemma* 1 summarizes these patients' choices between *M*, *C*, and no anesthesia.

Lemma 1.

(i) If $t^C < t^M < 1$, or equivalently if $p^C < (p^M - p^C)/(\mathrm{q} - 1) < 1$, *M* and *C* will co-exist in the market: patients would choose *M* for $t \in (t^M, 1]$, *C* for $t \in (t^C, t^M)$, and no anesthesia service for $t \in [0, t^C)$.

(ii) If $t^M > 1$, or equivalently if $(p^M - p^C)/(q - 1) > 1$, only *C* will exist in the market: patients would choose *C* for $t \in (t^C, 1]$ and no anesthesia service for $t \in [0, t^C)$.

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provide necessary anesthesia, as in the case of short-duration local anesthesia for a simple surgical procedure or dental treatment. For some procedures, such as colonoscopies, sedatives can be used instead of anesthesia.

(iii) If $t^M < t^C$, or equivalently if $(p^M - p^C)/(q - 1) < p^C$, only *M* will exist in the market: patients would choice *M* for $t \in (p^M/q, 1]$ and no anesthesia service for $t \in [0, p^M/q)$.

Proof) See Appendix 1.1.

As discussed earlier, Rosenbach and Cromwell (1988) find that the practice pattern of anesthesia providers confirms to the prediction of *Lemma 1* (i), demonstrating preference toward *M* over *C* with higher risk anesthesia. While the demand for *M* and the demand for *C* co-exist nationwide as in *Lemma 1* (i), there exist many local anesthesia markets where the only observed pattern of professional anesthesia is either *M* or *C*.[18] Thus, we will consider all three cases of anesthesia choices of *Lemma 1* in the following analysis.

Given *Lemma 1* on the patients' choice among *M*, *C*, and no anesthesia service, we can derive the market demands for *M* and *C*, denoted respectively by $D^M(p^M, p^C)$ and by $D^C(p^M, p^C)$. Let *H* represent the total annual number of surgery hours in the market, with $h(t)$ being the density function for hours associated with a type *t* surgery. Then the annual market demands for *M* and *C* are given by:

$$D^M(p^M, p^C) = H\int_{t^M}^{1} h(t)dt \text{ and } D^C(p^M, p^C) = H\int_{t^C}^{t^M} h(t)dt \text{ if } t^C < t^M < 1,$$

(2) $$D^M(p^M, p^C) = 0 \text{ and } D^C(p^M, p^C) = H\int_{t^C}^{1} h(t)dt \text{ if } t^M \geq 1, \text{ and}$$

$$D^M(p^M, p^C) = H\int_{p^M/q}^{1} h(t)dt \text{ and } D^C(p^M, p^C) = 0 \text{ if } t^M \leq t^C,$$

where $t^M \equiv (p^M - p^C)/(q - 1)$ and $t^C \equiv p^C$.

[18] According to the AANA Member Survey and the Area Resource File, there are 2049 counties with at least one anesthesia provider (MDA or CRNA) in the year 1999. Among theses counties, 794 out of 2949 counties have CRNAs only, and 126 out of 2049 counties either have only MDAs practicing solo (107) or have all CRNAs practicing under supervision (19).

By considering variations in the density function, $h(t)$ in (2), one can analyze how changes in the distribution of surgeries associated with different levels of anesthesia risk affect the anesthesia market. While such an analysis focusing on variations in the demand side of the anesthesia market can be of interest, we will focus on variations in the supply side of the anesthesia market in the following analysis. As emphasized in the introduction, there is a large variation in the ratio of MDAs to CRNAs across states, such as 0.60 in North Carolina and 4.94 in California in the year 2004. It is unlikely that such large variation in the relative numbers of MDAs and CRNAs is attributable to differences in demand for anesthesia services. This is because states with a large difference in their MDAs to CRNAs ratios often have populations with similar age and income distributions, as in the case of California and North Carolina.[19] On the other hand, it is well-documented that the supply of medical professionals, especially that of physicians, largely depends on the characteristics of local areas and varies widely across areas.[20]

Given our focus on supply-side variations in the anesthesia market, we assume that $H = 1$ and surgery hours are uniformly distributed over [0, 1], so that $h(t) = 1$.[21] This simplifies the demands for M and C into:

$$D^M(p^M, p^C) = 1 - (p^M - p^C)/(q-1) \text{ and } D^C(p^M, p^C) = (p^M - p^C) - p^C \text{ if } t^C < t^M < 1,$$

(2′) $$D^M(p^M, p^C) = 0 \text{ and } D^C(p^M, p^C) = 1 - p^C \text{ if } t^M \geq 1, \text{ and}$$

$$D^M(p^M, p^C) = 1 - (p^M/q) \text{ and } D^C(p^M, p^C) = 0 \text{ if } t^M \leq t^C,$$

where $t^M \equiv (p^M - p^C)/(q - 1)$ and $t^C \equiv p^C$.

<u>The Supply of Anesthesia</u>

In describing the supply side of the anesthesia service market, we introduce the following simplifying assumptions. The supply of CRNAs, denoted by a^C, is posited as a linear function of the

[19] For example, the share of the state population over 60 is about 14% in California and 16% in North Carolina.

[20] See Footnote 23 for a further discussion of this point.

[21] The qualitative results of this paper do not depend on this uniform distribution assumption.

CRNA's wage: $a^C(p^C) \equiv bp^C$, where p^C denotes the CRNA's wage per unit of service (as well as the unit price of *C*, because patients must pay the CRNA the wage for her service) and $b > 0$. In contrast, the supply of MDAs (the total hours of their services supplied) is fixed at $a^M \in [0,1]$, thus perfectly inelastic to the wage of the MDA, denoted by w^M.[22] As shown in Appendix 1.2, the main results of the analysis remain qualitatively the same when we relax the assumption of perfectly inelastic supply of MDAs, but this assumption substantially simplifies the exposition of the analysis. We model the variation on the supply side of the anesthesia market by varying a^M, reflecting variation in local characteristics that affect the supply of MDAs.[23]

The wage of the MDA, w^M is not necessarily equal to p^M because an MDA can supervise CRNAs to generate *M*, rather than practice alone. An MDA can practice alone, earning p^M from providing 1 unit of *M*, or she can supervise a number *n* (>1) of CRNAs concurrently, earning $n(p^M - p^C)$ from providing *n* units of *M* and paying each CRNA her market wage, p^C. For simplicity, we assume that *n* is fixed, but allow MDAs to choose between a solo practice and supervising CRNAs.[24] Denote the proportion of

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[22] The assumption that the supply of CRNAs is more elastic than the supply of MDAs seems quite plausible. Johnstone and Martinec (1993) state that ". . . CRNAs have less burdensome licensure and credentialing procedures which allow them to move from state to state more easily than MDAs and, as a result, local shortages of nurse anesthetists are easier to satisfy."

[23] We are implicitly assuming that the characteristics of the community where MDAs would reside to serve the anesthesia market determine a^M. It is well known that the supply of physicians, including MDAs, is very limited in rural and some inner-city areas while there is a high concentration of physicians in popular urban areas such as San Francisco and New York City. Because the characteristics of local communities are determined outside our model, a^M plays the role of an exogenous variable whose variations affect the market outcomes. See Council on Graduate Medical Education (1998) and Pasko and Smart (2005) for more detailed discussion of the geographic distribution of physicians.

[24] According to Cromwell (1999), regulations effectively constrain the maximum number of *n* to be 3. If such regulations are binding constraints for MDAs inclined to team practice, then we can set $n = 3$ in solving our model.

MDAs who choose to supervise CRNAs by $r \in [0,1]$. Then, the amounts of M and C supplied to the market, denoted respectively by S^M and S^C, are given by:

(3) $S^M(r; a^M) = (1 - r)a^M + nra^M$ and $S^C(p^C, r; a^M) = a^C(p^C) - nra^M$.

<u>The Market Equilibrium</u>

Given the demands for and supplies of M and C specified in ($2^/$) and (3), respectively, the equilibrium in the anesthesia market must satisfy:

(4) $D^M(p^M, p^C) = S^M(r\,; a^M)$ and $D^C(p^M, p^C) = S^C(p^C, r; a^M)$

The equilibrium conditions in (4) have two equations but three variables, p^M, p^C, and r, to be determined, possibly generating multiple equilibria. Note, however, that the equilibrium value for r, denoted by r^e, must satisfy the following conditions:

(5) $r^e = 0$ if $p^M > n(p^M - p^C)$, $r^e = 1$ if $p^M < n(p^M - p^C)$, and $r^e \in (0, 1)$ only if $p^M = n(p^M - p^C)$

If $p^M > n(p^M - p^C)$, then MDAs would earn more by practicing alone, thus $r^e = 0$. If $p^M < n(p^M - p^C)$, then MDAs would earn more by supervising n CRNAs, thus $r^e = 1$. For $r^e \in (0, 1)$, we must have $p^M = n(p^M - p^C)$, or equivalently, $p^C = [(n - 1)/n]p^M$. By replacing r in (4) with r^e in (5), we have the following equilibrium conditions for the anesthesia market:

(6) $D^M(p^M, p^C) = S^M(r^e\,; a^M)$ and $D^C(p^M, p^C) = S^C(p^C, r^e; a^M)$.

Thus 2 variables are to be determined by 2 equations, yielding a market equilibrium that is unique, if it exists.

Note that a^M, determines p^C, p^M, and r^e in (6), which in turn determine the earnings for CRNAs and MDAs and the extent of supervision of CRNAs by MDAs. While a^M is the number of MDAs in the anesthesia market, one may also perceive a^M as a parameter that reflects local characteristics that are conducive to more MDAs, ceteris paribus.[25] The following proposition characterizes the anesthesia market equilibrium, deriving the equilibrium values for p^C, p^M, w^M, r^e, S^M (= D^M), and S^C (= D^C) as functions of a^M:

Proposition 1. Given that $(n - 1)(q - 1) > 1$,

(i) if the number of MDAs is relatively small with $a^M < a^{M1} \equiv b/[(1 + b)\, n]$, then M and C coexist in the market, all MDAs provide anesthesia by supervising CRNAs, and an increase in MDAs does not affect the earnings of CRNAs, with $p^C = 1/(1 + b)$, $p^M = (q - 1)(1 - na^M) + p^C$, $w^M = n(q - 1)(1 - na^M) > p^M$, $r^e = 1$, $S^M = na^M$, and $S^C = 1 - p^C - S^M$,

(ii) if the number of MDAs is in an intermediate range with $a^{M1} \leq a^M < a^{M2} \equiv [bq(n - 1)]/[\, bqn(n - 1) + n^2]$, then only M exists in the market, all MDAs provide anesthesia by supervising CRNAs, and an increase in MDAs raises the earnings of CRNAs, with $p^C = na^M/b$, $p^M = q(1 - na^M)$, $w^M = n[q(1 - na^M) - na^M/b] > p^M$, $r^e = 1$, $S^M = na^M$, $S^C = 0$,

(iii) if the number of MDAs is relatively high with $a^M \geq a^{M2}$, then only M exists in the market, MDAs provide anesthesia both by supervising CRNAs and through solo practice, and an increase in MDAs reduces the earnings of CRNAs and raises the proportion of MDAs in solo practice, with $p^C = [bqn(n - 1)(1 - a^M)]/[b^2q(n - 1)^2 + bn^2]$; $p^M = w^M = [n^2(1 - a^M)]/[b(n - 1)^2 + n^2/q]$; $r^e = [bq(n - 1)(1 - a^M)]/\{[bq(n - 1)^2 + n^2]a^M\}$; $S^M = 1 - p^M/q$; $S^C = 0$.

Proof) See Appendix 1.1.

[25] As shown in *Appendix B* (and Figure B), we can relax the assumption of perfectly inelastic supply of MDAs by modeling it as a linear function of the MDA's wage, w^M: $a^M = -(c^M - \alpha^M) + bw^M$ with $\alpha^M \in [0, c^M - c^C]$. Then, an increase in α^M from 0 to $c^M - c^C$, a parameter reflecting local amenities that are conducive to more MDAs, will generate changes to p^C, p^M, w^M, r^e, S^M , and S^C that are qualitatively identical to those identified in *Proposition 1* for a corresponding increase in a^M .

Assuming $(n - 1)(q - 1) > 1$ guarantees that MDAs have an incentive to supervise CRNAs when the number of MDAs in the market is small.[26] With $a^M \approx 0$, $n(p^M - p^C) \approx n(q - 1)$ and $p^M \approx (q - 1) + 1/(1 + b)$ from *Proposition 1* (i), thus $n(p^M - p^C) > p^M$ if $(n - 1)(q - 1) > 1$. *Proposition 1* then shows that major characteristics of the market equilibrium change as the number of MDAs changes, dividing a^M into three different ranges. If the number of MDAs in the market is relatively small with $0 < a^M < a^{M1}$, then *M* and *C* coexist in the market while every unit of *M* is provided by a CRNA under an MDA's supervision. If the number of MDAs increases so that $a^{M1} \leq a^M < a^{M2}$, then only *M* exists in the market while all *M* is still provided by a CRNA under an MDA's supervision. If the number of MDAs gets large so that $a^M \geq a^{M2}$, then some MDAs start to practice alone but only *M* exists in the market.

Figure 2 illustrates how an increase in the number of MDAs (a^M) affects the CRNA's earnings (p^C), the MDA's earnings (w^M), and the fraction of CRNAs' supervised services (the amount of CRNAs' services under MDAs' supervision/the total amount of CRNAs' services). When the number of MDAs is small with $a^M < a^{M1}$, *M* will command a high price relative to the price of *C* due to its scarcity, with $p^M > p^C n/(n - 1)$. Therefore every MDA will find supervising *n* CRNAs more profitable than solo practice; $p^M > p^C n/(n - 1) \Leftrightarrow n(p^M - p^C) > p^M$, thus $r^e = 1$. An increase in the number of MDAs increases the supply of *M* at the rate of *n*, decreasing p^M, which in turn drives down the MDA's earnings, w^M, as shown in Figure 2. Note that as long as $a^M < a^{M1}$, the CRNA's earnings remain constant even when an increased supply of *M* is replacing *C* in the market. This holds because the increase in the supply of *M* raises the

[26] If $(n - 1)(q - 1) \leq 1/(1 + b)$, then MDAs would have no incentive to supervise CRNAs in a competitive anesthesia market. This contradicts the observation that MDAs often willingly choose to supervise CRNAs, especially in the case where the number of MDAs is small. If $1/(1 + b) < (n - 1)(q - 1) \leq 1$, then MDAs would have an incentive to supervise CRNAs and the market characterization will be similar to that in Proposition 1, except that the market will always have some CRNA-only services ($S^C > 0$) even when the number of MDAs is large. As this latter case generates a prediction that is similar to the one in *Proposition 1* regarding the relationship between CRNAs and MDAs, we will focus on the case of $(n - 1)(q - 1) > 1$.

MDAs' supervision-based demand for CRNAs at the same rate that M is replacing C in the market, thus exactly offsetting patients' decreased demand for C; $r^e = 1$ implies that the MDAs' demand for CRNAs is given by na^M, exactly the same amount of C that is replaced by M in the market. In Figure 2, the fraction of CRNAs' supervised services steadily increases with the number of MDAs per capita for $a^M \in [0, a^{M1})$ as the amount of CRNAs' services under MDAs' supervision (which equals na^M with $r^e = 1$) increases with the total number of CRNAs in the market being fixed at $bp^C = b/(1 + b)$.

When the number of MDAs in the market reaches a^{M1}, the price of M falls to the level at which patients will no longer buy C, eliminating C from the market altogether. Thus for $a^M \geq a^{M1}$ the demand for CRNAs' services comes solely from the MDAs' demand for CRNAs to supervise. Since each MDA would still find supervising CRNAs to be more profitable than solo practice when $a^M < a^{M2}$ with $p^M > p^C n/(n - 1)$, an increase in the number of MDAs increases the demand for CRNAs, raising the CRNA's earnings for $a^M \in [a^{M1}, a^{M2})$, as shown in Figure 2 (thus also increasing the supply of CRNAs). Stating it differently, all the CRNAs in the market at the wage $p^C = 1/(1 + b)$ have been appropriated by MDAs, so to bring more CRNAs into the market the wage must increase. This increase in the CRNA's earnings implies a higher cost and lower profit for the MDAs' supervision service, thus causing a faster decline in the MDA's earnings (w^M having a steeper slope for $a^M \in [a^{M1}, a^{M2})$ than for $a^M \in [0, a^{M1})$ in Figure 2) as the number of MDAs increases from a^{M1} to a^{M2}. Note also that in Figure 2, the fraction of CRNAs' supervised services reaches its maximum, 1, when the number of MDAs reaches a^{M1}. Recall that at $a^M = a^{M1}$ the price of M falls to the level that completely eliminates the patients' demand for C, forcing every CRNA to work under an MDA's supervision. The dearth of demand for C continues to hold for $a^M \geq a^{M1}$, so all CRNAs who are providing anesthesia are being supervised, and the fraction of CRNAs' supervised services remains at its maximum, 1.

The superior profitability of supervising CRNAs over MDAs' solo practice disappears when the number of MDAs reaches a^{M2}, since there $n(p^M - p^C) = p^M$. A further increase in the number of MDAs reduces the MDA's (implicit) earnings from her solo practice, p^M, but it reduces the MDA's earnings from supervision faster because a drop in p^M will reduce $n(p^M - p^C)$ by n times faster and p^C will also increase with a^M if $r = 1$. If the number of MDAs rises above a^{M2}, making solo practice a more profitable option for MDAs, then some MDAs will opt for solo practice. This movement of MDAs out of supervising (that generates n units of M) to solo practice (that generates 1 unit of M) will reduce the total supply of M, causing the price of M to increase. Because the resulting increase in p^M increases the profitability of supervision faster than that of a solo practice, the profitability of these two alternatives will be equalized after a certain number of MDAs switch from supervision to solo practice. As the number of MDAs in the market increases, more MDAs will switch from supervision to solo practice until $p^M = p^C n/(n - 1)$, where $\partial r^e/\partial a^M < 0$ for $a^M \geq a^{M2}$. This increase in the proportion of M provided by MDAs acting alone reduces the rate of decline in the earnings of MDAs (a flatter slope of w^M in Figure 2), as it reduces the rate of increase in M resulting from an increase in the number of MDAs. This shift away from supervision by MDAs after a^{M2} causes a decline in demand for CRNAs, lowering the CRNA's earnings, as shown in Figure 2. Even though p^C is falling as the number of MDAs increases for $a^M \geq a^{M2}$, this does not create a demand for C because the price of M is also declining.

In summary, *Proposition 1* provides the following characterization of the relationship between MDAs and CRNAs. When the number of MDAs in the market is not too large, with $a^M < a^{M2}$, an increase in MDAs is not bad news for CRNAs. For $a^M < a^{M1}$, the increase in the number of MDAs does not matter for CRNAs as p^C remains constant, and for $a^M \in [a^{M1}, a^{M2})$, an increase in MDAs may raise the wage rate of CRNAs. Thus, as long as $a^M < a^{M2}$, MDAs enter the market as complements for CRNAs (even though they reduce and eventually eliminate C in the market). However, when there are too many MDAs in the market ($a^M \geq a^{M2}$), this complementary effect disappears and the substitution effect begins to dominate with $\partial p^C/\partial a^M < 0$.

Although the non-linear relationship between MDAs and CRNAs predicted by *Proposition 1* (complements for low values of a^M and substitutes for high values of a^M) is interesting, we do not find it confirmed by the data. On the contrary, we find an opposite non-linear relationship between MDAs and

CRNAs in a companion paper, Chang et al. (2009), which focuses on empirically identifying the relationship between MDAs and CRNAs: MDAs and CRNAs are substitutes for low values of a^M and they are complements for high values of a^M. It is important to note that the model in this section has ignored the well-documented lobbying activities by MDAs and CRNAs, which might influence the relationships described above. Consequently, the next section introduces into the model the possibility that MDAs may lobby to limit the professional independence of CRNAs, and analyzes the effects of such lobbying on the anesthesia market.

3. Model with Lobbying by MDAs

As discussed in the introduction, both MDAs and CRNAs have been quite active in promoting the interests of their own groups over various aspects of the anesthesia market. Most notably, the interests of these two groups diverge over the issue of how much autonomy CRNAs should have: CRNAs typically demand full autonomy for their practice (claiming that supervision by MDAs is unnecessary), whereas anesthesiologists often try to impose a requirement that CRNAs be supervised by MDAs. The lobbying efforts of both groups are directed toward politicians, hospital managers, managed care organizations, and other health policy makers.[27]

To model lobbying activity in the anesthesia market, we introduce the following simplifying assumptions. First, the outcome of lobbying activity is binary: either no autonomy (*NA*) for the practice of CRNAs, or full autonomy (*FA*). If the outcome is *FA*, then the competitive model of the previous section describes the market. However, if the outcome of lobbying is *NA*, it eliminates the demand and

[27] One article reported that in the election cycle for the year 2000 a group representing MDAs had contributed "more than $1 million," while a group representing CRNAs contributed $400,000. Personal Business, *New York Times*, October 8, 2000.

supply of C from the market.[28] Secondly, we assume lobbying is done only by MDAs, not by CRNAs. Although in reality CRNAs are also quite active in lobbying, we will focus on lobbying by MDAs as the major determinant of the outcome of lobbying activities. While one could model CRNAs also engaging in lobbying (for full autonomy of their practice), the characterization of the outcome of lobbying activities will be qualitatively similar to the one identified in this section.[29] Finally, we assume that there is a critical level of lobbying expenditure, K^L, such that NA will be the outcome if and only if the MDAs' expenditure exceeds K^L.

To characterize the lobbying activities by the MDAs and the outcomes, we need to compare the rent generated by successful lobbying with its cost. Because the outcome of lobbying is binary, the rent per MDA (denoted by l) will equal the difference between the MDA's earnings under NA (w^M_{NA}) and the MDA's earnings under FA (w^M in Section 2): $l \equiv w^M_{NA} - w^M$. For $a^M < a^{M2}$,

$$(7) \qquad w^M_{NA} = n(p^M - p^C) = n[q(1- na^M) - (na^M)/b],$$

where $p^M = q(1 - S^M)$, $S^M = nra^M$, $p^C = nra^M/b$, and r (the proportion of MDAs who supervise CRNAs) = 1 in the absence of supply of C under NA. In fact, $w^M_{NA} = w^M$ in Section 2 for $a^M > a^{M1}$, because the patients' demand for C would already have been eliminated by low values for p^M even under FA when the number of MDAs exceeds a^{M1}. This implies that $l \equiv w^M_{NA} - w^M = 0$ for $a^M \geq a^{M1}$, thus there is no

[28] The assumption of binary outcomes is mainly for simplification. As discussed later in this section, MDAs' lobbying activity could reduce patients' willingness to pay for C through a campaign to denigrate the quality of C. In that case, an increase in MDAs' lobbying activity would reduce the demand for C *gradually*.

[29] Because our analysis focuses on how changes in the supply (condition) of MDAs affect the anesthesia market with the supply curve of CRNAs held constant, the lobbying incentives of MDAs are most affected by a change in the number of MDAs in the market. This implies that the CRNAs' lobbying activities will not affect the qualitative characterization of the outcome of lobbying activities across markets even when we formally introduce such activities into our model.

incentive for lobbying by MDAs. Without loss of generality, therefore, we can focus on the case where $a^M < a^{M1}$ for the analysis.

From (7), we can now derive the total rent for MDAs from lobbying as a function of a^M ($< a^{M1}$), denoted by $L(a^M)$, as follows

$$(8) \qquad L(a^M) = la^M = (w^M_{NA} - w^M)a^M = (n/b)[b - n(1 + b)a^M]a^M.$$

Then, the MDAs would carry out lobbying as long as $L(a^M) > K^L$. This observation leads to the following proposition concerning lobbying by MDAs:

Proposition 2. If the MDAs' lobbying expenditure required for the *NA* (no autonomy) outcome for CRNAs' practice is not too high with $K^L < b/[4(1 + b)]$, lobbying by MDAs will achieve the *NA* outcome if the number of MDAs is neither too high nor too low in the market with $a^M \in (a^{ML}_{Min}, a^{ML}_{Max})$, where $a^{ML}_{Min} \equiv \{b - [b^2 - 4b(1 + b)K^L]^{1/2}\}/[2n(1 + b)]$ and $a^{ML}_{Max} \equiv \{b + [b^2 - 4b(1 + b)K^L]^{1/2}\}/[2n(1 + b)]$, having $a^{ML}_{Min} > 0$ and $a^{ML}_{Max} < a^{M1}$.

Proof) See Appendix 1.1.

The smaller the number of MDAs in the market, the larger the rent each MDA will obtain from achieving the *NA* outcome, as shown in Figure 3 by the larger gap between w^M_{NA} and w^M for low values of a^M. However, when the number of MDAs is too small ($a^M < a^{ML}_{Min}$), the cost of a successful lobbying effort per MDA would be too large. Because $\partial L/\partial a^M > 0$ and $\partial^2 L/\partial (a^M)^2 < 0$ for $a^M \leq a^{M1}$ as illustrated in Figure 2, there exists a critical number of MDAs in the market (a^{ML}_{Min}), above which MDAs can conduct a successful lobbying effort, and there exists another critical number of MDAs (a^{ML}_{Max}), above which the per capita rent is too small for lobbying to be profitable.

The lobbying activities described in *Proposition 2* change the variables in Figure 3 over the range $[a^{ML}_{Min}, a^{ML}_{Max}]$ from taking values of the dotted lines to taking values of the bold lines. When the number of MDAs is very small, the increase in a^M does not affect the CRNA's earnings. However, once the number reaches a critical level, a^{ML}_{Min}, then the MDAs' lobbying will force the CRNAs to work only under their supervision (the fraction of CRNAs' supervised services jumps to 1), creating an abrupt discontinuous decline in the CRNA's earnings, as shown in Figure 3. An increase in a^M after this critical level will raise the CRNA's earnings as the MDAs will demand more CRNAs to supervise, but the earnings under *NA* will still be lower than the level of earnings that CRNAs could have achieved under full autonomy (*FA*). Once a^M passes another critical level, a^{ML}_{Max}, then MDAs will lose interest in lobbying activities, CRNAs will regain the same level of earnings as under *FA*, and the fraction of CRNAs supervised will fall from 1 to the level under *FA*.

In Figure 3, the discrete jumps in the earnings and supervised fraction of CRNAs are results of our assumption of binary outcomes. For example, one can model the lobbying of MDAs as attempts to reduce patients' valuation of CRNA-only services. With such a model, the changes in the earnings and practice modes of CRNAs will be continuous as the number of MDAs increases.[30] However, the finding of this section that the (collective) return to MDAs from lobbying first increases, and then declines, as the number of MDAs increases, is robust against alternative models. This implies that our key qualitative results are robust. Those results, illustrated in Figure 3, are that successive increases in the number of MDAs will first reduce the earnings of CRNAs and increase the extent of their supervision, and then increase CRNAs' earnings and reduce their supervision as long as the number of MDAs is not "too large" (specifically, as long as $a^M \leq a^{M2}$ for the changes in CRNA's earnings, and $a^M \leq a^{ML}_{Max}$ for the

[30] More specifically, a campaign by MDAs to denigrate the quality of CRNAs' independent practice, represented by $d \in [0, 1]$, could reduce the patients' valuation of C according to $V^C(t) = (1 - d)t$. When the cost of negative campaigning is $e \cdot d^2$ with e denoting a cost parameter, the earnings of CRNAs are a concave and continuous function in a^M with $p^C = [1 - (1- na^M)na^M]/\{ [1 - (1- na^M)na^M]b +1\}$. Moreover, the fraction of CRNAs' supervised services will be a convex and continuous function of a^M as long as e <1/2 and a^M is small enough to allow C to exist in the market. The proof of this result is available upon request.

changes in the extent of supervision). A further increase in the number of MDAs will once again reduce the earnings of CRNAs and increase their supervision, but these changes are not caused by lobbying.

Using a very detailed survey data on the earnings of CRNAs and their modes of practice, including the number of MDAs and other relevant demographic variables, Chang et al. (2009) empirically investigate the relationship between MDAs and CRNAs across different anesthesia markets. Their findings are broadly consistent with our model with lobbying by MDAs: the concave relationship between CRNAs' earnings and the number of MDAs and the convex relationship between CRNAs' supervision and the number of MDAs, for the counties where the number of MDAs is not "too large."[31] In addition to this empirical study, one can also find more anecdotal support for the model with lobbying. As mentioned earlier, many studies have documented conflicts between CRNAs and MDAs over the scope of CRNAs' independent practice, especially since the 1970s when many MDAs entered the market, which was previously dominated by CRNAs.

4. Summary, Welfare Implications, and Concluding Remark

In this paper we have developed a simple theoretical model of the multifaceted economic relationships between CRNAs and MDAs in the anesthesia market. By analyzing this market as one with vertically differentiated services, the model shows how the level of MDAs per capita affects the earnings of CRNAs and MDAs, their mode of practice, and the incentive of MDAs to curtail independent practice of CRNAs. This paper provides a model that can explain the complex economic relationships between

[31] It statistically confirms the concave relationship between CRNAs' earnings and the number of MDAs, and the convex relationship between CRNAs' supervision and the number of MDAs, for the counties where the number of MDAs is not "too large." Although we cannot directly observe lobbying by MDAs, including the proxy variable for lobbying in our estimation generates (theoretically) predicted effects on CRNAs' earnings and on the share of cases supervised.

CRNAs and MDAs in settings where they often work together, but engage in fierce conflicts over the scope of practice of CRNAs.

While this paper mainly focuses on developing a theoretical model to explain the complex economic relationship between CRNAs and MDAs, one can also use the model to conduct a welfare analysis; we have done so in Appendix 1.3. Figure 4 compares the total surplus attainable under alternative ways that the market can provide anesthesia: CRNAs practicing with full autonomy and the option of being supervised by MDAs (*FA* case), CRNAs practicing with full autonomy but no option of supervision (*NS* case), and CRNAs who can practice only under supervision (*NA* case). While the *FA* case in Figure 4 depicts the *FA* case analyzed in section 2 and 3, the *NA* case in Figure 4 assumes that CRNAs can provide anesthesia only under the supervision of MDAs. The total surplus of the *NA* case in Figure 4 is the surplus that would result from successful lobbying by MDAs with their lobbying costs taken into account (meaning that they are a part of the total surplus). The *NS* case in Figure 4 assumes there is no possibility of team practice, with CRNAs and MDAs independently providing *C* and *M*, respectively.

First, note that TS_{FA} (total surplus under the *FA* case) is strictly greater than TS_{NS} (total surplus under the *NS* case). The collaboration among anesthesia providers, namely the voluntary supervision of CRNAs by MDAs, should be welfare enhancing as it creates more value for participants in our model: the MDAs' supervision raises the quality of CRNAs' services, and such collaboration will occur voluntarily only when consumers are willing to pay more for their combined services than for the sum of their individual services. Also note that TS_{FA} is strictly greater than TS_{NA} (total surplus under *NA* case) for $a^M < a^{M1}$ and they become identical for $a^M \geq a^{M1}$. Recall that our model assumes a perfectly competitive market with perfectly informed participants and price takers. Thus, eliminating restriction on the way that CRNAs can practice should not reduce total welfare. Requiring CRNAs to work under MDAs' supervision reduces the total surplus for $a^M < a^{M1}$ because it eliminates the chance to realize a mutually beneficial trade between CRNAs and potential consumers of their services. Finally, note that

TS_{NS} is strictly greater than TS_{NA} for low values of a^M but the reverse is true for high values of a^M. The welfare cost of requiring CRNAs to work under MDAs' supervision is very high when the supply of MDAs is very limited because there is only a small additional amount of *M*, but a large loss of *C*, so that TS_{NA} is strictly lower than TS_{NS}. When the supply of MDAs increases, then the elimination of *C* caused by required supervision of CRNAs gets smaller (disappearing if $a^M \geq a^{M1}$), and eventually the welfare cost of required supervision becomes less than the cost of no supervision.[32]

There are various ways to extend our model by relaxing some of its assumptions. For example, there was a rapid (absolute as well as relative) increase in the supply of MDAs per capita, between the 1970 and the middle of the 1990s. To investigate how much of this increase was attributable to the growth of surgeries involving greater risk, we can relax the assumption of uniformly distributed surgery hours over different types of anesthesia services. Another way to extend this research is to use its theoretical framework to analyze other professions with overlapping responsibilities. One can apply our model of vertically differentiated services to analyze economic relationships between nurse practitioners and primary care physicians, opticians and ophthalmologists, or certified nurse midwives and obstetrician-gynecologists. This approach can be useful in understanding the complex economic relationships in these and other professions with overlapping responsibilities.

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[32] It is necessary to provide a caveat to avoid potential misunderstanding of the results of our welfare analysis in Figure 4. One should not attach any economic significance to the fact that the total surplus rises with an increase in the supply of MDAs in Figure 4. This is a direct result of our model's simplifying assumption of a perfectly-inelastic supply of MDAs. Because of this assumption, a greater supply of MDAs does not impose any additional welfare cost on the market. However, the assumption of a perfectly-inelastic supply of MDAs does not invalidate the comparison of total surplus shown in Figure 4: for any given supply condition of MDAs, the logic involved in the welfare ranking of *FA*, *NS*, and *NA* cases should be valid even when we relax the assumption of an inelastic supply of MDAs.

Appendix 1.1.

Proof of Lemma 1.

(*i*) the case where $t^C < t^M < 1$: $[V^M(t) - p^M] - [V^C(t) - p^C] = (q-1)t - (p^M - p^C) > 0$ for $t > t^M = (p^M - p^C)/(q-1)$, implying that consumers with their surgery type $t \in (t^M, 1]$ would prefer *M* over *C*. $[V^M(t) - p^M] - [V^C(t) - p^C] = (q-1)t - (p^M - p^C) < 0$ for $t < t^M$, implying that consumers with their surgery type $t \in [0, t^M)$ would prefer *C* over *M*, but consumers with their surgery type $t \in [0, t^C)$ would prefer not-buying any professional anesthesia service over buying *C* because $V^C(t) - p^C = t - p^C < 0$ for $t < t^C = p^C$.

(*ii*) the case where $t^M > 1$: $[V^M(t) - p^M] - [V^C(t) - p^C] = (q-1)t - (p^M - p^C) < 0$ for $t < t^M$ (>1), implying that all consumers would prefer *C* over *M*. Consumers with their surgery type $t \in [0, t^C)$ would prefer not-buying any professional anesthesia service over buying *C* because $V^C(t) - p^C = t - p^C < 0$ for $t < t^C = p^C$, but consumers with their surgery type $t \in (t^C, 1]$ would buy *C* with $V^C(t) - p^C > 0$.

(*iii*) the case where $t^M < t^C$: Consumers with their surgery type $t \in (t^C, 1]$ would prefer buying *C* over not-buying any professional anesthesia service with $V^C(t) - p^C \geq 0$, but all of such consumers would prefer *M* over *C* with $[V^M(t) - p^M] - [V^C(t) - p^C] = (q-1)t - (p^M - p^C) > 0$ for $t > t^C > t^M = (p^M - p^C)/(q-1)$. While consumers with surgery type $t \in [0, t^C)$ would prefer not-buying any professional anesthesia service over buying *C*, consumers with surgery type $t > p^M/q$ would prefer buying *M* over not-buying any anesthesia service with $[V^M(t) - p^M] = qt - p^M > 0$ for $t > p^M/q$.

Proof of Proposition 1.

For any $a^M > 0$, note that p^M will always be low enough to have $t^M < 1$, or equivalently, $(p^M - p^C) < (q-1)$ so that $D^M > 0$ in the equilibrium. Because a^M is fixed, there should be enough demand for *M* so that MDAs can utilize all of their service units in the market.

(*i*) We will first prove that $p^C(q-1) < (p^M - p^C)$ in the equilibrium for $a^M \approx 0$. If $p^C(q-1) \geq (p^M - p^C)$ for $a^M \approx 0$, then $p^M \approx q$ from $D^M(p^M, p^C) = 1 - p^M/q = S^M(r^e; a^M) = (1 - r^e)a^M + nr^e a^M \approx 0$, which in turn requires $p^C \approx 1$ or $p^C > 1$ to satisfy $p^C(q-1) \geq (p^M - p^C)$. This leads to a contradiction because $S^C(p^C,$

r^e; a^M) = $a^C(p^C) - nr^e a^M \approx bp^C > D^C(p^M, p^C) = 0$. For $a^M \approx 0$, therefore, $p^C(q-1) < (p^M - p^C) < (q-1)$, which implies that $D^M(p^M, p^C) = 1 - t^M$ and $D^C(p^M, p^C) = t^M - t^C$ from (2$^{/}$).

When $a^M \approx 0$, thus $D^M(p^M, p^C) = 1 - t^M = S^M(r^e; a^M)$ and $D^C(p^M, p^C) = t^M - t^C = S^C(p^C, r^e; a^M)$, which implies that $p^M \approx (q-1) + p^C$ and $p^C \approx 1/(1+b)$ for any $r^e \in [0, 1]$. Given $(n-1)(q-1) > 1$, $p^M \approx (q-1) + 1/(1+b) < n(p^M - p^C) = n(q-1)$, thus $r^e = 1$ for $a^M \approx 0$. With $r^e = 1$, $p^M = (q-1)(1 - na^M) + p^C$, and $p^C = 1/(1+b)$ from $D^M(p^M, p^C) = 1 - t^M = S^M(r^e; a^M)$ and $D^C(p^M, p^C) = t^M - t^C = S^C(p^C, r^e; a^M)$.

With $r^e = 1$, an increase in a^M will lower $n(p^M - p^C)$ faster than it lowers p^M as $\partial[n(p^M - p^C)]/\partial a^M = -n^2(q-1) < \partial p^M/\partial a^M = -n(q-1)$, creating the possibility of $p^M > n(p^M - p^C)$ for large enough values of a^M. In fact, it is easy to show that $p^M > n(p^M - p^C)$ iff $a^M > \{1 - [1/(1+b)(n-1)(q-1)]\}/n \equiv a^{Mc}$ with a positive demand for C and $r^e = 1$. From (2$^{/}$), however, note that the demand for C may disappear before a^M reaches a^{Mc} if $(p^M - p^C) \le p^C(q-1)$. Given $p^C = 1/(1+b)$ and $p^M = (q-1)(1 - na^M) + p^C$, $(p^M - p^C) \le p^C(q-1)$ iff $a^M \ge a^{M1} \equiv \{1 - [1/(1+\mathrm{b})]\}/\mathrm{n}$. Indeed, $a^{M1} < a^{Mc}$ with $(n-1)(q-1) > 1$.

For $a^M < a^{M1}$, therefore, $r^e = 1$, $p^M = (q-1)(1 - na^M) + p^C$, and $p^C = 1/(1+b)$ with $w^M = n(p^M - p^C) = n(q-1)(1 - na^M) > p^M$. Because every *MDA* provides *M* through supervising *n* CRNAs, $S^M = na^M$ and $S^C(p^C, r^e; a^M) = a^C(p^C) - na^M = 1 - p^C - S^M$.

(***ii***) First, we can show that $(p^M - p^C) \le p^C(q-1)$ for $a^{M1} \le a^M < a^{Mc}$ by contradiction. Assume that $(p^M - p^C) > p^C(q-1)$ for $a^{M1} \le a^M < a^{Mc}$ so that $D^M(p^M, p^C) = 1 - t^M$ and $D^C(p^M, p^C) = t^M - t^C$ from (2$^{/}$). Then, $n(p^M - p^C) > p^M$ with $r^e = 1$ as shown in (*i*) for $a^M < a^{Mc}$, thus, $r^e = 1$. This in turn implies that $p^M = (q-1)(1 - na^M) + p^C$, and $p^C = 1/(1+b)$, having $(p^M - p^C) \le p^C(q-1)$ for $a^{M1} \le a^M < a^{Mc}$, thus leading to a contradiction.

For $a^{M1} \le a^M < a^{Mc}$, we have $(p^M - p^C) \le p^C(q-1)$ under which $D^M(p^M, p^C) = 1 - p^M/q$ and $D^C(p^M, p^C) = 0$ from (2$^{/}$). From $D^M(p^M, p^C) = 1 - p^M/q = S^M(r^e; a^M) = (1 - r^e)a^M + nr^e a^M$, we obtain $p^M = q[1 - (1 - r^e)a^M - nr^e a^M]$. Because the demand for CRNAs comes solely from MDAs' supervision demand for CRNAs with $D^C(p^M, p^C) = 0$, the demand for CRNAs equals to $nr^e a^M$. To have the demand and the supply for CRNAs equalized in the equilibrium, $nr^e a^M = a^C(p^C)$, implying that $p^C = nr^e a^M/b$. Given that $p^M = q[1 - (1 - r^e)a^M - nr^e a^M]$ and $p^C = nr^e a^M/b$, $n(p^M - p^C) > p^M$ with $r^e = 1$ iff $a^M < a^{M2} \equiv [bq(n - 1)]/[bqn(n - 1) + n^2]$. Note that $a^{Mc} - a^{M2} = \{b(n-1)n[(n-1)q - n] + n^2[(n-1)(q-1) - 1]\}/\{n(1+b)(n-1)(q-1)[bqn(n-1) + n^2]\} > 0$ with $(n-1)(q-1) > 1$, thus $a^{M2} < a^{Mc}$. For $a^{M1} \leq a^M < a^{M2}$, therefore, $r^e = 1$, $p^C = na^M/b$, and $p^M = q(1 - na^M)$ with $w^M = n(p^M - p^C) > p^M$. Given that $p^C = na^M/b$ and $p^M = q(1 - na^M)$, one can check that $(p^M - p^C) \leq p^C(q - 1)$ iff $a^M \geq a^{M1}$. Therefore, $S^C = D^C = 0$ for $a^{M1} \leq a^M < a^{M2}$. Once again every *MDA* provides *M* through supervising *n* CRNAs, thus $S^M = na^M$ for $a^{M1} \leq a^M < a^{M2}$.

(*iii*) Let's first assume that $(p^M - p^C) \leq p^C(q - 1)$ for $a^M \geq a^{M2}$, having $p^M = q[1 - (1 - r^e)a^M - nr^e a^M]$ and $p^C = nr^e a^M/b$ from (6). Then, $n(p^M - p^C) = p^M$ with $r^e = 1$ and $n(p^M - p^C) > p^M$ with $r^e < 1$ at $a^M = a^{M2}$. At $a^M = a^{M2}$, therefore, $r^e = 1$, $p^M = q(1 - na^M)$ and $p^C = na^M/b$. For $a^M > a^{M2}$, however, $n(p^M - p^C) < p^M$ with $r^e = 1$, implying that $r^e < 1$ for $a^M > a^{M2}$. Now the question is finding $r^e \in (0, 1)$ such that $n(p^M - p^C) = n\{q[1 - (1 - r^e)a^M - nr^e a^M] - nr^e a^M\} = p^M = q[1 - (1 - r^e)a^M - nr^e a^M]$ or $r^e = 0$ with $n(p^M - p^C) < p^M$. From solving $n\{q[1 - (1 - r^e)a^M - nr^e a^M] - nr^e a^M\} = q[1 - (1 - r^e)a^M - nr^e a^M]$, we obtain $r^e = [bq(n - 1)(1 - a^M)]/\{[bq(n - 1)^2 + n^2]a^M\}$ and $n(p^M - p^C) = nq(1 - a^M) > p^M = q(1 - a^M)$ with $r^e = 0$ for $a^M < 1$. For $a^M \geq a^{M2}$, therefore, $r^e = [bq(n - 1)(1 - a^M)]/\{[bq(n - 1)^2 + n^2]a^M\}$ with $r^e = 1$ at $a^M = a^{M2}$ and $r^e = 0$ at $a^M = 1$. We obtain $w^M = p^M = n(p^M - p^C)$ and p^C as functions of a^M as in *Proposition 1* (*iii*) by plugging-in this value for r^e into $p^M = q[1 - (1 - r^e)a^M - nr^e a^M]$ and $p^C = nr^e a^M/b$. From $S^M(r^e ; a^M) = D^M(p^M, p^C) = 1 - p^M/q$ and $S^C(p^C, r^e; a^M) = D^C(p^M, p^C) = 0$, we have $S^M = 1 - p^M/q$ and $S^C = 0$.

One potential issue regarding the above result for $a^M \geq a^{M2}$ is whether the assumption of $(p^M - p^C) \leq p^C(q - 1)$ is satisfied for $a^M \geq a^{M2}$ despite the fact that p^C is decreasing in response to an increase in a^M. To check whether this assumption is satisfied for $a^M \geq a^{M2}$, we can calculate $p^C(q - 1) - (p^M - p^C)$ using the values for p^C and p^M in *Proposition 1* (*iii*). This yields that $p^C(q - 1) - (p^M - p^C) = [q(n - 1) - n]bqn(1 - a^M)/[b^2q(n - 1)^2 + bn^2] > 0$ for $a^M < 1$ with $(n-1)(q-1) > 1$ and $p^C(q - 1) - (p^M - p^C) = 0$ for $a^M = 1$. Therefore, $(p^M - p^C) \leq p^C(q - 1)$ for $a^M \geq a^{M2}$.

Proof of Proposition 2.

$L(a^M)$ reaches its maximum value, $b/[4(1 + b)]$ when $a^M = b/[2n(1 + b)]$, having $\partial L/\partial a^M = 0$. Therefore, K^L needs to be smaller than $b/[4(1 + b)]$ to have any lobby activities to generate a positive rent. With $K^L < b/[4(1 + b)]$, we can derive the values for $a^{ML}{}_{Min}$ and $a^{ML}{}_{Max}$ by solving $L(a^M) = K^L$ with respect to a^M.

Appendix 1.2 on the case of a linear supply function of MDAs

In this appendix, we relax the assumption of a perfectly inelastic supply of MDAs by modeling it as a linear function of the MDA's wage, w^M, having $a^M = -(c^M - \alpha^M) + bw^M$ with $\alpha^M \in [0, c^M - c^C]$ and $c^M > c^C$ (≥ 0). While we keep the assumption of a linear supply function of CRNAs, with $a^C = -c^C + bp^C$ with $c^C \in [c^C_{Min}, c^C_{Max}]$, note that we relax the assumption of setting $c^C = 0$ for the supply of CRNAs. This allows for the possibility of only MDAs existing in the market, as shown later. The assumption that the slope of the MDAs' supply curve is the same as that of the CRNAs' (both being b) is for expositional simplicity: making the slope of CRNAs' supply be greater than that of MDAs would not affect the qualitative results of the analysis. Given that both groups' supply curves have an identical slope, we model a higher cost of supplying MDAs compared with that of CRNAs by the assumption that $\alpha^M \in [0, c^M - c^C]$ above, which implies that $(c^M - \alpha^M) \geq c^C$.

One can interpret these parameters, c^C, c^M, and α^M in the following way. c^C (more precisely, c^C/b) represents the reservation wage for any CRNAs to enter the market, thus potentially reflecting the cost of training to become CRNAs. In a similar manner, $c^M - \alpha^M$ represents the reservation wage for any MDA to enter the market. Thus, $(c^M - \alpha^M) \geq c^C$ reflects that the cost of MDA training is typically higher than that of CRNA training. What about α^M? Note that a higher value for α^M implies a lower reservation wage for MDAs. One way to interpret α^M is as a level of local amenities to which MDAs are attracted. When α^M is higher with more attractive local amenities, the reservation wage for MDAs is lower and there will be more MDAs with the same wage. We assume that changes in α^M do not affect the demand for anesthesia. We also assume that changes in α^M do not affect the supply of CRNAs in the market, a potentially strong assumption. One way to justify this assumption is to argue that local amenities are often luxury goods to which people in a higher income bracket (MDAs) would respond more than people in a lower income bracket (CRNAs).

To compare the case of a linear supply function of MDAs with the case of a perfectly inelastic supply in Section 2, we analyze how an increase in α^M affects p^C, p^M, w^M, r^e, S^M (= D^M), and S^C (= D^C). Similar to Figure 2, Figure A illustrates how an increase in α^M, representing a greater supply of MDAs in the market, affects $w^C = p^C$, w^M, and the fraction of CRNAs' supervised services. As shown in Figure A, an increase in α^M generates qualitatively identical effects on these variables as an increase in a^M does in Figure 2. When α^M is relatively small with $\alpha^M < \alpha^{M2}$ so that the number of MDAs in the market is not large enough to induce some MDAs to opt out of supervising CRNAs for solo practice, then an increase in α^M, and a resulting increase in MDAs is not bad news for CRNAs. For $\alpha^M < \alpha^{M1}$, the increase in the number of MDAs does not matter to CRNAs as $w^C = p^C$ remains constant, and for $\alpha^M \in [\alpha^{M1}, \alpha^{M2})$, an increase in MDAs may raise the wage of CRNAs. Thus, as long as $\alpha^M < \alpha^{M2}$, MDAs enter the market as complements for CRNAs (even though they reduce and eventually eliminate *C* from the market for $\alpha^M \geq \alpha^{M1}$). However, when there are enough MDAs in the market, with $\alpha^M \geq \alpha^{M2}$, this complementary effect disappears and the substitution effect begins to dominate, with $\partial w^C/\partial \alpha^M < 0$. Similar to Figure 2, the fraction of CRNAs' supervised services reaches its maximum, 1, when the level of local amenities reaches α^{M1}. At $\alpha^M = \alpha^{M1}$, the price of *M* falls to the level that completely eliminates the patients' demand for *C*, forcing every CRNA to work under an MDA's supervision. The dearth of demand for *C* continues to hold for $\alpha^M > \alpha^{M1}$, so all CRNAs who are providing anesthesia are being supervised.

Now let us suppose that CRNAs and MDAs cannot work together as a team. To allow all possible combinations of anesthesia providers to arise in the market (*C* only, *C* and *M*, or *M* only) depending on the level of $\alpha^M \in [0, c^M - c^C]$, in the absence of the supervision possibility, we have $c^C_{Min} = b/[(q-1)b + 1]$ and $c^C_{Max} = (q-1)b^2 + qb$. Note that we are finding the range of possible c^C that allows all possible provider mixes under the assumption of no supervision of CRNAs by MDAs. As discussed below, this helps us to understand the complementarity between CRNAs and MDAs that comes from the supervision of CRNAs by MDAs. If $c^C > c^C_{Max} = (q-1)b^2 + qb$, then for any α^M satisfying $c^M - \alpha^M \geq c^C$, only CRNAs will exist in the market. If $c^C < c^C_{Min} = b/[(q-1)b + 1]$, then MDAs and CRNAs will co-exist in the market even when α^M takes its maximum value with $\alpha^M = c^M - c^C$, thus eliminating the possibility of having only MDAs in the market. Henceforth, we will focus on the case with $c^C \in [c^C_{Min}, c^C_{Max}]$ where $c^C_{Min} = b/[(q-1)b + 1]$ and $c^C_{Max} = (q-1)b^2 + qb$. To guarantee the existence of CRNAs even in the absence of MDAs in the market, we also assume that $b > c^C$.

Now let us reinstate the assumption that CRNAs and MDAs can work together as a team. As in section 2, we assume that $(n-1)(q-1) > 1$, which guarantees that MDAs have an incentive to supervise CRNAs when the number of MDAs in the market is small due to a low value of α^M. Finally, we set the value of c^M to be $bn(q-1)$, which is strictly greater than $c^C_{Max} = (q-1)b^2 + qb$ with $(n-1)(q-1) > 1$: having $c^M = bn(q-1)$ makes $a^M = 0$ (no MDAs in the market) with $\alpha^M = 0$ even when MDAs can supervise CRNAs. Given these assumptions on the values of b, c^C, c^M, and α^M, *Proposition A* characterizes the market equilibrium as follows, depending on the level of $\alpha^M \in [0, c^M - c^C]$:

Proposition A. Given that $(n-1)(q-1) > 1$,

(i) if the number of MDAs is relatively small with $\alpha^M < \alpha^{M1} \equiv c^M - (1 + c^C)[bn^2(q-1) + 1]/n(1 + b) + 1/n$, then M and C coexist in the market, all MDAs provide anesthesia through supervising CRNAs, and an increase in MDAs with a higher value of α^M does not affect the earnings of CRNAs, with $p^C = (1 + c^C)/(1 + b)$, $p^M = (q-1)[1 + (c^M - \alpha^M)n]/[bn^2(q-1) + 1] + p^C$, $w^M = n(q-1)[1 + n(c^M - \alpha^M)]/[bn^2(q-1) + 1] > p^M$, $r^e = 1$, $S^M = n[-(c^M - \alpha^M) + bw^M]$, and $S^C = 1 - p^C - S^M$,

(ii) if the number of MDAs is in an intermediate range with $\alpha^{M1} \leq \alpha^M < \alpha^{M2} \equiv c^M - [(1 + c^C)bn^2q + bq - bnq + nc^C]/[n^2(bq + 1) - bnq]$, then only *M* exists in the market, all MDAs provide anesthesia through supervising CRNAs, and an increase in MDAs with a higher value of α^M raises the earnings of CRNAs, with $p^C = [c^C + (1 + c^C)bn^2q - (c^M - \alpha^M)n]/[b + bn^2(bq + 1)]$, $p^M = [q + (1 + c^C)n^2q + (c^M - \alpha^M)nq]/[1 + n^2(bq + 1)]$, $w^M = n[bq - c^C + (c^M - \alpha^M)n(bq + 1)]/[b + bn^2(bq + 1)] > p^M$, $r^e = 1$, $S^M = n[-(c^M - \alpha^M) + bw^M]$, and $S^C = 0$,

(iii) if the number of MDAs is relatively high with $\alpha^{M2} \leq \alpha^M < \alpha^{M3} \equiv c^M - c^C(bnq + n)/(nbq - bq) + 1$, then only *M* exists in the market, MDAs provide anesthesia both through supervising CRNAs and solo-practice, and an increase in MDAs with a higher value of α^M reduces the earnings of CRNAs and raises the proportion of MDAs in solo practice, with $p^C = (n - 1)[(c^M - \alpha^M)nr^e - c^C)]/b(nr^e - n + 1)$, $p^M = w^M = n[(c^M - \alpha^M)nr^e - c^C)]/b(nr^e - n + 1)$, $r^e = [(c^M - \alpha^M + 1)b(n - 1)q - c^Cn(bq + 1)]/\{c^Cbn(n - 1)q + bn^2q - (c^M - \alpha^M)[n^2 + b(n - 1)^2q]\}$, $S^M = 1 - p^M/q$, and $S^C = 0$.

(iv) if the number of MDAs is very high with $\alpha^M \geq \alpha^{M3}$, then only MDAs (no CRNA) exist in the market, and MDAs provide anesthesia only through solo-practice, with $p^M = w^M = (c^M - \alpha^M + 1)q/(bq + 1)$, $r^e = 0$, $S^M = 1 - p^M/q$, and $S^C = 0$.

The proof of *Proposition A* will follow practically the same logics/steps as the proof of *Proposition 1*. Therefore, we do not provide the proof of *Proposition A*, but it is available upon request.

Note a few new points associated with *Proposition A*. As stated in *Proposition A* (iv) and shown in Figure A, we now have a case where only MDAs exist in the market, providing anesthesia through solo practice, if $\alpha^M \geq \alpha^{M3}$. While the case with only MDAs in the market is relatively rare (Footnote 18 indicates that 107 out of 2049 counties have MDAs only), *Proposition A* does yield such a case. The opposite case of CRNAs only in the market may also arise in the current set-up, if $\alpha^M = 0$ or if we allow α^M to have negative values, implying negative local amenities that dissuade MDAs from entering the market (and a higher price of *M* eliminates any demand for *M*). As mentioned in Footnote 18, 794 out of 2049 counties have CRNAs only.

Finally, we discuss the complementary relationship between CRNAs and MDAs that comes from the supervision of CRNAs by MDAs. We can identify such a complementary relationship by comparing the case where MDAs cannot supervise CRNAs with the case where they can. One can show that CRNAs always benefit, or at least do not lose from the possibility of their voluntary supervision by MDAs. Denoting a CRNA's wage under no supervision possibility by p^{CS}, $p^{CS} = (1 + c^C)/(1 + \mathrm{b}) = p^C$ for $\alpha^M \leq \alpha^{M1S} \equiv c^M - [bc^C + b^2(q-1) + bq]/(1 + b)$ and $p^{CS} = [(c^M - \alpha^M + 1) + c^C + bc^C(q-1)]/[1 + b + bq + b^2(q-1)] > p^C$ for $\alpha^M \in (\alpha^{M1S}, \alpha^{M2S})$ with $\alpha^{M2S} \equiv c^M - [c^C(bq + 1)/b - 1]$. Note that there will be no CRNA under this scenario if $\alpha^M \geq \alpha^{M2S}$ ($<\alpha^{M3}$) but the possibility of supervision would allow CRNAs to practice for $\alpha^M \in [\alpha^{M2S}, \alpha^{M3})$, demonstrating once again how CRNAs benefit from the supervision possibility. For any given supply condition of MDAs, the possibility of working with MDAs will always benefit CRNAs! To understand this result intuitively, consider the case where $\alpha^M \approx (>)\ \alpha^{M1S}$ so that there is a relatively small number of MDAs in solo practice with no supervision possibility. Because the presence of MDAs in solo practice creates competition for CRNAs, the price of *C* will be lower than the price that prevails in the absence of MDAs, $p^{CS} = (1 + c^C)/(1 + \mathrm{b})$ with $\alpha^M \leq \alpha^{M1S}$. If, however, we allow MDAs to supervise CRNAs, the price of *C* will go back up to $(1 + c^C)/(1 + \mathrm{b})$, the level that CRNAs enjoys in the absence of (solo-practicing) MDAs. This occurs because all MDAs choose to supervise CRNAs (as $\alpha^M \approx \alpha^{M1S} < \alpha^{M1}$), thus the consumers' substitution of M for C caused by MDAs' provision of *M* is exactly offset by the MDAs' demand for CRNAs to supervise. If all MDAs choose to supervise CRNAs as in the case with $\alpha^M < \alpha^{M2}$, the supervision possibility practically eliminates the MDAs' competitive pressure against CRNA services (and even increases the demand for CRNAs with $\alpha^M > \alpha^{M1}$). Even when only some MDAs choose to supervise CRNAs as in the case with $\alpha^M > \alpha^{M2}$, the supervision possibility will still reduce (partially eliminate) the MDAs' competitive pressure, raising the wage of CRNAs as a result.

We can also show that MDAs strictly benefit from the possibility of supervising CRNAs as long as α^M is not too high. For example, MDAs cannot enter the market without the possibility of supervising CRNAs if $\alpha^M \leq \alpha^{M1S}$ because there would be no demand for M at the reservation wage of MDAs. Even when $\alpha^M \leq \alpha^{M1S}$, MDAs would enter with the supervision possibility because they can supervise multiple CRNAs concurrently and can earn a higher payoff even after paying CRNAs their market price. We can also show that the wage that MDAs can earn under the supervision possibility, w^M, is higher than the wage that MDAs can earn without the supervision possibility, denoted by w^{MS}, for low enough values for α^M, with $w^{MS} = [(c^M - \alpha^M + 1)(q + bq - b) + c^C]/[1 + b + bq + b^2(q - 1)]$ for $\alpha^M \in [\alpha^{M1S}, \alpha^{M2S}]$ and $w^{MS} = (c^M - \alpha^M + 1)q/(bq + 1)$ for $\alpha^M > \alpha^{M2S}$. However, such complementarity between CRNAs and MDAs arising from the supervision possibility is no longer valid when α^M is greater than a critical value. If $\alpha^M = \alpha^{M2S}$, for example, one can easily show that $w^{MS} < w^M$, which implies that MDAs collectively would benefit from not supervising any CRNAs. When there are many MDAs, the supervision possibility leads to a large increase in the supply of M in the market (as each MDA's supervision service implies n units of M instead of 1), which will lead to a large decrease in the price of M, dominating the potential gain that MDAs may realize from multiplying each of their service units by n through supervising CRNAs.

Appendix 1.3.

First, note that the market equilibrium under the *FA* case is analyzed in Section 2 and the one under the *NA* case is analyzed in Section 3. Using the equilibrium values of p^M, p^C, a^C, r^e, S^M (= D^M), S^C (= D^C), we can obtain the corresponding total surplus (consumer surplus + producer surplus) as a function of the supply of MDAs:

$$TS_{FA} = q(2 - na^M)na^M/2 + (1 - na^M)^2/2 + 1/[2(1 + b)] \text{ for } a^M \in [0, a^{M1}),$$

$$= q(2 - na^M)na^M/2 - (na^M)^2/2b \text{ for } a^M \in [a^{M1}, a^{M2}),$$

$$= \{q[bq(n-1)^2 + n^2]^2 - qn^4(1 - a^M)^2 - bq^2n^2(n-1)^2(1-a^M)^2\}/\{2[b(n-1)^2 + n^2]\}$$

for $a^M \in [a^{M2}, 1]$, and

$$TS_{NA} = q(2 - na^M)na^M/2 - (na^M)^2/2b \text{ for } a^M \in [0, a^{M1}), \text{ and}$$

$$= TS_{FA} \text{ for } a^M \in [a^{M1}, 1],$$

where $TS_{NA} = TS_{FA}$ for $a^M \in [a^{M1}, 1]$ comes from the fact that there is no demand for C for $a^M \in [a^{M1}, 1]$ even under the *FA* case, making the prohibition of solo practice of CRNAs a non-binding constraint.

To obtain the total surplus under the *NS* case as a function of the supply of MDAs, we need to determine the equilibrium values of p^M, p^C, and $a^C = S^C$ (= D^C) as functions of $a^M = S^M$ (= D^M). Once again, it is easy to show that MDAs are specialized in anesthesia for patients with higher risk than those served by CRNAs. Then, $p^M = [q - 1 + 1/(1 + b)](1 - a^M)$, $p^C = (1 - a^M)/(1 + b)$, and $a^C = b(1 - a^M)/(1 + b)$, which in turn implies that $TS_{NS} = q(2 - a^M)a^M/2 + b(1 - a^M)^2/[2(1 + b)]$. Given these expressions for TS_{FA}, TS_{NA}, and TS_{NS} as functions of a^M, we can show that $TS_{FA} > TS_{NS}$ for $a^M \in (0, 1)$, $TS_{FA} > TS_{NA}$ for $a^M \in [0, a^{M1})$, and $TS_{NS} > TS_{NA}$ for low enough values of a^M, but $TS_{NA} > TS_{NS}$ for high enough values of a^M, as illustrated in Figure 4.

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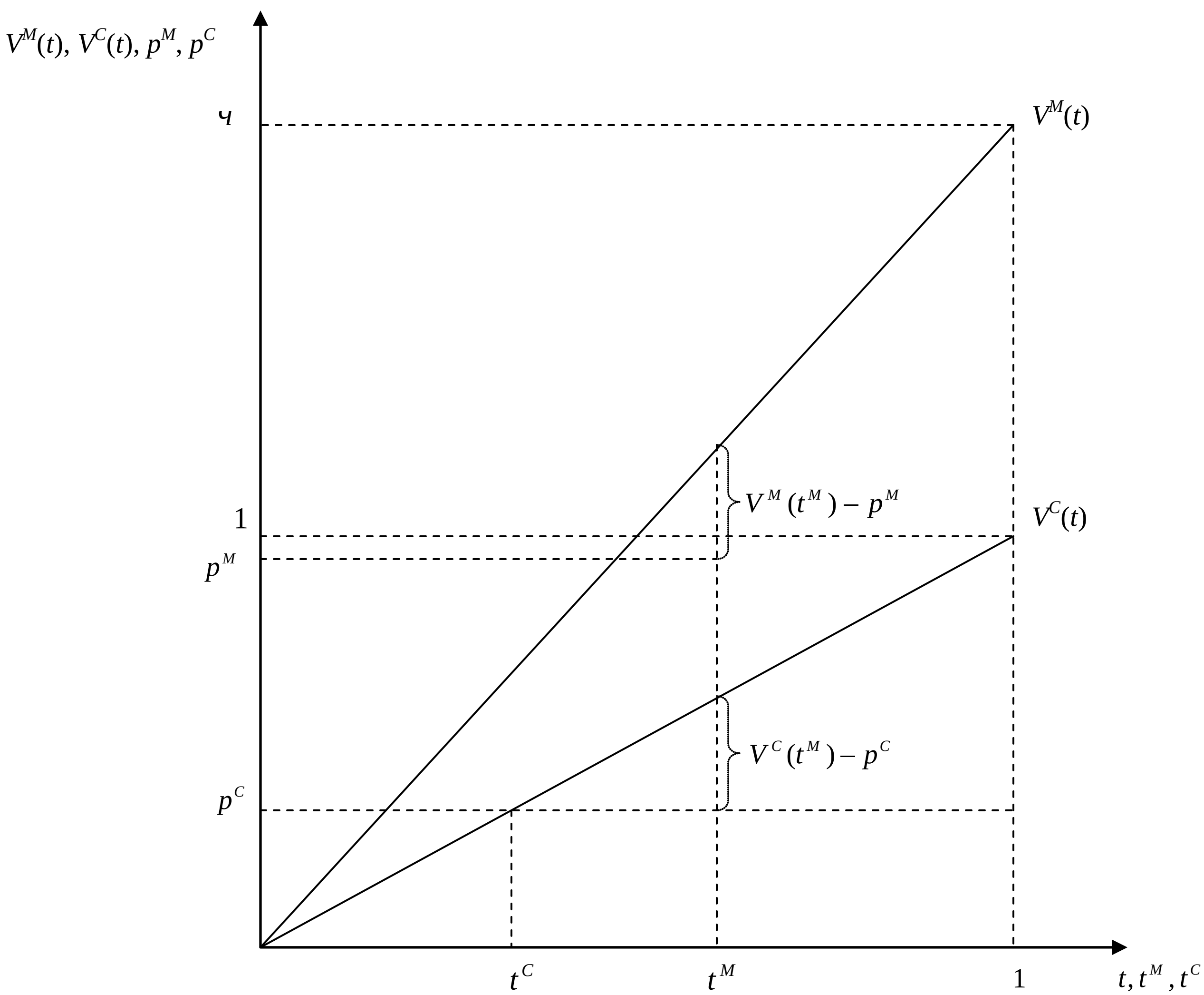

Figure 1. Demands for *C* and *M*

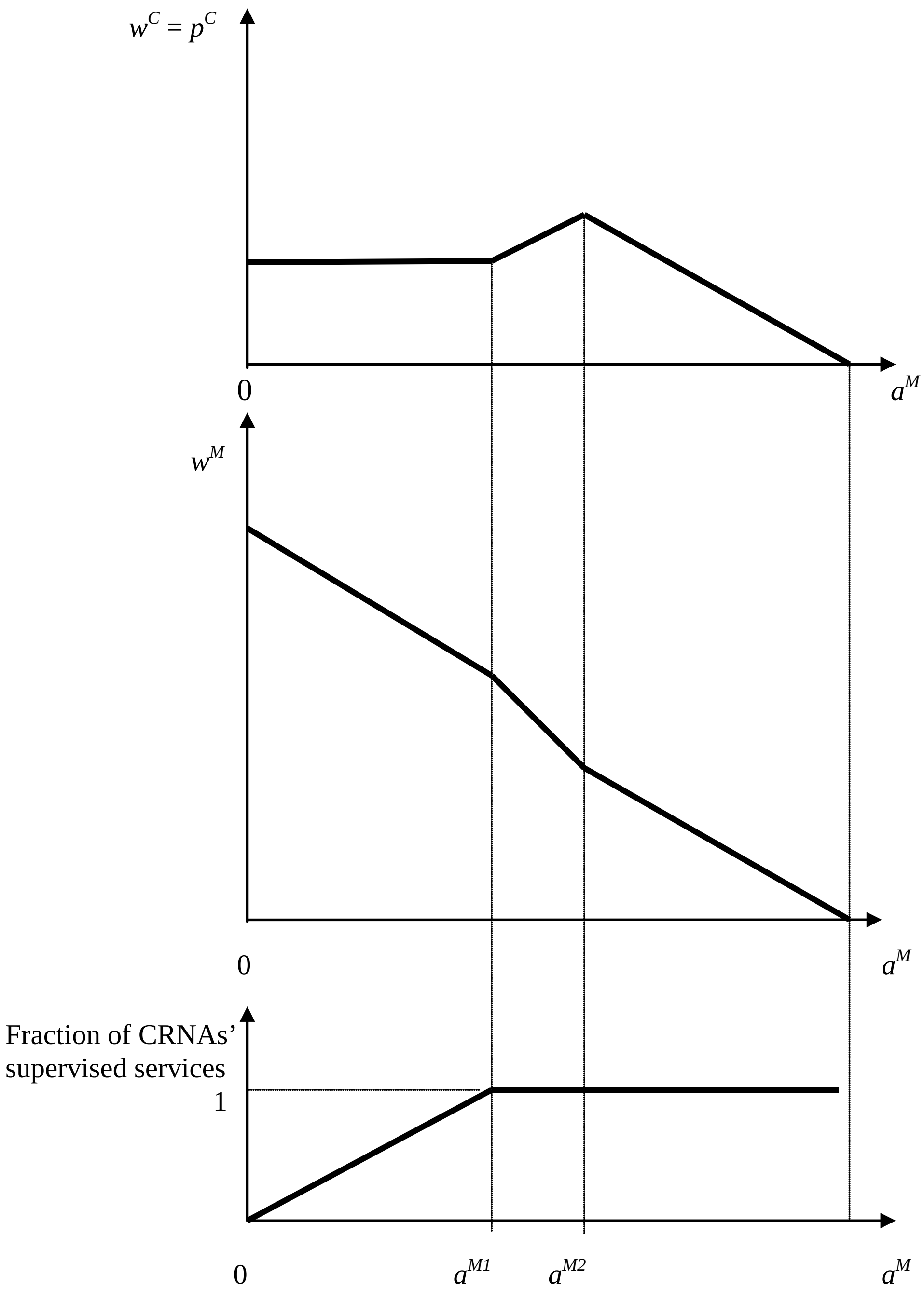

Figure 2. The effect of a^M on p^C, w^M, and the fraction of CRNAs who are supervised.

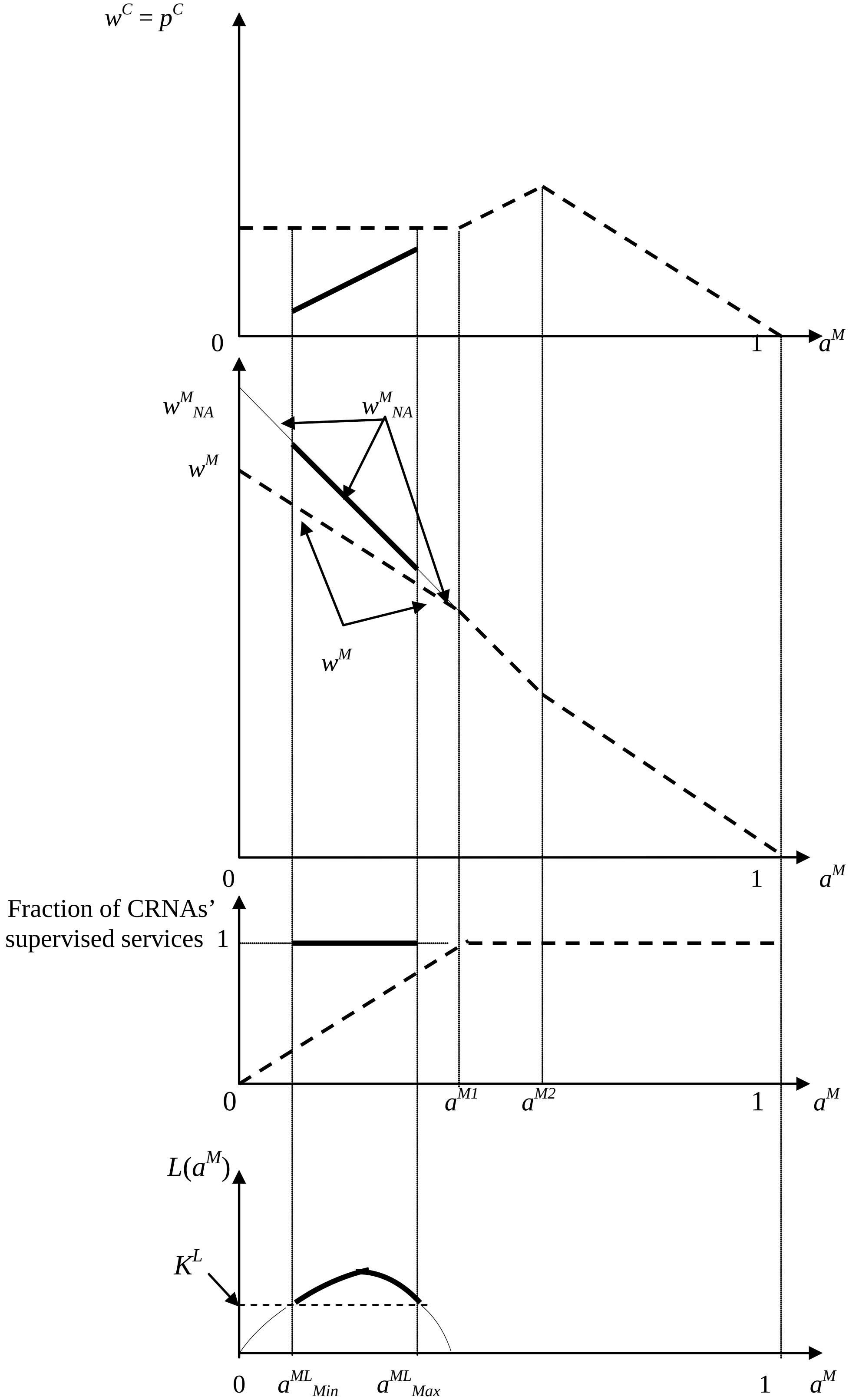

Figure 3. The effect of MDAs' lobbying on p^C, w^M, and the ratio of supervised CRNAs

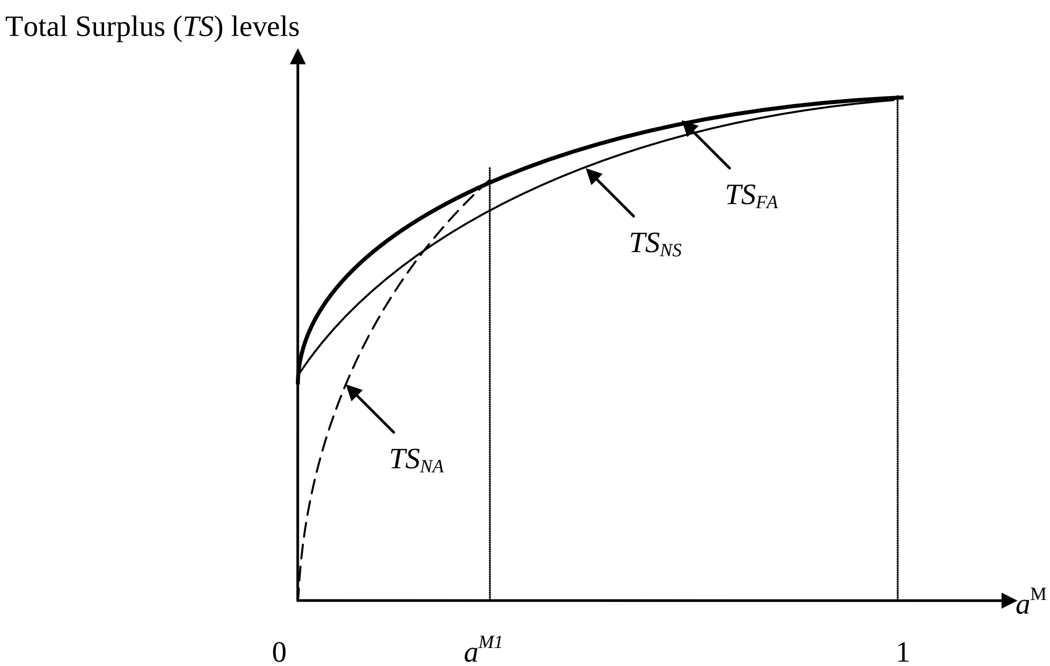

Figure 4. Comparison of Total Welfare under Full Autonomy of CRNAs (TS_{FA}), under No Autonomy of CRNAs (TS_{NA}), and under No Supervision (TS_{NS})

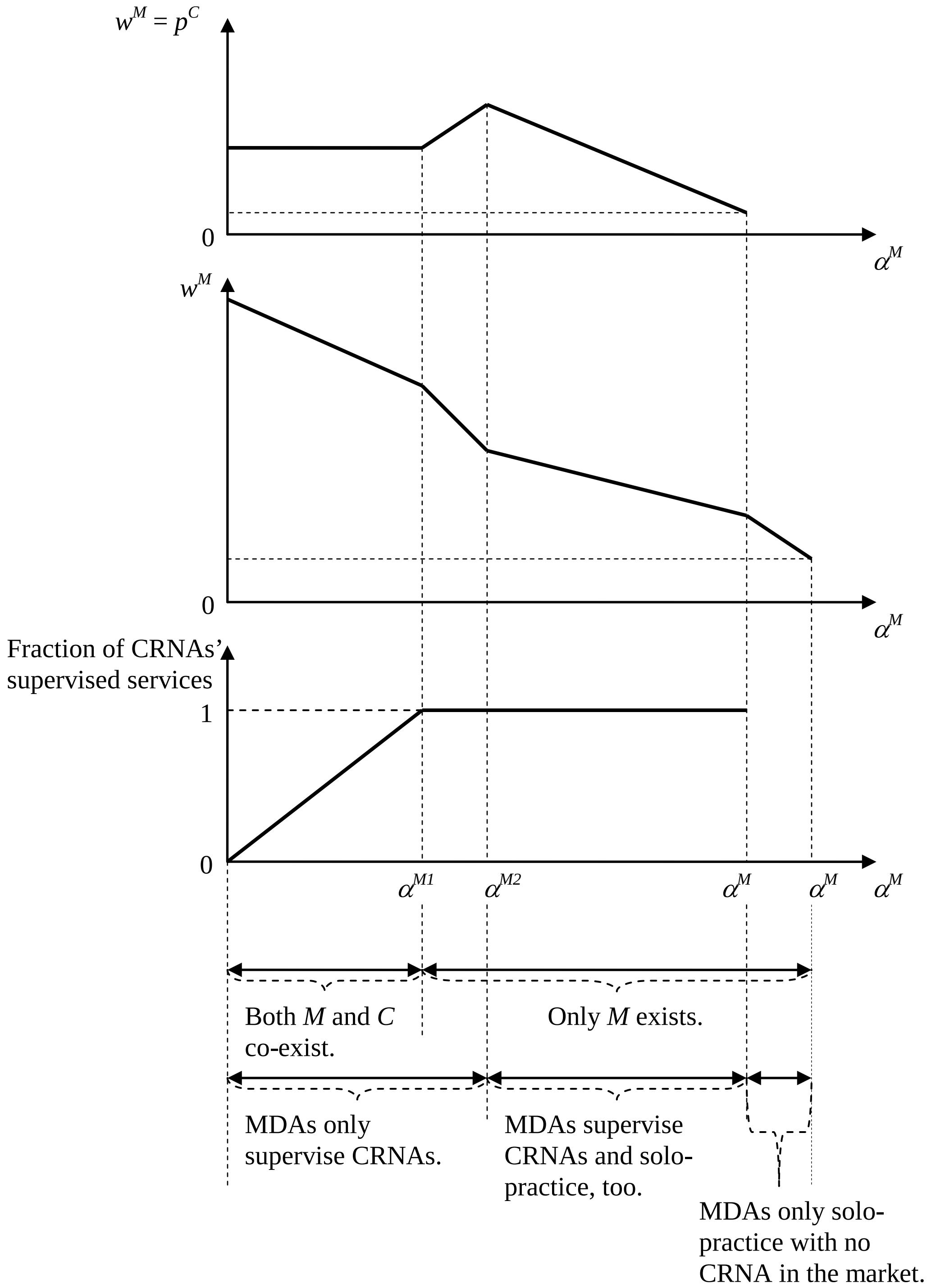

Figure A. The effect of α^M on p^C, w^M, and the fraction of CRNAs who are supervised