Veterinary Supply, Gender and Practice Location Choices in the United States, 1990-2010

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Abstract: The United States veterinary profession has changed markedly over the past 20 years. The human population has increased by 24% whereas the number declaring veterinarian as their profession has increased by 50% and the profession's female share has increased from 27% to 50%. We discuss some economics surrounding the allocation of male and female veterinarians across space and then estimate bivariate tobit models of location choice for 1990, 2000 and 2010. Females are less responsive to the presence of large animals than are males. For both genders, responsiveness has generally declined over time. The trend is strongest for hogs whereas responsiveness has held steady for horses. Using animal caretakers as a proxy for companion animals, we find that female veterinarians have become more responsive to this indicator over the twenty years. Female employment in a region is consistently more responsive to region income than is male employment while females have also consistently preferred to work by a veterinary college. All else equal, female and male veterinarians tend not to locate in rural areas. Aversion to rural areas has remained fixed over time among males but has strengthened among females.

Keywords: Market incentives, Lifestyle preferences, Occupational activities, Practice location

1. Introduction

The practice of veterinary medicine in the United States is in flux, leading to a variety of concerns about how the needs of those using and supplying veterinary services are being met (Kelly et al., 2013). One of the more contentious questions is whether there is a shortage in veterinarians in general, and food animal veterinarians in particular. Existing literature has addressed this concern with contrasting conclusions. Some suggest that serious shortage exists and will continue in the foreseeable future (Prince *et al.*, 2006; Narver, 2007). This conclusion is often based on views about social needs not being accounted for in market transactions, where animal welfare, food safety and detection of exotic diseases are examples. However the preponderance of evidence indicates no shortage, and even a surplus in veterinarian supply (Getz, 1997; Brown and Silverman, 1999; Kelly et al., 2013; AVMA, 2013). This conclusion is typically arrived at through market analysis, and is undergirded by the expansion in training capacity at colleges of Veterinary Medicine in recent years. Since growth in demand has not been as strong, many believe that additional supply is weighing down returns to investment in the career (Nolen, 2013).

Notwithstanding the above, programs such as the Veterinary Medicine Loan Repayment Program (VMLRP) indicate a policy concern that veterinarian shortage situations exist in some service areas such as food animal practice and rural areas (Wang et al., 2012). In addition, survey results suggest that rural areas are generally not preferred by veterinarians (Villaroel et al., 2010). Intertwined with concerns about declining participation in large and food animal practice are trends in gender composition. Recent decades witnessed a dramatic increase in female veterinary student graduation. According to AVMA statistics, in 2009 for the first time female veterinarians outnumbered their male counterparts with 44,802 female veterinarians and 43,196 male veterinarians. Lofstedt (2003) has suggested a causal relationship between the increase in female share in all veterinary college graduates and the decline in participation among recent veterinary graduates in food animal practice. Her view is supported by results from an AVMA survey that only 4% of female veterinary graduates in the class of 2001 entered large animal practice compared with 13% of male counterparts. The phenomenon is occurring throughout high income countries. Heath (2007), for Australia, found that 76% of males vs. 88% of females are working with small animals, while Kostelnik et al. (2010) discuss similar trends in Germany.

This paper's primary objectives are to explore the impacts of rurality and gender on veterinarian's location choice as well as how they have evolved over time. We do so by use of United States census data. Survey methods allow for in-depth inquiry into the demographics of and motivation for particular career choices. However, this approach covers a small subset of the population and is prone to selection bias, while the survey population is seldom followed over time. Instead we consider U.S. Equal Employment Opportunity (EEO) and census data which is more objective and allows for comparison of trends across 1990, 2000 and 2010.

Our working hypothesis is that market forces determine where veterinarians locate. In this paper we first discuss the nature of pertinent market and related forces. It is true that public programs are in place to influence veterinarian practice location in the United States and elsewhere but these are limited in scale and scope, see Wang et al. (2012) for an overview. Suasion efforts have also been run by veterinary associations and colleges, but again these have been limited in scale and scope. We know of no efforts to shape gender composition of veterinary service supply.

After discussing market and related forces, we then provide a brief conceptual model to clarify how these forces interact and to validate the equilibrium spatial location model that we will posit for empirical analysis. In the empirical analysis we use a bivariate Tobit model where male and female veterinarians are determined by the number of animals in different species, rurality and other factors. As an alternative perspective, we also provide logistic models to identify factors that determine the presence of a veterinarian in a region and the plurality status of female veterinarians in a region. We discuss our findings, and then conclude with an overview of policy issues relevant to matching supply with demand in the veterinary profession.

2. Economic Considerations

Labor force participation among women in the United States has increased from 36% in 1955 (DiCecio et al., 2008) to about 58% in 2011.[1] Changing social conditions and a revision in expectations at the societal level have precipitated increased female attendance at college

[1] See http://data.worldbank.org/indicator/SL.TLF.CACT.FE.ZS.

(Goldin, 2006). Labor shocks arising from World War II may have been responsible for some of this change (Goldin and Olivetti, 2013).

A recalibration of the expectation to participate in the workforce during marriage and childrearing years can increase markedly the expected return on investment in professional qualifications. This effect will be reinforced when on-the-job learning and skill acquisition complement coursework and when rewards from client relationship development are recognized; all generally important features of clinical professions. Females with medical, dentistry, law and advanced management degrees as a share of all recipients all grew dramatically toward parity with males over the period 1965-2005 (Goldin, 2006). Goldin and Katz (2012) note that the U.S. pharmaceutical profession is now dominated by females. They suggest that the profession's structural change away from proprietor operated dispensaries toward employment in national chains or hospitals has allowed for more flexible, family-friendly terms of employment. Similarly Golden argues that companion animal focused practices with regular hours and scalable work activities also afford career flexibility, see Wessel (2010).

According to U.S. Census Bureau data, between 1970 and 2010 the United States' population expanded by 52%. Between 1971 and 2010 American Veterinary Medical Association (AMVA) records show an expansion from 25,665 to 90,201, or a 251% expansion, in actively employed association members, see Kelly et al. (2013). The supply of DVM training capacity is determined in a decentralized manner, much of it being supported by state and federal tax dollars. Board certification is centralized in the United States where all states recognize the North American Veterinary Licensing Exam (NAVLE). Much has been written on the extent to which the primary actual purpose of licensing is the ostensible goal of signaling and otherwise promoting quality or, alternatively, is intended to control supply, see Kleiner (2006). The first attempt NAVLE pass rate for senior DVM students at accredited programs was 92% in Fall 2012 and was 40% for students at programs not accredited by the American

Veterinary Medical Association's Council on Education. These numbers are typical so it is hard to argue that supply management is an intent.

Of course, four year degree holders need to be willing to enroll. Economic principles hold that enrollment will not meet capacity if prospective future terms of employment are insufficiently competitive with those offered by alternative career choices. As more enroll, prospective future supply increases and rational expectations about future veterinary service prices decline. Willingness to enter such a program will also depend on factors beyond future expected returns. Many are likely motivated to enter primarily out of interest in working with animals and promoting animal wellbeing. Other motivations might include the opportunity to blend professional practice with entrepreneurship, and to work in the field of applied science.

Price for services is not determined by supply and demand alone. Perceptions about service quality also matter. Presumably if admissions offices are effective in identifying potential then standards will be higher when training capacity is low. It is the collective responsibility of government and the profession, through Board examinations, to identify and enforce acceptable standards of competency. Ideally, information channels, law suits and professional oversight would suffice to ensure adequate competency among practitioners. However, professional service markets are fraught with information asymmetries in that relevant information is difficult for the lay person to obtain and assess. Demand for services will depend on public perceptions about standards. Independent of salary issues, supply will also depend on public perceptions about standards to the extent that potential practitioners value a profession's reputation.

Governments heavily subsidize training at many professional schools, veterinary and otherwise. They can do so by assuming the capital cost of expanding training capacity, and also by subsidizing tuition. One motivation for providing such subsidies arises from the view that these highly trained business professionals will create positive economic externalities, perhaps through developing businesses in technically advanced industries. There are also social concerns that commercial loan markets are insufficient to ensure that able and motivated students from less advantaged backgrounds can finance their training without assistance. The choice of subsidy instrument should reflect policy goals. If the intent is to facilitate educational access by financially constrained students then tuition subsidies would suffice without recourse to expanding capacity.

Expansion in DVM supply would weigh on profession salaries unless demand also expands as robustly. Salaries have approximately kept pace with inflation over the period 1965-2007, see Figure 10-2 in Kelly et al. (2013) and compare poorly with peer group professions such as pharmacy, dentistry and medicine. To the extent that males do, or expect to, commit to a full-time career and be a family's primary income provider, these data may explain the decline in male share of veterinarians.

According to Census data, the share of the U.S. population that is urban was 73.7% in 1980, 75.2% in 1990, 79.0% in 2000 and 80.7% in 2010. The presence of family members with a farm background and of rural practice mentors ranks high among factors influencing entry into rural practice (Schmitz et al., 2007; Villarroel et al., 2010). These connections are declining as agriculture, and especially animal agriculture, becomes more concentrated (MacDonald and Korb, 2011). Although veterinarians may in general prefer a rural lifestyle to the extent that it admits opportunities to integrate animals into their personal lives, other lifestyle preferences such as access to family education opportunities and to leisure services also affect veterinarian location choices (Jelinski et al., 2009).

These lifestyle considerations may have a gender bias. For example, 58.1% of the civilian non-institutionalized female population aged 16 and over were in the workforce in 2011 whereas the figure for males was 70.5%. Employed married females are more likely to be in dual career families than are employed married males. Highly educated females are more likely than other females to be married to highly educated males while employment opportunities for such individuals are concentrated in urban areas (Murray, 2012). Female DVMs, who are highly educated but not so highly paid, may choose to locate in urban areas in order to accommodate their spouse's career whereas male DVMs may not have the same incentives to do so. Rurality also has supply side implications. Service costs increase as distance to the nearest service provider increase. These costs have to be borne by someone and will deter market activity in rural areas when compared with urban areas.

There are many sources of demand for veterinary services. Traditionally, demand to cure farm animals dominated total demand. Growth in the non-farm population, greater overall affluence and changing demographics have shifted demand toward companion animals since the 1960s. Real per capita income has increased while its dispersion has also grown (DeNavas-Walt et al., 2012), creating more opportunities to serve affluent companion animal owners. More than 70% of U.S. veterinarians whose employment status is known to the AMVA are at least partly engaged in companion animal practice (Kelly et al., 2013). In addition, the nature of farm-level demand has changed. Commercial herds have become larger (MacDonald and Korb, 2011) with lower returns per animal so that individual attention is no longer profitable. Correspondingly, disease management has become preventive and is increasingly administered at the herd level.

Demand outside private practice includes local, state and federal government, institutions of higher education, the armed services and industry. These sources of employment, although significant and likely growing, account for less than 20% of all veterinarians. The most significant of these alternative employments is at institutes of higher education, where about 6,500 are located (see Table 1-1 in Kelly et al., 2013). These may be employed in teaching, research, outreach to animal owners and others or clinical activities. Thus one would expect demand to be particularly high in regions that include a veterinary college. Veterinarians may also wish to locate near a veterinary college for many reasons. They may have interned there, a spouse may have started a career in the region while the DVM was being trained or the veterinarian may value career advancement opportunities that proximity to a college provides. Again there may be a gender dimension. Average age at first marriage in the United States is 28.6 for males and 26.6 for females (U.S. Census Bureau, 2011). To the extent that DVMs follow this pattern, females are more likely to marry into a career environment while completing their training than are men.

We take the major effects on the marketplace to be as follows. On the demand side, an increase over time in per capita income would suggest increased willingness to pay for companion animal veterinarian services. In addition, structural change in animal agriculture has likely decreased demand for food animal health services. On the supply side, an increase in overall supply has occurred with particular growth in the supply of female DVMs. Consider for the moment an increase in supply of female DVMs only. If we assume that female DVMs prefer working with companion animals then we may apply the following logic. At given salaries, the number of companion animals that the stock of veterinarians are willing to serve increases relative to the number of food animals they are willing to serve. All else equal, the price of companion animal veterinary services should fall by more than the price of food animal veterinary services in order to restore equilibrium. On the other hand, growth in income should place upward pressure on prices and income for companion animal veterinarians. Thus, supply and demand side considerations should lead to strong upward growth in the number of companion animal veterinarians. But the effects on incomes in the companion animal side of the market, when compared with the food animal side of the market, are less clear.

3. Conceptual Model

We consider two markets, rural and urban. Demands for veterinary services are given as:

$$D^r(\cdot) = \varsigma_0^r - \varsigma_1^r p^r + \varsigma_2^r p^{\mathrm{ag}}; \qquad D^u(\cdot) = \varsigma_0^u - \varsigma_1^u p^u + \varsigma_2^u Y; \tag{1}$$

where D^j and p^j are demands and prices, respectively, with $j = r$ for rural and $j = u$ for urban. One can also think of p^r and p^u as, respectively, rural and urban veterinarian incomes. Of course demand is downward sloping in that $\varsigma_1^j > 0, j \in \{r, u\}$. Rural demand increases with agricultural output prices, p^{ag}, so that $\varsigma_2^r > 0$ while urban demand increases with disposable income, Y, so that $\varsigma_2^u > 0$.

The stocks of women and men DVMs are given as K^f and K^m, respectively, with total stock $K = K^f + K^m$. These stocks are assumed to be exogenous in that they come to be for reasons outside the present model, perhaps due to the social trends that allow increased opportunities for women, changing views on animal welfare, or as the outfall of expansion in the Land Grant Universities. Aggregate preferences for urban and rural practice are modeled as quasi-logistic as follows;

$$\begin{aligned}
&\text{Share of females in rural market:} \quad && S^{f,r}(I^{f,r}, I^{f,u}) = \frac{A^f(I^{f,r})}{A^f(I^{f,r}) + B^f(I^{f,u})}; \\
&\text{Share of females in urban market:} \quad && S^{f,u}(I^{f,u}, I^{f,r}) = \frac{B^f(I^{f,u})}{A^f(I^{f,r}) + B^f(I^{f,u})}; \\
&\text{Share of males in rural market:} \quad && S^{m,r}(I^{m,r}, I^{m,u}) = \frac{A^m(I^{m,r})}{A^m(I^{m,r}) + B^m(I^{m,u})}; \\
&\text{Share of males in urban market:} \quad && S^{m,u}(I^{m,u}, I^{m,r}) = \frac{B^m(I^{m,u})}{A^m(I^{m,r}) + B^m(I^{m,u})}.
\end{aligned} \tag{2}$$

Here the functions $A^f(\cdot), A^m(\cdot), B^f(\cdot)$ and $B^m(\cdot)$ are monotone increasing while the functions $I^{f,r}, I^{f,u}, I^{m,r}$ and $I^{m,u}$ are linear indices signifying strength of preference for different job characteristics, including animal mix in practice, price for services, preference for rural practice location, etc. Full details on how such aggregate preferences can emerge upon integrating out idiosyncratic preferences characterized by the extreme value distribution can be found in McFadden (1974).

From (1) and (2) above, when supply and demand are equated then

$$(3a)\ \text{Equilibrium in rural markets:}\quad \varsigma_0^r - \varsigma_1^r p^{r,*} + \varsigma_2^r p^{\text{ag}} = K^m S^{m,r}(\cdot) + K^f S^{f,r}(\cdot);$$
$$(3b)\ \text{Equilibrium in urban markets:}\quad \varsigma_0^u - \varsigma_1^u p^{u,*} + \varsigma_2^u Y = K^m S^{m,u}(\cdot) + K^f S^{f,u}(\cdot); \tag{3}$$

where $p^{r,*}$ and $p^{u,*}$ represent equilibrium veterinarian service prices in rural and urban markets, respectively.

Upon summing the equations in (3) we obtain

$$\varsigma_0^r + \varsigma_0^u - \varsigma_1^r p^{r,*} - \varsigma_1^u p^{u,*} + \varsigma_2^r p^{\text{ag}} + \varsigma_2^u Y = K. \tag{4}$$

So if the total stock of veterinarians, K, increases then equilibrium across markets will be restored by a decrease in the price of services provided in rural areas, $p^{r,*}$, or in the price of services provided in urban areas, $p^{u,*}$, or in both. Similarly, for a given total stock of veterinarians an increase in income or farm animal prices will allow for an increase in the prices of veterinarians services provided in rural and urban areas. Relation (4) connects aggregate demand with aggregate supply, but it does not address how DVM supply is allocated between rural and urban markets. We will shortly turn to this spatial allocation issue.

We specify the linear indices as

$$\begin{aligned} I^{f,r} &= \alpha^{f,r} + \alpha^f p^r + \alpha^{f,\text{la}} z^{\text{la},r} + \alpha^{f,\text{sm}} z^{\text{sm},r}; \\ I^{f,u} &= \alpha^{f,u} + \alpha^f p^u + \alpha^{f,\text{la}} z^{\text{la},u} + \alpha^{f,\text{sm}} z^{\text{sm},u}; \\ I^{m,r} &= \alpha^{m,r} + \alpha^m p^r + \alpha^{m,\text{la}} z^{\text{la},r} + \alpha^{m,\text{sm}} z^{\text{sm},r}; \\ I^{m,u} &= \alpha^{m,u} + \alpha^m p^u + \alpha^{m,\text{la}} z^{\text{la},u} + \alpha^{m,\text{sm}} z^{\text{sm},u}; \end{aligned} \tag{5}$$

where $z^{\text{la},r}, z^{\text{sm},r}, z^{\text{la},u}$ and $z^{\text{sm},u}$ enumerate the number of large and small animals in representative rural (with superscript r) and urban (with superscript u) practice locations. All coefficients are held to be positive so that veterinarians prefer more income and like to treat all animals. The relative magnitudes of these coefficients reflect relative preferences for salary over different animal types treated and for rural over urban practice locations.

Upon inserting (4) into (5), using $p^{u,*} = (\varsigma_0^r + \varsigma_0^u - \varsigma_1^r p^{r,*} + \varsigma_2^r p^{\text{ag}} + \varsigma_2^u Y - K)/\varsigma_1^u$, we obtain equilibrium indices written in terms of $p^{r,*}$ only as,

$$\begin{aligned}
I^{f,r,*} &= \alpha^{f,r} + \alpha^{f} p^{r,*} + \alpha^{f,\mathrm{la}} z^{\mathrm{la},r} + \alpha^{f,\mathrm{sm}} z^{\mathrm{sm},r};\\
I^{f,u,*} &= \alpha^{f,u} + \frac{\alpha^{f}(\varsigma_0^r + \varsigma_0^u - \varsigma_1^r p^{r,*} + \varsigma_2^r p^{\mathrm{ag}} + \varsigma_2^u Y - K)}{\varsigma_1^u} + \alpha^{f,\mathrm{la}} z^{\mathrm{la},u} + \alpha^{f,\mathrm{sm}} z^{\mathrm{sm},u};\\
I^{m,r,*} &= \alpha^{m,r} + \alpha^{m} p^{r,*} + \alpha^{m,\mathrm{la}} z^{\mathrm{la},r} + \alpha^{m,\mathrm{sm}} z^{\mathrm{sm},r};\\
I^{m,u,*} &= \alpha^{m,u} + \frac{\alpha^{m}(\varsigma_0^r + \varsigma_0^u - \varsigma_1^r p^{r,*} + \varsigma_2^r p^{\mathrm{ag}} + \varsigma_2^u Y - K)}{\varsigma_1^u} + \alpha^{m,\mathrm{la}} z^{\mathrm{la},u} + \alpha^{m,\mathrm{sm}} z^{\mathrm{sm},u}.
\end{aligned} \tag{6}$$

When employing (3), (4) and (6) we may rewrite equilibrium in rural markets as

$$\varsigma_0^r - \varsigma_1^r p^{r,*} + \varsigma_2^r p^{\mathrm{ag}} = \frac{K^m A^m(I^{m,r,*})}{A^m(I^{m,r,*}) + B^m(I^{m,u,*})} + \frac{K^f A^f(I^{f,r,*})}{A^f(I^{f,r,*}) + B^f(I^{f,u,*})}. \tag{7}$$

It should not be a surprise that scaling up the stocks of male and female DVMs, by allowing $K^m \to \lambda K^m$ and $K^f \to \lambda K^f$ with $\lambda > 1$, will decrease both $p^{r,*}$ and $p^{u,*}$.

Instead of dwelling on other, quite intuitive, sensitivities, we inquire into how a change in gender share, while keeping total stock fixed, affects the equilibrium value of p^r. Notice that the rural service price arises in each index in (7). In the appendix we show the following:

$$\frac{dp^{r,*}}{dK^f}\Big|_{\substack{K \text{ held} \\ \text{fixed}}} \overset{\text{sign}}{=} S^{m,r,*}(\cdot) - S^{f,r,*}(\cdot), \tag{8}$$

where again the superscripted * signifies evaluation at market equilibrium. Hence,

Proposition 1: *Suppose that the proportion of all female veterinarians that practice in rural locations is smaller than the proportion of all male veterinarians that practice in rural locations. Then an increase in the share of female veterinarians, while holding the total stock of veterinarians fixed, will increase the price of rural veterinary services and decrease the price of urban veterinary services.*

The effect on urban service price, $p^{u,*}$, is obtained from (4). To be explicit about implications of (8), use the expressions in (2) to obtain

$$S^{m,r,*}(\cdot) - S^{f,r,*}(\cdot) \overset{\text{sign}}{=} \frac{A^m(\alpha^{m,r} + \alpha^m p^{r,*} + \alpha^{m,\text{la}} z^{\text{la},r} + \alpha^{m,\text{sm}} z^{\text{sm},r})}{B^m\left(\alpha^{m,u} + \alpha^m p^{u,*} + \alpha^{m,\text{la}} z^{\text{la},u} + \alpha^{m,\text{sm}} z^{\text{sm},u}\right)} - \frac{A^f(\alpha^{f,r} + \alpha^f p^{r,*} + \alpha^{f,\text{la}} z^{\text{la},r} + \alpha^{f,\text{sm}} z^{\text{sm},r})}{B^f\left(\alpha^{f,u} + \alpha^f p^{u,*} + \alpha^{f,\text{la}} z^{\text{la},u} + \alpha^{f,\text{sm}} z^{\text{sm},u}\right)}. \tag{9}$$

For the sake of clarification in argument, suppose differences in preferences between male and female preferences are captured entirely by preference indices and furthermore, as is standard in logistic analysis, that the index transformation functions are exponential. Let this function be of form $e^{\eta I}$, $\eta > 0$, so that the right-hand side in (9) becomes

$$\begin{aligned}
&\frac{e^{\eta I^{m,r}}}{e^{\eta I^{m,u}}} - \frac{e^{\eta I^{f,r}}}{e^{\eta I^{f,u}}} \overset{\text{sign}}{=} \Delta + (\alpha^m - \alpha^f)(p^{r,*} - p^{u,*});\\
&\Delta = \Delta^{m-f,r-u} + \Delta^{m-f,\text{la}}(z^{\text{la},r} - z^{\text{la},u}) + \Delta^{m-f,\text{sm}}(z^{\text{sm},r} - z^{\text{sm},u});\\
&\Delta^{m-f,r-u} \equiv \alpha^{m,r} - \alpha^{m,u} - \alpha^{f,r} + \alpha^{f,u};\\
&\Delta^{m-f,\text{la}} \equiv \alpha^{m,\text{la}} - \alpha^{f,\text{la}};\\
&\Delta^{m-f,\text{sm}} \equiv \alpha^{m,\text{sm}} - \alpha^{f,\text{sm}}.
\end{aligned} \tag{10}$$

Therefore,

$$\frac{dp^{r,*}}{dK^f}\Big|_{\substack{K \text{ held}\\ \text{fixed}}} \overset{\text{sign}}{=} \Delta + (\alpha^m - \alpha^f)(p^{r,*} - p^{u,*}). \tag{11}$$

Let us dwell for a moment on Δ, its sign and its composition. Component $\Delta^{m-f,r-u} \equiv \alpha^{m,r} - \alpha^{m,u} - \alpha^{f,r} + \alpha^{f,u}$ is a difference in difference or comparative preference. It is positive if, all else equal, male veterinarians prefer rural locations more than female veterinarians do. Note that $\alpha^{m,r} - \alpha^{m,u}$ and $\alpha^{f,r} - \alpha^{f,u}$ can both be negative and yet the difference can be positive. The preponderance of males and females can both dislike rural life intensely. What matters here is comparative preference. Thus if the occupation pool shifts increasingly toward female practitioners then female rural salaries will have to rise in order to draw professionals, be they male or female toward rural locations. Component $\Delta^{m-f,\text{la}}(z^{\text{la},r} - z^{\text{la},u})$ is the product of the male-female preference differential for large animals, $\alpha^{m,\text{la}} - \alpha^{f,\text{la}}$, and the rural practice to urban practice differential in large animals, $z^{\text{la},r} - z^{\text{la},u}$. Presumably $z^{\text{la},r} > z^{\text{la},u}$ so that if men have a comparative preference in treating large animals then $\Delta^{m-f,\text{la}}(z^{\text{la},r} - z^{\text{la},u}) > 0$, Δ will be more positive (or less negative) and the shift toward a more female profession is more likely to increase rural veterinary income. Quantity $\Delta^{m-f,\text{sm}}(z^{\text{sm},r} - z^{\text{sm},u})$ can be interpreted similarly. We summarize as follows.

Proposition 2: *Suppose that i) female and male preferences for income are the same, or* $\alpha^m = \alpha^f$*. Then an increase in the share of female veterinarians, while holding the total stock of veterinarians fixed, will increase the price of rural veterinary services and decrease the price of urban veterinary services if and only if* $\Delta > 0$.

ii) female preference for income is greater than male preference for income, or $\alpha^m < \alpha^f$*, and also that equilibrium income in rural practice is less than that in urban practice. Then* $\Delta > 0$ *is a sufficient condition for an increase in the share of female veterinarians, while holding the total stock of veterinarians fixed, to increase the price of rural veterinary services and decrease the price of urban veterinary services.*

iii) female preference for income is less than male preference for income, or $\alpha^m > \alpha^f$*, and also that equilibrium income in rural practice is greater than that in urban practice. Then* $\Delta > 0$ *is a sufficient condition for an increase in the share of female veterinarians, while holding the total stock of veterinarians fixed, to increase the price of rural veterinary services and decrease the price of urban veterinary services.*

Two further comments are warranted. It may seem to be somewhat circular to explain a derivative of rural returns to veterinary practice as a function of the magnitude of those returns, as is the case in expression (11). Terms included in Δ and also $\alpha^m - \alpha^f$ affect the value of $p^{r,*}$ so direct consideration of Δ and $\alpha^m - \alpha^f$ do not capture all of their impacts on the derivative.

This would be a concern were parameters in Δ and $\alpha^m - \alpha^f$ the only determinants of $p^{r,*}$ and $p^{u,*}$. However agricultural output prices, p^{ag}, area income, Y, aggregate veterinarian stock, K, and female component, K^f, all have independent impacts on rural and urban returns to practice. So we can be sure that very high area income will push up willingness to pay for companion animal services so that $p^{r,*} < p^{u,*}$ can occur independent of parameters in Δ and $\alpha^m - \alpha^f$ while very high agricultural output prices will ensure that $p^{r,*} > p^{u,*}$ regardless of parameters in Δ and $\alpha^m - \alpha^f$.

Finally, consider when $\Delta + (\alpha^m - \alpha^f)(p^{r,*} - p^{u,*}) > 0$. Then a shift toward a more female veterinary profession further increases rural incomes, decreases urban professional incomes and maintains the sign of $\Delta + (\alpha^m - \alpha^f)(p^{r,*} - p^{u,*})$. However, the comparative static can also work at cross purposes. If $\Delta + (\alpha^m - \alpha^f)(p^{r,*} - p^{u,*}) > 0$, $\alpha^m < \alpha^f$ and $p^{r,*} \geq p^{u,*}$ then an increase in K^f could lead to a switch in the sign of $\Delta + (\alpha^m - \alpha^f)(p^{r,*} - p^{u,*})$ so that any further increase in K^f would cause a decrease in $p^{r,*}$ and an increase in $p^{u,*}$. Monotonicity in sign is not guaranteed.

4. Materials and Methods

4.1. Data collection and management

For the analysis the unit of concern was the county or county set in the United States' 48 contiguous states. Alaska, Hawaii and unincorporated territories were excluded in large part because their extreme geographic features would distort findings.

The number of veterinarians in a county or county set in years 1990, 2000 and 2010 were obtained from Equal Employment Opportunity (EEO) tabulations. Data for 2010 were taken from the EEO tabulation of 2006-2010, which is comparable to tabulations from 1990 and 2000 censes. EEO tabulation data contain the number of female, male and total veterinarians. Note that EEO Tabulation data in years 2000 and 2010 use county sets. County sets are aggregations of one or more contiguous counties such that the aggregated human population exceeds 50,000. EEO Tabulation data for 1990, however, are provided for each county, regardless of population. For the purpose of consistency, we have grouped counties in the 1990 dataset into the county set defined in both 2000 and 2010. As these two regrouped datasets lead to very similar model estimates, therefore we will only present results from the 1990 dataset when grouping by 2000 county sets.

For each county, livestock species numbers were obtained from the USDA Census of Agriculture from census years 1992, 2002 and 2007. Data for livestock were all cattle (labeled cattle), all hogs (hogs) and all horses (horses). Consistent and reliable data were not available on pet populations at the county level of analysis. Thus, we choose nonfarm animal caretakers as a proxy variable for pets. According to the Bureau of Labor Statistics, these animal caretaker duties are to "Feed, water, groom, bathe, exercise, or otherwise care for pets and other nonfarm animals, such as dogs, cats, ornamental fish or birds, zoo animals, and mice." The source of nonfarm animal caretakers is also EEO Tabulation data.

We also included two other demographic variables to capture willingness to pay for veterinarian services. These variables were the county set's human population in 1990, 2000 and 2010, and the average per capita income data from the preceding year. These data were extracted from U.S. Census Bureau, decennial censi conducted in 1990, 2000 and 2010.

The Index of Relative Rurality (IRR) was also obtained for each county. This index is based on four dimensions, being a county's population, population density, extent of urbanized (built-up) area and distance to the nearest metro area (Waldolf, 2006). This variable was included in the model to account for how rurality can affect equilibrium spatial location of veterinarians through how it enters their preferences and costs of doing business.

Distance to the nearest veterinary college, as calculated by CDXZipStream software, was obtained for each county set. For a detailed description of the method, see Wang et al. (2012). To account for distinctive effects associated with counties in which a veterinary college is located, we distinguished these counties by use of a veterinary college indicator variable labeled 'college.' For the purpose of analysis, we have converted the spatial reference unit for all the variables into county sets. Table 1 provides summary statistics for all county set level variables.

4.2. Models

A bivariate Tobit model to capture possible interdependence between female and male veterinarian locations. This interdependence could be due to location of practices in larger market towns that can serve plural counties, to marriage between veterinarians or to other omitted variables. The model can be specified as the following form:

$$y_{1i}^* = x_i'\beta_1 + u_{1i}; \qquad y_{1i} = \max\{y_{1i}^*, 0\}; \tag{12}$$

$$y_{2i}^* = x_i'\beta_2 + u_{2i}; \qquad y_{2i} = \max\{y_{2i}^*, 0\}; \tag{13}$$

where y_{1i}^* and y_{2i}^* are latent variables for female and male veterinarians, respectively. Their censored counterparts are y_{1i} and y_{2i}, which are the observed numbers of female and male veterinarians. The vector of explanatory variables is denoted by x_i, which include animal caregiver, cattle, hogs, horses, (human) population, income, college, distance to college and the rurality index; while u_{1i} and u_{2i} are the error terms that take a bivariate normal distribution, $BVN(x_i'\beta_1, x_i'\beta_2, \sigma_1^2, \sigma_2^2, \rho)$. Here σ_1^2 and σ_2^2 are the standard deviations of the marginal distributions for latent variables y_{1i}^* and y_{2i}^*, while ρ stands for the correlation coefficient. Note that the coefficient estimate in the Bivariate Tobit model reflects how a unit change in an independent variable affects the expected value of the latent dependent variable, i.e., $\partial E(y^*) / \partial x_k = \beta_k$. The marginal effect on the expected value of the dependent variable is calculated as $\partial E(y)/\partial x_k = \Phi(X\beta/\sigma)\beta_k$ (McDonald and Moffitt, 1980) where $\Phi(\cdot)$ is the cumulative normal distribution function.

In order to supplement insights from regressions (12)-(13), we also include two logistic regression models. In Logistic Model A, our response variables take binary values; 1 whenever the county has at least one veterinarian and 0 otherwise. The intent is to shed light on factors determining the presence of a veterinarian and how their importance has changed over time without regard to gender. For Logistic Model B we use only the subset of county sets which contain at least one veterinarian. The response variable is assigned value 1 if female veterinarians outnumber male veterinarians and 0 otherwise. The intent is to consider determinants of gender composition and its change over time without regard to the number of veterinarians in the county set. Both Model A and Model B can be expressed in the form:

$$\begin{aligned}\ln\left(\frac{s_i}{1-s_i}\right) &= \gamma_0 + \gamma_1\text{caregiver}_i + \gamma_2\text{cattle}_i + \gamma_3\text{hogs}_i + \gamma_4\text{horses}_i + \gamma_5\text{population}_i \\ &\quad + \gamma_6\text{income}_i + \gamma_7\text{college}_i + \gamma_8\text{distance}_i + \gamma_9\text{rurality}_i + \eta_i,\end{aligned} \tag{14}$$

where η_i represents the random error term. In Model A, s_i is the estimated probability that the *i*th county has at least one veterinarian, whereas in Model B, s_i can be viewed as the estimated probability that there are more female veterinarians in the *i*th county. The bivariate Tobit model and the Logistic models specified in this section were estimated using SAS 9.2.

5. Results

5.1. Descriptive Statistics

From Table 1 we can see that at the county set level, the national average number of male veterinarian has changed little over the past two decades. However, the number of female veterinarians has increased by 173% over the same period, surpassing male veterinarians slightly by 2010. At the regional level, statistics as depicted by Table 2 show that the number of male veterinarians declined in the Northeast and Midwest but increased in the South and West, regions with more rapidly expanding human populations. The number of female veterinarians increased by well over 100% in all four regions. Among all regions, Midwest experienced the slowest increase in total veterinarian number while West experienced the fastest growth.

In Table 3, veterinarians are grouped by rurality index. We can see that about 60% of male veterinarians are working in the 30%ile most urban areas and about 16% work in the 30%ile most rural areas. These fractions have not changed much over the years. Compared to their male counterparts, female veterinarians have been more concentrated in urban areas throughout the years. Around 70% of the female veterinarians work in urban areas, while only about 10% work in rural areas and the fraction has shrunk somewhat over the decades. Location choices suggest more female veterinarians are working with small animals. Since 16% > 9%, these data support $S^{m,r,*}(\cdot) - S^{f,r,*}(\cdot)$ in Proposition 1 and so suggest that a shift in profession gender composition toward females, holding total stock fixed, should increase rural salaries and decrease urban salaries.

A proxy variable for the unknown number of pets, animal caretaker, demonstrated a steady increase from 1990 to 2010 (Table 1), mirroring an increase in pet industry expenditures as revealed by American Pet Products Association (APPA)'s survey (http://www.americanpetproducts.org/press_industrytrends.asp, visited on 5/21/2014). The number of animal caretakers increased by 69% over the period.

Among livestock populations, cattle numbers have remained about the same across the past three decades. However this population is more concentrated than before, as the maximum number increased from 1.4 million in 1992 to 1.9 million in 2007. In similar manner, spatial concentration has occurred in the hog industry with the maximum hog number in 2007 doubled when compared to 1992. The horse population has increased by 91% over the period, increasing dramatically between 1990 and 2000. The average rurality index value has declined across the years, indicating an urbanization effect experienced by many areas.

5.2. Model estimates and interpretation

5.2.1. Bivariate Tobit model

Tables 4 shows the coefficient estimates of the Bivariate Tobit model, along with marginal effects, ME, for different dependent variables. Table 5 shows response elasticities, as computed from Table 4 coefficients and Table 1 variable means. Response elasticities are computed as $(\text{ME for } x)\times\bar{x}/\bar{y}$ where $\bar{x}$ is the regressor variable mean.

A review of Table 5 indicates that both male and female DVMs are responsive to animal caregivers. Males are more responsive to cattle than are females, and female responsiveness is declining. Male responsiveness to swine is very low while women DVMs are no longer responsive to the presence of swine. These estimates reflect the declining relevance of farmed animals for the veterinary profession at large. Amongst large animals, DVMs are most responsive to horses. This sensitivity appears to have weakened somewhat over time among women DVMs but has held steady among men.

Sensitivity to population is not strong, where inclusion of animal caretakers may have adequately controlled for how pet numbers vary with the human population. DVM employment is very sensitive to per capita income. This sensitivity reflects a likely strong pet service elasticity in response to household income. When compared with men, the extent of women DVMs in a region is markedly more sensitive to income. Women DVMs are also comparatively more responsive to the presence of a college in the county set. Although the signs are generally as is to be expected, distance to a veterinary college is not important.

DVMs are averse to rurality while women DVMs have become markedly more averse to rurality over time. Bear in mind that these three snap-shot regressions over time are not to be taken as evidence that DVMs are moving out of rural areas. Data in Table 3 establish that veterinarian presence in the most rural areas has grown by 54% since 1990, roughly equal to growth in the most urban areas although one should bear in mind that the whole country has become less rural. Since 2000, the number of veterinarians in the 30%ile most rural areas has grown by 11%, while growth in the most urban areas has been 28%. Given the growth in overall stock of veterinarians, it is only in a relative sense that they increasingly shun rural areas. Since 2000, a disproportionate fraction of the net increase in DVMs has chosen to locate in metropolitan areas.

5.2.2. Logistic model A

Table 6 lists the coefficient and point estimates for Logistic model A, where the dependent variable takes value 1 if there were at least one veterinarian in the county set and 0 otherwise. For 1990, statistically significant variables are the proxy for companion animals (caregiver) as well as cattle, hogs and horses. Note that when cattle number increases by one unit (i.e., 1,000 cattle), then the odds ratio for veterinarian availability increased by factor 1.012. The odds ratio increase for hogs and horses were 1.009 and 1.294, respectively. It is intuitive, and consistent with our formal model, that when animal value increases then the odds ratio for veterinarian availability will also increase. As a low value animal, hogs no longer had a significant impact on veterinarian availability in 2000 and 2010.

When per capita income increases by $1,000, the odds ratio for veterinarian availability also increases by about 1.3 in each of the three census years. This indicates that area income directly affects expenditure on veterinarian services. Income generally plays a more important role than the number of animals. Rurality also became significant in 2010, though it was not in 1990 and 2000. In 2010, when rurality increases by one unit (i.e., from most urban to most rural), the odds ratio for veterinarian presence increases by the factor 8.11. It appears that veterinary practices are being set up in locations that were passed over by earlier DVM cohorts. Note however that the average number of veterinarians in more rural places is generally lower compared to the urban areas (tables 3 and 4). This phenomenon may also explain the declining magnitudes across time of many coefficients in Table 6. If veterinarians are present almost everywhere then many factors influencing demand explain the number of veterinarians but no longer explain their presence.

The point estimate for veterinary college is greater than 999.99, meaning that veterinarians can definitely be found if there is a veterinarian college located in the same place. It is not significant however, because veterinarians also exist in places where no veterinary college exists. Distance to a veterinary college had a negative impact on veterinarian presence but, as tables 4 and 5 also suggests, it has declined in significance.

5.2.2. Logistic model B

The purpose of logistic model B is to determine potential factors that cause female veterinarians to outnumber male veterinarians in a county set. Results are displayed in Table 7. A pattern that rings clear across the years is that whenever cattle and hog numbers increase in a region then the male share in all DVMs increases. Turning to our proxy for pets, in 1990 the probability that female veterinarians outnumbered male veterinarians fell as the number of animal caregivers increased. In 2000 and 2010 this is no longer the case. Instead, income and college became significant in these two years. Specifically, when either income increases or a veterinary college is present in an area then the odds that female veterinarians outnumber male veterinarians significantly increases. There is also some evidence of declining interest among women DVMs in caring for horses. The overall picture then is that although the number of female veterinarians has greatly increased, they have been drawn to work on companion animals, in colleges, and in higher income areas.

6. Conclusions and Discussion

In this article we have studied how market forces and the increasing supply of veterinarians have affected veterinarian location and veterinarian activities in the United States between 1990 and 2010. We have paid particular attention to the increasing supply of female veterinarians. Two findings that pertain to large animals are that presence of swine in an area have marginal impact on veterinarian demand while cattle and horses are increasingly served by male veterinarians. Female veterinarians are very sensitive to companion animal numbers and to an area's average per capita income. Having sought to control for other factors, our results suggest that both genders express a disinclination to locate in rural areas and also that this disinclination has grown over time. A logistic model seeking to account for presence of a veterinarian on an area suggests that practitioners have competed by locating in places that were passed over by previous generations of practitioners.

It remains for future work to address why students with promising alternative career paths have been willing to incur substantial debt in order to enter a profession with salaries that are low when compared with medical careers requiring comparable training. If widespread public disquiet about overcapacity has provided insufficient warning then surely widely available information about low and declining salaries should have sufficed? Do students assume that those responsible for that capacity are well-incentivized to match supply with demand? Have political considerations peculiar to Land Grant Institutions played a role? To what extent are student loans a factor? When compared with other medical professions, are prospective student veterinarians distinctively vocation-drive or particularly naïve? Why have other medical professions escaped this excess capacity outcome? Might DVM specializations that reduce movement between farmed animal and companion animal sectors allow for more targeted capacity interventions?

It also remains for future work to establish guidance on prospective long-run veterinary service demand in a changing profession. Although the effects of changes in gender composition and refocusing toward companion animals may have largely run their course, other issues are emerging. Veterinary services are not as heavily regulated as disciplines in human medicine, providing animal owners with alternatives not available in the human medicine arena. Internet search now provides opportunities for lay diagnosis, however ill-advised.

Conflict of interest statement

The authors can identify no conflicts of interest that might have influenced this work.

References

AVMA (American Veterinary Medical Association), 2013. 2013 U.S. Veterinary Workforce Study: Modeling Capacity Utilization, Final Report. Center for Health Workforce Studies, University of Albany, April 16. Available at: https://www.avma.org/KB/Resources/Reports/Documents/Veterinarian-Workforce-Final-Report-LowRes.pdf

Brown, J.P., Silverman, J.D., 1999. The current and future market for veterinarians and veterinary medical services in the United States. Journal of the American Veterinary Medical Association, 215(2, July 15), 161-183.

DeNavas-Walt, C., Proctor, B.D., Smith, J.C., 2012. Income, Poverty, and Health Insurance Coverage in the United States: 2011. Current Population Report P60-243, United States Department of Commerce, United States Census Bureau, Washington DC, September.

DiCecio, R., Engemann, K.M., Owyang, M.T., Wheeler, C.H., 2008. Changing trends in the labor force: a survey. Federal Reserve Bank of St. Louis Review, 90(1), 47-62.

Dohoo, I., Martin, W., Stryhn, H., 2003. Veterinary Epidemiologic Research. AVC Inc., Prince Edward Island, Canada.

Getz, M., 1997. Veterinary Medicine in Economic Transition. Iowa State University Press, Ames IA.

Goldin, C., 2006. The quiet revolution that transformed women's employment, education, and family. American Economic Review, 96(2), 1-21.

Goldin, C., Katz, L.F., 2012. The Most Egalitarian of all Professions: Pharmacy and the Evolution of a Family-Friendly Occupation, National Bureau of Economic Research Working Paper 18410, Cambridge MA, September.

Goldin, C., Olivetti, C., 2013. Shocking labor supply: a reassessment of the role of World War II on women's labor supply. American Economic Review, 103(3), 257-262.

Heath, T.T., 2007. Longitudinal study of veterinary students and veterinarians: family and gender issues after 20 years. Australian Veterinary Journal, 85(7), 290-295.

Jelinski, M.D., Campbell, J.R., Naylor, J.M., Lawson, K.L., Derkzen, D., 2009. Factors associated with the career path choices of veterinarians in western Canada. Canadian Veterinary Journal, 50(6), 630-636.

Kelly, A.M., Allen, S.W., Beasley, V.R., Buntain, B., Childers, H.E., Fox, J.G., Getz, M., McNamara, T.S., Miller, G.Y., Osburn, B.I., Pauly, M.V., Quimby, F.W., Reed, W.M., Shadduck, J.A., Stoto, M.A., Sutherland, S.F., 2013. "Workforce Needs in Veterinary Medicine." Committee to Assess the Current and Future Workforce Needs in Veterinary Medicine; Board on Agriculture and Natural Resources; Board on Life Sciences; Division on Earth and Life Studies; National Research Council, Washington, DC, 334 pages, http://www.nap.edu/openbook.php?record_id=13413&page=1

Kleiner, M.M., 2006. Licensing Occupations: Ensuring quality or restricting competition? W.E. Upjohn Institute for Employment Research, Kalamazoo, MI.

Kostelnik, K., Lotz, F., Sötje, L., Heuwieser, W., 2010. Die Feminisierung der Tiermedizin und der Nachwuchsmangel in der Nutztierpraxis. Tierärztliche Praxis (in German with English abstract), 38(3), 156-164.

Lofstedt, J., 2003. Gender and veterinary medicine. Canadian Veterinary Journal, 44(7), 533-535.

MacDonald, J. Korb, P., 2011. Agricultural Contracting Update: Contracts in 2008. Economic Information Bulletin No. 72, United States Department of Agriculture, Economic Research Service, Washington DC, February.

McDonald, J.F., Moffitt, R.A., 1980. The uses of tobit analysis. Review of Economics and Statistics, 62(2), 318-321.

McFadden, D.L., 1974. Conditional logit analysis of qualitative choice behavior. In: Zarembka, P. (Ed.), Frontiers in Econometrics. Academic Press, New York, pp. 105-142.

Murray, C.A., 2012. Coming Apart: The state of white America, 1960-2010. Crown Forum, New York.

Narver, H.L., 2007. Demographics, moral orientation, and veterinary shortages in food animal and laboratory animal medicine. Journal of the American Veterinary Medical Association, 230(12, June 15), 1798-1804.

Nolen, R.S., 2013. Stakeholders respond to AVMA workforce study: AAHA, AAVMC, AAEP, AABP, AASV, SAVMA comment on excess capacity finding. Journal of the American Veterinary Medical Association, 242(11, June 1), 1449-1450.

Prince, J.B., Andrus, D.M., Gwinner, K.P., 2006. Future demand, probable shortages, and strategies for creating a better future in food supply veterinary medicine. Journal of the American Veterinary Medical Association, 229(1, July 1), 57-69.

Schmitz, J.A., Vogt, R.J., Rupp, G.P., Brodersen, B.W., Abel, J.M., Wohlers, A.R., Marx, D.B., 2007. Factors associated with practice decisions of Nebraska Veterinarians regarding type of practice and community size. Journal of Veterinary Medical Education, 34(3), 340-349.

U.S. Census Bureau, 2011. Table MS-2. Estimated Median Age at First Marriage, by Sex: 1890 to the Present. Release date: May 2011.

Villarroel, A., McDonald, S.R., Walker, W.L., Kaiser, L., Dewell, R.D., Dewell, G.A., 2010. A survey of reasons why veterinarians enter rural veterinary practice in the United States. Journal of the American Veterinary Medical Association, 236(8, April 15), 849-857.

Waldorf, B., 2006. A continuous multi-dimensional measure of rurality: moving beyond threshold measures. Annual meetings of the American Agricultural Economics Association, Long Beach, CA; July 23-26.

Wang, T., Hennessy, D.A., O'Connor, A.M., 2012. Where are the veterinarian shortage areas anyway? Preventive Veterinary Medicine, 104(3-4), 198-206.

Wessel, D., 2010. Harvard professor wonders: why are there so many women veterinarians? Wall Street Journal, January 4, http://blogs.wsj.com/economics/2010/01/04/harvard-prof-wonders-why-are-there-so-many-women-veterinarians/.

Table 1. County set descriptive statistics -1990[a], 2000 and 2010

Variable	Year	Mean	Std. Dev.	Min.-Max.	Year	Mean	Std. Dev.	Min.-Max.	Year	Mean	Std. Dev.	Min.-Max.
Male veterinarians	1990	24.84	39.84	0-749	2000	25.11	36.5	0-455	2010	24.68	39.54	0-690
Female veterinarians	1990	9.045	20.10	0-356	2000	16.40	30.8	0-380	2010	24.71	47.55	0-665
Animal caregiver	1990	73.52	138.51	0-1,105	2000	83.78	147.8	0-3,130	2010	124.47	236.2	0-4,485
Cattle ($\times 10^3$)	1992	67.92	114.36	0-1,401	2002	67.50	121.6	0-1,487	2007	66.42	132.4	0-1,902
Hogs ($\times 10^3$)	1992	40.07	110.33	0-1,235	2002	42.84	160.9	0-2,456	2007	46.80	188.7	0-2,584
Horses ($\times 10^3$)	1992	1.449	1.582	0-15	2002	2.580	2.465	0-26.97	2007	2.774	2.724	0-31.13
Population ($\times 10^3$)	1990	171.65	370.78	21-8,863	2000	194.97	410.0	25-9,519	2010	207.82	432.3	28-9,819
Distance (miles)	-----	125.74	92.56	0-666	-----	126.78	93.4	0-666.3	-----	121.04	81.61	0-602
Veter. College $\in \{0,1\}$	1990	0.019	0.137	0-1	2000	0.019	0.14	0-1	2010	0.019	0.14	0-1
Income ($\times 10^3$)	1989	9.748	2.521	2.6-21	1999	14.61	3.46	4.4-29.4	2009	17.76	4.210	6.8-44.0
Rurality $\in [0,1]$	1990	0.429	0.158	0-0.84	2000	0.381	0.18	0.04-0.74	2010	0.377	0.14	0-0.75

[a] County level data for 1990 are regrouped into the 1,409 county sets that were used in 2000.

Table 2. Veterinarians by Region, 1990-2010

	1990		2000		2010		Percent Change, 1990-2010		
	Male	Female	Male	Female	Male	Female	Male	Female	Total
Northeast	5,300	2,694	5,311	4,374	5,230	6,715	-1.3%	149.3%	49.4%
Midwest	10,073	2,932	9,747	5,779	9,460	8,020	-6.1%	173.5%	34.3%
South	12,748	4,374	13,162	7,729	13,490	12,505	5.8%	185.9%	51.9%
West	7,393	2,915	7,597	5,453	7,980	8,890	7.9%	205.0%	63.6%
U.S.	35,514	12,915	35,817	23,335	36,160	36,130	1.8%	179.8%	49.2%

Table 3. Veterinarians by Rural Index, 1990-2010*. Parentheses indicate the percentage of that gender.

	1990		2000		2010	
	Male	Female	Male	Female	Male	Female
30%ile most urban	21,023 (60.1%)	8,921 (70.0%)	20,222 (57.2%)	15,636 (67.7%)	21,425 (60.0%)	24,332 (68.0%)
30%ile most rural	5,479 (15.7%)	361 (10.1%)	5,851 (16.5%)	2,228 (9.64%)	5,918 (16.6%)	3,056 (8.54%)

*1990 data is regrouped in 2000 county set.

Table 4. Parameter estimates for *Bivariate Tobit* model –*Male and Female Veterinarians*

	1990				2000				2010			
	Male		Female		Male		Female		Male		Female	
Variable	Max Lik'hood (ML) Coeffi.	Marg. Effect (ME) Coeffi.	ML Coeffi.	ME Coeffi.	ML Coeffi.	ME Coeffi.	ML Coeffi.	ME Coeffi.	ML Coeffi.	ME Coeffi.	ML Coeffi.	ME Coeffi.
intercept	-5.46		-28.22		-17.56		-37.40		-18.99		-35.95	
caregiver	0.203	0.154[c]	0.057	0.028[c]	0.175	0.133[c]	0.144	0.088[c]	0.099	0.066[c]	0.152	0.087[c]
cattle	0.023	0.017[c]	0.002	0.001	0.026	0.020[c]	0.003	0.002	0.019	0.013[c]	-0.001	-0.0003
hogs	0.021	0.016[c]	0.005	0.003	0.009	0.007[b]	0.002	0.001	0.012	0.008[c]	-0.008	-0.004
horses	2.538	1.924[c]	1.802	0.884[c]	1.750	1.328[c]	0.718	0.436[b]	1.786	1.190[c]	1.472	0.839[c]
population	0.011	0.008[b]	0.021	0.010[c]	0.001	0.0009	0.003	0.002	0.017	0.011[c]	-0.001	-0.0007
income	1.724	1.307[c]	2.326	1.142[c]	1.778	1.35[c]	2.517	1.528[c]	1.476	0.983[c]	2.498	1.425[c]
college	37.83	28.68[c]	35.67	17.50[c]	32.99	25.04[c]	55.03	33.41[c]	26.68	17.78[c]	66.23	37.76[c]
distance	-0.022	-0.016[c]	-0.005	-0.002	0.011	0.008	-0.000	-0.000	-0.001	-0.000	-0.005	-0.003
rurality	-21.98	-16.66[c]	-6.552	-3.215[a]	-22.70	-17.23[c]	-10.10	-6.128[a]	-30.17	-20.1[c]	-45.52	-25.96[c]
rho	18.422[c]		14.595[c]		21.33[c]		19.602[c]		27.04[c]		32.61[c]	

Notes: a, b and c indicate significance at 10%, 5% and 1% levels, respectively.

Table 5. Response elasticities based on Bivariate Tobit model –Male and Female Veterinarians

	caregiver	cattle	hogs	horses	population	income	college	distance	rurality
Female, 1990	0.228	0.008	0.013	0.142	0.190	1.230	0.037	-0.028	-0.152
Male, 1990	0.456	0.046	0.025	0.112	0.055	0.513	0.022	-0.081	-0.288
Female, 2000	0.450	0.009	0.004	0.069	0.020	1.361	0.039	0	-0.142
Male, 2000	0.444	0.053	0.012	0.136	0.007	0.785	0.019	0.042	-0.261
Female, 2010	0.436	0	-0.008	0.094	-0.006	1.024	0.029	-0.013	-0.396
Male, 2010	0.334	0.034	0.015	0.134	0.093	0.708	0.014	-0.002	-0.307

Table 6. Parameter estimates for *Logistic* model A (1=there is at least one veterinarian in the county set)

	1990		2000		2010	
Variable	ML Coeffi.	Point Estimate	ML Coeffi.	Point Estimate	ML Coeffi.	Point Estimate
intercept	-2.5903	–	-4.2390	–	-5.3430	–
caregiver	0.0248	1.025[c]	0.0160	1.017[b]	0.0037	1.004[c]
cattle	0.0121	1.012[c]	0.0067	1.007[b]	0.0057	1.006[b]
hogs	0.0089	1.009[c]	0.0006	1.001	-0.0001	1.000
horses	0.2579	1.294[a]	0.3123	1.367[b]	0.0478	1.049[c]
population	0.0070	1.007	0.0113	1.011[b]	0.0141	1.014
income	0.2542	1.289[c]	0.3135	1.368[c]	0.2649	1.303[c]
college	13.472	>999.9	12.3413	>999.99	14.377	>999.99
distance	-0.0022	0.998[a]	-0.0012	0.999	-0.0014	0.999
rurality	0.5077	1.661	0.9907	2.693	2.0931	8.110[a]

Notes: a, b and c indicate significance at 10%, 5% and 1% levels, respectively.

Table 7. Parameter estimates for *Logistic* model B (1=female veterinarian outnumbers male veterinarian in the county set where at least one veterinarian exists)

	1990		2000		2010	
Variable	ML Coeffi.	Point Estimate	ML Coeffi.	Point Estimate	ML Coeffi.	Point Estimate
intercept	-2.748	–	-1.222	–	-0.682	–
caregiver	-0.005	0.995[b]	0.001	1.001	0.0008	1.001
cattle	-0.005	0.995[c]	-0.004	0.996[b]	-0.002	0.998[b]
hogs	-0.003	0.997[a]	-0.002	0.998[a]	-0.003	0.997[c]
horses	0.030	1.031	-0.082	0.921[a]	-0.015	0.985
population	0.001	1.001	-0.0004	1.000	-0.0004	1.000
income	0.053	1.055	0.055	1.057[b]	0.049	1.050[c]
college	0.783	2.187	1.409	4.093[c]	0.794	2.212[a]
distance	0.002	1.002[b]	-0.001	0.999	-0.0005	0.999
rurality	1.032	2.807	-0.885	0.413	-0.493	0.611

Notes: a, b and c indicate significance at 10%, 5% and 1% levels, respectively.

Appendix

<u>Demonstration of relation (8)</u>:

Bearing in mind that $K^m \equiv K - K^f$, completely differentiate (7) with respect to $p^{r,*}$ and K^f to obtain

$$\begin{Bmatrix} -\frac{K^m A_I^m(I^{m,r,*})}{A^m(I^{m,r,*})+B^m(I^{m,u,*})}\frac{dI^{m,r,*}}{dp^{r,*}} + \frac{K^m A_I^m(I^{m,r,*})A^m(I^{m,r,*})}{[A^m(I^{m,r,*})+B^m(I^{m,u,*})]^2}\frac{dI^{m,r,*}}{dp^{r,*}} \\ +\frac{K^m B_I^m(I^{m,u,*})A^m(I^{m,r,*})}{[A^m(I^{m,r,*})+B^m(I^{m,u,*})]^2}\frac{dI^{m,u,*}}{dp^{r,*}} - \frac{K^f A_I^f(I^{f,r,*})}{A^f(I^{f,r,*})+B^f(I^{f,u,*})}\frac{dI^{f,r,*}}{dp^{r,*}} \\ +\frac{K^f A_I^f(I^{f,r,*})A^f(I^{f,r,*})}{[A^f(I^{f,r,*})+B^f(I^{f,u,*})]^2}\frac{dI^{f,r,*}}{dp^{r,*}} + \frac{K^f B_I^f(I^{f,r,*})A^f(I^{f,u,*})}{[A^f(I^{f,r,*})+B^f(I^{f,u,*})]^2}\frac{dI^{f,u,*}}{dp^{r,*}} - \varsigma_1^r \end{Bmatrix} dp^{r,*} \tag{A1}$$
$$= \left\{S^{f,r,*}(\cdot) - S^{m,r,*}(\cdot)\right\} dK^f \big|_{\substack{K \text{ held} \\ \text{fixed}}},$$

which may be re-written as

$$\begin{Bmatrix} -\varsigma_1^r - \frac{K^m A_I^m(I^{m,r,*})B^m(I^{m,u,*})}{[A^m(I^{m,r,*})+B^m(I^{m,u,*})]^2}\frac{dI^{m,r,*}}{dp^{r,*}} + \frac{K^m B_I^m(I^{m,u,*})A^m(I^{m,r,*})}{[A^m(I^{m,r,*})+B^m(I^{m,u,*})]^2}\frac{dI^{m,u,*}}{dp^{r,*}} \\ -\frac{K^f A_I^f(I^{f,r,*})B^f(I^{f,u,*})}{[A^f(I^{f,r,*})+B^f(I^{f,u,*})]^2}\frac{dI^{f,r,*}}{dp^{r,*}} + \frac{K^f B_I^f(I^{f,u,*})A^f(I^{f,r,*})}{[A^f(I^{f,r,*})+B^f(I^{f,u,*})]^2}\frac{dI^{f,u,*}}{dp^{r,*}} \end{Bmatrix} dp^{r,*} \tag{A2}$$
$$= \left\{S^{f,r,*}(\cdot) - S^{m,r,*}(\cdot)\right\} dK^f \big|_{\substack{K \text{ held} \\ \text{fixed}}}.$$

Some algebra then establishes

$$\begin{Bmatrix} \left[\frac{B_I^m(I^{m,u,*})}{B^m(I^{m,u,*})}\frac{dI^{m,u,*}}{dp^{r,*}} - \frac{A_I^m(I^{m,r,*})}{A^m(I^{m,r,*})}\frac{dI^{m,r,*}}{dp^{r,*}}\right]\frac{A^m(I^{m,r,*})B^m(I^{m,u,*})}{[A^m(I^{m,r,*})+B^m(I^{m,u,*})]^2}K^m \\ +\left[\frac{B_I^f(I^{f,r,*})}{B^f(I^{f,u,*})}\frac{dI^{f,u,*}}{dp^{r,*}} - \frac{A_I^f(I^{f,r,*})}{A^f(I^{f,r,*})}\frac{dI^{f,r,*}}{dp^{r,*}}\right]\frac{A^f(I^{f,r,*})B^f(I^{f,u,*})}{[A^f(I^{f,r,*})+B^f(I^{f,u,*})]^2}K^f - \varsigma_1^r \end{Bmatrix} dp^{r,*} \tag{A3}$$
$$= \left\{S^{f,r,*}(\cdot) - S^{m,r,*}(\cdot)\right\} dK^f \big|_{\substack{K \text{ held} \\ \text{fixed}}},$$

and so

$$\left\{\begin{array}{l}\left(\frac{d\ln[B^m(I^{m,u,*})]}{dI^{m,u,*}}\frac{dI^{m,u,*}}{dp^{r,*}}-\frac{d\ln[A^m(I^{m,r,*})]}{dI^{m,r,*}}\frac{dI^{m,r,*}}{dp^{r,*}}\right)S^{m,r,*}(\cdot)S^{m,u,*}(\cdot)K^m+\\ \left(\frac{d\ln[B^f(I^{f,u,*})]}{dI^{f,u,*}}\frac{dI^{f,u,*}}{dp^{r,*}}-\frac{d\ln[A^f(I^{f,r,*})]}{dI^{f,r,*}}\frac{dI^{f,r,*}}{dp^{r,*}}\right)S^{f,r,*}(\cdot)S^{f,u,*}(\cdot)K^f-\varsigma_1^r\end{array}\right\}dp^{r,*} \tag{A4}$$
$$=\left\{S^{f,r,*}(\cdot)-S^{m,r,*}(\cdot)\right\}dK^f\,\Big|_{\substack{K\text{ held}\\ \text{fixed}}}.$$

Finally,

$$\frac{dp^{r,*}}{dK^f}\Big|_{\substack{K\text{ held}\\ \text{fixed}}}=\frac{S^{f,r,*}(\cdot)-S^{m,r,*}(\cdot)}{\left\{\begin{array}{l}\left(\frac{d\ln[B^m(I^{m,u,*})]}{dI^{m,u,*}}\frac{dI^{m,u,*}}{dp^{r,*}}-\frac{d\ln[A^m(I^{m,r,*})]}{dI^{m,r,*}}\frac{dI^{m,r,*}}{dp^{r,*}}\right)S^{m,r,*}(\cdot)S^{m,u,*}(\cdot)K^m+\\ \left(\frac{d\ln[B^f(I^{f,u,*})]}{dI^{f,u,*}}\frac{dI^{f,u,*}}{dp^{r,*}}-\frac{d\ln[A^f(I^{f,r,*})]}{dI^{f,r,*}}\frac{dI^{f,r,*}}{dp^{r,*}}\right)S^{f,r,*}(\cdot)S^{f,u,*}(\cdot)K^f-\varsigma_1^r\end{array}\right\}}. \tag{A5}$$

Now the denominator can be signed as follows:

$$\overbrace{\left(\overbrace{\frac{d\ln[B^m(I^{m,u,*})]}{dI^{m,u,*}}}^{>0}\overbrace{\frac{dI^{m,u,*}}{dp^{r,*}}}^{<0}-\overbrace{\frac{d\ln[A^m(I^{m,r,*})]}{dI^{m,r,*}}}^{>0}\overbrace{\frac{dI^{m,r,*}}{dp^{r,*}}}^{>0}\right)}^{<0}\overbrace{S^{m,r,*}(\cdot)S^{m,u,*}(\cdot)K^m}^{>0}$$
$$+\overbrace{\left(\overbrace{\frac{d\ln[B^f(I^{f,u,*})]}{dI^{f,u,*}}}^{>0}\overbrace{\frac{dI^{f,u,*}}{dp^{r,*}}}^{<0}-\overbrace{\frac{d\ln[A^f(I^{f,r,*})]}{dI^{f,r,*}}}^{>0}\overbrace{\frac{dI^{f,r,*}}{dp^{r,*}}}^{>0}\right)}^{<0}\overbrace{S^{f,r,*}(\cdot)S^{f,u,*}(\cdot)K^f}^{>0}-\overbrace{\varsigma_1^r}^{>0}<0. \tag{A6}$$

<u>Demonstration of relation (10)</u>:

$$
\begin{aligned}
\frac{e^{\eta I^{m,r}}}{e^{\eta I^{m,u}}} - \frac{e^{\eta I^{f,r}}}{e^{\eta I^{f,u}}} &= e^{\eta(I^{m,r} - I^{m,u})} - e^{\eta(I^{f,r} - I^{f,u})} \\
&= e^{\eta\left(\alpha^{m,r} - \alpha^{m,u} + \alpha^{m}(p^{r,*} - p^{u,*}) + \alpha^{m,\mathrm{la}}(z^{\mathrm{la},r} - z^{\mathrm{la},u}) + \alpha^{m,\mathrm{sm}}(z^{\mathrm{sm},r} - z^{\mathrm{sm},u})\right)} \\
&\quad - e^{\eta\left(\alpha^{f,r} - \alpha^{f,u} + \alpha^{f}(p^{r,*} - p^{u,*}) + \alpha^{f,\mathrm{la}}(z^{\mathrm{la},r} - z^{\mathrm{la},u}) + \alpha^{f,\mathrm{sm}}(z^{\mathrm{sm},r} - z^{\mathrm{sm},u})\right)} \\
&\overset{\mathrm{sign}}{=} \Delta + (\alpha^{m} - \alpha^{f})(p^{r,*} - p^{u,*}); \\
\Delta = \Delta^{m-f,r-u} &+ \Delta^{m-f,\mathrm{la}}(z^{\mathrm{la},r} - z^{\mathrm{la},u}) + \Delta^{m-f,\mathrm{sm}}(z^{\mathrm{sm},r} - z^{\mathrm{sm},u}); \\
\Delta^{m-f,r-u} &\equiv \alpha^{m,r} - \alpha^{m,u} - \alpha^{f,r} + \alpha^{f,u}; \\
\Delta^{m-f,\mathrm{la}} &\equiv \alpha^{m,\mathrm{la}} - \alpha^{f,\mathrm{la}}; \\
\Delta^{m-f,\mathrm{sm}} &\equiv \alpha^{m,\mathrm{sm}} - \alpha^{f,\mathrm{sm}}.
\end{aligned}
\tag{A7}
$$