Appendices to accompany: Health Care Spending in the US vs UK: The Roles of Medical Education Costs, Malpractice Risk and Defensive Medicine

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The document consists of Appendices A through H. Appendices A and B contain the proofs of propositions 3 and 4, respectively. Appendix C contains the proof that d^* and t^* maximize doctor's utility. Appendices D, E and F contain proofs of propositions 6, 8, 9 and 10. Appendix G shows how our model is extended to account for a risk of dropping out of medical school (suppressed in the text to conserve on notation). Appendix H contains our calculations of diagnostic spending levels in the US and UK.

A Proof of Proposition 3

This section presents a proof of comparative statics in partial equilibrium, in the model without consultation time (see Section 3.1).

Denote $y = w - \gamma f - p$ and $\bar{b} = b - \gamma f$, and $Z(d) = \frac{K'(d)}{\rho'(d)}$. Note that:

$$Z'(d^*) = \frac{-K''(d^*) - K'(d^*)\frac{\rho''(d^*)}{-\rho'(d^*)}}{-\rho'(d^*)} > 0$$

By total differentiation of 7 , we obtain:

$$\begin{aligned}
\frac{dd^*}{d\gamma} &= A_1\ f\ \left[u'(\bar{b}) - u'(y)\right] > 0 \\
\frac{dd^*}{dw} &= A_1\ u'(y) > 0 \\
\frac{dd^*}{dp} &= A_1\ [-u'(y)] < 0
\end{aligned}$$

$$\begin{aligned}
\frac{dd^*}{db} &= A_1\ [-u'(\bar{b})] < 0 \\
\frac{dd^*}{d\mu} &= A_1\ \frac{-\left[u(y) - u(\bar{b})\right]}{\mu} < 0
\end{aligned}$$

where $A_1 = \frac{\beta}{Z'(d^*)\mu\ [1-\beta(1-\rho(d^*))]}$, $A_1 > 0$.

Thus, as claimed, . QED

B Proof of Proposition 4

This section presents a proof of comparative statics in full equilibrium, in the model without consultation time, see Section 3.2.

Recall, equilibrium conditions are given by:

$$\begin{cases} u(w^* - \gamma f - p) - u(b - \gamma f) + \mu K(d^*) = & \frac{1-\beta(1-\rho(d^*))}{1-\beta} \cdot [u(w_o) - u(b - \gamma f)] \\ u(w^* - \gamma f - p) - u(b - \gamma f) + \mu K(d^*) = & \frac{\mu[1-\beta(1-\rho(d^*))]}{\beta} \cdot \frac{K'(d^*)}{\rho'(d^*)} \\ p = & (1+\alpha)\Psi\rho(d^*)M \end{cases}$$

Note that the left hand sides of the first two equilibrium equations are equal. Hence, we can write the optimal level of diagnostics as a function of $w_o, b - \gamma f$ and μ as follows:

$$\frac{K'(d^*)}{\rho'(d^*)} = \frac{\beta}{\mu(1-\beta)} [u(w_o) - u(b - \gamma f)] \tag{1}$$

Denote $Z(d) = \frac{K'(d)}{\rho'(d)}$. From our assumptions we have $Z'(d) > 0$ for $d > d_P^*$. Moreover, $Z(d_P^*) = 0$. To show that the equilibrium exists, the following condition must be satisfied:

$$Z(d_{max}) > \frac{\beta}{\mu(1-\beta)} [u(w_o) - u(b - \gamma f)] \tag{2}$$

Under this condition, equation (1) gives a solution for the level of diagnostics prescribed in equilibrium. Total differentiation of (1) yields:

$$\begin{aligned} \frac{dd^*}{d\gamma} &= A_2 \, f \, u'(b - \gamma f) > 0 \\ \frac{dd^*}{dw_o} &= A_2 \, u'(w_o) > 0 \\ \frac{dd^*}{db} &= A_2 \, [-u'(b - \gamma f)] < 0 \\ \frac{dd^*}{d\mu} &= A_2 \, \frac{-[u(w_o) - u(b - \gamma f)]}{\mu} < 0 \end{aligned}$$

where $A_2 = \frac{\beta}{Z'(d^*)\mu(1-\beta)}$, $A_2 > 0$.

Thus, in equilibrium, the level of diagnostics is increasing in the tuition fee and the opportunity wage, and decreasing in the post-malpractice wage and doctors' degree of altruism for patients. Furthermore, we also have:

$$\begin{aligned} \frac{dd^*}{dM} &= 0 \\ \frac{dd^*}{d\alpha} &= 0 \end{aligned}$$

so the optimal level of diagnostics is not affected by the size of malpractice fine M or the insurance loading α. *QED*

The equilibrium wage is given by:

$$u(w^* - \gamma f - (1+\alpha)\Psi\rho(d^*)M) = u(w_o) + \frac{\beta\rho(d^*)}{1-\beta}\left[u(w_o) - u(b-\gamma f)\right] - \mu K(d^*) \quad (3)$$

By total differentiation of (3) we have that:

$$\frac{dw^*}{dM} = (1+\alpha)\Psi\rho(d^*) > 0$$
$$\frac{dw^*}{d\alpha} = \Psi\rho(d^*)M > 0$$

Thus, higher levels of malpractice fine M or the insurance loading α translate into higher equilibrium wages. Total differentiation of (3), also allows us to obtain the derivative of the equilibrium wage with respect to the tuition fee:

$$u'(y)(\frac{\partial w^*}{\partial\gamma} - f - (1+\alpha)M\Psi\rho'(d^*)\frac{\partial d^*}{\partial\gamma}) = \frac{\partial d^*}{\partial\gamma}\left\{-\mu K'(d^*) + \frac{\beta}{1-\beta}\rho'(d^*)\left[u(w_o) - u(\bar{b})\right]\right\} + \\ + \frac{\beta}{1-\beta}f\rho(d^*)u'(\bar{b})$$

where we denote $y = w^* - \gamma f - (1+\alpha)\Psi\rho M$ and $\bar{b} = b - \gamma f$. Note that because doctors optimize the number of diagnostics, condition (1) implies the term in curly brackets is zero. So we have:

$$\frac{dw^*}{d\gamma} = f\left[1 + \frac{\beta}{1-\beta}\frac{u'(\bar{b})}{u'(y)}\rho(d^*)\right] - (1+\alpha)M\Psi\left[-\rho'(d^*)\right]\frac{dd^*}{d\gamma} \quad (4)$$

By using the expression for $\frac{\partial d^*}{\partial\gamma}$ from the proof of proposition 3, we obtain:

$$\frac{dw^*}{d\gamma} = fu'(\bar{b})\frac{\beta}{1-\beta}\left[\frac{1-\beta}{\beta}\frac{1}{u'(\bar{b})} + \frac{\rho(d^*)}{u'(y)} - \frac{(1+\alpha)\Psi}{\mu}\frac{-\rho'(d^*)}{Z'(d^*)}M\right]$$

Thus, the physician wage in equilibrium is increasing in the tuition fee iff:

$$\frac{dw^*}{d\gamma} > 0 \iff M < \bar{M}_\gamma = \frac{Z'(d^*)}{-\rho'(d^*)}\frac{\mu}{(1+\alpha)\Psi}\frac{1}{u'(y)}\left[\frac{1-\beta}{\beta}\frac{\mu u'(y)}{u'(\bar{b})} + \rho(d^*)\right] \quad (5)$$

The right hand side of (5) is a threshold for level of the malpractice fine, below which the effect of tuition fees on the physician wage is positive.[1]

[1]Note that the right hand side of (5) does not depend on M. First, the optimal level of diagnostics does not depend on the size of malpractice fines. Moreover, the value of $y = w^* - \gamma f - (1+\alpha)\rho(d^*)M$ is given by the equilibrium condition (15), hence it also does not depend on M (because wages will always adjust to compensate for higher M). Therefore, it is legitimate to say that the right hand side of (5) forms a threshold for the values of malpractice fines, under which the effect of tuition fees on doctor's wages in the equilibrium is positive.

Finally, we consider how the equilibrium wage depends on the opportunity wage w_o, the post-malpractice wage b and the degree of altruism μ:

$$\frac{dw^*}{dw_o} = u'(w_o)\frac{\beta}{1-\beta}\left[\frac{1-\beta(1-\rho(d^*))}{\beta u'(y)} - \frac{(1+\alpha)\Psi}{\mu}\frac{-\rho'(d^*)}{Z'(d^*)}M\right]$$

$$\frac{dw^*}{dw_o} > 0 \iff M < \bar{M}_{w_o} = \frac{Z'(d^*)}{-\rho'(d^*)}\frac{\mu}{(1+\alpha)\Psi}\frac{1}{u'(y)}\left[\frac{1-\beta}{\beta} + \rho(d^*)\right]$$

$$\frac{dw^*}{db} = -u'(b-\gamma f)\frac{\beta}{1-\beta}\left[\frac{\rho(d^*)}{u'(y)} - \frac{(1+\alpha)\Psi}{\mu}\frac{-\rho'(d^*)}{Z'(d^*)}M\right]$$

$$\frac{dw^*}{db} < 0 \iff M < \bar{M}_b = \frac{Z'(d^*)}{-\rho'(d^*)}\frac{\mu}{(1+\alpha)\Psi}\frac{1}{u'(y)}\rho(d^*)$$

$$\frac{dw^*}{d\mu} = \frac{-K(d^*)}{u'(y)} + \frac{(1+\alpha)\Psi}{\mu}\frac{-K'(d^*)}{Z'(d^*)}M$$

$$\frac{dw^*}{d\mu} < 0 \iff M < \bar{M}_\mu = \frac{Z'(d^*)}{-K'(d^*)}\frac{\mu}{(1+\alpha)\Psi}\frac{K(d^*)}{u'(y)} \iff$$

$$M < \bar{M}_\mu = \frac{f'(d^*)}{-\rho'(d^*)}\frac{\mu}{(1+\alpha)\Psi}\frac{1}{u'(y)}\left[\rho(d^*) - \frac{1-\beta}{\beta}\frac{u(y)-u(w_o)}{u(w_o)-u(\bar{b})}\right]$$

These conditions give thresholds on the values of malpractice fines M, under which wages in the equilibrium will be increasing in the opportunity wage w_o, decreasing in the post-malpractice wage, and decreasing in the degree of altruism μ. *QED*

Comment 1: Note that

$$\bar{M}_\mu < \bar{M}_b < \bar{M}_\gamma < \bar{M}_{w_o}$$

Hence, if $M < \bar{M}_\mu$, the equilibrium wage is increasing in tuition and the opportunity wage but decreasing in the post-malpractice wage and the doctor's altruism. However, if $M > \bar{M}_{w_o}$ then all these effects are reversed. In between, there exists a range of values of malpractice fines for which the signs of the effects of altruism, the post-malpractice wage, tuition and the opportunity wage are reversed, in that order.

Comment 2: The direct positive effect of tuition on the physician wage is captured by the first term in (4). The indirect equilibrium effect that arises because higher tuition leads to more diagnostic testing, which in turn lowers malpractice risk and malpractice premiums, is captured by the second term in (4). This equilibrium effect will be stronger, the higher is the malpractice fine. This is the only channel through which increased diagnostics (due to higher tuition) affects wages in the equilibrium. This effect is present, even though doctors optimize number of diagnostics, because they do not internalize the fact that the level of diagnostics they choose will affect the insurance premiums on the market.

C Proof that d^* and t^* maximize doctor's utility

First derivatives of the function $D(d,t)$ are as follows:

$$\frac{\partial D}{\partial d} = \frac{1}{1-\beta(1-\rho(d^*))}\left[-\beta\rho'(d^*)\left(D(d^*,t^*)-\frac{u(b-\gamma f)}{1-\beta}\right)-\mu p_d u'(I)+\mu h'(d^*)+\frac{q}{n}\omega'(\tau^*)\right]$$

$$\frac{\partial D}{\partial t} = \frac{1}{1-\beta(1-\rho(d^*))}\{u'(y^*)w+v'(t^*)+\mu n s'(nt^*)-\mu n w u'(I)\}$$

where where $\tau^* = \frac{q}{n}d^*$.

If there exists a point (d^*,t^*), such that these first derivatives at (d^*,t^*) are equal to zero, then, at this point, the second order derivatives are the following:

$$\frac{\partial^2 D}{\partial d^2} = \frac{-\beta\rho''(d^*)\left(D(d^*,t^*)-\frac{u(b-\gamma f)}{1-\beta}\right)+\mu h''(d^*)+\frac{q^2}{n^2}\omega''(\tau^*)}{1-\beta(1-\rho(d^*))} < 0$$

$$\frac{\partial^2 D}{\partial t^2} = \frac{1}{1-\beta(1-\rho(d^*))}\left\{u''(y^*)w^2+v''(t^*)+\mu n^2 s''(nt^*)\right\} < 0$$

$$\frac{\partial^2 D}{\partial d \partial t} = 0$$

Then $D_{dd}D_{tt}-D_{dt}^2 > 0$ and $D_{dd} < 0, D_{tt} < 0$, hence the point (d^*,t^*) is a local maximum.

To prove existence of this maximum, we need to add extra assumptions on the values of functions, such that D_d and D_t cross 0 at some point:

1. $D'(d) > 0$ for $d < d_P^*$:

$$-\beta\rho'(d)\left(D(d,t^*)-\frac{u(b-\gamma f)}{1-\beta}\right)+\mu[-p_d u'(I)+h'(d)]+\frac{q}{n}\omega'(\frac{q}{n}d) > 0$$

   The second term will be positive (by definition of d_P^*). The first term will be positive iff $u(b-\gamma f) < u(y)+\mu K(d,t^*)$ for each $d < d_P^*$, which means that K should not be too low for $d < d_P^*$. The last term will be negative, which gives the following condition to be satisfied:

$$-\frac{q}{n}\omega'(\frac{q}{n}d) < -\beta\rho'(d)\left(D(d,t^*)-\frac{u(b-\gamma f)}{1-\beta}\right)+\mu[-p_d u'(I)+h'(d^*)]$$

2. $D'(d) < 0$ for $d = d_{max}$:

$$-\beta\rho'(d)\left(D(d,t^*)-\frac{u(b-\gamma f)}{1-\beta}\right)+\mu[-p_d u'(I)+h'(d^*)]+\frac{q}{n}\omega'(\frac{q}{n}d) < 0$$

The second term, $\frac{\partial K(d_{max},t^*)}{\partial d}$ and the third term are negative. Hence, this condition will be satisfied iff:

$$K'(d_{max}) + \frac{q}{n}\omega'(\frac{q}{n}d_{max}) < \frac{\beta\rho'(d_{max})}{\mu}\left(D(d_{max},t^*) - \frac{u(b-\gamma f)}{1-\beta}\right)$$

Hence, K must decrease fast enough for high values of d

3. $D'(t) > 0$ for $t = t_{min}$:

$$u'(wt_{min} - p - \gamma f)w + \mu ns'(nt_{min}) > -v'(t_{min}) + \mu nwu'(I)$$

4. $D'(t) < 0$ for $t = t_{max}$:

$$u'(wt_{max} - p - \gamma f)w + \mu ns'(nt_{max}) < -v'(t_{max}) + \mu nwu'(I)$$

Consider the case when $t \in [0,1]$ denotes the share of individual time spent working. Then, there will exist a solution $t^* \in [\frac{p+\gamma f}{w^*}, 1]$ iff:

$$\begin{aligned} u'(0)w^* &> -v'(\frac{p+\gamma f}{w^*}) - \mu ns'(n\frac{p+\gamma f}{w^*}) + \mu nwu'(I)) \text{ , and} \\ v'(1) &< -u'(w^* - p - \gamma f)w^* - \mu ns'(n) + \mu nwu'(I) \end{aligned}$$

These conditions will be satisfied if we let $u'(0) \to +\infty$, $s'(n\frac{p+\gamma f}{w^*})$, $v'(\frac{p+\gamma f}{w^*})$ and $u'(I)$ be bounded, and if $v'(1) \to -\infty$, $u'(w^* - p - \gamma f)$ and $s'(n)$ be bounded. In particular, they will be satified for $u(c) = \log(c)$ and $v(t) = \theta_t \log(1-t)$.

D Proof of Proposition 6

This section presents a proof of comparative statics in partial equilibrium, in the model with consultation time, see Section 4.1.4.

In equation 10, the first order condition for diagnostics, the optimal level of diagnostics is expressed as a function of optimal physician consultation time t^*. However, t^* appears in this equation only inside the function that is optimized, $D(d,t)$. We can therefore apply the envelope theorem, according to which:

$$\frac{dD(d^*,t^*)}{d\eta} = \frac{\partial D(d^*,t^*)}{\partial \eta}$$

Similarly, as t_b^* is chosen to maximize lifetime utility after malpractice, for all η other than β we have:

$$\frac{d[u(bt_b^* - \gamma f) + v(t_b)]}{d\eta} = \frac{\partial[u(bt_b^* - \gamma f) + v(t_b)]}{\partial \eta}$$

Hence, we do not have to use the total derivatives of t^* and t_b^* with respect to all parameters. Thus, the total derivatives of d^* are given by:

$$\begin{aligned}
\frac{dd^*}{dw} &= B_1 V_1^{-1} t^* u'(y^*) > 0 \\
\frac{dd^*}{d\gamma} &= B_1 V_1^{-1} f \left[u'(\bar{b}) - u'(y^*) + \mu n \psi u'(I)\right] > 0 \\
\frac{dd^*}{dp} &= B_1 V_1^{-1} \left[-u'(y^*)\right] < 0 \\
\frac{dd^*}{db} &= B_1 V_1^{-1} \left[-u'(\bar{b})\right] < 0 \\
\frac{dd^*}{d\mu} &= -B_1 V_1^{-1} \mu^{-1} \left[u(y^*) + v(t^*) - u(\bar{b}) - v(t_b^*)\right] < 0 \\
\frac{dd^*}{dw_o} &= 0
\end{aligned}$$

$$\begin{aligned}
\frac{dd^*}{dp_d} &= V_1^{-1} \mu u'(I) \left[-B_1 d^* + 1\right] < 0 \\
\frac{dd^*}{dI} &= V_1^{-1} \left\{B_1 \mu \left[u'(I) - u''(I)\left(p_d d^* + nzwt^* + n\psi(1-\gamma)f\right)\right] + \mu p_d u''(I)\right\} > 0
\end{aligned}$$

where $B_1 = \frac{\beta\rho'(d^*)}{1-\beta(1-\rho(d^*))}$, $B_1 < 0$, and $V_1 = -\beta\rho''(d^*)\left\{D(d^*, t^*) - \frac{u(bt_b^* - \gamma f)}{1-\beta}\right\} + \mu h''(d^*) + \frac{q^2}{n^2}\omega''(\tau^*)$, $V_1 < 0$. *QED*

The remaining results are obtained as follows:

$$\begin{aligned}
\frac{dt^*}{d\gamma} &= V_2^{-1} \left[-fwu''(y^*)\right] > 0 \\
\frac{dt^*}{dp} &= V_2^{-1} \left[-wu''(y^*)\right] > 0 \\
\frac{dt^*}{dI} &= V_2^{-1} \left[-nzwu''(I)\right] > 0 \\
\frac{dt^*}{d\mu} &= V_2^{-1} \left[ns'(nt^*) - nzwu'(I)\right] \overset{s'(nt) > zwu'(I)}{>} 0 \\
\frac{dt^*}{dn} &= V_2^{-1} \left[\mu\left[s'(nt^*) - zwu'(I) + nt^* s''(nt^*)\right]\right] \overset{s'(nt) > u'(I)\left[zw + \frac{\psi}{t^*}(1-\gamma)f\right]}{>} 0 \\
\frac{dt^*}{db} &= 0 \\
\frac{dt^*}{dw_o} &= 0 \\
\frac{dt^*}{dp_d} &= 0
\end{aligned}$$

where $V_2 = -[w^2 u''(y^*) + v''(t^*) + \mu n^2 s''(nt^*)], V_2 > 0$. *QED*

E Proof of Proposition 8

To prove that the (d^*, t^*, w^*) equilibrium exists and is unique, we first prove that there exists a unique d^* satisfying the equilibrium conditions. Then, we prove that, conditional on the value of d^*, there exists a unique solution for (t^*, w^*).

Recall that the equilibrium (d^*, t^*, w^*) is given by the following conditions:

$$\frac{\partial D}{\partial d} = 0 \iff -\beta\rho'(d^*)\left\{D - \frac{U_b}{1-\beta}\right\} = \mu\left[p_d u'(I) - h'(d^*)\right] - \frac{q}{n}\omega'(\tau^*) \quad (6)$$

$$\frac{\partial D}{\partial t} = 0 \iff u'(y^*)w^* + v'(t^*) + \mu n\left[s'(nt^*) - zw^* u'(I)\right] = 0 \quad (7)$$

$$D = \frac{U_0}{1-\beta} \quad (8)$$

$$p = (1+\alpha)\Psi\rho(d^*)M \quad (9)$$

where $\tau^* = \frac{q}{n}d^*$, $y^* = w^* t^* - p - \gamma f$ and $D = D(d^*, t^*, w^*)$.

1. Existence and uniqueness of d^*

   Equilibrium value of d^* is given by combining conditions (6) and (8):

   $$-\beta\rho'(d^*)\left\{\frac{U_0}{1-\beta} - \frac{U_b}{1-\beta}\right\} - \mu\left[p_d u'(I) - h'(d^*)\right] + \frac{q}{n}\omega'(\frac{q}{n}d^*) = 0$$

   Note that this condition does not depend on t^* or w^*. We can therefore define a function $\psi(d)$ equal to the LHS of the above condition. Then $\psi'(d)$ is given by:

   $$\psi'(d) = -\rho''(d)\frac{\beta}{1-\beta}(U_0 - U_b) + \mu h''(d) + \frac{q^2}{n^2}\omega''(\frac{q}{n}d)$$

   First, at $d \geq d_P^*$, the first element of $\psi(d)$ is positive because $\rho' > 0$. The second element is positive, by definition of d_P^*. The last term is negative. $\psi(d)$ will then be positive for each $d \geq d_P^*$ under the following necessary condition satisfied at $d = d_P^*$ (by concavity of ω, h and convexity of ρ, it will be then satisfied for all $d \geq d_P^*$):

   $$-\frac{q}{n}\omega'(\frac{q}{n}d_P^*) < -\rho'(_P^*) + \mu[-p_d u'(I) + h'(_P^*)]$$

   Hence, the necessary condition is that the marginal disutility of time spent on analysing diagnostics at the patient's optimum is low enough.

Next, at $d = d_{max}$, the first element of $\psi(d)$ will be positive but small (by convexity of ρ). The second element will be negative, by the fact that $d_{max} > d_P^*$. Finally, the last term will be highly negative, by concavity of ω. $\psi(d_{max})$ will then be negative if

$$-\rho'(d_{max})\frac{\beta}{1-\beta}(U_0 - U_b) < \mu\left[p_d u'(I) - h'(d_{max})\right] - \frac{q}{n}\omega'(\frac{q}{n}d_{max})$$

This condition says that the marginal benefit of prescribing more diagnostics at very high level of diagnostics is small enough.

The function ψ is continuous, moreover, under the conditions stated above $\psi(d_P^*) > 0$ and $\psi(d_{max}) < 0$, therefore there must exist a point d^* at which $\psi(d^*) = 0$.

By convexity of ρ and concavity of h and ω, and under the assumption that $U_0 \geq U_b$, $\psi'(d) < 0$, so the function ψ is decreasing. Hence, under the conditions stated above, there exists a unique d^* satisfying the equilibrium conditions.

2. Uniqueness of (t^*, w^*).

   Here we prove that, if there exists a (t^*, w^*) solution of the equilibrium, then it is unique.[2]

   To prove uniqueness of (t^*, w^*), first note that condition (7) defines a function $t^*(w)$ and (8) a function $w^*(t)$.

   First, consider (7) and denote:

$$\psi_t(t, w) = u'(wt - p - \gamma f)w + v'(t) + \mu n\left[s'(nt) - zwu'(I)\right]$$

   By convexity of u, v and s, $\frac{\partial \psi_t}{\partial t} < 0$, hence for a fixed w, ψ_t is decreasing. Therefore, there can be only one t that satisfies $\psi_t(t, w) = 0$. Hence, $t(w)$ is a function. Moreover, by calculating $t'(w)$ we show that t is increasing in w:

$$t'(w) = \frac{-u''(y)w^2 - v''(t) - \mu n s''(nt)}{u''wt + u' - \mu nzu'(I)} > 0$$

   Similarly, consider condition (8), which can be written as $\psi_w(t, w) = 0$, using the definition of $D(d^*, t^*, w^*)$:

$$\begin{aligned}\psi_w(t, w) \quad = \quad & \frac{1}{1-\beta(1-\rho(d^*))}\Big\{u(w^*t^* - \gamma f - p) + v(t^*) + \omega(\frac{q}{n}d^*) - U_b + \mu\big[u(I) \\ & - u'(I)\left[p_d d^* + nzw^*t^* + n\psi(1-\gamma)f\right] + h(d^*) + s(n^*t^*)\big]\Big\} + \frac{U_b - U_0}{1-\beta}\end{aligned}$$

   Then, for a fixed t, ψ_w is increasing in w iff:

$$\frac{\partial \psi_w}{\partial w} > 0 \iff u'(y^*) - nzu'(I) > 0$$

[2] Proving existence is not trivial, so we focus on proving that if we find an equilibrium, it will be unique.

Under this condition, condition (8) defines w as a function of t. The first derivative of this function is given by:

$$w'(t) = -\frac{u'(y)w + v'(t) + \mu n s'(nt) - \mu n z w u'(I)}{t\left[u'(y) - \mu n z u'(I)\right]}$$

Note that the numerator of this condition is the same as condition (7). Hence, all stationary points of $w(t)$ are points of its intersection with the function $t(w)$. Moreover, at all such stationary points $t = t_0$, the function $w(t)$ is convex:

$$w''(t_0) = -\frac{u''(y)w^2 + v''(t_0) + \mu n^2 s''(nt_0)}{t_0\left[u'(y) - \mu n z u'(I)\right]} > 0$$

It is easy to prove using Weierstrass theorem that if a function of one variable is convex at all stationary points, there must exist only one such stationary point, which is the global minimum of this function. Hence, there exists only one point of intersection of functions $w(t)$ and $t(w)$. Therefore, there exists a unique (t^*, w^*) satisfying the equilibrium conditions.

Q.E.D.

F Proof of Propositions 9 and 10

We consider a simplified equilibrium in which we assume the insurance premium p is fixed exogenously. In this case we can calculate comparative statics by total differentiation of the following conditions F_d, F_t and F_w:

$$\begin{aligned}
F_d: &\quad -\frac{\beta\rho'(d^*)\left[u_0(w_o, t_o^*, c_T, t_T, l) - u(bt_b^* - \gamma f) - v(t_b^*)\right]}{1-\beta} + \mu\left[-p_d u'(I) + h'(d^*)\right] + \frac{q}{n}\omega'(\tau^*) = 0 \\
F_t: &\quad u'(y^*)w^* + v'(t^*) + \mu n\left[s'(nt^*) - z w^* u'(I)\right] = 0 \\
F_w: &\quad u(y^*) + v(t^*) + \omega(\tau^*) + \mu\left[u(I) - u'(I)\left(p_d d^* + nzw^*t^* + n\psi(1-\gamma)f\right) + h(d^*) + s(nt^*)\right] \\
&\quad -u_0(w_o, t_o^*, c_T, t_T, l) - \frac{\beta\rho(d^*)}{1-\beta}\left[u_0(w_o, t_o^*, c_T, t_T, l) - u(bt_b^* - \gamma f) - v(t_b^*)\right] = 0
\end{aligned}$$

For any quantity of interest X we obtain:

$$\begin{aligned}
\frac{dd^*}{dX} &= \frac{\frac{\partial F_d}{\partial X}}{\rho''(d^*)\frac{\beta}{1-\beta}(u_0 - u_b) - \mu h''(d) - \frac{q^2}{n^2}\omega''(\tau^*)} \\
\frac{dw^*}{dX} &= \frac{-\frac{\partial F_w}{\partial X}}{t^*\left[u'(y^*) - nz\mu u'(I)\right]} \\
\frac{dt^*}{dX} &= \frac{\frac{\partial F_t}{\partial X} + \frac{dw^*}{dX}\left[u''(y^*)w^*t^* + u'(y^*) - nz\mu u'(I)\right]}{-\left[u''(y^*)w^{*2} + v''(t^*) + \mu n^2 s''(nt^*)\right]}
\end{aligned}$$

Proof diagnostics:

$$
\begin{aligned}
\frac{dd^*}{d\gamma} &= -B_3 V_3^{-1} f \, \left[u'(bt_b^* - \gamma f) + \beta^{-l} \frac{p_{noT}}{1 - p_{noT}} u'(w_o t_{noT}^* - \gamma f) \right] > 0 \\
\frac{dd^*}{db} &= B_3 V_3^{-1} t_b^* u'(bt_b^* - \gamma f) < 0 \\
\frac{dd^*}{dw_o} &= -B_3 V_3^{-1} \beta^{-l} u'(w_o t_o^*) t_o^* > 0 \\
\frac{dd^*}{dc_T} &= -B_3 V_3^{-1} (\beta^{-l} - 1)(-u'(c_T)) < 0 \\
\frac{dd^*}{dt_T} &= -B_3 V_3^{-1} (\beta^{-l} - 1)(-v'(t_T)) > 0 \\
\frac{dd^*}{dl} &= -B_3 V_3^{-1} (-\beta^{-l} \log \beta) \left[u(w_o t_o) + v(t_o) - u(c_T) - v(t_T) \right] > 0 \\
\frac{dd^*}{d\mu} &= B_3 V_3^{-1} \frac{\left[u_0(w_o, t_o^*, c_T, t_T, l) - u(bt_b^* - \gamma f) - v(t_b^*) \right]}{\mu} < 0
\end{aligned}
$$

$$
\begin{aligned}
\frac{dd^*}{dp_d} &= -V_3^{-1} \mu u'(I) < 0 \\
\frac{dd^*}{dI} &= -V_3^{-1} \mu p_d u''(I) > 0 \\
\frac{dd^*}{dp} &= 0 \\
\frac{dd^*}{dn} &= 0
\end{aligned}
$$

where $B_3 = \frac{\beta \rho'(d^*)}{1-\beta}$, $B_3 < 0$, and $V_3 = \rho''(d^*) \frac{\beta}{1-\beta} \left[u_0(w_o, t_o^*, c_T, t_T, l) - u(bt_b^* - \gamma f) - v(t_b^*) \right] - \mu h''(d^*) - \frac{q^2}{n^2} \omega''(\tau^*)$, $V_3 > 0$.

Proof wages:

$$
\begin{aligned}
\frac{dw^*}{d\gamma} &= V_4^{-1} f \left[u'(y^*) + (1-B_4)u'(\bar{b}) - \mu n \psi u'(I) + B_4\, \beta^{-l} \frac{p_{noT}}{1-p_{noT}} u'(w_o t^*_{noT} - \gamma f) \right] \\
&\quad > 0 \text{ if } \mu n \psi u'(I) \text{ small} \\
\frac{dw^*}{db} &= V_4^{-1}(1-B_4) \cdot \; [-u'(bt^*_b - \gamma f)]\, t^*_b < 0 \\
\frac{dw^*}{dw_o} &= V_4^{-1} B_4 \cdot \; \beta^{-l} u'(w_o t_o) t_o > 0 \\
\frac{dw^*}{dc_T} &= V_4^{-1} B_4 \cdot \; (\beta^{-l} - 1)\,(-u'(c_T)) < 0 \\
\frac{dw^*}{dt_T} &= V_4^{-1} B_4 \cdot \; (\beta^{-l} - 1)\,(-v'(t_T)) > 0 \\
\frac{dw^*}{dl} &= V_4^{-1} B_4 \cdot \; (-\beta^{-l} \log \beta)\, [u(w_o t_o) + v(t_o) - u(c_T t_T) - v(t_T)] > 0 \\
\frac{dw^*}{d\mu} &= V_4^{-1}[-K(d^*, t^*)] < 0 \\
\frac{dw^*}{dp_d} &= V_4^{-1} \mu d^* u'(I) > 0 \\
\frac{dw^*}{dI} &= V_4^{-1}\, [-\mu u'(I) + \mu u''(I)(p_d d^* + nzw^* t^* + n\psi(1-\gamma)f)] < 0 \\
\frac{dw^*}{dp} &= V_4^{-1} u'(y^*) > 0 \\
\frac{dw^*}{dn} &= V_4^{-1} t^* \mu \left[zwu'(I) - s'(nt) + \frac{\psi}{t^*}(1-\gamma) f u'(I) \right] \overset{s'(nt) > u'(I)(zw + \frac{\psi}{t^*}(1-\gamma)f)}{<} 0
\end{aligned}
$$

where $B_4 = \frac{1-\beta(1-\rho(d^*))}{1-\beta}$, $0 < B_4 < 1$ and $V_4 = t^*\,[u'(y^*) - nz\mu u'(I)]$. $V_4 > 0$ by 17.

Proof hours:

$$\frac{dt^*}{d\gamma} = \frac{V_5^{-1} f[u'(y^*) - \mu nzu'(I)]}{t^*} \cdot \Bigg\{ 1 + E_5\, t^* \left[1 + \frac{\mu n(z-\psi)u'(I) + (1-B_5)u'(\bar{b}) + B_5\, \beta^{-l} \frac{p_{noT}}{1-p_{noT}} u'(c_{noT})}{u'(y^*) - \mu nzu'(I)} \right] \Bigg\} <> 0$$

$$\frac{dt^*}{db} = V_5^{-1} E_5 \cdot (1-B_5)\,(-u'(bt_b^* - \gamma f))\, t_b^* > 0$$

$$\frac{dt^*}{dw_o} = V_5^{-1} E_5 \cdot B_5\, \beta^{-l} \cdot u'(w_o t_o)\, t_o < 0$$

$$\frac{dt^*}{dc_T} = V_5^{-1} E_5 \cdot B_5\, (\beta^{-l} - 1)(-u'(c_T)) > 0$$

$$\frac{dt^*}{dt_T} = V_5^{-1} E_5 \cdot B_5\, (\beta^{-l} - 1)\,(-v'(t_T)) < 0$$

$$\frac{dt^*}{dl} = V_5^{-1} E_5 \cdot B_5[u(w_o t_o) + v(t_o) - u(c_T t_T) - v(t_T)]\, (-\beta^{-l} \log \beta) < 0$$

$$\frac{dt^*}{d\mu} = V_5^{-1}\, [n\, [s'(nt) - zwu'(I)] - KE_5] \overset{\text{suff. } s'(t) > zwu'(I)}{>} 0$$

$$\frac{dt^*}{dp_d} = V_5^{-1} E_5 \cdot \mu\, d^*\, u'(I) < 0$$

$$\frac{dt^*}{dI} = V_5^{-1}\, [-nz\mu wu''(I) - E_5 \cdot\ \mu\, [u'(I) - u''(I)(p_d d^* + nzw^* t^*)]] > 0$$

$$\frac{dt^*}{dp} = V_5^{-1} \left[-u''(y^*)w + \frac{u'(y^*)}{t^*} E_5 \right] < 0$$

$$\frac{dt^*}{dn} = \mu V_5^{-1}\, [nt^* s''(nt^*) + (1 - E_5 t^*)\, [s'(nt) - zwu'(I)] + E_5 \psi (1-\gamma) f u'(I)] <> 0$$

where $V_5 = -[u''(y^*)(w^*)^2 + v''(t^*) + \mu n^2 s''(nt^*)]$, $V_5 > 0$, $B_5 = \frac{1-\beta(1-\rho(d^*))}{1-\beta}$, $0 < B_5 < 1$ and $E_5 = \frac{u''(y^*)w^*t^* + u'(y^*) - nz\mu u'(I)}{t^*[u'(y^*) - nz\mu u'(I)]}$. By (18), $E_5 < 0$.

(If $p_{noT} = 0$ and $u = \log c$) hours worked increase in the size of tuition fee as long as the wage after committing malpractice is not too low:

$$\frac{dt^*}{d\gamma} > 0 \overset{u=\log c}{\iff} bt_b^* - \gamma f > \frac{\beta\rho(d^*)}{1-\beta} \frac{(p + \gamma f + nz\mu \frac{y^*}{I} y^*)}{1 - nz\mu \frac{w^* t^* + y^*}{I}} = y\, \frac{\beta\rho(d^*)}{1-\beta}\, \frac{w^* t^* - y + ynz\mu \frac{y}{I}}{y - (w^* t^* + y) nz\mu \frac{y}{I}} = 0.0041y$$

G Framework accounting for the risk of dropping out

We present here a simple theoretical framework to model dropping out from the medical training. We assume that there is a p_{noT} probability that an individual drops out from the training. To simplify, we assume that individuals follow the whole training and drop out immediately after. They then receive wage w_o, but have to pay back their educational debt γf in each period of their career.

Those who have dropped out will set their working hours t to maximize their lifetime utility $\frac{U_{noT}}{1-\beta}$ where $U_{noT} = U(w_0 t - \gamma f, t, 0)$. Hence, they will choose to work t^*_{noT} hours according to the optimality condition:

$$u'(w_0 t^*_{noT} - \gamma f) w_0 + v'(t^*_{noT}) = 0$$

The per period utility after dropping out will then be given by $u_{noT} = u(w_0 t^*_{noT} - \gamma f) + v(t^*_{noT})$.

The candidate for a doctor will then decide to follow medical training iff

$$(1 - p_{noT}) \left\{ \sum_{k=0}^{l-1} \beta^k U_T + \beta^l D \right\} + p_{noT} \frac{u_{noT}}{1-\beta} \quad \geq \quad \frac{U_0}{1-\beta} \iff D > \frac{u_0}{1-\beta}$$

where $U_0 = U(w_0 t_0, t_0, 0)$, $U_T = U(c_T, t_T, 0)$ and:

$$u_0(w_0, t_0, c_T, t_T, l, p_{noT}, u_{noT}) = \frac{U_0 - p_{noT} u_{noT}}{1 - p_{noT}} + (\beta^{-l} - 1) \left[\frac{U_0 - p_{noT} u_{noT}}{1 - p_{noT}} - U_T \right]$$

Note that in this case u_0 will be a function of tuition fees, such that:

$$\frac{\partial u_0}{\partial \gamma} = f \beta^{-l} \frac{p_{noT}}{1 - p_{noT}} u'(w_0 t^*_{noT} - \gamma f)$$

H Estimating Diagnostic Spending in the US and UK

It is difficult to measure total diagnostic spending in the US because the national accounts are not organized services, but rather by who pays for services. The UK is also difficult, as diagnostics are not a single line item in the NHS budget. However, by combining several data sources it is possible to develop reasonable estimates of diagnostic spending in both countries.

H.1 The US Evidence

H.1.1 Employer provided insurance

Employer provided health insurance (EPHI) covers 55% of healthcare costs in the US, so it is by far the largest payer. The Health Care Cost Institute (2015), henceforth HCCI, provides detailed data on healthcare spending of people under 65 with EPHI based on claims data of roughly 40 million individuals (see Tables A18 and A20 in Health Care Cost Institute (2015)), but it only itemizes outpatient spending on diagnostics. According to these data, mean per capita spending in 2014 was $4967 of which 83.7% was reimbursed. Diagnostic imaging and laboratory tests accounted for $328 and $218 of reimbursed expenses, respectively, and $67 and $56 of out-of-pocket (OOP) spending. Thus, total outpatient spending on diagnostics ($669) accounted for 13.5% of total healthcare costs of people covered by EPHI. (Of this 13.5%, imaging is 8.0% and lab testing is 5.5%).[3],[4]

H.1.2 Medicare

Next, we estimate diagnostics as a fraction of Medicare costs. Medicate provides insurance for those 65 and over. It consists of Part A, which pays for in-patient hospital care, and Part B, which pays for physician fees and services and out-patient care. According to MedPac (2015), per capita Medicare spending in 2013 was $4264 under Part B, and $3695 under Part A (see Chart 1-2). Of the $2.5 trillion spent on personal health care (PHC) in 2013, Medicare accounted for 22%. Thus, it was the second largest payer after EPHI.

[3] A study by the Blue Cross Blue Shield Association estimated that $70 billion was spent on diagnostic imaging in the US in 2000 (see Rothenberg and Korn (2005), Rothenberg (2003)). The MEPS based measure of total health expenditures in 2000 was $1.11 trillion, so that imaging was roughly 6.4% of health spending. This compares with the 8.0% figure we found in the HCCI data for 2014. Another source of data on diagnostic spending is US census data on the revenue of medical and diagnostic laboratories (NAICS Code 6215, SIC Codes 8071, 8090, 8093, 8099). Total revenue of these firms in 2012 was $47 billion. This is a lower bound because it excludes hospital based facilities, and only includes laboratories that bill directly to patients. In light of this, the $70 billion total estimate obtained by BCBS seems plausible.

[4] Similary, Hornỳ et al. (2014) analyze Truven Health Analytics MarketScan commercial insurance claims data for 2007-11. The commercially insured US population accounts for roughly 55% of total healthcare spending, and these data sample about 1/3 of that population (30 to 40 million people per year). They report that outpatient diagnostic imaging spending was roughly 8% of total health care spending from 2007-2011, that same as our estimate. There is no clear trend over the period, suggesting that diagnostic spending stabilized after about 2005.

H.1.3 Medicare Part A

In October 1983 Medicare Part A adopted the prospective payment system (PPS) for inpatient hospital services. Under the PPS, hospitals receive a fixed capitation payment for each patient, based on their DRG condition code. Under capitation, it is very difficult to determine how much is spent on specific procedures, such as diagnostic testing and imaging.

Burney and Schieber (1985) report total Medicare spending on diagnostic testing and imaging for 1983, the last year for which a total that includes both Parts A and B is available. In 1983, total Medicare spending was $15.9 billion, of which diagnostic imaging accounted for 8.4%, while lab testing accounted for 8.0%, giving a total of 16.4% for diagnostics.

Of this 16.4%, Part A accounted for 5.9%. Burney and Schieber (1985) further noted that the figure for Part A is an under-estimate, as the PPS was already in effect for the last 3 months of 1983. Thus, we scale it up by 25%, giving an estimate of 7.4% for diagnostic spending accounted for by Part A in 1983. This gives a total diagnostic share in Medicare of 17.9%.

This figure is remarkably similar to the figure of 17.1% we obtained earlier for the population covered by EPHI. Obviously, however, the Medicare Part A figure is for a much earlier period. But, while diagnostic spending increased in subsequent years,[5] most evidence suggests it has not changed substantially as share of total Medicare spending.

H.1.4 Medicare Part B

Under Part B, physicians bill Medicare for specific procedures, based on the physician fee schedule (PFS), so spending on diagnostic testing and imaging is readily available. Lee et al. (2013) examined CMSs Physician Supplier Procedure Summary claims data, which include all services paid under the PFS. In 2011, per capita spending on imaging was $374, while that on lab testing was $190. Total spending was $3638, so diagnostic testing was 15.5% of Part B spending (of which 10.3% was imaging while 5.2% lab testing). Similarly, Baicker et al. (2007) document that in 2001 per patient spending under Part B was $262 for imaging and $141 on lab tests. Total PFS spending was $2169 per patient, so diagnostics were 18.6% of the total (of which imaging was 12.1% and lab tests were 6.5%).[6] Simply

[5] For instance, based on MedPACs reports to Congress, Medicare spending for imaging services more than doubled from 2000 to 2005, from $6.6 billion to $13.7 billion, an average annual growth rate twice the overall rate of growth in physician fee schedule services. According to Miller (2005), Medicare spent $5.7 billion on diagnostic imaging in 1999, increasing to $9.3 billion in 2003.

[6] There are many studies that document spending on diagnostic imaging (alone) by Medicare Part B. For example, Dodoo et al. (2013) examined spending and utilization of diagnostic imaging from 2003 to 2011 using the PSPS data. They reported that diagnostic imaging made up 14% of Medicare Part B spending in 2011. They note that spending grew in the early 2000s but declined in the second half of the decade (in part due to the lower reimbursement rates), so that spending in 2011 was back to the 2003 level. Spending per Part B enrollee increased from $294 in 2003 to $418 in 2006, and then fell to $390 in 2010.

taking the mean of these two studies we obtain a 17.1% estimate of the Part B spending share on diagnostics.[7]

H.1.5 Total Medicare Spending

Our best estimates of the diagnostic share of Medicare spending are 17.9% for Part A and 17.1% for Part B.[8] According to US Department of Health and Human Services (2013), in 2011 spending on Part A was $255 billion Part B was $226 billion. Thus, Part A was about 53% of total Medicare spending.[9] Taking a weighted average of our figures, we estimate the diagnostic share of Medicare spending is 17.5%.

H.1.6 Summary of the US Evidence

We concluded (in section A) that 17.1% is a reasonable estimate of diagnostic spending as as share of total healthcare costs in the under 65 population that is largely covered by EPHI. We also concluded (in section B) that 17.5% is a reasonable estimate of the diagnostic share of Medicare spending (for the 65 and over population). Given the the under 65 population accounts for 69% of total healthcare spending, we conclude that 17.2% is a good estimate of the fraction of US health spending devoted to diagnostic testing. There is no evidence that the share of diagnostic spending has grown significantly since about 2005. While diagnostic spending has risen substantially over that period, so has total spending.

According to OECD (2016) total US healthcare spending was 16.4% of GDP in 2011. But that headline figure includes items like public health, nursing home care and infrastructure investment that are not part of health spending as defined in our calculations (i.e., these costs are not covered by EPHI or Medicare). A more accurate reflection of our demominator is the part of health spending devoted to curative and rehabilative care and ancillary sevices, which covers inpatient and outpatient care. According to Eurostat (http://ec.europa.eu/eurostat), this was roughly 69.4% of total spending in the US in 2011. Thus, we estimate that (17.2)(.694) = 11.94% of total US healthcare spending was devoted to diagnostics in 2011. This represents (11.94)(.164) = 1.96% of GDP.

They also calculate, using the MEPS data, that average spending for all medical visits by the elderly was $3631 in 2003, and rose to $4029 in 2007 and $4388 in 2010. Thus, diagnostic imaging accounted for 8.1%, 10.4% and 8.9%, respectively, of total Part B spending in these three years.

[7] According to the MEPS data, in 2011 spending for the 65 and over population was $414 billion while that for the under 65 was $916 billion. Thus, spending for those 65 and over was 31% of total spending.

[8] We have very good diagnostic spending share estimates for Part B for the 2000s, and for total Medicare for 1983, but we lack more recent information for Part A due to the adoption of the PPS. However, given that the over 65 population accounts for 31% of total spending, and that inpatient spending under Part A accounts for only about of Medicare spending, our estimate of diagnostic spending should not be too sensitive to how we impute the fraction of Part A that is attributable to diagnostics.

[9] Burney and Schieber (1985) note that, in 1983, about 62% of Medicare charges for physicians' services were for inpatient care (Part A). So the relative size of Part A has declined over time.

H.2 The UK Evidence

In 2013, total UK health expenditure was 150.6bn, with 125.5bn being public expenditure, and 25.1bn private (see Lewis and Cooper (2015)). We first estimate the share of diagnostics in public spending.

Ideally, to obtain total diagnostic spending for the UK, we would use data from the four separate national health systems: NHS England, Scotland, Wales and Northern Ireland. Unfortunately, data for diagnostic imaging is only published by NHS England, while data on lab testing is only published by NHS Scotland. Thus, we will extrapolated the English and Scottish data to the whole UK, assuming diagnostic shares are the same in all four countries. Given the identical training of clinicians in the four countries, and their common professional organisations, it is plausible their diagnostic shares would be similar.

NHS England represents 89% of British public health spending (i.e., 112bn, see Lafond (2015)). Hence, our data contains most diagnostic imaging activity in the UK.

The data on the number of imaging procedures carried out by NHS England (see NHS England (2015)) is divided into the the following six broad categories: X-rays, CT scans, MRIs, ultrasound, radioisotopes, and fluoroscopy (see Table A1 of this appendix). In order to obtain total expenditure, we combine these quantity data with data on prices and costs.

UK Department of Health (2014) reports data on prices for CT scans, MRIs, ultrasound, radioisotopes, and fluoroscopy.[10], [11] The prices differ by aspects of the procedure. For instance, the price of an MRI depends on number of regions scanned and whether contrast is used. To obtain the price of an average MRI, we take a weighted average by volume across these subcategories. The resulting average prices are presented in the third row of Table A1.

Finally, to calculate the price of X-rays, we use NHS tariff information with a market force factor equal to 1.2. (Market force factors represent the additional costs for hospitals located in expensive areas, and range from 1 to 1.3).

The last row of Table 1 reports our estimates of total spending on radiology procedures, obtained by multiplying the average price and volume data. We estimate that total spending on radiology procedures by NHS England is roughly 2.57bn. Extrapolating to public spending for the whole UK we obtain $(2.57)/(.89) = 2.89$bn for imaging.

[10] Reference costs are defined as the average unit cost to the NHS of providing defined services to NHS patients in England, and are collected annually. The National Schedule of Reference Costs gives the most comprehensive picture available of how 244 NHS providers (98 NHS trusts and 146 NHS foundation trusts) spent 58.3bn delivering healthcare to patients in 2013-14.

[11] These data include information on the number and price of subcategories of procedures carried out as part of medical activities such as outpatient appointments, direct access or other settings. We assume the number of imaging procedures carried out as part of these activities is representative for all NHS activities.

Table 1: Volume, prices and value of imaging services in NHS England in 2013/2014

	X-Rays	CT	MRI	Ultra -sound	Radio -isotopes	Fluoro -scopy	Total
no. of procedures (in mln)	23	5.2	2.7	10	0.6	1.3	42.9
per 1000	435	98	51.7	188.2	11.8	25.2	809.8
average prices	£30.0*	£103.5	£149.3	£58.8	£258.6	£135.5	
value of services in mln £	£691.6	£537.9	£409.3	£586.4	£161.5	£181.0	£2,567.8

Comment: *average price of an X-ray 25 multiplied by a market force factor 1.2 Source: NHS data: National Schedule of Reference in 2013 and number of imaging activities in 2013/2014.

Next we consider laboratory tests. According to the data for NHS Scotland, in 2013/2014, 288mln was spent on laboratory and 249mln on radiology tests (see NHS Scotland (2014)). This gives a ratio of laboratory to radiology spending of 1.157. By assuming this ratio applies in other UK nations, we are able to estimate that spending on lab tests in the UK was roughly (2.89)(1.157) = 3.34bn in 2013.

Combining information on spending on laboratory and radiology tests, we estimate total UK public spending on diagnostics of 6.23bn, which is 4.96% of public health spending in 2013.

Next we estimate spending on diagnostics in the private sector. Unfortunately, there is no data on spending in the entire private sector. We therefore use the information on healthcare provider revenues, which was provided to us by two of the major private healthcare providers in the UK (with a combined market share of 26%). These providers report that, in 2014, 16% and 12% of their revenue was earned from diagnostic activity.[12] By correcting these figures for the share of the procedures carried out by these providers that were ordered by the public sector, we estimate that 14% and 10% of their revenue was earned due to diagnostic activities for private patients only. We take the average, 12%, as our estimate of the diagnostic share of private healthcare spending.[13] The gives (25.1bn)(.12) = 3.01bn for private spending on diagnostics.

Combining our public and private estimates, we infer that diagnostics accounted for roughly 9.24bn of total UK health spending in 2013. This is 6.14% of total UK health spending. Given that GDP in UK in 2013 was 1713bn, we estimate that the diagnostic spending share of GDP was 9.24/1713 = 0.54% in 2013.

[12]This information was obtained by us in private correspondence with these providers, and is not available in any official report.

[13]This figure is likely to be an overestimate, because we use data from two large providers. Smaller private healthcare providers tend to outsource their diagnostic activities to larger providers.

H.3 Summary Comments

Two interesting facts emerge from our analysis. First, and most obviously, the US diagnostic share of GDP is roughly $(1.96)/(0.54) = 3.6$ times greater than the UK share. As we note in the main text, according to OECD data other advanced economies like Germany and France have diagnostic shares similar to the UK level, so it is the US that is the outlier. Second, and more subtly, it is interesting that the diagnostic share of health spending in the UK private sector (12%) is much higher than for the public sector (5%). In fact, our estimate of the UK private sector share is very similar to our estimate of for the share of diagnostics in total US healthcare spending (11.94%). Notably, in the private setting in the UK, physicians are subject to personal malpractice risk, so they would have incentives to engage in defensive medicine.

References

Baicker, K., Fisher, E. S., and Chandra, A. (2007). Malpractice liability costs and the practice of medicine in the Medicare program. *Health Affairs*, 26(3):841–852. 16

Burney, I. and Schieber, G. (1985). Medicare physicians' services: The composition of spending and assignment rates. *Health care financing review*, 7(1):81. 16, 17

Dodoo, M. S., Duszak, R., and Hughes, D. R. (2013). Trends in the utilization of medical imaging from 2003 to 2011: clinical encounters offer a complementary patient-centered focus. *Journal of the American College of Radiology*, 10(7):507–512. 16

Health Care Cost Institute (2015). 2013 health care cost and utilization report. Technical report, HCCI. 15

Hornỳ, M., Burgess, J. F., Horwitt, J., and Cohen, A. B. (2014). Advanced diagnostic imaging in privately insured patients: recent trends in utilization and payments. *Journal of the American College of Radiology*, 11(7):692–697. 15

Lafond, S. (2015). Current NHS spending in England. Technical report, The Health Foundation. 18

Lee, D. W., Duszak Jr, R., and Hughes, D. R. (2013). Comparative analysis of medicare spending for medical imaging: sustained dramatic slowdown compared with other services. *American Journal of Roentgenology*, 201(6):1277–1282. 16

Lewis, J. and Cooper, J. (2015). Expenditure on healthcare in the UK 2013. Technical report, Ofiice for National Statistics. 18

MedPac (2015). Medpac data book: Health care spending and the medicare program. www.medpac.gov. 15

Miller, M. (2005). Recommendations on imaging services: Testimony of mark miller, executive director of medpac before the subcommittee on health, committee on ways and means, u.s. house of representatives. march 17, 2005. Technical report, Medicare Payment Advisory Commission (MedPAC). 16

NHS England (2015). Annual imaging and radiodiagnostics data, imaging and radiodiagnostics time-series table and graph, 1995 to 2014. https://www.england.nhs.uk/statistics/statistical-work-areas/diagnostics-waiting-times-and-activity/imaging-and-radiodiagnostics-annual-data. 18

NHS Scotland (2014). Scottish health service costs: Year ended march 2015. http://www.isdscotland.org/Health-Topics/Finance/Costs/Detailed-Tables/Laboratory.asp. 19

OECD (2016). OECD health statistics 2016. http://www.oecd.org/els/health-systems/health-data.htm. 17

Rothenberg, B. M. (2003). Medical technology as a driver of healthcare costs: diagnostic imaging. *Chicago (IL): Blue Cross and Blue Shield Association*. 15

Rothenberg, B. M. and Korn, A. (2005). The opportunities and challenges posed by the rapid growth of diagnostic imaging. *Journal of the American College of Radiology*, 2(5):407–410. 15

UK Department of Health (2014). Reference costs 2013-2014. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/380322/01_Final_2013-14_Reference_Costs_publication_v2.pdf. 18

US Department of Health and Human Services (2013). CMS statistics. *Washington, DC: Centers for Medicare and Medicaid Services (CMS Pub. No. 03504)*. 17