On the Codetermination of Tax-Financed Medical R&D and Healthcare Expenditures: Models and Evidence[‡]

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Abstract: This paper develops a model of voter choices over support for tax-financed healthcare R&D and healthcare and provides statistical evidence that is consistent with the theoretical analysis. Healthcare expenditures and the level of healthcare technology are not entirely independent phenomena, as often assumed in theoretical and empirical work. Voter interests imply that electoral support for subsidizing healthcare R&D is likely to exist in both private and public healthcare systems. These subsidies in turn tend to increase the rate of innovation and thereby long-run demand for and cost of healthcare through effects on the effectiveness and the menu of available healthcare treatments.

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1. Introduction. The links between social insurance, healthcare technology, and R&D

Healthcare expenditures are a major part of the budgets of all OECD countries, and have grown during most of the post-war period at an accelerating rate. A good deal of the increase in expenditures is evidently the consequence of technological innovation. The menu of treatments and domain of treatable health problems has expanded rapidly as new drugs, surgical procedures, and diagnostic methods were developed. The expansion of the menu of healthcare treatments is partly the result of an unpredictable series of random insights and discoveries by scientists and engineers, but it is not entirely so. A broad range of public policies encourage research and development (R&D) efforts, and these tend to accelerate the rate of innovation in healthcare as in other fields. Therefore, the present state of healthcare technology is partly a consequence of policy choices made in the past. By encouraging healthcare R&D, past policy choices have had significant effects on the menu of healthcare treatments available today and thereby on the extent of healthcare expenditures.

This paper focuses on the choice problem faced by voters who recognize the interdependencies between healthcare R&D and the menu of treatments available for health risks. It uses implications of such choices to construct an election-based model of policy formation for healthcare systems that include potential innovations in treatments. Such an analysis is useful for several reasons. First, efforts to construct a model, force theorists to carefully specify relationships among what are believed to be key variables that affect the phenomenon of interest. By modelling such relationships, their properties can often be deduced in an “other things being equal” environment. In cases in which specific predictions result, the models can be calibrated and subjected to a variety of empirical tests. In cases in which no sharp predictions are generated, a well-constructed model can draw attention to particular variables and neglected relationships, some of which may be counterintuitive and would have gone unrecognized without a well-developed model. In the case of the healthcare sector, such neglected relationships may be vitally important, given the cost and growth rates of the healthcare programs and treatments.

Second, a good model provides behavioral foundations that can inform subsequent estimation strategies. For example, if support for healthcare R&D and the demand for tax-financed healthcare are codetermined, statistical efforts to explain or forecast the demand for tax-financed healthcare should not treat technology as an exogenous variable. Doing so will generate biased estimates of both parameters and standard errors, and thus error-prone assessments of current and future demands for healthcare.

Part 2 develops a model of a forward-looking voter's support for subsidizing healthcare research and development in a setting where healthcare services are partly tax-financed and partly financed through out of pocket expenditures. The policy choices analyzed are long term ones that include consideration of one's own future ailments and treatments for them. Forward looking voters of median age will support subsidies for healthcare research and development when they believe that subsidies will accelerate innovation at a reasonable cost and thereby improve the menu of healthcare procedures available when their own future ailments emerge.[1] The curative properties of new healthcare treatments, in turn, partly determine the demand for tax-financed healthcare insurance or services. (Similar results are obtained for settings in which all healthcare is privately financed as shown in Appendix A.)

The practical relevance of the theoretical analysis is demonstrated in Part 3 of the paper, which provides statistical evidence that electoral support for policies supporting healthcare research and development and public healthcare systems are simultaneously determined and that estimation strategies that ignore that codetermination tend to yield biased results.

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[1] See Thomson (2017) for evidence that R&D tax credits increase the pace of innovation.

2. Voter support for tax-financed healthcare insurance and subsidies for healthcare research and development

Although healthcare R&D and healthcare services have been significant areas of public policy for at least a half century, there has been little analysis of how governmental support for healthcare R&D has affected the overall system of healthcare. Research on healthcare innovation has largely consisted of case studies on the ex-post effects of innovation on healthcare costs and patient welfare. For example, the effects of particular technological developments on healthcare costs have been studied by Newhouse (1992) and Okunade and Murthy (2002) for the United States, and by Okunade et al. (2004) and Oliveira et al. (2005) for various subsets of OECD countries. Both case studies and statistical evidence suggests that innovation has increased demand for healthcare and related products (Weisbrod 1991).

Nonetheless, research on the political economy of healthcare treats technology as an exogenous variable. For example, Bethencourt and Galasso (2008) use a median voter model to explore political complementarities between public healthcare and social security, and find that these are strengthened by technological innovations that increase public healthcare productivity and longevity. Moreno Ternero, and Roemer (2007) use a model of party competition that explains why political parties may agree to cover the latest and most expensive medical techniques available in political equilibrium, although the parties may disagree about the best way to fund the coverage. Healthcare technology is assumed to be exogenous in all these models. Their results, however, suggest that subsidies for healthcare R&D are a fundamental determinant of the size of the welfare state through effects on per capita healthcare expenditures in both the private and public sectors. Congleton, Batinti, and Pietrantonio (2017) provide statistical evidence that government support for healthcare research tends to increase healthcare expenditures in both simple and complex healthcare systems, although their analysis also treats healthcare technology as an exogenous variable.

This paper employs a model similar to that used in Congleton, Batinti, and Pietrantonio's (2017) analysis of complex healthcare systems. Their model is modified to focus attention on interdependencies between healthcare demand and support for R&D, and largely ignores the complexity of the public healthcare systems that tend to emerge from electoral pressures. We use the usual rational-choice methodology of game theory and economics, which implies that voters are self-interested and have unbiased estimates of the tradeoffs involved in choosing healthcare policies. The mathematics developed shows that voters do not have to have the entire healthcare system in their minds at once to assess the relative merits of health care policies but can sequentially optimize in a manner that achieves the same results.

We use a variation of the standard health stock/status utility function developed in Grossman (1972) to characterize consumer/patient/citizen interests in healthcare and healthcare innovation.[2] Each consumer/citizen/patient, $i = 1, \ldots, N$ has a Bernoulli utility function $u(c, H)$. There are two possible states of the world for each person: H^B is a "Bad" state (unwell, unhealthy) and H^G is a "Good" state (well, healthy). $H^G - H^B$ is the severity of the illness. We focus on a single health risk to reduce notational and narrative complexity.[3]

We assume that the health risk of interest is one that most voters believe should be pooled and that the corresponding insurance-delivery system should be tax financed. This requires the median voter's tax cost for insuring or treating the illness of interest to be lower under a tax-financed system

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[2] This approach is widely used in healthcare research, as for example in Wagstaff (1986) and Koç (2004).

[3] The Grossman model assumes that utility is state dependent, which his to say one's state of health affects the marginal utilities of other goods and services. Empirical support of state dependency has consistently been found in the literature. For a review, see Finkelstein, Luttmer and Notowidigdo (2009). Our model can be generalized by by treating the (H^G, H^B) health states and their associated treatments as vectors of the health risks that people confront.

than his or her cost under a private system.[4] The government is assumed to use an earmarked tax to fund both healthcare expenditures and subsidies for healthcare R&D. The tax is assumed to be a proportional income tax with average and marginal rate t.

Revenues are used to fund treatment level g for the condition of interest and to provide a subsidy of amount S for R&D for treatments of the health risk.[5] In addition to the tax-funded healthcare expenditures, individuals can “top up” by purchasing supplemental treatment(s) in the private market. The total healthcare expenditure by individual i in the unwell state can thus be written as $h_i = m_i + g$, with m_i being the private out-of-pocket financed component and g the tax-financed component.

We assume that the healthy state cannot be improved upon, so healthcare expenditures only take place in the low-health state. The extent to which expenditures improve one’s health depends on the technology available, θ. Healthcare expenditures in the unwell state improve health from $H^B\ to\ q(h_i, \theta)H^B$, where function q is the curative or health production function for the condition of interest. In cases in which effective treatments exist, function q increases with the level of medical expenditures, $h_i,$ and with the state of technological progress, $\theta = \phi(S)$, which together characterize the effectiveness of healthcare, $Q_h > 0$, $Q_\theta > 0$, and $Q_{h\theta} > 0$.[6] Healthcare can improve a patient’s health state but not to a level greater than the good state, thus, $1 < q(h_i, \theta) < \frac{H^G}{H^B}$.

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[4] See Congleton, Batinti, and Pietratonio (2017) for the mathematical conditions required for this to be the case. Congleton et. al demonstrate that it is the variation in these conditions among health risks that can generate complex healthcare systems.

[5] Earmarked taxes for healthcare services are common in OECD nations. The assumption that the same tax is used to finance healthcare R&D is less realistic but allows us to focus on a single tax system rather than two. An alternative interpretation of the model would be that both the insurance program and R&D subsidies are financed out of general revenues and that all other government expenditures are assumed to be constant during the period of analysis, as with the usual ceteris paribus assumptions.

[6] We neglect private R&D expenditures in the model to simplify the analysis and narrative. Function ϕ can be regarded as either an “other things being equal” representation of the link between tax-financed support for R&D

The voter-consumer-patient is assumed to have income Y_i, which is spent on personal consumption, private healthcare services, and healthcare taxes. Income Y_i is assumed to be exogenous and is thus the same in both health states.[7] The price of medical care varies with technology and is represented as $\gamma(\theta)$. After-tax personal consumption is $c_i = Y_i(1-t)$ in the well state, and is $c_i = Y_i(1-t) - \gamma(\theta)m_i$ in the unwell state. We consider only curative medicine, so the probability of being in the unwell state, π_i, (morbidity) is also assumed to be exogenous.[8]

The utility levels associated with the well and unwell states are:

$U^G = u_i^G(Y_i\,(1-t), H^G)$ if individual *i* is well, which occurs with probability $(1-\pi_i)$

$U^B = u_i^B[y_i(1-t) - \gamma(\theta)m_i, H^B q(m_i + g, \theta)]$ if individual *i* is unwell, which occurs with probability π_i

As we are dealing with a single healthcare condition, we can rewrite $H^B q(m_i + g, \theta)$ as $H(h_i, \theta)$, which reduces the complexity of reporting the mathematical results.

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and innovations that increase healthcare technology, holding private R&D constant, or as a function that accounts for the effects of tax-financed support for R&D on all R&D and thereby on all innovations in the healthcare sector. The latter is our preferred interpretation.

[7] When the choice is considered a lifetime choice and relevant health problems occur towards the end of life, this is a plausible assumption. Most of one's lifetime income is realized in the period before the period in which debilitating diseases emerge.

[8] The assumption that the probability of being affected by the health risk is exogenous eliminates the moral hazard problem, because changes in the cost of healthcare generated by private and public insurance will not directly or indirectly affect health risks. This may seem like an extreme assumption, because it is clear that lifestyle choices do affect a variety of health risks (Mokdad, Marks, Stroup, & Gerberding 2004; Knoops et al. 2004). However, it bears noting that many "unhealthy" behaviors have diminished as tax-financed healthcare systems became more extensive and inclusive. Tobacco usage has fallen during the past half century, as have highway fatalities, and consumption of saturated fats. For health conditions in which treatments are not very effective (that is those for which $q(h_i, \theta)$ is substantially less than 1), most of the risk associated with "ill behavior" is still borne by the persons choosing the behavior of interest. In such cases, moral hazard problems tend to be minimal.

Given tax-financed healthcare service g, the voter's objective function over private and public healthcare can be written as:

$$U_i^e = (1-\pi_i)\, u_i(y_i(1-t), H^G) + \pi_i\, u[y_i(1-t) - \gamma(\phi(S))m_i, H(h_i, \phi(S))] \qquad [1]$$

Individuals in their roles as voters will imagine ideal levels of personal consumption, personal expenditures on healthcare, ideal government healthcare service levels, and ideal levels of healthcare R&D subsidies. If the choices are thought of as lifetime choices, the decisions reached can be regarded as lifetime totals or average annual expenditures.

Given the voter's expected utility function, we could simply differentiate with respect to the control variables, set the results equal to zero, and thereby characterize a typical voter's ideal healthcare system. Then, we could identify the median voter and thereby characterize the electoral equilibrium healthcare system. However, somewhat greater understanding of relevant choices is provided if we adopt what might be called the ridgeline method of analysis: first, characterizing ideal private and public healthcare demand functions and then using those functions to characterize ideal support levels for healthcare R&D subsidies. The overall equilibrium from this approach emerges as an intersection of ridgelines, analogous to the intersection of best-reply functions in a Nash equilibrium. The ridgeline approach can be used to characterize a sequential thought process, a separation of responsibilities within government, or the usual median voter equilibrium (if one exists). This approach also allows more straightforward comparative statics results because it holds more aspects of the choice setting constant.

2.1 The Demand for Private Supplemental Healthcare

As a point of departure, we initially assume that there are no government subsidies for healthcare R&D and focus on the individual's choice outside the voting booth. In this setting, the individual regards the tax-financed healthcare system and medical technology to be exogenously determined. His or her choice in this setting is simply how much to spend on private healthcare, given the existing state of technology, taxes, and tax-financed healthcare services.

The tax rate confronted by the individual voter can be characterized if the government is assumed to face a binding balanced budget constraint, which is plausible for large, long-term programs such as healthcare. The sum of the N individual tax payments in the polity of interest equals the total expenditure on treatments in that polity.

$$t\sum_{i}^{N} y_i = \bar{\pi} N \gamma(\theta) g \tag*{[2]}$$

This allows the tax rate to be written as a function of the average income of taxpayers, $\bar{y}$, the price of healthcare, $\gamma(\theta)$, average morbidity, $\bar{\pi}$, and program benefit level, g.

$$t\bar{y} = \gamma(\theta) g\, \bar{\pi} \text{ or } 0 < \ t = \gamma(\theta) g \frac{\bar{\pi}}{\bar{y}} < 1 \tag*{[3]}$$

Substituting into the original objective function, we obtain the following expression:

$$\begin{gathered} U_i^e = (1-\pi_i)\, u\left[y_i\left(1-\gamma(\theta) g \frac{\bar{\pi}}{\bar{y}}\right), H^G\right] + \\ + \pi_i\, u\left[y_i\left(1-\gamma(\theta) g \frac{\bar{\pi}}{\bar{y}}\right) - \gamma(\theta) m_i, H(m_i+g,\theta)\right] \end{gathered} \tag*{[4]}$$

The individual's private supplemental demand for healthcare can be characterized by differentiating equation 4 with respect to m_i, the private purchase of healthcare by voter i, and setting the result equal to zero. The first-order condition is:

$$\begin{gathered} \frac{\partial U_i^e}{\partial m_i} = -\gamma u_c^B\left[y_i - \gamma(\theta)\left(\bar{\pi}\frac{y_i}{\bar{y}}\right) g - \gamma m_i, H(m_i+g,\theta)\right] \\ + u_H^B\left[y_i - \gamma(\theta)\left(\bar{\pi}\frac{y_i}{\bar{y}}\right) g - \gamma(\theta) m_i, H(m_i+g,\theta)\right] H_h(m_i+g,\theta) = 0 \end{gathered} \tag*{[5]}$$

This first-order condition allows the private demand for supplemental healthcare to be characterized as:

$$\overset{*}{m}_i = m(y_i, \pi_i, g;\ \gamma, \Theta, \bar{\pi}, \bar{y}, H^G) \qquad [6]$$

The demand function is similar to the private demand derived in Appendix A, although it characterizes supplemental private healthcare expenditures and includes factors associated with the tax-financed program: the benefit provided through government (g) and the average characteristics (income and morbidity) of the population $(\bar{\pi}, \bar{y})$ of voter-taxpayers. Only taxpayers whose overall demand for healthcare exceeds g purchase private healthcare, because private and tax-financed health expenditures are assumed to be perfect substitutes for one another. The comparative statics of private healthcare expenditures clearly differ for high and low demand voters.

Lemma 1.1 characterizes the demand for private healthcare for the subset of patients that "top up" the tax-financed program with private expenditures, i.e. those with interior solutions for equation 11. Proofs are in appendix B.

Lemma 1.1. *i) The demand for private healthcare is downward sloping; ii) medical care is a normal good; iii) morbidity does not affect private healthcare demand in the unwell state,* $\frac{\partial \overset{*}{m}}{\partial \pi} = 0$*; iv) private healthcare expenditures may rise or fall with technology;* $\frac{\partial \overset{*}{m}}{\partial \Theta}$[9] *cannot be signed and depends on the impact that technological change has on healthcare marginal costs and benefits; v) private healthcare expenditures fall with the average probability of the health problem (morbidity)* $\frac{\partial \overset{*}{m}}{\partial \bar{\pi}} < 0$*; vi) increases with average income,* $\frac{\partial \overset{*}{m}}{\partial \bar{y}} > 0$*; and vii) falls with government healthcare benefits,* $\frac{\partial \overset{*}{m}}{\partial g} < 0$.

The effects of a tax-financed program are twofold. An increase in healthcare provided by government programs decreases private expenditures. Private expenditures will fall dollar for dollar as the government expenditures increase, holding tax rates constant.[10] Any associated increase in the tax

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[9] Also in this case, $U_{m\theta}|_{ex\ price} = H_{h\theta}u_H - H_\theta(\gamma u_{cH} - u_{HH}H_h)$ and $U_{m\theta_{end\ price}} = U_{m\theta_{ex\ price}} + U_{m\gamma}\gamma_\theta F_{m\theta}$ has exactly the same structure as the one we showed in a previous section with respect to an undistinguishable aggregate quantity h.

[10] This is can be demonstrated with equation 6.3 above. Given the healthcare insurance system, the private medical services demanded by voter i is $h_i^* = h\big((1-t)y_i, \gamma, \pi, H^G, H^B, \phi(S^*)\big) = g + m_i^*$, which implies that

rate used to provide healthcare benefits implies that total expenditures will fall by somewhat more than dollar for dollar, because after-tax income falls and lower after-tax income implies lower private healthcare demand.

Changes in average income and average morbidity in the population also affect the demand for private healthcare through effects on the tax price of the public healthcare provided.[11] For example, an increase in average morbidity, ceteris paribus, increases the tax price required to support a given benefit level, which by reducing after tax income, decreases private expenditures by those topping up their healthcare. In contrast, an increase in average income reduces the tax rate required to fund a given benefit level, which tends to increase private expenditures for those whose demand for healthcare is greater than the current program g, caeteris paribus. Such changes also tend to influence the level of tax-financed healthcare and subsidies for healthcare R&D, as shown below.

2.2 Voting for Tax-Financed Healthcare with Exogenous Technology

Given voter demands for out-of-pocket healthcare expenditures, we next analyze a typical voter's demand for tax-financed healthcare. Tax-financed systems that include subsidies for healthcare R&D are analyzed in the next section. We first characterizes the median voter's preferred government benefit level for the case in which technology is given, which allows us to contrast the results of electoral models with exogenous technology with ones in which technology is endogenous. We begin by

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$\mathrm{m}_\mathrm{i}^* = h_i^* - g$. Voters with demands that are smaller than the median voters ideal level, g*, will spend nothing on private healthcare. Voter-patients who would otherwise have spent more, will top up the benefit provided by the government. It is voters who would otherwise spend more than g, whose expenditures fall dollar for dollar as the government healthcare benefit increases, ceteris paribus.

[11] This is not an electoral effect, but a consequence of the assumed balanced budget rule, and the *caeteris paribus* nature of partial derivatives.

specifying the typical voter’s objective function given his or her private demand for healthcare, given government healthcare g:

$$\begin{aligned} U_i^e = (1-\pi_i)\, u_i &\left[y_i - \gamma(\theta)\left(\bar{\pi}\frac{y_i}{\bar{y}}\right) g, H^G\right] \\ &+ \pi_i\, u_i\left[y_i - \gamma(\theta)\left(\bar{\pi}\frac{y_i}{\bar{y}}\right) g - \gamma(\theta)\overset{*}{m}_i, H\left(\overset{*}{m}_i + g, \theta\right)\right] \end{aligned} \qquad [7]$$

$\left(\bar{\pi}\frac{y_i}{\bar{y}}\right)$ is the marginal tax cost implied by the tax regime used to finance health insurance, which varies with voter income, y_i.

The median voter is a typical voter with median income and median healthcare risk. His or her ideal tax-financed healthcare system is characterized by the healthcare level, $\overset{*}{g}$, that maximize his or her expected utility. Given the perfect substitutability of private and public healthcare, public healthcare is only demanded by the median voter if it is less expensive than private healthcare, which will be the case if $\left(\bar{\pi}\frac{y^v}{\bar{y}}\right) < \pi^v$, where y^v is the median voter’s pretax income and π^v is her morbidity. In that case, the median voter satisfies all of his or her demands for healthcare through the public program, and $\overset{*}{m}_i = 0$. Otherwise, s/he will be content with an entirely private healthcare system and demand a government program of size zero.[12]

The median voter’s support for tax-financed healthcare services satisfies the following first-order condition:

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[12] We assume that the same healthcare providers are used; thus it is the risk pooling system and distribution of income and health risks that determine this in our model, rather than differences between private providers and public providers. Differences in the effectiveness of two alternative systems of healthcare service delivery would also affect this choice; however, the effective quality adjusted price is still likely to be determined for the most part by the fiscal system. If the marginal tax price is higher than the marginal cost of private insurance over the entire range of interest, the median voter will favor the private system analyzed in appendix A. Such systems were, of course, common among OECD countries before World War II, when healthcare technology was relatively primitive and most treatments relatively inexpensive or ineffective.

$$\frac{\partial \overset{*}{U}_i^e}{\partial g} = -\gamma(\theta)\left(\bar{\pi}\frac{y_i}{\bar{y}}\right)(1-\pi)\,u_c^G + \pi\,\left[-\gamma(\theta)u_c^B\left(\bar{\pi}\frac{y_i}{\bar{y}}\right) + \; u_H^B H_h\right] = 0 \qquad [8]$$

The pattern of healthcare predicted is dichotomous with a majority of voters relying entirely on the tax-financed system and a minority of voters topping up that system with private out-of-pocket expenditures (or private insurance), as characterized above (e.g., those for whom $\left(\overset{*}{m}_i\right) > 0$).

Lemmas 1.2 and 1.3 apply to the case where the median voter prefers a tax-financed benefit, $\overset{*}{g}$, that is greater than zero. Proofs are in appendix B.

Lemma 1.2 *Preferences over benefit levels, g, are concave, and thus single peaked in the g-policy domain. A median-voter equilibrium exists with respect to benefit levels. The policy preferred by the median voter is* $\overset{*}{g} = g\ (Y^v, \pi^v;\ \gamma(\theta), \theta, \bar{y}, \bar{\pi})$, *where* y^v *and* π^v *are the median voter's income and morbidity (which are not necessarily the median income and morbidity of the respective distributions).*

Lemma 1.3 *The demand for benefit level* $\overset{*}{g}$ *(i) falls as healthcare costs increase, (ii) is negatively related to the private demand m for healthcare; (iii) is negatively affected by average morbidity and (iv) positively by average income. The effect of increases in healthcare technology, personal income, and morbidity are ambiguous because of fiscal interdependencies.*

The results reported in the appendix indicate that an increase in median morbidity tends to increase the tax-financed benefit level demanded. An increase in the median voter's morbidity increases her marginal benefits from tax-financed insurance and reduces its price relative to private insurance, which would tend to price health risks. Morbidity, for example, tends to increase with the median voter's age. The effect of technological advance is similar to that found for private systems in appendix A. However, in this case innovation also affects utility in the healthy state through its effect on the tax price of the public healthcare system. The effect of technological innovation on the demand for tax-financed health insurance is determined by the marginal increase in the effectiveness of healthcare generated by technological innovation, which affects both the median voter's own private demand and his or her cost for realizing particular health states via tax-funded insurance.[13]

The median voter's fiscal constraints are determined by the average characteristics of the population. An increase in average morbidity implies an increase in the tax price $\gamma\left(\bar{\pi}\frac{y_i}{\bar{y}}\right)$, which reduces the desired level of social insurance. Given $y^v < \bar{y}$, an increase in the average income implies an increase in the median voter's ideal level of social insurance, because it reduces the tax price for social insurance, $\gamma\left(\bar{\pi}\frac{y_i}{\bar{y}}\right)$, which increases the median voter's demand for tax-financed healthcare, other things being equal. Healthcare expenditures, thus, tend to rise as economic growth takes place and with increases in the average age of the society of interest, because average morbidity increases with average age.[14]

2.3 Electoral support for subsidized healthcare R&D within a tax-financed healthcare systems

We now proceed to the case in which tax-financed healthcare systems and support for healthcare R&D subsides are simultaneously determined. To bring subsidies for R&D into the model, the fiscal

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[13] See Congleton, Batinti, and Pietratonio (2017) for discussion of how the vector of treatments and possibilities for risk sharing and service delivery affect the composition of healthcare systems. We neglect such effects in this paper in order to focus on the tax financed healthcare R&D and service level relationships.

[14] This analysis of fiscal parameters focuses on changes of average income that do not directly affect median income. A change in the distribution of income may change both the average value of income and in the income of the median voter, in which case the result for a change in average income is ambiguous. Nonetheless, though more complicated, the aging effect is still positive. The numerator of the comparative statics effect is equal to $-\gamma\alpha(\pi_a)u_c^G - \gamma(1-\pi)u_{cH}^G H_a^B + \pi_a\left(-\gamma\alpha(\pi_a)u_c^B + u_H^B H_h^B\right) + \pi\left(-\gamma\alpha u_{cH}^B H_a^B + u_{HH}^G H_a^B H_h^B + u_H^B H_{ha}\right) > 0$. This is because the term $-\gamma\alpha(\pi_a)u_c^B + u_H^B H_h^B > 0$ in order for the first-order condition to produce and internal solution for $\overset{*}{g}$. Here $\alpha = \left(\bar{\pi}\frac{y_i}{\bar{y}}\right)$.

constraint is modified to take account of the cost of the subsidies and the anticipated effect of subsidies on healthcare technology, $\Theta = \phi(S)$.

$$t = \overset{*}{g}\gamma(\phi(S))\left(\frac{\bar{\pi}}{\bar{y}}\right) + \left(\frac{\mathrm{S}}{\bar{y}}\right) \qquad [9]$$

A typical voter's expected utility is now the following:

$$\begin{aligned} U_i^e = {} & (1-\pi_i)\, u_i^G \left[y_i - \overset{*}{g}\gamma\big(\phi(S)\big)\left(y_i \frac{\bar{\pi}}{\bar{y}}\right) - \left(\frac{\mathrm{S}}{\bar{y}}\right) y_i\right] \\ & + \pi_i\, u_i^B \left[y_i - \overset{*}{g}\gamma(\phi(S))\left(y_i \frac{\bar{\pi}}{\bar{y}}\right) - \left(\frac{\mathrm{S}}{\bar{y}}\right) y_i - \gamma(\phi(S))\overset{*}{m}, H\left(\overset{*}{m} + \overset{*}{g}, \phi(S)\right)\right] \end{aligned} \qquad [10]$$

Differentiating equation 10 with respect to R&D support level S, characterizes the median voter's ideal tax-financed support level for R&D, $\overset{*}{S}$. The median voter's ideal healthcare system includes the median voter's ideal support for healthcare R&D, $\overset{*}{S}$, with anticipated technology level $\Theta = \phi(\overset{*}{S})$, his or her ideal tax-financed healthcare level $\overset{*}{g} = g\left(Y^v, \pi^v;\ \gamma\left(\phi(\overset{*}{S})\right), \phi(\overset{*}{S}), \bar{y}, \bar{\pi}\right)$, and his or her ideal out-of-pocket expenditure $\overset{*}{m}_i = m\left(y_i, \pi_i, \overset{*}{g};\ \gamma(\phi(\overset{*}{S})), \phi(\overset{*}{S}), \bar{\pi}, \bar{y}, H^G\right)$. Out-of-pocket expenditures are zero for the median voter and most other voters, but are greater than zero for persons with relatively high income and morbidity for reasons discussed above.

All four components of the median voter's ideal healthcare system are codetermined and reflect a variety of complex tax, risk pooling, and health risk tradeoffs.

2.4 Issues concerning the median voter outcome

When two policies are simultaneously determined, a median voter equilibrium is less likely to exist. A stable median voter outcome requires sufficient symmetry in the distribution of voter ideal points to generate a unique multi-dimensional median voter (Plott, 1967). Alternatively, one can assume that the political institutions solve cycling problems associated with asymmetries in the distribution of voter ideal points by inducing median voter outcomes one dimension at a time, Shepsle (1979). In the second case, an institutionally induced equilibrium is characterized by the intersection of the best reply functions of the median voters in each policy dimension.

Analytically, the Shepsle solution is similar to, but not identical to, the median voter outcome developed above. To demonstrate this, we rewrite a typical voter's expected utility function for use in the standard optimization methodology, given their private demand for healthcare:

$$U_i^e = (1-\pi_i)\, u_i \left[y_i - \gamma\big(\phi(S)\big)\left(\bar{\pi}\frac{y_i}{\bar{y}}\right) g \;-\; \left(\frac{\mathrm{S}}{\bar{y}}\right) y_i, H^G\right]$$

$$+\;\pi_i\, u_i \left[y_i - \gamma(\phi(S))\left(\bar{\pi}\frac{y_i}{\bar{y}}\right) g - \gamma(\theta)\overset{*}{m}_i \;-\; \left(\frac{\mathrm{S}}{\bar{y}}\right) y_i, H\left(\overset{*}{m}_i + g, \phi(S)\right)\right] \qquad [11]$$

The respective median voter's ideal points are found by differentiating equation 11 with respect to g and S and setting the results equal to zero. In the case where two different voters are pivotal, similar first-order conditions are found, but the identifying subscripts differ ($i\ and\ j$). If the utility functions are assumed to be the same, but differences in income and morbidity exist, the mathematics of the first-order conditions will closely resemble each other. The relevant first-order conditions are:

$$\frac{\partial \overset{*}{U_i^e}}{\partial g} = -\gamma(\theta)\left(\bar{\pi}\frac{y_i}{\bar{y}}\right)(1-\pi_i)\, u_c^G + \pi_i \left[-\gamma(\theta) u_c^B \left(\bar{\pi}\frac{y_i}{\bar{y}}\right) + \; u_H^B H_h\right] = 0 \qquad [12.1]$$

$$\frac{\partial \overset{*}{U_j^e}}{\partial S} = \left[-g\gamma(\phi_S)\left(\bar{\pi}\frac{y_j}{\bar{y}}\right) - \frac{y_j}{\bar{y}}\right](1-\pi_j)\, u_c^G + \pi_j \left\{\left[-\mathrm{g}\gamma(\phi_S)\left(\bar{\pi}\frac{y_j}{\bar{y}}\right) - \frac{y_j}{\bar{y}}\right] u_c^B + \; u_H^B H_\theta \phi_S\right\} \; = 0 \qquad [12.2]$$

for the case in which neither median voter purchases private healthcare. In the case where the same median voter(s) decide on both dimensions, $i = j$.

The electoral policy equilibrium requires both first-order conditions to be satisfied simultaneously. In the case where $i = j$, the median voter ideals, $\overset{*}{g}\ and\ \overset{*}{S}$, are the same as those developed above using the ridgeline method, although the demand functions describing them are slightly different. It is the case in which $i \neq j$ that is of greatest interest here. The implicit function theorem allows equation 12.1 to be rewritten as:

$$\overset{*}{g}_i = v(y_i, \pi_i, \Theta, \bar{\pi}, \bar{y}, H_i^G)$$

and equation 12.2 as

$$\overset{*}{S}_j = w(y_j, \pi_j, g, \bar{\pi}, \bar{y}, H_j^G).$$

A policy equilibrium occurs when both pivotal voters (or pivotal cabinet ministers) are simultaneously on their best replay functions:

$$\overset{**}{g}_i = v\left(y_i, \pi_i, \phi(\overset{**}{S}_j), \bar{\pi}, \bar{y}, H_i^G\right) \text{ and } \overset{**}{S}_j = w\left(y_j, \pi_j, \overset{**}{g}_i, \bar{\pi}, \bar{y}, H_j^G\right).$$

Figure 1 illustrates such an equilibrium and also the interdependence between tax-financed healthcare program size and decisions to subsidize R&D. As drawn, the equilibrium is dynamically stable, and a series of myopic "other things being equal" adjustments will converge to the equilibrium strategy pair.

At the equilibria, there is little difference between the one median voter and two median voter results. However, this may not be the case away from the equilibrium position. Dynamics are unimportant in the pure median voter case but may be important in the institutionally induced equilibrium. If different voters or different representative committees adopt their policies sequentially, rather than moving directly to the Nash equilibrium, the result may converge to the equilibrium or diverge in either direction. In cases in which myopic adjustments do not converge (as would be the case if the best-reply labels were reversed), explosive growth in both healthcare expenditures and R&D may occur. In such cases, a shock that increased in healthcare R&D support above equilibrium levels would generate support for additional healthcare spending, which would increase support for further R&D support and so on.[15]

As in the previous cases, voter-patients with demands for healthcare greater than g^{**} will top up with private healthcare, given the schedule of medical procedures associated with the technology generated by the subsidy. All these cases imply that the relative size of the public and private healthcare systems and R&D support are codetermined by essentially the same factors.

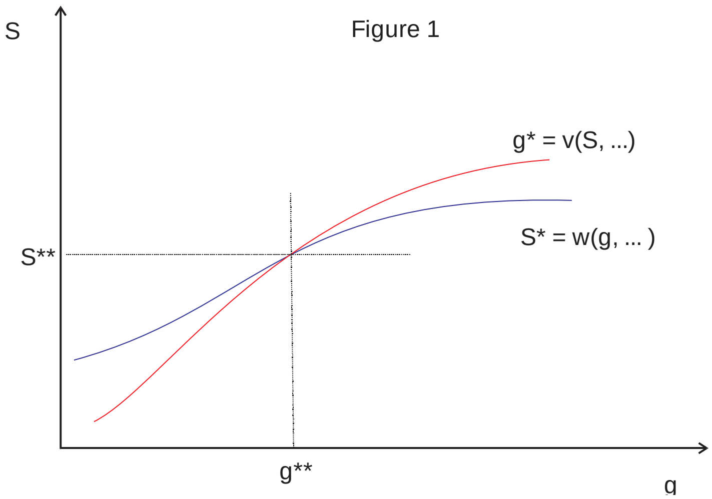
Figure 1

3. Empirical Support for the Codetermination Hypothesis: Data and Results

We next explore the main implications of the above analysis for OECD healthcare systems. To investigate whether the tax-financed healthcare R&D and tax-financed healthcare services are

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[15] As drawn the slope of the $\overset{*}{g}_i$ ridgeline function is greater than that of the $\overset{*}{S}_j$ ridgeline function. In that case, myopic adustments in response to small perturbations around the equilibrium $(\overset{**}{g}_i, \overset{**}{S}_j)$ would return one to the equilibrium. In cases in which the slope of the $\overset{*}{S}_j$ is greater than that of the $\overset{*}{g}_i$ ridgeline function, myopic adjustments in response to small perturbations around the equilibrium move one either toward infinity or toward zero, depending upon whether the perturbation generates an initially above or below equilibrium level of support for healthcare services and support for healthcare R&D.

codetermined, we use government budget data from the OECD. The GBOARD database is especially useful for this project, because it provides information about government budgets by category, including healthcare and healthcare R&D for about 800 country-year observations. The data used in our statistical analysis cover 1981–2014. Table 1 provides descriptive statistics for the data collected, which are mostly from the OECD-GBAORD database. The data are not uniformly available for all countries, so an unbalanced panel is used for our estimates. Details about the panel (breakdowns of observations by country) are provided in Appendix C.

Table1. Descriptive Statistics

Variable	N	Mean	SD	Min	Max
Real Government Healthcare Expenditures Per Capita (Log) (PPP-CP 2010, OECD)	779	7.610	0.480	6.050	8.880
Real Government-Funded Medical R&D (Log) (10 year average, GBAORD-OECD)	779	4.340	1.980	-0.380	10.29
Real Government-Funded Medical R&D (Log) (15 year average, GBAORD-OECD)	779	4.260	1.960	-0.380	10.11
Real Government-Funded Medical R&D (Log) (20 year average, GBAORD-OECD)	779	4.210	1.940	-0.380	9.960
GDP Per Capita Log (PPP, CP 2010, OECD)	779	10.33	0.330	9.360	11.41
Mortality (Log) (Circulatory, OECD)	779	5.980	0.360	5.060	6.740
Long-Term Interest Rates (Index, OECD)	678	6.310	3.200	0.650	22.50

The electoral model developed in part 2 implies that healthcare spending and R&D expenditures are determined by parameters of the median voter's optimization problem, which include personal and average income, and personal and average health risks. Median and average income are normally highly correlated, so we use per capita real income as our income variable. Data on median health risks are unavailable, so we use a population average health risk (circulatory related diseases) as our health risk variable.

We begin by regressing the log of several moving averages of real tax-financed R&D spending per capita on real tax-financed per capita healthcare spending (PPP, 100 = 2010) to demonstrate that the correlation implied by the model is present in the data. In each case, the correlation between tax-financed expenditures on healthcare and healthcare R&D is positive and statistically significant at the .01 level. Robust standard errors are in parentheses.[16]

Table 2: Bivariate Results: Moving Averages of Real R&D Expenditures

Explanatory Variable	(1) R&D MA5 Pooled OLS	(2) R&D MA10 Pooled OLS	(3) R&D MA15 Pooled OLS	(4) R&D MA20 Pooled OLS
Government Healthcare Expenditures Per Capita(Real, Log)	0.0856*** (0.00743)	0.0845*** (0.00752)	0.0817*** (0.00775)	0.0794*** (0.00794)
Observations	777	779	779	779
R-squared	0.128	0.123	0.112	0.104

Note: Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Table 3 reports estimates of the median voter's demand for tax-financed healthcare, $\overset{*}{g} = g\left(Y^v, \pi^v;\ \gamma\left(\phi(\overset{*}{S})\right), \phi(\overset{*}{S}), \bar{y}, \bar{\pi}\right)$. As in the model, voter income and morbidity are assumed exogenously determined.[17] The level of technology is characterized with real government R&D

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[16] We use real total national expenditures on R&D rather than per capita expenditures, because of public goods aspects of many healthcare innovations. The model treats healthcare R&D expenditures and the resulting innovations as local public goods. (Estimates using per capita R&D expenditures yielded similar results and are available on request.) "5 yrs MA" should be read as 5 years (from t-4 to t) moving average of the log of government expenditures in healthcare R&D as in GBOARD dataset. Similarly, for 10 (cols. 2 and 6), 15 cols. (3 and 7), and 20 (cols. 4 and 8) years moving averages. Logged vales are used so that the coefficient estimates can be interpreted as elasticities.

[17] In the model, these are proximate causes of voter assessments of their ideal healthcare systems. These, in turn, may be caused by past behaviors including decisions to invest in human capital and to consume diets thought to be health inducing. To the extent that such choices were largely induced by family culture and genetics, income and health risks can be regarded as exogenous at the level of the individual. Such deeper causal issues are, however, beyond the scope of this paper, which focuses on proximate causes.

spending (represented with the moving average of R&D).[18] We undertake two estimation strategies. The first ignores the simultaneity of tax-financed healthcare and R&D expenditures and simply applies the usual regression techniques for pooled data sets. These results are reported in columns 1–3. The results are consistent with the model. Per capita expenditures rise with past R&D expenditures, voter income, and morbidity, as predicted by our model. Note that the size of the coefficient on the moving averages of R&D expenditures was reduced by including the two other explanatory variables and the country and year fixed effects.

Our model implies that these estimates are likely to suffer from simultaneous-equation bias because government healthcare and R&D spending are codetermined. To account for the simultaneity of the choices of tax-financed healthcare R&D and healthcare expenditures, we employ the two-stage least squares method using long-term real interest rates as the identifying variable in first-stage estimates of the moving averages of tax-financed support for healthcare R&D. Along a steady-state economic growth path, the real interest rate reflects rates of technological innovation and capital accumulations; both of which may be expected to affect the productivity of healthcare R&D but not directly affect healthcare demand.[19] Country and year fixed effects are included in the regressions for both stages. Columns 4–6 report the two-stage results. Note that the coefficient estimates are substantially larger for R&D

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[18] Recall that healthcare technology has been modeled as $\Theta = \phi(S)$, with S being government support levels for healthcare research and development. Technology may be influenced by private expenditures and also technological developments in other fields, but again our focus is on proximate cause. These other contributions to technological advance are assumed to be constant for the purposes of analysis, or, equivalently, driven at the margin by policies supportive of healthcare R&D, which are proxied by direct expenditures on healthcare research and development.

[19] The OECD calculates long-term interest rates from moving averages of interest rates on 10-year government bonds, net of national inflation rates. These should approximate the risk-free rates required for the steady-state Fisher equation to hold.

expenditures in the two-stage estimates than in the single-stage estimates that ignored simultaneity problems.

Table 3: Single- and Two-Stage Estimates of Log Real Per Capita Government Healthcare Spending

	(1)	(2)	(3)	(4)	(5)	(6)
		OLS			2SLS	
	MA10	MA15	MA20	MA10	MA15	MA20
MA Public Health R&D (Log of PPP CP 2010)	0.0385***	0.0390***	0.0417***	0.0655**	0.120***	0.195***
	(0.00726)	(0.00797)	(0.00870)	(0.0281)	(0.0327)	(0.0458)
RGDP PC (Log, PPP CP 2010)	0.809***	0.813***	0.811***	0.733***	0.726***	0.707***
	(0.0497)	(0.0499)	(0.0500)	(0.0496)	(0.0515)	(0.0536)
Mortality (Log, Circulatory Morbidity Rate)	0.160***	0.152***	0.146***	0.165*	0.248***	0.328***
	(0.0480)	(0.0479)	(0.0476)	(0.0861)	(0.0877)	(0.0996)
Fixed Country Effects	x	x	x	x	x	x
Year Fixed Effects	x	x	x	x	x	x
Observations	779	779	779	680	680	680
R-squared	0.981	0.981	0.981	0.979	0.977	0.972
Min Eigenvalue				67.85	65.48	51.37
F-stat				49.99	49.47	35.86
Durban-Hausman-Wu P-value				0.15	0.00	0.00

Source: OECD.

Results from the first-stage regressions are presented in Table C2 of Appendix C. Two of the test statistics can be used to assess the strength of the first-stage estimates. The F-statistic for the first-stage regression demonstrates that our instrumented values for the moving averages of R&D expenditures fit the actual values very well. We also report the Min-eigenvalue as suggested in Stock and Yogo (2002). These values (minimum eigenvalues) have to be compared with tables reported in their paper, which for a 10% F-test threshold is 16.38. Both the minimum eigenvalue and F-stat are above their respective thresholds. With respect to issues concerning endogeneity and exogeneity, we rely on the model's logical structure, but also report the standard Durbin test for endogeneity and Durbin-Hausman-Wu test. The null of exogeneity is rejected (p <0.001) for both for MA15 and MA20 in the first-stage estimates.

Together, the results in Tables 3 and C2 suggest that the model developed characterizes significant aspects of the politics of healthcare expenditures. The variables that the model directs attention to account for most of the variation in tax-supported R&D and healthcare expenditures within the OECD during the period of the study. The 2SLS results suggest that ignoring the simultaneity of healthcare and R&D spending choices causes the impact of tax-financed R&D support on healthcare demand to be underestimated (biased downward). The elasticities found in the 2sls estimates are about three times those of the ols estimates, implying that a long-run (20-year) 1% increase in R&D expenditures increases the size of annual health spending by about 0.2%.

4. Conclusions

Voters have good reason to support expenditures on healthcare R&D in areas in which significant increases in effectiveness are anticipated at relatively little tax cost. Innovations can broaden the menu of healthcare treatments and increase the effectiveness of existing treatments. Both effects tend to increase the overall demand for healthcare. Individuals will demand more healthcare in their roles as private citizens and in their roles as voters. Public policies that accelerate the rate of innovation in healthcare thus also tend to accelerate total healthcare expenditures.

The model estimates are consistent with the theoretical analysis. We find significant relationships between past healthcare R&D expenditures and current healthcare expenditures. We also find evidence that tax-financed R&D and healthcare expenditures are codetermined by fiscal and risk factors relevant for voter choices. Insofar as governmental support for healthcare and related R&D are codetermined, shocks to the political equilibria simultaneously affect tax-financed support for R&D and long-run tax-financed healthcare expenditures. That simultaneity is not captured by models or estimation strategies that ignore technological advance or assume that technology is exogenous, rather than codetermined with healthcare expenditures. The two-stage estimates find a larger effect for past R&D on current healthcare expenditures than found in single-stage estimates.

Although, we have explored these interdependencies using relatively straightforward models and statistical methods, the model implies that these relationships characterized are complex, nonlinear, and not entirely obvious. It is, thus, reasonable to question the extent to which voter calculations and intuitions reflect those complexities. Commonsense implies that some voters are likely to take more complete account of the relationships than others. Nonetheless, voters have more direct experience with healthcare than with many other public policies. Tax financing is often of the earmarked variety, which makes the tax price of healthcare relatively easy to estimate. Together, these imply that any bias in voter beliefs is likely to be smaller for healthcare than for most other policy areas. If approximately median results emerge from democratic politics, the results share properties with median estimators, which tend to be unbiased and relative robust as long as reasonably complete information is taken into account by the median voter (Congleton 2007). In such cases, competitive elections are likely to advance median voter interests as assumed in the model and for the purposes of estimation.

This is not to say that interest groups outside and inside government have no effects on healthcare policies, but it is to say that electoral pressures can account for much of the character of present-day healthcare systems in stable democracies. The models and estimates developed in this paper demonstrate that a median voter model focuses one's attention on variables and interdependencies that can largely account for the recent history of healthcare expenditures and R&D subsidies within OECD countries.

Although the particular innovations that emerge through direct and indirect support for medical innovation cannot be known beforehand, the results suggest that pivotal voters believe that the effectiveness of healthcare is likely to be improved through innovation. This conclusion has indirectly produced a great increase in healthcare expenditures, but an increase that is not likely to be regarded as a problem or mistake by the forward-looking voters whose support induced the policies that accelerated rates of healthcare innovation during the past half century.

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Appendices

Appendix A: Support for Healthcare R&D Subsidies When Only Privately Provided Healthcare Is Available

Table A1. Key Model Variables and Relationships

Variable	Variables' and Functions' Definition
H^B	Health Status in the unwell state
H^G	Health Status in the well state
π_i	Probability of the occurrence of the unwell state
$Q = q(h_i, \theta)$	Healthcare production function. Function of medical care h_i and technology, identified by the parameter θ
m_i	Privately-funded healthcare
g	Tax-financed healthcare
$h_i = m_i + g$	Medical care is the sum of privately and tax-financed healthcare
c_i	Personal Consumption
y_i	Personal Income
$\gamma(\theta)$	Price of medical care h_i
t	Proportional tax rate
$\bar{y}$	Population's Average Income
$\bar{\pi}$	Population's Average Morbidity Rate
N	Population of taxpayer-consumers
$\theta = \phi(S)$	Innovation Function: Characterizes technology as function of tax-financed support for healthcare R&D

As above, the consumer-patient is initially assumed to have income Y_i, which is spent on healthcare and consumption. The price of medical care is γ, which implies that personal consumption is $c_i = y_i - \gamma h_i$ for out-of-pocket expenditure h_i. The productivity of healthcare is determined by technology, Θ.

$U^G = u_i^G(y_i, H^G)$ if individual i is well, which occurs with probability $(1 - \pi_i)$

$U^B = u_i^B[y_i - \gamma h_i, H^B q(h_i, \Theta)]$ if he or she is unwell, which occurs with probability π_i

The Von Neumann Morgenstern expected utility function U_i^e is thus:

$$U_i^e = \pi_i U^B + (1 - \pi_i)U^G = \pi_i u_i^B[y_i - \gamma h_i, H^B q(h_i, \Theta)] + (1 - \pi_i) u_i^G(y_i, H^G) \qquad [1A]$$

Health status is assumed to be valued in itself, $u_H > 0$, and to increase the marginal utility of ordinary consumption, $u_{Hc} > 0$. These assumptions together with the usual assumptions of diminishing marginal returns imply that the utility functions and schedule of medical treatments are strictly concave. An individual's private demand for healthcare in the unwell state can be determined by differentiating the expected utility function associated with equation 1 with respect to healthcare expenditure h_i and setting the result equal to zero.

$$L = \frac{\partial U_i^e}{\partial h_i} = \pi_i[u_c^B(-\gamma) + u_H^B H^B Q_h] = 0 \qquad [2A]$$

This result together with the implicit function theorem implies that an individual's demand for medical care h_i^*, can be written as $h_i^* = h(y_i, \gamma, H^B, \theta)$.[20]

An individual's demand for healthcare varies with personal income, the cost of healthcare, the possible health states, the probability of those states, and healthcare technology.

Lemma A1. *Ordinary healthcare is a normal good, with a downward-sloping demand curve, but expenditures on healthcare may increase or decrease as technology (effectiveness) improves, ceteris paribus.*

These properties can be demonstrated by applying the implicit function and composite differentiation rules to equation 2. Equations [3.1] to [3.4] characterize the comparative statics of individual i's demand for healthcare.

$$E(h_y^*) = \frac{L_y}{-L_h} = \pi_i \frac{u_{cc}^B(-\gamma) + u_{Hc}^B H^B Q_h}{-u_{hh}} > 0 \qquad [3.1A]$$

$$E(h_\gamma^*) = \frac{L_\gamma}{-L_h} = \pi_i \frac{u_{cc}^B(\gamma h) - u_c^B - u_{cH}^B(h) H^B Q_h}{-u_{hh}} < 0 \qquad [3.2A]$$

$$E(h_{H^B}^*) = \frac{L_{H^B}}{-L_h} = \pi_i \frac{u_{Hc}^B(-\gamma) m(h_i, \theta) + u_H^B Q_h + u_{HH}^B H^B Q_h}{-u_{hh}} \gtreqless 0 \qquad [3.3A]$$

$$E(h_\theta^*) = \frac{L_\theta}{-L_h} = \pi_i \frac{u_{cH}^B(-\gamma) Q_\theta + u_{HH}^B H^B Q_h Q_\theta + u_H^B H^B Q_{\theta h}}{-u_{hh}} \gtreqless 0 \qquad [3.4A]$$

Recall that all the first derivatives of the utility and healthcare production functions are positive or zero, the cross partials are positive, and the second derivatives are negative. These are sufficient conditions

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[20] Neither the curvatures nor continuity assumed completely rule out corner solutions. For example, equation 1 implies that in cases in which no effective treatment exists, $Q_h = 0$, and no healthcare expenditures would be undertaken. In that case, the marginal costs of healthcare are always greater than its benefits in subjective utility terms. At the other extreme, improvements in poor health (reduced suffering) might be so great that one's entire income is spent on healthcare. Although these cases are not without interest, the mathematical section for the most part focuses on health problems for which interior solutions exist.

for strict concavity and also for downward-sloping demand curves for ordinary goods and services. Thus, in the case where $Q_\theta > 0$, the standard assumptions unambiguously determine the signs of the derivatives with respect to price and income; although surprisingly not with respect to technology or health state. Demand for healthcare diminishes with price and increases with income.[21]

The effect of small changes in technology or health state on the quantity of healthcare demand depends on the relative size of three terms. The first two terms of the derivative with respect to technology in equation 3.4A show that an increase in effectiveness, other things being equal, tends to diminish the level of healthcare spending. These effects are partially or entirely offset by the demand effect of the increased effectiveness of healthcare expenditures (the last term in the numerator). The latter must dominate for health expenditures to rise in the absence of technologically induced price effects.[22] This ambiguity does not occur in cases in which the menu of effective treatments is expanded by innovation. A change in Q_h from zero to greater than zero, implies that spending increases from 0 to some positive amount (see equation 2) whenever the marginal improvement in health-generated exceeds its cost. As the menu of treatments expands, the demand for healthcare either increases or remains zero.

The results are also ambiguous with respect to health state. The middle term in the numerator of equation 3.3A is positive and the others are negative. Better health in the unwell state increases the opportunity cost of healthcare and diminishes its value, and so healthcare expenditures tend to decline, unless the additional health and utility generated by treatment $(u_H^B Q_h)$ are large relative to those two effects. The denominator is the negative of the second derivative of composite utility function U with respect to h, which is positive given that U and Q are strictly concave.

Voters, as consumer-patients, understand that technological improvements can improve healthcare outcomes and increase expected utility by increasing the effectiveness of healthcare and thereby reducing health risks. Voters may thus be willing to subsidize healthcare research and development. However, as shown below voters will disagree about the ideal level of support. We focus on cases in which healthcare R&D produces technological innovations that make treatments of already treatable conditions more

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[21] Applying the implicit function rule to equation 2 for *π* yields $h_\pi^* = \frac{L_\pi}{-L_h} = [u_C^B\,(-\gamma) + u_H^B H^B Q_h]/-u_{hh} = 0$, which has the value zero at *h**, because the numerator is zero according to the first-order condition characterized by equation 2. However, expected healthcare expenditures are affected by the probability of the unwell state, $\pi_i E_i^* = \pi_i \gamma\, h_i^*$.

[22] This ambiguity would not be changed if we included price effects, as with $\gamma_\theta > 0$. It would simply add other terms to those that determine the net effect of innovation on healthcare demand.

effective, although cases in which innovations allow previously untreatable healthcare problems to be addressed are also of interest, because these most directly increase the demand for healthcare.

Healthcare R&D subsidies are assumed to be financed with an earmarked proportional tax on voter income or expenditures. The existence of such a tax has effects on consumption in both health states with $c_i^G = (1-t)y_i$ and with $c_i^B = (1-t)y_i - \gamma h_i^*$. The amount collected from such a tax is represented as $t\bar{y}N$, where t is the tax rate, $\bar{y}$ is average income and N is the population of tax payers in the community of interest. Although we focus on a single healthcare condition, the results can easily be extended to vectors of independent health problems, H^B, treatment schedules, and types of healthcare R&D.

Subsidies induce improvements in healthcare technology, but at a diminishing rate, $\theta = \phi(S)$ with $\theta_S > 0$ and $\theta_{SS} > 0$. Expected utility for the purposes of voting can be represented as:

$$U_i^e = (1-\pi_i)u\big((1-t)y_i, H^G\big) + (\pi_i)u\left((1-t)y_i - \gamma h_i^*, H^B q\big(h_i^*, \phi(tN\bar{y})\big)\right) \qquad [4A]$$

with $h_i^* = h((1-t)y_i, \gamma, \phi(tN\bar{y}), \pi, H^A, H^B)$. Differentiating with respect to *t* allows a voter's ideal level of tax support, *t**, to be characterized as:

$$\begin{aligned}\frac{\partial U_i^e}{\partial t} &= (1-\pi_i)u_c^G(-y_i) + \pi_i\{u_c^B\big(-y_i - \ \gamma[h_{i\,Y}^*(-y_i) + \ h_\theta^*\theta_S\,(N\bar{y})]\big) + \\ &\quad + u_H^B H^B Q_h[\,h_y^*(-\bar{y}) + h_\theta^*\theta_S\,(N\bar{y})] + \ u_H^B H^B Q_\theta \theta_S\, N\bar{y}\} = 0\end{aligned} \qquad [4.1A]$$

or simplifying using the results from equation $2A$, a voter's preferred earmarked tax for healthcare R&D subsidies, t^*,will satisfy:

$$\frac{\partial U_i^e}{\partial t} = (1-\pi_i)u_c^G(-y_i) + \pi_i[U_c^B(-y_i) + \ u_H^B H^B Q_\theta \theta_S\, N\bar{y}] = 0 \qquad [5A]$$

The first two terms characterize the marginal cost of the R&D tax, which reflect the effects of lower after-tax income.[23] The last term characterizes the marginal benefit from the increased healthcare effectiveness associated with innovation.

Lemma A2. *Voter support for R&D subsidies is not universal. Only in the case in which substantial improvements in the effectiveness of healthcare are anticipated are subsidies for R&D supported by a typical voter.*

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[23] There are a broad range of subsidy methods for R&D, including tax preferences, patents, conditional grants, direct expenditures on R&D. In cases in which a progressive income tax is used, rather than a proportional tax, similar conditions will hold for marginal tax rates. In the case of patents, the marginal cost of stronger patent protection is through effects on prices, rather than tax payments per se. The effects of strengthening patent protections also reduce income available for purchase of nonmedical services and thus are similar to the tax effects modeled.

Recall that an increase in the effectiveness of healthcare increases healthcare expenditures while a decrease in after-tax income decreases it. The first two terms of equation 5 are less than zero, and taxes and subsidies would be set equal to zero if the increase in healthcare induced by the subsidy improvement in technology is insufficient to offset the effects of lower after-tax income. Thus, the model predicts that some existing treatments should receive no R&D subsidies.

Only healthrisks for which R&D is expected to significantly increase effectiveness of treatments at relatively low cost will be favored by voters. The anticipated marginal increase in the effectiveness of healthcare treatments must exceed its marginal tax cost. Insofar as both the marginal tax cost and anticipated marginal benefits vary among voters, it is likely that only a subset of voters will support R&D subsidies.

R&D subsidies imply that healthcare technology and their associated medical care schedule(s) are no longer exogenous parameters taken as given by voters, but partly determined by public policy choices made by voters. Given the equilibrium subsidy rate, the menu of health treatments and the median voter's preferred level of private healthcare are determined by associated innovations, which we assume are increasing in taxpayer support for healthcare R&D.

$$S^* = t^* N \bar{y} \qquad [6.1A]$$

$$M^* = m\big(h_i, \phi(S^*)\big) \qquad [6.2A]$$

$$h_i^* = h\big(y_i, \gamma, \pi_i, H^G, H^B, \phi(S^*)\big) \qquad [6.3A]$$

The comparative statics developed above imply that healthcare demand may increase or decline relative to the case in which technology is taken as given. Whether healthcare demand increases or declines depends on the extent to which effectiveness is increased and any associated effects on costs. Major innovations, such as vaccinations, may reduce expenditures, whereas innovations that increase effectiveness but at a higher cost, such as heart transplants, tend to increase expenditures.

Appendix B: Mathematical Derivations for Lemmas of Section 2

Proof of Lemma 1.1:

The income, price and morbidity effects have the same sign as in the baseline case. (See Lemma A2.1.) We here focus on the proofs for vi, vii, and viii.

$$\frac{\partial \overset{*}{m}}{\partial g} = \frac{\gamma^2 u^B_{cc}\left(\bar{\pi}\frac{y_i}{\bar{y}}\right) - \gamma u^B_{cH} H_h - \gamma\, u^B_{cH}\left(\bar{\pi}\frac{y_i}{\bar{y}}\right) H_h + u^B_{HH} {H_h}^2 + u^B_H H_{hh}}{-\pi\left[\gamma^2 u_{cc} - 2\gamma u_{cH} {H^B}_h + u_{HH} {{H^B}_h}^2 + u_H {H^B}_{hh}\right]} < 0,$$

with:

$$\pi\left[\gamma^2 u_{cc} - \ 2\gamma u_{cH} {H^B}_h + u_{HH} {{H^B}_h}^2 + \quad + u_H {H^B}_{hh}\right] < 0 = F_{mm} \equiv SOC$$

$$\frac{\partial \overset{*}{m}}{\partial \bar{\pi}} = \frac{\gamma^2 u^B_{cc} \frac{y_i}{\bar{y}}\, g - \gamma\, u^B_{cH} \frac{y_i}{\bar{y}}\, g\, H_h}{-SOC} < 0$$

$$\frac{\partial \overset{*}{m}}{\partial \bar{y}} = \frac{-\gamma^2 u^B_{cc} \frac{y_i}{\bar{y}^2}\bar{\pi}\, g + \gamma\, u^B_{cH}\ \frac{y_i}{\bar{y}^2}\bar{\pi}\, g}{-SOC} > 0$$

Proof of Lemma 1.2

The envelope theorem implies that $(-\gamma(\theta)u^B_c + u^B_H H_h) = \frac{\partial U^e_i}{\partial m} = \ 0$, so we can rewrite the first-order condition as:

$$\frac{\partial U^e_i}{\partial g} = -\gamma(\theta)\left(\bar{\pi}\frac{y_i}{\bar{y}}\right)(1-\pi)\, u^G_c + \pi\left[-\ \gamma(\theta)\left(\bar{\pi}\frac{y_i}{\bar{y}}\right) u^B_c + \ u^B_H H_h\ \right] = 0$$

After rearranging, the key relationship can be written in the following way: $\gamma\ \left(\bar{\pi}\ \frac{y_i}{\bar{y}}\right)\ E(u_c) = \ \pi\, u^B_H H_h$. The expected marginal costs from public insurance (left side of the equality) are equal to the expected marginal benefits (right-hand side). Expected marginal costs depend on γ, the public production cost of social insurance, the term $\left(\bar{\pi}\ \frac{y_i}{\bar{y}}\right)$, which is the fiscal distortion from public financing, and which for a voter with average income will just be equal to $\bar{\pi}$. On the "benefits" side, we find that the marginal benefits from public insurance depend on own morbidity π, preferences on health status u^B_H (a subjective component) and on the size of healthcare effectiveness on health status H_h (objective component). For simplicity, let $\alpha_{i/j} = \bar{\pi}\frac{y_{i/j}}{\bar{y}}$, then:

$$U_{gg} = \gamma^2(\alpha_i)^2(1-\pi_i)u^G_{cc} + \ +\pi_i \times [u^B_{cc}(-\gamma\alpha_i)\left(-\gamma\alpha_i - \gamma m_g\right) + u^B_{cH}(-\gamma\alpha_i)H_h\left(m_g+1\right) +$$
$$+ u^B_{cH}H_h\left(-\gamma\alpha_i - \gamma m_g\right) + u^B_{HH}H^2_h(m_g+1) + u_H H_{hh}(m_g+1)]$$

Recall that $m_g < 0$. If $-m_g < min(1,\alpha_i)$, then $U_{gg} < 0$. When $m^* = 0$, then $m_g = 0$. The pivotal voter is fully or overinsured under public coverage. In such cases, $U_{gg} < 0$ is clearly less than zero given the assumptions on preferences and technology in A1 and A2. The next comparative statics are based on the zero out-of-pocket expenditures.

Proof of Lemma 1.3

$$\frac{\partial \overset{*}{g}}{\partial y} =$$

$$\frac{-(1-\pi)\gamma \left[\left(\frac{\bar{\pi}}{\bar{y}}\right) \ u_c^G + y_i \left(\frac{\bar{\pi}}{\bar{y}}\right) u_{cc}^G \left(1-\gamma\left(\frac{\bar{\pi}}{\bar{y}}\right) g\right)\right] + \pi \left[-\gamma\left[\left(\frac{\bar{\pi}}{\bar{y}}\right) u_c^B + \ y_i \left(\frac{\bar{\pi}}{\bar{y}}\right) u_{cc}^B \left(1-\gamma\left(\frac{\bar{\pi}}{\bar{y}}\right) g\right)\right] + u_{cH}^B \left(1-\gamma\left(\frac{\bar{\pi}}{\bar{y}}\right) g\right)\right.}{-SOC}$$

Note that the numerator can also be written in terms of the expected values:

$$-\gamma \frac{\bar{\pi}}{\bar{y}} E(u_c) - \ \gamma(1-t) y_i \frac{\bar{\pi}}{\bar{y}} E(u_{cc}) + (1-t)\, \pi\, u_{cH}^B H_h$$

assuming $\left(\frac{\bar{\pi}}{\bar{y}}\right) \cong 0$, in which case the sign will be positive.

When state dependence is completely characterized by health status and is positive (marginal utility is higher in the health state), the effect of personal morbidity is positive.

$$\frac{\partial \overset{*}{g}}{\partial \bar{\pi}} = \frac{-\gamma \frac{y_i}{\bar{y}} \, (1-\pi) u_c^G - \ \gamma\left(\bar{\pi}\frac{y_i}{\bar{y}}\right)(1-\pi)\left(-\gamma \frac{y_i}{\bar{y}} g\right) u_{cc}^G + \pi\left[-\gamma \frac{y_i}{\bar{y}} u_c^B - \gamma\left(\bar{\pi}\frac{y_i}{\bar{y}}\right) u_{cc}^B \left(-\gamma \frac{y_i}{\bar{y}} g\right) + u_{cH}^B \left(-\gamma \frac{y_i}{\bar{y}} g\right)\right]}{-soc} < 0$$

Appendix C: Supplementary Data and Empirical Analysis

Table C1. Unbalanced Panel 1981–2013

Country	Full Sample Obs	IV Sample Obs	Full – IV Diff
Australia	30	30	0
Austria	33	24	9
Belgium	32	32	0
Canada	31	31	0
Czech Republic	14	13	1
Denmark	32	26	6
Estonia	11	0	11
Finland	33	26	7
France	23	23	0
Germany	23	23	0
Greece	25	15	10
Hungary	9	9	0
Iceland	23	18	5
Ireland	30	30	0
Israel	18	16	2
Italy	21	19	2
Japan	26	25	1
Korea	13	12	1
Luxembourg	13	13	0
Mexico	22	11	11

Netherlands	33	33	0
New Zealand	14	21	–7
Norway	33	29	4
Poland	7	10	–3
Portugal	25	17	8
Slovak Republic	14	10	4
Slovenia	15	8	7
Spain	33	33	0
Sweden	28	27	1
Switzerland	16	32	–16
United Kingdom	32	32	0
United States	30	30	0
Total	**742**	**678**	**64**

Table C2. First-stage of 2WFE-2SLS Regressions
Dependent variable: MA of Tax Financed Medical R&D

	(1) **MA10**	**(2)** **MA15**	**(3)** **MA20**
Real Long-Term Interest Rate	-0.0962***	-0.0914***	-0.0771***
	(0.0136)	(0.0130)	(0.0129)
GDP PC (log of PPP CP2010)	-0.0788	-0.137	-0.0517
	(0.160)	(0.147)	(0.129)
Mortality (Circulatory)	-2.111***	-1.838***	-1.491***
	(0.248)	(0.223)	(0.200)
Country Fixed Effects	x	x	x
Year Fixed Effects	x	x	x
Observations	680	680	680
R-squared	0.983	0.986	0.988