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Abstract

Although the technological change in medicine has been widely recognized as the major driver of rising healthcare costs, there is very little research that directly estimates this effect. This paper uses both a single-equation and a simultaneous equations approach to empirically investigate the interactive relationship between technological innovation and the growth of health expenditure in the context of the pharmaceutical market in Taiwan. Based on observing 182 therapeutic groups between 1997 and 2006, we find evidence to support the argument that technological innovation and health expenditure are simultaneously determined as technological innovation and the growth of health expenditure are endogenous rather than exogenous. Specifically, we find that therapeutic groups associated with higher pharmaceutical expenditure are likely to attract more new products to the market. Meanwhile, therapeutic groups with more new products are associated with higher pharmaceutical expenditures. An important implication of the paper is that the cost containment policy will not only affect the growth of health expenditure, but will also affect the progress of technological innovation in the health sector.

Keywords: Technological innovation, new drugs, health expenditure, simultaneous equation model

JEL classification: I11, I19

Introduction

Health expenditures measure a country's final consumption of health care goods and services plus capital investment in health care infrastructure. The international comparison of health expenditures reveals two stylized facts. First, at a point in time, there is substantial variation in health expenditures across countries, not only in terms of health expenditures, but also as a share of GDP. Second, over time, a large number of countries that have been studied, irrespective of whether their health expenditure levels were initially high or low, experience a similar trend in health expenditure growth. In particular, the growth rate of health expenditures has constantly exceeded the growth rate of GDP.

These stylized facts have provided an impetus for research on the causes of these increases. The bulk of the empirical evidence provides consistent findings on the determinants of personal health expenditures. National income (that is, GDP per capita) is the most important determinant of the cross-sectional variation in health expenditures (see Gerdtham et al. [9]). While differences in income alone can explain most of the cross-sectional variation in health expenditures, growth in income cannot explain why health expenditures have risen so substantially over time. Other factors, such as population aging, increased coverage of health insurance, growth in the number of health professionals and hospital capacity, and lower productivity growth

in the service sector than in other sectors of the countries' economies, may explain part of the story. However, Newhouse [19] explained that the above-mentioned factors, taken together, can only account for less than half of the long-run growth in health expenditures. Instead, Newhouse [19] argued that the major part of the increase in health expenditures stems from technological change in health care. Included in technological change are newly-developed types of equipment and pharmaceuticals as well as new surgical technologies and the development and diffusion of such technological tools as renal dialysis.

This view is supported by empirical evidence and is also widely accepted by health economists [8, 21]. However, researchers have traditionally treated technological change in medicine as an exogenous factor, but technological change in medicine – like technological change in the economy as a whole – is, in fact, endogenous, or generated by factors within the healthcare system.[1]

The purpose of this paper is to investigate empirically the determinants of the technological change in medicine and its impact on healthcare costs. Specifically, we estimate a two-equation model that contains both technological innovation and health expenditure. We compare the empirical results from treating technological innovation as an endogenous variable as compares with treating it as an exogenous variable in the

[1] An exception is Okunade and Murthy [21]. They used the Granger causality test to check the exogeneity of technological innovation, instead of treating technological innovation as exogenous.

simultaneous equation model. As a substantial amount of technological progress in medicine has taken the form of pharmaceutical innovation in recent years, we use the pharmaceutical market as an example to test our hypothesis regarding exogeneity versus endogeneity. Specifically, we test the following two hypotheses: (1) the therapeutic groups associated with higher pharmaceutical expenditure are likely to attract more entries of new products; and (2) the therapeutic groups associated with more pharmaceutical innovation tend to have higher levels of pharmaceutical expenditure.

The remainder of the paper is organized as follows. Section 2 provides a review of the research that investigates the effects of technological change on the growth of health expenditure, and the determinants that affect the progress of technological change. Section 3 briefly describes the features of the pharmaceutical market in Taiwan. Section 4 provides an analytical framework to explain the interaction between the entry of new drugs and health care costs. Section 5 describes the data and methodology used in the empirical analysis. Section 6 presents and analyzes the empirical results, and Section 7 summarizes the findings and discusses some policy implications.

Previous Research

Since the publication of the seminal paper in Kleiman [11] and Newhouse [20], the determinants of health expenditure have been the focus of research in the field of health economics. A considerable number of studies in this line highlight the role of income to explain cross-country variations and long-run growth in health expenditure [2-4]. However, little attention has been given to testing the role of technological innovation in accounting for health expenditure growth. A plausible explanation for the paucity of such research is that searching for an appropriate proxy for technological change in medicine can be difficult.

Okunade and Murthy [21] overcame this difficulty by using total R&D spending and R&D spending specific to health care in the United States as proxies for health care technology. They found empirical evidence in support of Newhouse's [19] argument that technological change is a statistically significant long-run driver of the rising health care expenditure.

Although the research that directly estimates the effects of technological innovation on rising healthcare costs has been scarce, a growing body of research has paid attention to the effect of technological change in medicine on improvements in population health which, in turn, provides additional information on alternative measures of technological innovation in practice. Along this line of research, some

studies have focused on technological change in medicine, in general, while others have focused on pharmaceutical innovation, in particular. For example, Papageorgious, Savvides and Zachariadis [22] argued that the rest of the world may benefit from medical technological change occurring in countries at the frontier of medical technology. They measured the diffusion of technological change in medicine by medical imports as well as the diffusion in the forms of ideas, e.g., the number of foreign-trained medical students.

Other studies that have focused specifically on pharmaceutical innovation rely on three different types of proxies to measure technological change: (1) the cumulative number of drugs approved with new molecular entities; (2) newer drugs as a proportion of total prescriptions; and (3) the average vintage of drugs [13-15]. For example, Lichtenberg [15] used the first approach and emphasized that approval of new molecular entities represents the most important form of innovation. Using the cumulative number of new molecular entities available in the market by year, Lichtenberg [15] found a significantly positive relationship between his measure of pharmaceutical innovation and life expectancy in the USA and in a sample containing data from 52 countries.

These studies treat technological change as an exogenous variable, and hence do not address the issue of how the technological change in medicine evolves over time.

As noted by Smith et al. [23], the rate of technological innovation does not expand independently of the historical context but is rather influenced by various factors, such as the size of the market, rising income and more generous insurance coverage. As a result, a growing body of research has attempted to explain the major drivers of technological innovation in health care.

In this line of research, we illustrate two studies that have documented the empirical relationship between the size of the market and the progress of pharmaceutical innovation. First, using data from the USA, Finkelstein [6] investigated whether an increase in market size resulting from changes in health policies affects R&D investment behavior in the vaccine industry.[2] By comparing changes in the number of new vaccine clinical trials between treatment diseases (affected by the policies) and control diseases (not affected by the policies), she found evidence that the expansion of market size induced by changes in health policies has significantly positive effect on rates of innovation in vaccine markets. The estimates indicate that a $1 increase in annual expected market revenue from a vaccine leads to

[2] In 1991, the U.S. Centers for Disease Control recommended that all infants be vaccinated against hepatitis B. In 1993, Medicare provided insurance coverage for influenza vaccinations administered to its beneficiaries. These two policies increased the potential market size for vaccines which, in turn, in combination with the adoption of a no-fault compensation system for injuries attributable to use of certain childhood vaccines in 1986, substantially increased the expected return from developing new vaccines for infectious diseases.

a six cent increase in vaccine R&D investment.

Second, Acemoglu and Linn [1] measured changes in market size from demographic trends in the USA. During a recent 30-year period, demographic trends led to a decline in the market for drugs mostly consumed by the young (age 0-30). In contrast, markets for drugs mostly consumed by the middle-aged have increased. Acemoglu and Linn [1] found that the change in potential market size, which is measured by a combination of the number of consumers and their incomes, has a significantly positive impact on pharmaceutical innovation: a one percent increase in potential market size leads to about a four percent increase in the entry of new drugs.

In addition, the rate of technological innovation is influenced by rising incomes and more generous insurance coverage. Hall and Jones [10] developed a conceptual framework for explaining why health expenditures are commanding a rising share of national income in many high-income countries. In their framework, they argued that the marginal utility of non-health-care consumption is declining, but that the utility of spending on health is not. As a result, nations spend an increasing share of their income on health care as their national incomes rise. This argument is supported by empirical evidence that the value of life increases twice as fast as income which, in turn, implies that people are willing to pay more for technological innovation as their incomes rise.

As Finkelstein [7] noted, a major expansion in health insurance coverage, which occurred when Medicare was introduced, would lead to market-wide changes. The substantial increases in the demand for care which lead to corresponding increases in revenue are likely to be sufficient to more than offset the fixed cost of entry (e.g., building a new facility, or obtaining regulatory approval for entry). Thus, given the fact that a major demand stimulus occurred, one can expect many providers to enter the market. Furthermore, rates of return on medical research and development are likely to increase, leading to a substantial amount of technological change. This argument is supported by the empirical evidence. Finkelstein [7] found that the introduction of the U.S. Medicare program led to substantial new hospital entry and new technology adoption.

In summary, the previous research has documented the empirical relationship that technological change in medicine is endogenous in the sense that the rate of technological innovation is influenced by various factors inherent in the health care system, such as the size of the market, income and health insurance. The technological innovation, in turn, becomes a major driver of rising healthcare costs. Based on these previous studies, we test empirically the determinants of the technological innovation and their impact on health expenditures in the context of the pharmaceutical market in Taiwan – a country with rapid economic growth and

universal health insurance.[3]

Background

Taiwan initiated the National Health Insurance (NHI) program on March 1, 1995, which covers all citizens. The insurance coverage includes outpatient services, inpatient services and prescription drugs. After implementing the NHI program, the adoption of NHI formula is an important avenue for new prescription drugs to enter into the Taiwanese pharmaceutical market, as most physicians generally prescribe only those drugs that are reimbursed by the NHI program. In the Bureau of NHI, a public agency in charge of administering the NHI program in Taiwan, there is a pharmaceutical committee comprised of physicians, government officials, and academics, to determine the NHI formula. After drugs have obtained the approval and licenses for marketing from the Department of Health, most of these prescription drugs will be included in the NHI formula if the single public payer and pharmaceutical manufacturers reach an agreement on the level of the regulated reimbursement prices. There have been around 25,700 drug items that have been approved in the NHI formula. In 2011, there are still around 16,700 drug items reimbursed by the NHI program.[4]

With respect to the reimbursement scheme, the initial reimbursement prices of

[3] The mean annual growth rate during the period 1997-2006 is around 4.4%.
[4] Source: http://www.nhi.gov.tw/

on-patent branded drugs are based on the median prices of ten developed countries, and the upper limit price of off-patent branded drugs is around 85% of the international median price.[5] Thereafter, the reimbursement prices will be updated based on a two-year price survey and adjustment. On the demand side, currently the maximum copayment of pharmaceuticals is only NT$ 200, resulting in the brands of drugs for patients mainly those determined by physicians.[6]

Thus, the feature of the Taiwanese pharmaceutical market is that the retail prices of new drugs are regulated by a universal health insurance program [18]. As previous research has focused only on the elderly population by using Medicare data [7] or obtaining results from competitive pharmaceutical and health insurance markets [1], this paper provides empirical evidence in the context of the pharmaceutical market regulated by a universal health insurance program which covers the entire population.

Empirical Framework

To test our hypothesis, an empirical model is constructed using two equations: the entry of new drugs and pharmaceutical expenditure. Equations explaining the determinants of new drugs (NEW) and pharmaceutical expenditure (EXP) are given as follows:

$$NEW_{it} = \beta_1 + \beta_2 EXP_{it} + \beta_3 X_{it} + \mu_{it} \quad (1)$$

[5] The BNH includes Australia, Belgium, Canada, France, Germany, Japan, Sweden, Switzerland, UK and USA as a reference group for international comparison.
[6] The average exchange rate during the period 1997-2006 is US$1=NT$32.7.

$$EXP_{it} = \alpha_1 + \alpha_2 NEW_{it} + \alpha_3 Z_{it} + \varepsilon_{it} \quad (2)$$

where *i* denotes the therapeutic category and *t* indexes the year, X_{it} and Z_{it} are vectors of control variables pertaining to the determinants of the technological innovation and pharmaceutical expenditure, respectively, and ε and μ are random error terms. As NEW and EXP are determined simultaneously, NEW and EXP are hypothesized endogenous variables.

In order to test the endogeneity of EXP and NEW, the one-period lagged values of EXP and NEW are used as suitable instruments to test the null hypothesis of exogeneity (whereby OLS and IV estimates of the parameters in equations (1) and (2) are asymptotically equivalent) against the alternative hypothesis of endogeneity (wherein the OLS and IV estimates converge to different constants). The Hausman [11] test enables a test of whether the OLS and IV estimates are significantly different from each other, in which case EXP and NEW are endogenous.

In addition, we need to use exclusion restrictions to identify the parameters for the simultaneous equations model. The lagged value of EXP is solely in the NEW equation, and the lagged value of NEW is used only in the EXP equation. Thereafter, we use three-stage least squares (3SLS) to estimate the simultaneous relationship between NEW and EXP by using the covariance matrix from the second stage and suitable instruments for the endogenous explanatory variables.

The fixed-effects method and 181 therapeutic dummies are used to control for the unobservable characteristics of the therapeutic groups that may be correlated with the endogenous variables. In addition, the log transformation model is used to estimate equation (2) as the distribution of the pharmaceutical expenditures tends to be skewed to the right.

The Data and Variables

The data used in this paper are from two sources. First, we obtained data on new drugs included in the formula of the NHI program from the Bureau of National Health Insurance. This data set provides information regarding the drug identification number (ID), ingredient name, brand name, dosage, reimbursement price, and the anatomical therapeutic chemical (ATC) code classification system.

Second, we obtained data on pharmaceutical expenditures and other variables from a longitudinal data set, which contains one million individuals (about 5% of the total population in Taiwan) randomly selected from the registry of NHI beneficiaries in 2005. The sampling file was then merged with insurance claim files that trace back all the medical utilization records of the same individuals in each year and follow their medical utilization data for subsequent years, hereafter referred to as the NHI sampling claims data.

The NHI sampling claims data were made publicly available through the

National Health Research Institute. This data set contains detailed records on the utilization of personal health-care services, including outpatient visits, hospital admissions and prescription drugs. The data on prescription drugs provide the drug identification number, the quantity utilized and total drug expenditures. The advantage of this data set is that all the medical utilization data can be linked together for the same patient. In addition, this data set is based on national sampling data and serves as an adequate representation of the population data. Thus, the summation of drug expenditure across all patients represents the aggregate spending for the same drug in Taiwan.

Between 1996 and 2006, 556 new drugs were added to the NHI formula.[7] Table 1 shows the distribution of these new drugs across therapeutic groups (defined by the first level of the ATC code). The therapeutic groups that have relatively more pharmaceutical innovation, as measured by the total accumulated numbers of new drugs included in the NHI formula during the sample period, include drugs for the central nervous system (N), antineoplastic and immunomodulating agents (L), anti-infectives (J), as well as drugs for the alimentary tract and metabolism (A), and for the cardiovascular system (C). The number of new drugs in these five groups accounts for about 62% of all new drugs. In contrast, the expenditure on drugs for

[7] In the data set, the forms of new prescription drugs include new molecular entities, formulations, combinations, and indications.

these five groups accounted for nearly 75% of NHI pharmaceutical expenditure in 2006. This suggests that therapeutic groups with relatively more pharmaceutical innovation are associated with higher shares of pharmaceutical expenditure. Alternatively, this also suggests that the therapeutic groups with higher expenditure shares are likely to attract more entries of new products.

In this paper, the observation unit is the therapeutic category, as defined by a four-digit ATC code.[8] As can be seen in the last column of Table 1, the total number of therapeutic categories in our data set is 182. The sample covers the period from 1997 to 2006, which gives a balanced panel model with 1,820 observations.

Table 2 illustrates the definitions and summary statistics of the variables. The first key variable in our empirical analysis is the technological innovation. Following the approach adopted in Lichtenberg [15], we measure the technological innovation in the pharmaceutical market by the accumulated number of new pharmaceutical products in each therapeutic category, as given by the variable NEW. [9] This variable ranges from 0 to 27 in the data set, with a mean of 1.63, indicating that there is substantial variation in pharmaceutical innovation across therapeutic groups.

The second key variable in our empirical analysis is the size of the market which

[8] In the ATC classification system, the one-digit, three-digit, four-digit, and five-digit codes represent the anatomical main group (1st level), therapeutic subgroup (2nd level), pharmacological subgroup (3rd level), and chemical subgroup (4th level), respectively.

[9] A new pharmaceutical product is defined here as one that was included in the NHI formula after 1996.

is measured by the annual pharmaceutical expenditure in each therapeutic group. This variable is represented by the variable EXP and expressed in real terms (in 2006 New Taiwan dollars). There is also a substantial variation in annual pharmaceutical expenditure across therapeutic groups.

Other control variables used in the empirical analysis include the characteristics of the demand side and supply side of the market within each therapeutic group, as well as the major reforms of the payment system in Taiwan. The demand-side variables include mean age of patients who utilize the drugs in each therapeutic categories and the number of patients (PT) that use drugs. The supply-side variables include: (1) the competition in the pharmaceutical market, as measured by the Herfindahl-Hirschman index (HHI) in each therapeutic group; and (2) the size of the buyer, which is measured by the market share (in terms of NHI drug expenditure) of products purchased by larger hospitals, including academic medical centers and metropolitan hospitals (HOSB).

We also add a dummy variable to control the effect of the payment system reform. The variable representing the implementation of the hospital global budget (GB) is set to 0 before 2002, and to 1 thereafter, to measure the impact of the payment system reform for the hospital sector that came into effect in July 2002.

Empirical Results

The empirical results are presented in Table 3. The second and third columns of Table 3 contain the results for the therapeutic fixed effects model, as estimated by OLS, while the fourth and fifth columns in Table 3 shows the results for the therapeutic fixed effects as estimated by IV, that is, by treating EXP and NEW as endogenous variables. The last two columns of Table 3 illustrate the results for the fixed effect model estimated by 3SLS, using 181 dummy variables for the therapeutic categories.

The Hausman test statistics shown at the bottom of Table 3 lead to rejection of the null hypothesis that EXP and NEW are exogenous, in which case they are endogenous. Therefore, the OLS estimates will be biased and inconsistent, and hence lead to biased inferences regarding the simultaneous determination of technological innovation and health expenditure. Based on the fixed effect model estimated by 3SLS, the elasticity of technological innovation with respect to pharmaceutical expenditure is 1.1481, which is about 46.5% ((1.1481-0.7836)/0.7836) larger than that estimated by single-equation IV method. Similarly, we find the elasticity of pharmaceutical expenditure with respect to technological innovation is 0.2139, as estimated by the fixed effect model estimated by 3SLS. This value is about 43.8 % ((0.2139-0.1487)/0.1487) larger than that estimated by the single-equation IV method.

These results suggest that technological innovation and the growth of health expenditure create an interactive and reinforcing cycle. Thus, the effect of technological innovation on the growth of health expenditure will be biased if estimation fails to take into account the interactive nature of technological change in medicine. Thus, we base the following discussion on the simultaneous equations model that accounts for the endogeneity of EXP and NEW using the 3SLS method.

As expected, the coefficients of EXP are positive and statistically significant, indicating that an increase in the size of the market, as measured by the NHI pharmaceutical expenditure, leads to more rapid progress in technological change in medicine, as measured by the accumulated number of new pharmaceutical products. The estimates indicate that a 10% increase in pharmaceutical expenditures leads to an increase of 11.5% in the entry of new drugs (elasticity = 1.8714/1.63). Moreover, the entry of new pharmaceutical products significantly increases pharmaceutical expenditures. The estimated elasticity reported in the fifth column of Table 3 is about 0.21 (= 0.1312*1.63), indicating that a 10% increase in the entry of new drugs leads to an increase of 2.1% in the pharmaceutical expenditure.

Combining these two effects, the results suggest that technological change in medicine and the growth of health expenditure are simultaneously determined as they are both endogenous variables. On the one hand, an increase in health expenditure

implies an expansion in the size of the market which, in turn, provides strong incentives for technological innovation. In other words, as long as new technology is a normal good, the increase in incomes in conjunction with more resources allocated to the health care sector over time will lead to greater utilization of new-technology treatments. Moreover, the health insurance coverage of prescription drugs is quite generous in Taiwan, thereby creating an incentive for new drugs to be included in the NHI formula.

On the other hand, an increase in the rate of technological innovation introduces more new pharmaceutical products into the health care system which in turn fuel the rise in health expenditure. Previous research indicates that because of the higher prices and progress of new technology, the adoption of new drugs might increase health expenditures through two channels: treatment substitution and treatment expansion [5]. Liu and Hsieh [17] show that the adoption of new oral hypoglycemic agents, like thiazolidinediones, increases the treatment cost of diabetes patients and the effect of treatment substitution is greater than that of treatment expansion.

With regard to the estimated coefficients of other control variables, the results are in general consistent with prior expectations. On the demand side, we find that the estimated coefficients for the number and average age of patients (PT and AGE) and are positive and statistically significant in the EXP equation, indicating that

therapeutic groups, in which the products are used by more elderly patients, are more likely to have higher costs.

On the supply side, we find that the degree of market concentration is negatively associated with the entry of new products. This result suggests that a highly competitive market is likely to attract the entry of more new products.

We also find that the buyer size within the therapeutic group have a significantly positive impact on both the entry of new products and pharmaceutical expenditures. This result indicates that therapeutic markets with more big buyers, as measured by the higher market share of larger hospitals, are more likely to attract new products to enter the market which, in turn, also have a more significant impact on the growth of pharmaceutical expenditures. This finding, in combination with the previous results, suggests that not only market size, but also the distribution of the market size toward larger buyers, have significant impacts on the entry of new products. A plausible explanation for this result is that larger buyers may help the supplier to save on marketing costs, and hence increase their expected returns. Thus, pharmaceutical firms are more likely to develop new products where their markets are concentrated toward larger hospitals.

The coefficients of GB are significantly positive in the equation of pharmaceutical expenditure, indicating that the implementation of global budgets

might increase the market size of pharmaceutical markets. This might stem from the nature of policy design that the pharmaceutical expenditure is removed from the overall budget before the reimbursement rate of non-drug treatments is determined, and the reimbursement rate of drugs is based on the public regulated price that is known prior to the delivery of the health care service. That is, under the current rule of global budgeting in Taiwan, the reimbursement price for non-drug treatment is variable, but the reimbursement price for drug treatment is fixed. Thus, in order to avoid the uncertainty in hospital revenues generated from non-drug treatments, hospitals have incentives to spend more on drugs.

Finally, we find that the estimated coefficient of the variable measuring the time trend is positive and significant in the NEW equation, indicating that the entry of new drugs increase over time.

Conclusion

This paper uses a simultaneous equations approach to investigate empirically the dynamic interactions between technological innovation and the growth of health expenditures. Using the pharmaceutical market in Taiwan for the 1997-2006 period, this paper has led to several important findings. First, we find that therapeutic groups associated with higher pharmaceutical expenditures are more likely to attract the entry of more new products. The estimated elasticity, which measures the responsiveness of

technological innovation with respect to health expenditure, is greater than 1, suggesting that the technological innovation is strongly influenced by market size.

Second, the results also confirm the previous finding of Okunade and Murthy [21] in that technological innovation is an important driver of rising health care costs. The results show that the estimated elasticity, which measures the responsiveness of health expenditure with respect to technological innovation, is 0.21.

Third, the Hausman test statistics indicate that technological innovation in medicine is endogenous in the simultaneous relationship with health expenditures. In addition, the estimated elasticity derived from the fixed effect model estimated by 3SLS is significantly different from that derived from the same model estimated by single-equation IV. This finding suggests that the effect of technological innovation on the growth of health expenditure will be statistically biased if we fail to take into account the simultaneity problem between technological innovation and health expenditure.

The empirical results of the paper have three important policy implications. First, technological changes in medicine and health expenditure are simultaneously determined in the sense that they work together and reinforce each other. Thus, the cost containment policy adopted in the health sector becomes a double-edged sword: it not only reduces the growth rate of health expenditure, but also reduces the rate of

technological innovation. Given that the technological change in medicine is an important contributor to improvements in the population's health, the simultaneous determination of technological innovation and health expenditure should lead the government to face a more severe policy dilemma in trying to control health care costs while also improving the population's health.

Second, given that the public sector funds the major portion of the health care expenditure in many countries, the public sector often chooses "new technology" as the target of a cost containment policy. As technological innovation is endogenous in the sense that many factors beyond the control of the public sector provide fuel to induce the progress of new technology (e.g., market size and income), the cost containment effort may not effectively control the growth of health expenditures. Rather, such a policy just shifts the financing of new technology from the public to the private sector. An increase in the private financing of new technology may become an access barrier to new technology among low-income populations. For the supply side, the cost containment policy may also decrease the rate of return for new-drug investment, thereby reducing the incentives for pharmaceutical innovation.

Third, improving health status is the main goal of health care policy, rather than containing health care costs. If the utilization of high-technology treatment improves health outcomes of the overall population, eventually the value of adopting

high-technology treatment might outweigh the increase in healthcare costs. Lichtenberg [16] shows that a higher quality of health care increases life expectancy, though it does increase health expenditures per capita. Therefore, creating a virtuous cycle between technological innovation and health expenditure by adopting new technology based on the cost-effective evidence would be an avenue for policy makers to shape their health care policy.

One limitation of the paper is that we only focus on pharmaceutical innovations. Other forms of technological change in medicine, such as diagnostic technological progress, also account for a large part of growth in health care expenditure. Future research may use diagnostic technologies to investigate the interactive relationship between technological innovation and the growth of health expenditure.

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Table 1

Accumulated numbers of new drugs between 1996 and 2006 and NHI spending on prescription drugs in 2006, by ATC categories

1st Level ATC Code	Description	Number of new drugs	Share of all new drugs (%)	NHI drug expenditure (in billion NT$)	Share of total drug expenditure (%)	Number of therapeutic categories in our data
N	Central nervous system	110	19.78	13.12	13.37	15
L	Antineoplastic and immunomodulating agents	70	12.59	9.76	9.95	8
J	Antiinfectives for systemic use	62	11.15	13.22	13.47	14
A	Alimentary tract and metabolism	55	9.89	12.70	12.94	36
C	Cardiovascular system	47	8.45	24.12	24.58	24
B	Blood and blood forming organs	42	7.55	8.15	8.31	12
R	Respiratory system	38	6.83	5.08	5.18	12
D	Dermatologicals	35	6.29	1.31	1.34	16
M	Musculoskeletal system	32	5.76	4.91	5.00	5
S	Sensory organs	28	5.04	1.17	1.19	11
G	Genitourinary system and sex hormones	24	4.32	2.36	2.41	13
H	Systemic hormonal preparations, excl. sex hormonal and insulin	8	1.44	1.67	1.7	9
V	Various	5	0.90	0.38	0.39	3
P	Antiparasitic products, insecticides and repellents	0	0.00	0.17	0.17	4
Total		556	100.00	98.12	100.00	182

Source: Bureau of National Health Insurance, Taipei, Taiwan.

Notes: 1. ATC is the abbreviation of the Anatomical Therapeutic Chemical classification system.

2. The amount of spending reported in this table excludes the NHI drug spending reimbursed by the flat payment system in clinics.

Table 2 Variable Definitions and Summary Statistics

Name	Definition	Mean (Std. Deviation)
Dependent variables		
NEW	Number of accumulated new pharmaceutical products in each therapeutic category	1.63 (3.27)
EXP*	Real annual pharmaceutical expenditure of each therapeutic category (in million NT$)	11.90 (24.36)
Independent variables		
AGE	Average age of patients who utilize the drugs in each therapeutic category	44.47 (12.87)
PT	Number of patients in each therapeutic category	55649 (109899)
HHI	Herfindahl-Hirschman Index in each therapeutic category	0.2761 (0.2261)
HOSB	The market share (in terms of NHI drug expenditure) of products purchased by academic medical centers and metropolitan hospitals	0.6288 (0.2155)
GB	Dummy = 1 after 2002 to represent the implementation of hospital global budget	0.5 (0.5)
TREND	Time trend	5.5 (2.87)
Number of observations		1,820

Note: The exchange rate was around 32.53 New Taiwan Dollars (TWD) per 1 US Dollar (USD) in 2006.

Source: 2005 NHI sampling claims data, calculated by authors.

Table 3 Regression Estimates

Variables	Fixed effects model estimated by OLS		Fixed effects estimated by IV (with lagged values as IV)		Simultaneous equation model (3SLS) with 181 therapeutic dummy variables[++] (with lagged values as IV)	
	NEW	Log (EXP)	NEW	Log (EXP)	NEW	Log (EXP)
Log (EXP) [+]	1.3564***		1.2772***		1.8714***	
	(0.0912)		(0.0977)		(0.0898)	
	[0.8321]		[0.7836]		[1.1481]	
NEW [+]		0.0881***		0.0912***		0.1312***
		(0.0059)		(0.0062)		(0.0057)
		[0.1436]		[0.1487]		[0.2139]
AGE	0.0306*	0.0402***	0.0446**	0.0374***	0.0210	0.0339***
	(0.0173)	(0.0043)	(0.0176)	(0.0043)	(0.0165)	(0.0041)
PT	6.44e-06***	3.17e-06***	3.55e-06	4.82e-06***	6.31e-06	4.29e-06***
	(2.17e-06)	(5.49e-07)	(2.70e-06)	(6.63e-07)	(2.54e-06)	(6.23e-07)
HHI	-1.7248***	-0.0124	-1.0957**	0.0658	-0.8519**	0.1300
	(0.4148)	(0.1063)	(0.4329)	(0.1077)	(0.4071)	(0.1013)
HOSB	0.8651*	0.7953***	1.4995***	0.7487***	1.0584**	0.6648***
	(0.4572)	(0.1149)	(0.4761)	(0.1178)	(0.4475)	(0.1108)
GB	-0.0278	0.0558**	0.0355	0.0972***	0.0493	0.0992***
	(0.1495)	(0.0381)	(0.1460)	(0.0363)	(0.1373)	(0.0341)
TREND	0.1781***	-0.0114	0.1541***	-0.0235***	0.1327***	-0.0325***
	(0.0284)	(0.0073)	(0.0306)	(0.0077)	(0.0288)	(0.0072)
Const.	-21.2232***	12.2515***	-20.9196***	12.3644***	-27.0991***	12.4144***
	(1.3356)	(0.2042)	(1.4475)	(0.2095)	(1.3571)	(0.2056)
R^2	0.3304	0.3168	0.2241	0.3929	0.8333	0.9713
Hausman(p-value)			0.000	0.000		
Obs.	1820	1820	1638	1638	1638	1638

Note: Fixed effects are for 182 therapeutic categories. *** 1% significance level; ** 5% significance level; *10% significance level

Standard errors are in parentheses. [+] Elasticities are in brackets. [++] The therapeutic dummies are not shown here to save space.