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Customizing Primary Care Delivery Using E-Visits

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Technologies that enable “e-visits”—remote interactions between patients and physicians—are touted as a way to improve and expand primary care. We study a setting in which a physician can divert some of the patient demand away from the office visits and into the e-visits, which utilize less of the physician’s service capacity while maintaining an appropriate quality of care. We explicitly model a distinguishing feature of primary care settings: patient office revisit intervals are determined jointly by the physician and her patients. Using our model, we identify settings where patients and physicians adopt e-visits. We analytically characterize the impact of e-visits on key system outcomes: panel size, patient health, and physician compensation. Notably, we identify settings—defined in terms of patient panel features, parameters of primary care delivery, and physician compensation scheme—in which at least one of the system outcomes suffers under e-visits. Our modeling approach highlights the importance of considering patient and physician responses to primary care interventions to understand their full impact.

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1. Introduction

In the complex landscape of the US healthcare reform, a central issue is redesigning the system of delivering medical care to meet the needs of patients. The additional demand, in part due to expanded coverage and an aging population, has spurred an active search for new approaches to care delivery that would result in better utilization of existing patient care capacity (Wishner and Burton 2017). This issue is particularly relevant for primary care, the major point of access to care for most patients.

In this study, we study new channels of care that enable primary care physicians to provide care virtually. Specifically, telemedicine offers physicians a channel to provide care without the patient coming to the practice and occupying a full appointment slot. These types of visits can take many forms, and for simplicity we will refer to them as “e-visits.” Such channels of care alter not only physician capacity and compensation, but also patient preferences regarding visits and consequently health. We ask two specific questions in this study. First, under what conditions is it beneficial for the patients and physicians to adopt e-visits? Second, if adopted, what are the impacts of e-visits on the performance indicators that a social planner cares about: panel size and patient health? Both questions have become especially relevant in light of the surge in telemedicine use in response to the COVID-19 pandemic.

The primary care environment is distinctively different from other, more procedural, care settings, in which an exogenously determined stream of arriving patients’ needs to be handled by one or multiple resources. In primary care, the arrivals of patients to the practice are not just the input to operational decision making, they are also the consequence of operational decisions the practice makes. Consider the case of a diabetic patient who is presently scheduled to visit the practice once every 4 weeks (we will later on define this as the revisit interval, or RVI for short). What happens if the practice decides to see such a patient every 8 weeks instead? Holding everything else constant, the physician could now handle twice as many patients. But, not everything will remain equal; the patient is now more likely to fall sick between visits, requiring some urgent (unscheduled) visits to the practice. This creates a dual responsibility for a physician: overseeing healthy patients in scheduled (routine) office visits and helping unhealthy patients during unscheduled (urgent) visits. Therefore, to analyze how the introduction of e-visits impacts the healthcare system, we need to develop a new approach in modeling patient demand. This new approach does not take arrivals to the practice as given, but instead explicitly models the underlying dynamics of patient health. As a result, patient demand for primary care emerges as an endogenous process governed by both patient preferences and physician financial incentives.

In our model, patients define a range of acceptable values for their scheduled office RVIs based on the trade-off between the cost associated with an office visit and the disutility of falling sick. On the other hand, the physician chooses the patient panel size and the RVI value to maximize her expected daily revenue subject to her daily appointment capacity. The physician's problem is a capacity-based revenue management model (Talluri and Van Ryzin 2005), in which the physician's revenue may be a mix of "fee-for-service" (FFS) (receiving a fixed fee for each office visit) and "capitation" (receiving a fixed fee for each patient on her panel) payments. This approach treats physicians and patients as active entities reacting to the changes in the care delivery system.

We use physician revenue as an indicator of how attractive e-visits are to physicians. On the patient side, we consider a homogeneous patient panel and define patient health as the expected portion of in-office visits devoted to routine check-ups as opposed to urgent matters related to "flare-ups" in chronic conditions or acute sickness episodes. (We also study heterogeneous patient panels in Appendix B.) The changes in the panel's overall health level reflect the impact of e-visits on patients. Finally, we treat the changes in the size of patient panel as an important societal measure of performance of the primary care system in providing primary care coverage.

The overarching theme of our results is that the endogenous nature of the patient and physician responses to e-visits has a direct impact on care outcomes. For example, the introduction of e-visits may change the degree of flexibility that patients display with respect to the range of RVI values they are willing to accept. Since the RVI values are jointly selected by patients and their physicians, e-visits may alter the balance between the scheduled and urgent visits, resulting in changes in patient health, as well as physician compensation and the number of patients that a physician can accommodate on her panel. Thus, ignoring the endogeneity in patient and physician responses may lead to starkly different conclusions on the impact of primary care innovations such as e-visits. For example, it is often argued that e-visits lead to larger panel sizes (Green et al. 2013) and improved patient health (Zhou et al. 2010). We show that the impact of e-visits on system outcomes depends on factors such as e-visit compensation scheme and patient panel characteristics, and in fact, e-visits can lead to smaller panel sizes and lower panel health.

We provide the analytical characterization of the physician's optimal RVI values in the settings with and without e-visits, as well as the patients' joint decision on e-visit adoption and the value of RVI. Then, to illustrate how system outcomes change when e-visits are introduced, we focus on a patient panel that is flexible in terms of RVI values before e-visits, and a physician whose FFS compensation for routine and urgent in-office visits is proportional to their respective duration. We consider two possible ways of compensating e-visits: "proportional FFS e-visit compensation" in which e-visits are compensated proportionally to the amount of physician capacity they consume, and "capitation e-visit compensation" in which the physician receives a daily capitation payment per patient for providing e-visits.

We demonstrate that e-visits may improve or worsen panel health for patients with intermediate health levels. These effects are driven by the patient and physician responses to the introduction of e-visits. First, if e-visits are sufficiently effective in replacing office visits, it is optimal for the patients to visit the physician frequently (through either channel); thus, panel health is guaranteed to improve if the physician chooses to adopt e-visits. This improvement in panel health is entirely driven by patient response. Second, we turn our attention to the settings in which e-visits do not change patient flexibility. In such settings, the impact of e-visits is dictated by the physician response. Under proportional FFS e-visit compensation, we show that e-visits do not have any negative effect on panel health. Under the capitation e-visit compensation, however, panel health can change in either direction.

We show that panel size is not guaranteed to increase with e-visits, and provide sufficient conditions for such an increase. Specifically, under the capitation e-visit compensation, the physician panel size may decrease; this effect could be due to patient or physician responses. Additionally, we show that e-visits are guaranteed to increase panel size under proportional FFS e-visit compensation.

We also show that e-visits may not be adopted because of the conflicting incentives of the patients and physicians under certain conditions. For example, if the effectiveness of e-visits is sufficiently high such that patients become inflexible and insist on short RVIs, the physicians may reject e-visits. In this case, although e-visits would improve panel health, they are not sustainable as they do not encourage physician participation by negatively impacting physician revenue and panel size. Such scenarios can happen under both capitation and proportional FFS e-visit compensation.

We extend these analytical results with numerical analyses based on real-world parameter estimates. The numerical results illustrate the set of parameters that lead to favorable or adverse e-visit effects. We also conduct an analysis of patient welfare that combines the health impact of e-visits with their effect on patient coverage through changes in panel size. Our paper is organized as follows. Section 2 reviews the relevant literature. Section 3 introduces the model at the core of the analysis. In section 4, we model and analyze the impact of e-visits, and in section 5, we present the numerical results. We conclude by discussing our findings in section 6.

2. Literature Review

In the operations management literature, several papers focus on matching patient demand and treatment capacity in primary care settings. Green et al. (2007) provide guidelines on patient panel sizing in primary care. Green and Savin (2008) and Liu and Ziya (2014) apply queuing analysis to study the effects of patient no-shows on physician panel sizes, and Zacharias and Armony (2016) study the joint problem of panel sizing and appointment scheduling. Ozen and Balasubramanian (2013) quantify the impact of case-mix on physician utilization and panel sizes, and Balasubramanian et al. (2012) show the advantages of provider flexibility and quantify the trade-off between access to and continuity of care. A key modeling element in these papers is the exogenous nature of patient demand for care. In contrast, we treat patient demand as an endogenous process governed by the physician's choice of RVI values consistent with patient preferences.

The related literature includes a number of studies that show the impact of compensation schemes on the policies healthcare providers adopt (e.g., Adida and Bravo 2018, Adida et al. 2016, Andritsos and Tang 2018, Guo et al. 2019). Our model of physician compensation resembles the one in McGuire (2000), as it has both FFS and capitation components. Similar to Shumsky and Pinker (2003), we study the response of primary care physicians to alternative compensation schemes, but, instead of looking at the role of a physician as a gatekeeper to the healthcare system, we study the physician's choice of office RVIs and patient panel size.

We also contribute to the literature that studies e-visits and telemedicine. Zhong et al. (2016) model the patient workflow in a primary care system in the presence of e-visits and evaluate the impact of a new mode of delivering care on the length of patient office visits. In our paper, we focus on the impact of e-visits on key performance indicators, such as patient health, physician revenue, and patient panel size. In related work, Çakici and Mills (2021) study teletriage, a system that provides medical advice to patients, and show that the effectiveness of teletriage depends on how patients respond to its introduction based on their perceived level of health.

Rajan et al. (2018) study the operational impact of telemedicine on a specialist serving a heterogeneous patient population suffering from chronic conditions. Our modeling approach differs from Rajan et al. (2018) in multiple ways as their model is geared toward a specialist rather than a primary care physician. First, the physician in their model optimizes patient service rate and service price, while we take these two quantities as given and focus instead on a physician's decision on patient RVIs. Second, the physician compensation contract in our model is a mix of FFS and capitation, a feature that is common in primary care, as compared to the FFS contract considered in Rajan et al. (2018). Third, we study the impact of RVI customization as compared to uniform RVI policy that is prevalent primary care (Schectman et al. 2005). Fourth, we consider FFS and capitation elements as e-visit payments by patients and e-visit compensation for the physician, both of which affect the physician and patient decisions regarding RVIs, while in their model the patient is only responsible for a copay that is modeled as a fraction of the price not covered by insurance.

An emerging literature on online telemedicine platforms is topically related to our work (Liu et al. 2018, Savin et al. 2019). While this literature focuses exclusively on the online interactions between patients and providers, our work models the environment where the care delivery includes a combination of online and in-office interactions. In particular, our analysis focuses on describing the co-existence between these two modes of care delivery.

This study is related to the work of Bavafa et al. (2019) in that both papers examine key primary care system outcomes (patient health, panel size, and physician compensation) and endogenize RVI values based on patient and physician preferences. Beyond that, the papers differ along every key dimension. For example, the present paper studies e-visits, a cost-based intervention, along with RVI customization by patient health status, whereas the focus of Bavafa et al. (2019) is on the impact of non-physician providers, a quality-based intervention. The theoretical models and subsequent results thus differ due to the separate goals of these papers. For example, the present paper examines variation in visit type compensation, physician compensation regime (allowing for combinations of FFS and capitation payments), and patient heterogeneity, none of which is studied in Bavafa et al. (2019).

Our model also builds on the extant literature on preventive maintenance (McCall 1965, Wu and Zuo 2010). The problem faced by the patient is a special case of the "age replacement" policy (Glasser 1967), and the physician's problem is related to the "machine interference" or "repairman problem" (Cho and Parlar 1991, Haque and Armstrong 2007, Stecke and Aronson 1985). In healthcare, Deo et al. (2013) study a related problem of determining RVIs for asthma patients in community-based chronic care setting using a Markovian disease progression model. The novel feature of our model, not addressed in the existing literature, is the interaction between the incentives of the patient ("machine") and the physician ("repairman"). In particular, in our model we allow not only the "repairman" but also the "machines" to actively respond to changes in care delivery, such as introduction of e-visits.

One of the key features of our model is the physician's decision regarding the frequency of patient scheduled visits, that is, RVI values. In particular, the physician's decision on RVIs is a function of patient health. Therefore, our work is related to prior work that study the timing of disease screening and treatment. A group of studies in this literature focuses on screening tests to detect the first incidence of a disease (Brailsford et al. 2012, Deo et al. 2015, Güneş et al. 2015, Helm et al. 2015, Kirch and Klein 1974, Maillart et al. 2008, Rauner et al. 2010), while another group focuses on treatment decisions for a previously detected condition (Alagoz et al. 2004, Ayer et al. 2012, Lavieri et al. 2012, Shechter et al. 2008). Our work differs from this literature since our goal is to develop insights on the interaction between patient preferences and physician incentives when deciding on patient RVIs rather than to develop a detailed high-fidelity model of a particular primary scare practice.

3. Traditional Mode of Care Delivery

We start the analysis by modeling the traditional mode of primary care delivery. In particular, we consider a primary care setting where a single physician provides in-office service to her patients. We focus on a homogeneous patient panel in the paper and derive results related to RVI customization for a heterogeneous patient panel in Appendix B. We assume that, following an office visit, a patient will fall into the sick state in the absence of care and will require an office visit after a random time period $\mathscr{T}$. We model $\mathscr{T}$ as taking one of the two discrete values:

$$\mathscr{T} = \begin{cases} T_l, & \text{with probability } q, \\ T_h, & \text{with probability } 1-q, \end{cases} \tag{1}$$

with $T_l < T_h$ and $0 \le q \le 1$, so that $\mathrm{E}[\mathscr{T}] = qT_l + (1-q)T_h$ and $\mathrm{Var}[\mathscr{T}] = 2(1-q)q(T_h - T_l)^2$. This simplified representation of the stochastic process of "falling sick" allows for tractable analysis of the care delivery. Also, the process described by Equation (1) possesses the increasing failure rate (IFR) property. The IFR implies, plausibly, that, as time since the last office visit increases, the patient is more likely to get sick. When a patient falls into the sick state, he is immediately treated by the physician in an office visit during which the patient is "restored" to the healthy state. Note that our model does not rely on the patient being restored to "full health" by an office visit after falling sick. We assume that the patient is being restored to a baseline state (which we call "healthy").

The goal of our modeling of patient health dynamics is to represent the IFR, that is, the increased likelihood for patients to get healthier if they visit their physician more frequently. After an office visit, the patient still falls sick with probability q after T_l time, so, for example, having a chronic condition would still translate into a pattern of office visits. Note that although the two-point distribution in Equation (1) is simple and allows us to make analytical progress, the three parameters T_l, T_h, and q can be characterized to match the first two moments of any distribution. The two-point distribution does miss the higher moments (e.g., third and fourth), but we consider this difference to be unlikely to result in qualitative changes in the insights derived from our model. We assume that all patients on the panel transition between "healthy" and "sick" states independently from each other. The value of q can be characterized as the level of overall "health" of the patients, as $\mathscr{T}$ is stochastically decreasing in q, so that the lower is q, the healthier are the patients.

In our model, the physician chooses the RVI which is the time until the next scheduled office visit. This choice, however, depends on the health of the patient panel. The use of scheduled office visits is analogous to the "age replacement" policy in the machine maintenance literature (Glasser 1967). In primary care, patients play an active role in setting the RVIs (Welch et al. 1999), so we use a two-stage model for the process of selecting the RVI that considers both patient and physician incentives. At the first stage, patients provide the physician with a range of RVI values they find acceptable. At the second stage, the physician chooses the RVI value among the alternatives provided by the patients. The role of the patients can be thought of as that of a Stackelberg leader that provides a constraint on the RVI values for the physician's optimization problem.

This modeling approach is similar to the classic "divide-and-choose" procedure (Brams and Taylor 1996). Note that there are other approaches in modeling the patient–physician interactions at a micro-level in this setting. One possible option is the Nash bargaining approach where the RVI value is set as a "compromise" between physician and patient preferences and is determined by optimizing a joint objective function constructed from the objectives of the two parties using a parameter that describes their relative bargaining power (Ellis and McGuire 1990). We consider the "divide-and-choose" approach to be more realistic compared to Nash bargaining in healthcare settings for two reasons. First, in practice, patients are likely to be willing to accept a range of RVI values instead of insisting on a single value. Second, the Nash bargaining approach relies on the knowledge of the "bargaining power" parameter that is difficult to reliably estimate in practice. Another option is a model in which the physician moves first and selects an RVI; then, the ultimate RVI value is determined after the patient adds noise to the physician-selected RVI value based on his preferences. Overall, although these models differ in their mathematical formulations, they lead to qualitatively similar outcomes.

3.1. Patient Preferences for Office Revisit Intervals

Suppose that, upon completion of every office visit of a patient, the next visit is scheduled in r time units. The patient's actual next office visit will occur after the random time interval $\min(\mathscr{T}, r)$. The expected value of this time between office visits calculated over the two-scenario distribution of $\mathscr{T}$ is given by

$$T(r)=\begin{cases} r, & r\le T_l,\\ qT_l+(1-q)r, & T_l<r\le T_h,\\ qT_l+(1-q)T_h, & r>T_h,\end{cases} \tag{2}$$

that is an increasing concave function of the RVI value r. Note that, in the presence of the scheduled RVI r, every office visit falls into one of two categories we label as "routine" and "urgent". Under the routine visit, the patient comes to the physician's office and is still in the "healthy" state, while under the urgent visit, the patient is in the "sick" state. For a given value of r, the probability that a particular office visit falls into the "routine" category is given by

$$\rho^r(r)=P(\mathscr{T}\ge r)=\begin{cases} 1, & r\le T_l,\\ 1-q, & T_l<r\le T_h,\\ 0, & r>T_h.\end{cases} \tag{3}$$

Note that in our model the time between patient visits to the physician is either T_l or T_h. Consider a patient with $r=T_h$; if the patient falls sick after T_l time units and visits the physician with an urgent visit, the patient's next visit is in T_h time from the urgent visit (not T_h-T_l). That is, the patient's previous appointment corresponding to T_h is canceled, and another appointment is scheduled for T_h time units upon the completion of the urgent visit.

We assume that during a "routine" visit to the physician's office a patient incurs the cost c_o, while during an "urgent" visit the same patient incurs the cost of $c_o(1+\eta)$, with $\eta\ge 0$. The factor η captures the additional cost associated with the patient being sick when visiting the office. Thus, expressed in the units of c_o, the expected cost associated with an office visit is

$$C(r)=\rho^r(r)+(1+\eta)(1-\rho^r(r))=\begin{cases} 1, & r\le T_l,\\ 1+q\eta, & T_l<r\le T_h,\\ 1+\eta, & r>T_h.\end{cases} \tag{4}$$

Patient preferences for the RVI values are governed by the objective of minimizing the long-run average cost of the patient. We use the standard renewal process framework to calculate the patient's long-run average cost as displayed below.[1]

$$D^o(r)=\frac{C(r)}{T(r)}=\begin{cases} \dfrac{1}{r}, & r\le T_l,\\ \dfrac{1+q\eta}{qT_l+(1-q)r}, & T_l<r\le T_h,\\ \dfrac{1+\eta}{qT_l+(1-q)T_h}, & r>T_h.\end{cases} \tag{5}$$

Lemma 1. *For given values of η and q, the global minimizer of Equation* (5) *is*

$$\bar{r}^o=\begin{cases} T_l, & q>\dfrac{1}{1+\dfrac{\eta}{\dfrac{T_h}{T_l}-1}},\\ T_h, & q\le\dfrac{1}{1+\dfrac{\eta}{\dfrac{T_h}{T_l}-1}}.\end{cases} \tag{6}$$

Lemma 1 states that the patient preference for RVI values switches from the lowest possible value of $\mathscr{T}$ to the highest possible value when his health level exceeds a certain threshold, that is, when q drops below $\frac{1}{1+\frac{\eta}{\frac{T_h}{T_l}-1}}$. Note that the threshold value for q is a decreasing function of the "sickness factor" η, indicating that the higher patient's sickness cost is, the easier it is for him to select more frequently scheduled office visits.

If patients knew the values of T_l, T_h, η, and q with perfect precision, the outcome of the patient RVI optimization problem would result in a single RVI value. In reality, however, patients are often more "flexible" in that they are willing to accept a set of RVI values instead of just one. We model this observation about patient flexibility regarding RVI values by introducing uncertainty in the value of η. In particular, we assume that while the values of T_l, T_h, and q are known to patients (as well as to their physicians), patients do not know the value of their sickness factor η with certainty, but, rather, know that this value is located in the interval $[\eta_{\min}, \eta_{\max}]$. To describe this interval, we use the following notation: we denote the center of the interval with $c = \frac{\eta_{\min}+\eta_{\max}}{2}$, and the half-length of the interval with $c\Delta = \frac{\eta_{\max}-\eta_{\min}}{2}$ with $\Delta \in [0, 1]$. Using this notation, the patient knows that η is in the interval $[c(1-\Delta), c(1+\Delta)]$.

Thus, in our model, the patient panel is characterized by a set of three parameters (q, c, Δ). In this set, the value of q describes the degree of overall health of patient panel: high (low) values of q can be characterized as "sick" ("healthy") panels. Assuming a symmetric distribution of η, the value of c corresponds to the average additional cost of a sick visit to the patient. Recall that c is the notional value that represents the center of the interval for the actual patient sickness factor, η. Thus, low values of c describe "stoic" patients, while high values of c correspond to "worried" patients. Finally, Δ stands for the degree of flexibility that a patient displays with respect to the choice of the RVI value: low values of Δ correspond to "inflexible" patients, while high values of Δ correspond to "flexible" patients. Note that our goal is to incorporate patient flexibility in the model rather than enabling the patients to make an optimal decision on RVI values given the distribution of η and the patients' risk profiles. Also, the insights derived from our analyses do not rest on the assumption that patients know the parameters of the time between visits distribution. For example, we would reach identical conclusions by assuming that η is known to the patients with certainty, and the value of q is uncertain. Similarly, multiple parameters in the patient problem could be uncertain, leading the patients to be flexible regarding RVI values. Such an approach, while useful, leads to complexities that are outside the scope of our parsimonious model.

Based on Lemma 1, patients know that the optimal RVI value is either T_l or T_h. Thus, given the uncertainty in the sickness factor η, patients accept the following set of RVI values depending on the flexibility parameter Δ: T_l, T_h, or both. In particular, if inequality $q \le \frac{1}{1+\frac{\eta}{\frac{T_h}{T_l}-1}}$ holds for any $\eta \in [c(1-\Delta), c(1+\Delta)]$, then the patients will select T_h as their preferred RVI value. In a similar fashion, if $q > \frac{1}{1+\frac{\eta}{\frac{T_h}{T_l}-1}}$ holds for any $\eta \in [c(1-\Delta), c(1+\Delta)]$, then the patients will select T_l as their preferred RVI value. However, if $\frac{1}{1+\frac{c(1+\Delta)}{\frac{T_h}{T_l}-1}} \le q \le \frac{1}{1+\frac{c(1-\Delta)}{\frac{T_h}{T_l}-1}}$, then the patients will be willing to accept any of the two RVI values, T_l or T_h. By letting $\{r^-, r^+\}$ denote the two RVI values that patients are willing to accept, we can formally express these observations as follows.

LEMMA 2.

$$\{r^-, r^+\} = \begin{cases} \{T_h, T_h\}, & q < q^-(c, \Delta), \\ \{T_l, T_l\}, & q > q^+(c, \Delta), \\ \{T_l, T_h\}, & q^-(c, \Delta) \le q \le q^+(c, \Delta), \end{cases} \quad (7)$$

where

$$q^-(c, \Delta) = \frac{1}{1+\frac{c(1+\Delta)}{\frac{T_h}{T_l}-1}}, \quad (8)$$

$$q^+(c, \Delta) = \frac{1}{1+\frac{c(1-\Delta)}{\frac{T_h}{T_l}-1}}. \quad (9)$$

Lemma 2 describes the impact of the level of health q on the range of RVI values acceptable for a patient panel. In particular, if patient health level is sufficiently low or high, the patient panel is "inflexible": for $q < q^-(c, \Delta)$ the patient panel only accepts T_h, and for $q > q^+(c, \Delta)$ the patients only accept the lowest RVI value T_l. On the other hand, for the health levels in the intermediate range, $q^-(c, \Delta) \le q \le q^+(c, \Delta)$, patients are "flexible" with respect to RVIs, allowing the physician to make that choice according to her preferences. The threshold values of q (i.e., $q^-(c, \Delta)$ and $q^+(c, \Delta)$) depend on c and Δ. Both thresholds are decreasing functions of c, but Δ affects them in opposing directions: the upper threshold is increasing in Δ and the lower threshold is decreasing in Δ. Therefore, increasing Δ expands the range of q for which the panel is flexible.

3.2. Appointment Capacity Allocation and Physician Compensation Schemes

We consider a physician who serves a homogeneous panel of N patients. Note that for simplicity we assume that N can take fractional values. We also assume that demand for the physician's services is sufficiently high, and the physician is able to select the overall size of her patient panel N. In choosing the size of her patient panel N and the RVI r, a physician is guided by her compensation scheme as has been shown by prior work, including Hickson et al. (1987), Gosden et al. (2001), Lee et al. (2010), Shumsky and Pinker (2003). Similar models have been developed in the operations management literature focusing on FFS and capitation contracts in healthcare (Adida and Bravo 2018, Andritsos and Tang 2018). Note that while models that consider a revenue-maximizing physician are common in the literature (e.g., Gupta and Wang 2008, Liu 2016), other terms such as patient health or social welfare may appear in the objective function of the physician.

In our analysis, we focus on two common incentive schemes: FFS and capitation (CAP). We assume that under the FFS incentive scheme a physician is paid a fixed amount R^r for each routine visit and R^u for each urgent visit. An urgent visit, requiring more effort and a longer time commitment from a physician, is compensated at a higher rate, that is, $R^u > R^r$. For example, Medicare and Medicaid FFS payments increase as a function of visit complexity: "established patient" visits can be billed under CPT[2] codes 99211–99215 (Brunt 2011). The expected daily compensation for a FFS physician is (using the renewal process framework)

$$\Pi_{FFS}(N, r) = N\left(\frac{\rho^r(r)R^r + (1-\rho^r(r))R^u}{T(r)}\right). \tag{10}$$

Under the capitation scheme a physician is paid a fixed amount (per time period, e.g., a year) for each patient on her panel. Thus, a "capitation" physician, effectively, focuses on maximizing the size of her patient panel N:

$$\Pi_{CAP}(N, r) = NR^d, \tag{11}$$

where R^d is the fixed daily compensation for each patient.

The physician's total compensation may be a combination of FFS and capitation components that reflects a mix of insurance policies used by the patients on her panel:

$$\begin{aligned}\Pi_\delta(N, r) &= \delta\Pi_{FFS}(N, r) + (1-\delta)\Pi_{CAP}(N, r)\\ &= N\left((1-\delta)R^d + \delta\left(\frac{\rho^r(r)R^r + (1-\rho^r(r))R^u}{T(r)}\right)\right),\end{aligned} \tag{12}$$

where δ refers to the proportion of physician daily compensation that is based on the FFS scheme. For example, if $\delta = 0$, the physician's compensation scheme is a pure capitation, and if $\delta = 1$, the physician's compensation scheme is a pure FFS. Note that all the revenue items in the model (i.e., R^r, R^u, and R^d) are paid by the patient's insurance company as opposed to by the patient himself. Patient's out-of-pocket expenses can be modeled as part of the patient cost shown in Equation (4). Also, while the capitation payments are not dependent on patient health or whether the visits are routine or urgent, the FFS payments are weighed by the fraction of patient visits that are routine because routine and urgent visits are compensated at different rates.

The problem of selecting patient panel size N and the office RVI r that a physician faces can be formulated as

$$\max_{N,\, r} \Pi_\delta(N, r) \tag{13}$$

$$\text{s.t. } N\left(\frac{\rho^r(r)\tau^r + (1-\rho^r(r))\tau^u}{T(r)}\right) \le A, \tag{14}$$

$$r \in \{r^-, r^+\}, \tag{15}$$

where Equation (14) represents the physician's capacity constraint. In particular, we assume that physician has to provide sufficient daily appointment capacity to deal with the total expected daily demand from all patients. (We derive this constraint using the standard renewal process framework similar to Equation (2)–(5).) In this inequality, τ^r (τ^u) is the time required by a routine (urgent) patient visit, and A is the physician's total daily service capacity. We assume that an urgent visit requires longer time commitment from a physician, so that $\tau^u > \tau^r$.

The physician's optimization problem in Equations (13)–(15) reflects the "divide-and-choose" approach to selecting the RVI values, where a physician chooses the optimal values among the ones acceptable to patients. We use the notation $\left\{\hat{N}, \hat{r}\right\}$ to denote the values of patient panel size and RVIs that optimize (13)–(15). Below we describe the values of $\left\{\hat{N}, \hat{r}\right\}$ for the setting with "flexible" patients. To provide the analytical characterization of the optimal solution to the physician's problem, we introduce the following quantities:

$$\bar{q}^\tau = \frac{1}{1 + \left(\frac{\frac{\tau^u}{\tau^r} - 1}{\frac{T_h}{T_l} - 1}\right)}, \tag{16}$$

$$\bar{q}^R = \frac{1}{1 + \left(\frac{\frac{R^u}{R^r} - 1}{\frac{T_h}{T_l} - 1}\right)}, \tag{17}$$

$$Q^T = \frac{\frac{T_h}{T_l}}{\frac{T_h}{T_l} - 1}, \tag{18}$$

$$\bar{R} = 1 + \frac{(1-\delta)R^d T_l}{\delta R^r}, \tag{19}$$

$$\Sigma = \left(1 - \frac{\bar{q}^\tau}{\bar{q}^R}\right)\left(\frac{\delta R^r}{(1-\delta)R^d T_l}\right). \tag{20}$$

The quantities in Equations (16)–(20) appear in future analytical derivations. The value of $\bar{q}^\tau$ is a measure of heterogeneity in terms of the time that the physician has to invest on routine and urgent visits. In a similar fashion, $\bar{q}^R$ measures heterogeneity in the revenue generated by routine and urgent visits. Q^T measures the spread of the RVI values for routine and urgent visits, for example, if T_h and T_l values are close, $Q^T \to +\infty$, while if they are far apart, $Q^T \to 1$. Both $\bar{R}$ and Σ are composite measures that describe the contributions of the capitation and FFS elements of physician compensation. $\bar{R}$ measures solely the revenue aspects and is monotone in δ, for example, as $\delta \to 0$ we have $\bar{R} \to +\infty$, and as $\delta \to 1$ we have $\bar{R} \to 1$. The expression for Σ, however, includes $\bar{q}^\tau$, $\bar{q}^R$, and $\bar{R}$; therefore, it is a composite measure that combines $\bar{R}$ with the factors that describe heterogeneity in revenue and capacity consumption between urgent and routine visits.

Proposition 1 *Consider a patient panel with* $q \in [q^-(c, \Delta), q^+(c, \Delta)]$. *Then, the optimal RVI values in Equations* (13)–(15) *are given by*

$$\hat{r} = \begin{cases} T_h, & q \le \dfrac{\bar{q}^\tau}{(1+\Sigma)^+}, \\ T_l, & \text{otherwise,} \end{cases} \tag{21}$$

where $x^+ = \max(x, 0)$.

For a flexible patient panel, Proposition 1 describes the optimal RVI value chosen by the physician. In particular, the physician uses a threshold strategy: if the panel is healthier than a threshold (i.e., $q \le \frac{\bar{q}^\tau}{(1+\Sigma)^+}$), the physician picks the large RVI (T_h); otherwise, she picks the small RVI (T_l). In Equation (21), the term $(1+\Sigma)^+$ is driven by the relative contributions of the capitation and FFS elements of physician compensation, for example, if $\delta \to 0$, then $\Sigma \to 0$ and $(1+\Sigma)^+ \to 1$. The proposition also specifies how the patient health level threshold depends on the key parameters in the physician's problem: τ^r, τ^u, R^r, R^u, T_h, T_l, and δ. For example, holding all other parameters constant, the patient health level threshold is a decreasing function of $\frac{\tau^u}{\tau^r}$, that is, as urgent visits become longer compared to routine visits, the physician becomes more inclined to choose the smaller RVI value.

Another insight from Proposition 1 is that the physician may choose T_l to increase panel size. Consider the case of a physician that is entirely compensated on a capitation basis (i.e., $\delta = 0$) and hence is incentivized to increase panel size. In this case, $\Sigma = 0$ in Equation (21), so the physician picks T_l if the patient panel is sufficiently sick, that is, $q > \bar{q}^\tau$. To see the intuition behind this result, suppose the physician picks an RVI of T_h for an excessively sick patient population. Most patients will fall sick before their routine appointment and need an urgent appointment; because urgent appointments consume more of the physician's capacity compared to the routine appointments (i.e., $\tau^u > \tau^r$), the physician capacity for handling patients is reduced.

As we show below, the expressions for the optimal RVI decisions could be simplified in the settings with "proportional" compensation rates, where $\frac{R^r}{\tau^r} = \frac{R^u}{\tau^u}$.

Corollary 1. *Consider a patient panel with* $q \in [q^-(c, \Delta), q^+(c, \Delta)]$ *under the "proportional" compensation* ($\frac{R^r}{\tau^r} = \frac{R^u}{\tau^u}$). *Then, the optimal RVI values in Equations* (13)–(15) *are given by*

$$\hat{r} = \begin{cases} T_h, & q \le \bar{q}^\tau, \\ T_l, & \text{otherwise.} \end{cases} \tag{22}$$

Corollary 1 states that, under the "proportional" compensation for urgent and routine visits, the physician's choice of RVI value is not a function of δ. The proportional compensation makes the FFS side of the physician incentives indifferent toward RVI values, so the physician focuses on the RVI value that maximizes the panel size. The difference between Equations (21) and (22) is that the proportionality of routine and urgent visit revenues results in $\bar{q}^\tau = \bar{q}^R$ and hence $\Sigma = 0$. Thus, whether the physician decides to see the patients as often or as infrequently as possible is governed exclusively by their health level, with the value of $\bar{q}^\tau$ serving as a "switching threshold."

4. Customizing Care Using E-Visits

In this section, we will look at how the introduction of e-visits alters the choice of RVIs for different patient groups, the total size of patient panel, and physician compensation. On the physician side, e-visits are characterized by the service time $\tau_e^r < \tau^r$ they require, the per-visit FFS compensation $R_e^r < R^r$, and the daily capitation compensation $R_e^d < R^d$. In the presence of e-visits, a fraction of patient demand for primary care is safely handled without patients having to come to the physician's office. We assume that the quality of online visits for this group of patient care requests is the same as the quality of face-to-face office visits. There is evidence that such tasks exist in primary care (Pelak et al. 2015), for example, medication review. In our model, we also assume that only a fraction of *routine* office visits, α_e^r, fit into such e-visit category, and that all urgent visits must still be handled at the office. While we believe that the latter is a realistic assumption, our model can be readily extended to the case where a finite fraction of urgent visits can also be attended to remotely. Also, to maintain parsimony, we do not model the details of e-visit interactions, so the fraction α_e^r represents the average "replaceability" of office visits with e-visits. For example, as we discuss in Appendix C, the model can incorporate "unsuccessful" e-visit attempts in which some e-visits need to be followed up with an office visit.

We consider a general setting where the physician "diverts" some of the routine visits to an "e-visit" channel of care. This, on the one hand, saves the physician some service time that can be allocated to more demanding and urgent cases, while, on the other hand, leads to a potential revenue loss due to lower compensation that e-visits may bring. At present, insurance companies and Centers for Medicare & Medicaid Services (CMS) are experimenting with different forms of payment for e-visits. A number of physician practices are experimenting with charging patients fixed annual fees (an analogue of R_e^d) as well as per-e-mail fees (an analogue of R_e^r) in exchange for offering e-visits (Fairview Health Services 2013, Reijonsaari et al. 2005). Similarly, CMS has been offering compensation plans such as Chronic Care Management (CCM) that charge the patients who sign-up a monthly fee (Twiddy 2015). In the absence of insurance support, the entire physician compensation for providing e-visits comes from patient out-of-pocket payments, and, as we discuss later, patients can choose not to adopt e-visits. Note that, even in the absence of out-of-pocket costs, a patient may not be able to use e-visits as a substitute for all routine visits, since some routine visits may require in-office care. Thus, we assume that $\alpha_e^r < 1$. Furthermore, if a patient avoids coming to the office for the routine visit and uses an e-visit instead, he does not incur the cost of visit c_o which is more than the cost of an e-visit (i.e., $R_e^r < c_o$). Note that c_o includes patient copay as well as the cost of visiting the physician's office in person (e.g., transportation, time). Also, patients still incur the cost $c_o(1+\eta)$ for an unscheduled visit. If the scheduled office RVI for patients is set at r, the expected visit cost, in units of c_o, in the presence of e-visits is

$$C^e(r) = \frac{\delta R_e^r}{c_o}\alpha_e^r\rho^r(r) + (1-\alpha_e^r)\rho^r(r) + (1+\eta)(1-\rho^r(r))$$
$$= \begin{cases} 1-\left(1-\frac{\delta R_e^r}{c_o}\right)\alpha_e^r, & r \le T_l, \\ (1-q)\left(1-\left(1-\frac{\delta R_e^r}{c_o}\right)\alpha_e^r\right)+q(1+\eta), & T_l < r \le T_h, \\ 1+\eta, & r > T_h. \end{cases} \tag{23}$$

Similar to Equation (5), we can define the expected daily cost for a patient as

$$D^e(r) = (1-\delta)R_e^d + \frac{C^e(r)}{T(r)} = \begin{cases} (1-\delta)R_e^d + \dfrac{1-\left(1-\frac{\delta R_e^r}{c_o}\right)\alpha_e^r}{r}, & r \le T_l, \\ (1-\delta)R_e^d + \dfrac{(1-q)\left(1-\left(1-\frac{\delta R_e^r}{c_o}\right)\alpha_e^r\right)+q(1+\eta)}{qT_l+(1-q)r}, & T_l < r \le T_h, \\ (1-\delta)R_e^d + \dfrac{1+\eta}{qT_l+(1-q)T_h}, & r > T_h. \end{cases} \tag{24}$$

We include the parameter δ in Equations (23) and (24) to keep the patient and physician models consistent. That is, a fraction δ of patients pay for e-visits via FFS payments (R_e^r), and a fraction $1-\delta$ pay the e-visit capitation fee (R_e^d). The RVI value that minimizes $D^e(r)$ is denoted by $\bar{r}^e$.

4.1. Patient and Physician Responses to E-Visits

Our modeling approach for e-visit adoption is similar to the way that RVI values are determined in that the patient is the first mover. In particular, the patient first decides whether he wants to adopt e-visits. Then, if the patient adopts e-visits, the physician decides whether she adopts given the patient's RVI flexibility. The physician's e-visit adoption decision is based on practice revenue, that is, the physician adopts e-visits only if they increase her revenue.

We start by describing the patient's decision regarding e-visit adoption. This choice is denoted by θ, where

$\theta = 1$ means that the patient chooses to adopt e-visits, and $\theta = 0$ means that the patient rejects e-visits. The patient's long-run average cost is given by

$$D(\theta, r) = \begin{cases} D^e(r), & \theta = 1, \\ D^o(r), & \theta = 0. \end{cases} \tag{25}$$

In the absence of uncertainty about the sickness factor, the patient's choice of adoption is given by the following:

$$\bar{\theta} = \begin{cases} 1, & D^e(\bar{r}^e) \le D^o(\bar{r}^o), \\ 0, & \text{o.w.} \end{cases} \tag{26}$$

The patient's preferences regarding RVIs and e-visit adoption are given by the following result, where $\bar{\theta}$ and $\bar{r}$ represent the patient's decisions regarding e-visit adoption and RVI value, respectively.

Proposition 2 *Under e-visits, for given values of α_e^r, η, and q, the global minimizers of the patient's long-run average cost, $D(\theta, r)$, are*

$$(\bar{\theta}, \bar{r}) = \begin{cases} (0, T_l), & q > \dfrac{1}{1 + \dfrac{\eta}{\frac{T_h}{T_l} - 1}}, \ \left(1 - \dfrac{\delta R_e^r}{c_o}\right)\alpha_e^r < (1-\delta) R_e^d T_l, \\[2ex] (0, T_h), & \left\{ q \le \dfrac{1}{1 + \dfrac{\eta_e^r}{\frac{T_h}{T_l} - 1}}, \ \left(1 - \dfrac{\delta R_e^r}{c_o}\right)\alpha_e^r < \dfrac{(1-\delta) R_e^d (q T_l + (1-q) T_h)}{(1-q)} \right\} \\[2ex] & \cup \left\{ \dfrac{1}{1 + \dfrac{\eta_e^r}{\frac{T_h}{T_l} - 1}} < q \le \dfrac{1}{1 + \dfrac{\eta}{\frac{T_h}{T_l} - 1}}, \ \left(1 - \dfrac{\delta R_e^r}{c_o}\right)\alpha_e^r < 1 + T_l \left((1-\delta) R_e^d - \dfrac{1 + q\eta}{q T_l + (1-q) T_h} \right) \right\}, \\[2ex] (1, T_l), & \left\{ q > \dfrac{1}{1 + \dfrac{\eta}{\frac{T_h}{T_l} - 1}}, \ \left(1 - \dfrac{\delta R_e^r}{c_o}\right)\alpha_e^r \ge (1-\delta) R_e^d T_l \right\} \\[2ex] & \cup \left\{ \dfrac{1}{1 + \dfrac{\eta_e^r}{\frac{T_h}{T_l} - 1}} < q \le \dfrac{1}{1 + \dfrac{\eta}{\frac{T_h}{T_l} - 1}}, \ \left(1 - \dfrac{\delta R_e^r}{c_o}\right)\alpha_e^r \ge 1 + T_l \left((1-\delta) R_e^d - \dfrac{1 + q\eta}{q T_l + (1-q) T_h} \right) \right\}, \\[2ex] (1, T_h), & q \le \dfrac{1}{1 + \dfrac{\eta_e^r}{\frac{T_h}{T_l} - 1}}, \ \left(1 - \dfrac{\delta R_e^r}{c_o}\right)\alpha_e^r \ge \dfrac{(1-\delta) R_e^d (q T_l + (1-q) T_h)}{(1-q)}, \end{cases} \tag{27}$$

where

$$\eta_e^r = \frac{\eta + \left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r}{1 - \left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r}. \tag{28}$$

The patient has four possible choices which stem from the combination of two decisions: e-visit adoption (i.e., $\bar{\theta} \in \{0, 1\}$) and RVI value (i.e., $\bar{r} = \{T_l, T_h\}$). Proposition 2 describes patient's choice when the patient knows the value of η with certainty. For example, the first case in Equation (27) describes a panel that is sufficiently sick combined with a sufficiently low e-visit impact factor, $\left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r$. Under such conditions, the patient chooses not to adopt e-visits and picks an RVI value of T_l.

We further illustrate the results of Proposition 2 using Figure 1. Figure 1a illustrates the conditions described in Equation (27). In particular, for sufficiently low values of e-visit impact factor, $\left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r$, patients choose not to adopt e-visits: if e-visits are not sufficiently effective in replacing office visits, e-visit adoption increases patient cost in the presence of the e-visit capitation fee (R_e^d). The areas labeled with $(\bar{\theta}, \bar{r}) = (0, T_h)$ and $(\bar{\theta}, \bar{r}) = (0, T_l)$ represent such conditions. Also, when patients opt to adopt e-visits, as e-visit impact factor increases patients gravitate toward more frequent scheduled routine visits (in-office and e-visit). Note that the fraction of office visits that can be replaced by e-visits is exogenous in the short run as it depends on factors such as the e-visit technology and practice style of the clinic. This value, however, may change over time as technology evolves and practices update their processes and protocols regarding e-visits. Figure 1a also shows that relatively sicker patient panels (large value of q) are more likely to adopt e-visits. These panels tend to need more frequent routine visits, so the e-visit cost savings are more substantial to them. Note that without the e-visit capitation fee, patients will adopt e-visits (for any q) as they are inherently cost saving ($R_e^r < c_o$).

As before, patients know that their sickness factor, η, is in the interval $[c(1 - \Delta), c(1 + \Delta)]$. Therefore, they may be flexible in terms of the RVI values that they find acceptable. When e-visits are introduced, patients decide on e-visit adoption and the acceptable range of RVIs simultaneously. We model this in the following way: patients adopt e-visits only if they decrease the patients' long-run average costs for all values of $\eta \in [c(1 - \Delta), c(1 + \Delta)]$. Figure 1b shows how patients' choice of e-visit adoption and their acceptable range of RVI values change as they become flexible ($\Delta = 0.9$). In the area marked as $(1, T_h) \sim (1, T_l)$ patients choose to adopt e-visits and accept both RVI values of T_l and T_h, and in the area marked as $(0, T_l) \sim (0, T_h)$ patients do not adopt e-visits but are flexible with both RVI values of T_l and T_h. In the rest of the areas, patients are inflexible with respect to RVI but may choose to adopt e-visits or not.

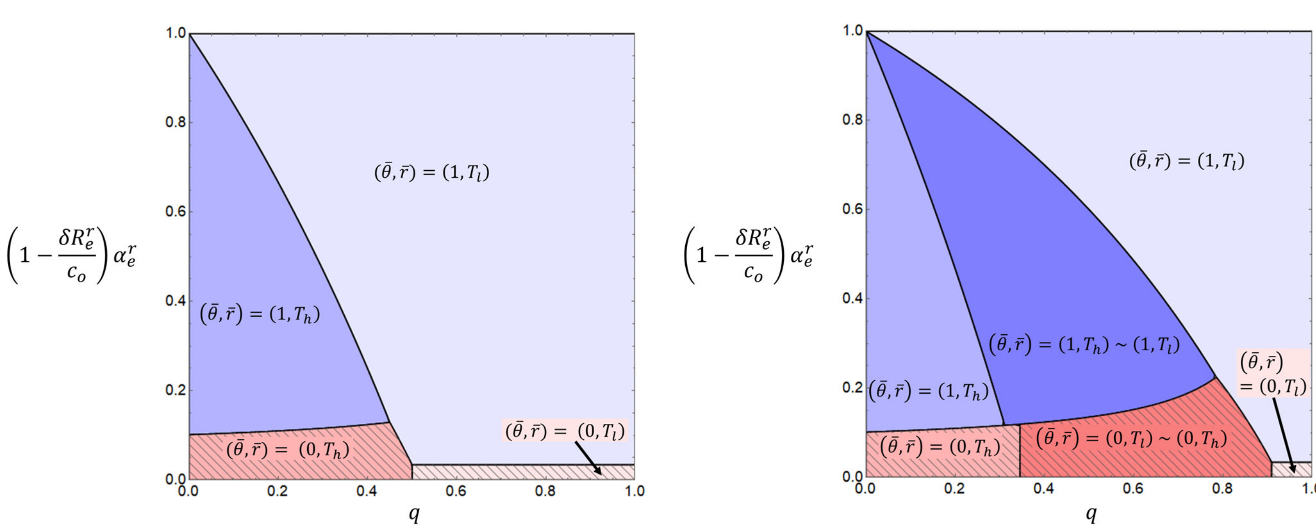
The areas where patients are flexible with respect to RVI values in Figure 1b become narrower as the e-visit impact factor increases. The presence of e-visits makes routine visits more affordable; thus, as the e-visit impact factor increases, patients are more likely to choose an RVI of T_l and be inflexible about the RVI value. In Figure 1b, we observe that for large values of e-visit impact factor (e.g., $\left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r = 0.8$), patients are inflexible for most values of q. At the same time, the share of q values that lead to inflexibility with T_l increases with the e-visit impact factor. This is an important observation as it demonstrates that when e-visits are effective at replacing office visits, they lead to less flexibility for the physician in terms of RVI choice.

As we discuss below, the introduction of e-visits can transform a flexible patient group into an inflexible one, and vice versa. For this analysis, we introduce the following threshold values for α_e^r:

$$\bar{\alpha}_e^r(q) = \frac{\left(\frac{1}{q} - 1\right)\left(\frac{T_h}{T_l} - 1\right) - c(1 - \Delta)}{\left(\left(\frac{1}{q} - 1\right)\left(\frac{T_h}{T_l} - 1\right) + 1\right)\left(1 - \frac{\delta R_e^r}{c_o}\right)}, \tag{29}$$

$$\underline{\alpha}_e^r(q) = \frac{\left(\frac{1}{q} - 1\right)\left(\frac{T_h}{T_l} - 1\right) - c(1 + \Delta)}{\left(\left(\frac{1}{q} - 1\right)\left(\frac{T_h}{T_l} - 1\right) + 1\right)\left(1 - \frac{\delta R_e^r}{c_o}\right)}. \tag{30}$$

Figure 1 **Patient's Choice Regarding E-Visit Adoption, $\bar{\theta}$, and Acceptable Range of RVI, $\bar{r}$, as a Function of Patient Health Levels, q, and E-Visits Impact Factor, $\left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r$, for Two Values of Patient Flexibility, Δ ($c = 2$, $\delta = 0.25$, $c_o = 20$, $T_h = 180$, $T_l = 60$, $R_e^d = 0.015$) [Color figure can be viewed at wileyonlinelibrary.com]**



(a) $\Delta = 0$ **(b)** $\Delta = 0.9$

PROPOSITION 3 (Patient flexibility with e-visits). *Consider a setting where patients choose to adopt e-visits.*

(a) *A flexible patient panel remains flexible upon the introduction of e-visits if and only if* $q^-(c, \Delta) \leq q \leq q^+(c, \Delta)$ *and* $\alpha_e^r \leq \bar{\alpha}_e^r(q)$.
(b) *A flexible patient panel becomes inflexible upon the introduction of e-visits if and only if* $q^-(c, \Delta) \leq q \leq q^+(c, \Delta)$ *and* $\alpha_e^r > \bar{\alpha}_e^r(q)$.
(c) *An inflexible patient panel becomes flexible upon the introduction of e-visits if and only if* $q < q^-(c, \Delta)$ *and* $\underline{\alpha}_e^r(q) \leq \alpha_e^r \leq \bar{\alpha}_e^r(q)$.

Part (a) of Proposition 3 highlights the case in which patient flexibility regarding RVI values is maintained following the introduction of e-visits. Parts (b) and (c), however, describe the critical levels of office visits "replaceability" with e-visits, α_e^r, that change the flexibility of the patient panel with respect to the RVIs. (Note that these thresholds can also be cast in terms of e-visit "impact factor" $\left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r$.) Specifically, part (b) describes the case in which flexible patients become inflexible under e-visits: if e-visits are sufficiently effective at replacing office visits, it is optimal for the patient to visit the physician as frequently as possible, that is, $(\bar{\theta}, \bar{r}) = (1, T_l)$. In a similar fashion, part (c) focuses on a relatively healthy panel that is inflexible with T_h before e-visits are introduced. When e-visits become sufficiently effective (i.e., $\alpha_e^r \geq \underline{\alpha}_e^r(q)$), the preventive visits at T_l intervals become cheap enough that the patients are willing to accept both T_l and T_h. If, however, e-visits become "too effective" at replacing office visit (i.e., $\alpha_e^r > \bar{\alpha}_e^r(q)$), then the panel becomes inflexible again, this time with T_l. Thus, the α_e^r condition in part (c) is that $\underline{\alpha}_e^r(q) \leq \alpha_e^r \leq \bar{\alpha}_e^r(q)$.

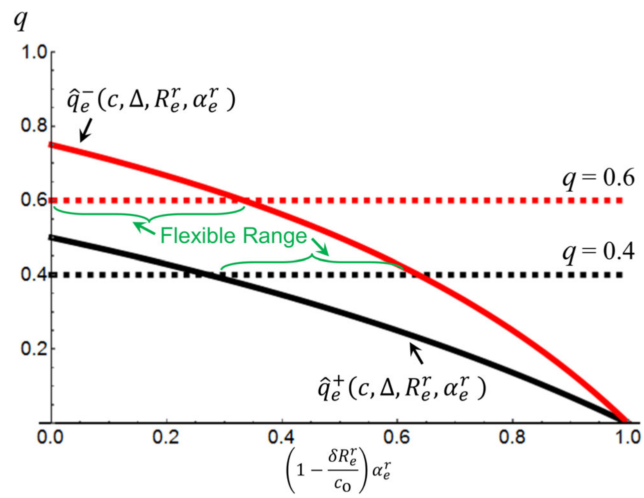
Figure 2 illustrates the results of Proposition 3 for a patient group with the expected sickness factor $c = 2$, flexibility parameter $\Delta = 0.5$, and the shortest and the longest "sickness" times of $T_l = 90$ and $T_h = 360$, respectively. Similar to Equations (8)–(9), if patients adopt e-visits there exist "critical" threshold values for patient health level that separate "flexible" patients from "inflexible" ones:

$$q_e^-(c, \Delta, R_e^r, \alpha_e^r) = \frac{1}{1 + \frac{c(1+\Delta) + \left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r}{\left(1 - \left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r\right)\left(\frac{T_h}{T_l} - 1\right)}}, \quad (31)$$

$$q_e^+(c, \Delta, R_e^r, \alpha_e^r) = \frac{1}{1 + \frac{c(1-\Delta) + \left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r}{\left(1 - \left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r\right)\left(\frac{T_h}{T_l} - 1\right)}}. \quad (32)$$

In this figure, the e-visit impact factor $\left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r$ is allowed to vary between 0 ("unattractive" e-visits) and 1 (costless e-visits that perfectly replace all routine visits). The results of part (a) and part (b) of Proposition 3 are illustrated by the behavior of patients with the "intermediate" level of health, $q = 0.6$. These patients remain flexible while the attractiveness of e-visits and their impact is low. They become inflexible and opt for the most frequent scheduled visits as the "e-visit" channel becomes more attractive. On the other hand, patients with "low" health level ($q = 0.4$) exhibit behavior described in part (c) of Proposition 3: while being inflexible and insisting on the most infrequent scheduled visits in the absence of e-visit channel, these patients become flexible once the level of attractiveness of e-visits rises. As the e-visits impact grows further, such patients may become inflexible again, but this time opting for the most frequent scheduled visits.

Figure 2 RVI Flexibility for Different Patient Health Levels q as a Function of E-Visits Impact Factor $\left(1 - \frac{\delta R_e^r}{c_o}\right)\alpha_e^r$ ($c = 2$, $\Delta = 0.5$, $T_h = 360$, $T_l = 90$) [Color figure can be viewed at wileyonlinelibrary.com]



We can also observe the results of Proposition 3 in Figure 1b. To simplify the illustration, suppose $R_e^r = 0$, so the y-axis corresponds to α_e^r. In the absence of e-visits, patient flexibility can be described by the points close to the x-axis: the patients are flexible for $q^-(c, \Delta) = 0.34 \leq q \leq 0.91 = q^+(c, \Delta)$. Consider $q = 0.5$ which is in the flexible range; based on Equation (29), the corresponding threshold value of α_e^r for this q is $\bar{\alpha}_e^r(0.5) = 0.6$. As described in parts (a) and (b) of Proposition 3, patients become inflexible if $\alpha_e^r > 0.6$ and are flexible otherwise (if they choose to adopt e-visits). To illustrate part (c) of the Proposition, consider $q = 0.2$ which is in the inflexible range under the traditional mode. Using Equations (29) and (30), the threshold values of α_e^r for $q = 0.2$ are $\bar{\alpha}_e^r(0.2) = 0.87$ and $\underline{\alpha}_e^r(0.2) = 0.47$. Thus, the patients are flexible with respect to RVIs and adopt e-visits if $0.47 \leq \alpha_e^r \leq 0.87$.

We now describe the physician's problem under e-visits, which alter the trade-offs that a physician faces in allocating her service capacity. The physician's objective function changes from Equation (12) to

$$\Pi^e_\delta(N, r) = \delta\Pi^e_{FFS}(N, r) + (1-\delta)\Pi^e_{CAP}(N, r) = N\left((1-\delta)\bar{R}^d_e + \delta\left(\frac{\rho^r(r)\bar{R}^r_e + (1-\rho^r(r))R^u}{T(r)}\right)\right), \tag{33}$$

where

$$\bar{R}^r_e = \alpha^r_e R^r_e + \left(1-\alpha^r_e\right)R^r, \tag{34}$$

$$\bar{R}^d_e = R^d_e + R^d. \tag{35}$$

The physician's problem under e-visits can be characterized as

$$\max_{N,\, r} \Pi^e_\delta(N, r) \tag{36}$$

$$\text{s.t. } N\left(\left(\frac{\rho^r(r)\bar{\tau}^r_e + (1-\rho^r(r))\tau^u}{T(r)}\right)\right) \le A, \tag{37}$$

$$r \in \{T_l, T_h\}, \tag{38}$$

where Equation (37) denotes the physician's capacity constraint with

$$\bar{\tau}^r_e = \alpha^r_e \tau^r_e + \left(1-\alpha^r_e\right)\tau^r. \tag{39}$$

Note that the optimization in Equations (36)–(38) includes e-visits only if patients choose to adopt as described in Proposition 2. We denote the RVI values optimizing (36)–(38) as $\hat{r}^e$. We will use the following quantities to characterize the optimal solution to Equations (36)–(38):

$$\bar{q}^\tau_e = \frac{1}{1+\left(\frac{\frac{\tau^u}{\bar{\tau}^r_e}-1}{\frac{T_h}{T_l}-1}\right)}, \tag{40}$$

$$\bar{q}^R_e = \frac{1}{1+\left(\frac{\frac{R^u}{\bar{R}^r_e}-1}{\frac{T_h}{T_l}-1}\right)}, \tag{41}$$

$$\bar{R}_e = 1 + \frac{(1-\delta)\bar{R}^d_e T_l}{\delta\bar{R}^r_e}, \tag{42}$$

$$\Sigma_e = \left(1-\frac{\bar{q}^\tau_e}{\bar{q}^R_e}\right)\left(\frac{\delta\bar{R}^r_e}{(1-\delta)\bar{R}^d_e T_l}\right). \tag{43}$$

These quantities are the e-visit parallels of the ones we described earlier in Equations (16)–(20). Hereafter, we focus on a patient panel that is flexible before e-visits to maintain the simplicity of the results:

$$q \in [q^-(c, \Delta), q^+(c, \Delta)]. \tag{44}$$

In particular, we are leaving out two cases. First, if a patient is inflexible before and after e-visits, the solution is trivial as there is no choice of RVI for the physician. Second, if an inflexible patient becomes flexible after e-visits (part c of Proposition 3), then our analytical characterizations hold as we derive the physician's choice of RVI when patients are flexible.

Proposition 4 *Consider a setting where patients choose to adopt e-visits, and the patient panel is homogeneous as described by Equation* (44).

(a) *Suppose that* $\alpha^r_e \le \bar{\alpha}^r_e(q)$. *Then, the optimal RVI values in Equations* (36)–(38) *are given by*

$$\hat{r}^e = \begin{cases} T_h, & q \le \dfrac{\bar{q}^\tau_e}{(1+\Sigma_e)^+}, \\ T_l, & \text{otherwise}, \end{cases} \tag{45}$$

where $x^+ = \max(x, 0)$.

(b) *Suppose that* $\alpha^r_e > \bar{\alpha}^r_e(q)$. *Then the optimal RVI values in Equations* (36)–(38) *are given by* $\hat{r}^e = T_l$.

The physician's choice of RVI under e-visits is presented in Proposition 4. In case (a) the patient stays flexible after e-visits, and the physician has a choice in the RVI values, while in case (b) the patient is inflexible with an RVI of T_l. We divide the paper's results into two sets. The first set of results relate to case (a): Propositions 5 (proportional e-visit compensation) and 6 (capitation e-visit compensation). The second set of results relate to case (b): Proposition 7. Note that in our model neither the patient nor the physician is forced to adopt e-visits. The patients make a choice based on utility considerations (Proposition 2), and the physician only adopts e-visits if it increases her revenue. Therefore, if e-visits are detrimental to the physician, she will stop offering them.

4.2. The Impact of E-Visits on System Outcomes

In this section, we characterize the changes in the three outcomes of interest—physician revenue, panel size, and panel health—resulting from the introduction of e-visits in primary care. The expected daily revenue as well as the overall health of the patient panel in the physician's care are key performance indicators for the physician and patients. The changes in the size of patient panel is an important indicator of overall primary care coverage that a given number of primary care physicians provides. We define panel health as the portion of office visits that are routine, that is, $\rho^r(r)$. Note that high values of $\rho^r(r)$ correspond to a well-maintained patient panel whose primary care needs are served mainly through routine visits. For an RVI of T_l, panel health is equal to its highest possible value, 1, and with an RVI of T_h, the value of panel health drops to its lowest possible value, $1-q$. These outcomes of interest reflect the potential attractiveness of e-visits to three key groups of stakeholders: physicians, patients, and the social planner.

We focus on a homogeneous, flexible patient panel as described in Equation (44), and a physician with "proportional" compensation for routine and urgent in-office visits and a mixture of FFS and capitation compensations modes:

$$\frac{R^r}{\tau^r}=\frac{R^u}{\tau^u},\ 0<\delta<1. \tag{46}$$

We consider two scenarios of e-visit incentives: "proportional FFS e-visit compensation" and "capitation e-visit compensation." Under proportional FFS e-visit compensation, the physician is only paid per e-visit, and the e-visit compensation is proportional to the duration of e-visits, that is, $\frac{R^r}{\tau^r}=\frac{R^u}{\tau^u}=\frac{R^r_e}{\tau^r_e}$ and $R^d_e=0$. Under capitation e-visit compensation, the physician is not paid for each e-visit, but receives a daily capitation payment per patient for providing e-visits, that is, $R^r_e=0$ and $R^d_e>0$. Recall that, as we described in Equations (23) and (24), the FFS and capitation e-visit payments come from their respective patient populations, for example, only fraction δ of the patients pay the FFS e-visit compensation.

PROPOSITION 5 (Proportional fee-for-service e-visit compensation). *Consider the setting described by Equation* (44), *and Equation* (46) *under "proportional fee-for-service e-visit compensation"* ($\frac{R^r}{\tau^r}=\frac{R^u}{\tau^u}=\frac{R^r_e}{\tau^r_e}$, $R^d_e=0$). *Noting that in such a setting patients are guaranteed to adopt e-visits, suppose that patients stay flexible after e-visit adoption, that is,* $\alpha^r_e\le\bar{\alpha}^r_e(q)$. *Then, the introduction of e-visits produces the following effects:*

(a) *Panel health improves if* $\bar{q}^\tau_e\le q\le\bar{q}^\tau$, *and remains unchanged otherwise.*
(b) *Panel size increases.*
(c) *Physician revenue increases.*

Proposition 5 describes the impact of e-visits on system outcomes when the physician is paid a proportional rate for e-visits, so her revenue per visit duration is the same for all types of visits (routine in-office, routine e-visit, and urgent in-office). The proposition also focuses on a setting in which patients are flexible both before and after e-visits are introduced. Note that since $R^d_e=0$ in Proposition 5, patients always opt to adopt e-visits because the long-run average cost is guaranteed to be lower with e-visits. The first insight from Proposition 5 is that, panel health is unaffected by e-visits if the panel is comprised of either rather sick or very healthy patients. Patient health, however, will improve for moderately healthy panels. The range of values for which panel health improves is between $\bar{q}^\tau$ and $\bar{q}^\tau_e$. In this range of q, the physician assigns an RVI of T_l after e-visits, while before e-visits, the physician's choice of RVI was T_h. As described earlier in the paper, changes in system outcomes occur through two mechanisms: patient response in the form of changes in RVI flexibility, and physician response in terms of RVI choice. In Proposition 5, changes in panel health are caused exclusively by physician incentives, since, in this particular setting, e-visits do not alter the degree of patient flexibility.

Both panel size and physician revenue increase when a proportional FFS approach is used for compensating e-visit care provided to flexible patients. In this setting, e-visits are on equal footing with other visit types in terms of revenue and are time saving for the physician. As a result, the physician uses e-visits to expand her panel size and earn more revenue. Recall that the physician adopts e-visits only if they increase her revenue. Thus, under proportional FFS e-visit compensation that does not change patient flexibility, the patients and physicians adopt e-visits regardless of the other problem parameters.

Based on Proposition 5, it may seem that the proportional FFS e-visit compensation can only lead to desirable outcomes. The objective functions of the two agents in the system (patient and physician), however, do not necessarily align perfectly (or align with the objective function of the social planner). As we later show in Proposition 7, this compensation scheme may lead to lack of e-visit adoption because of the way patients respond to e-visits.

For further analysis, it is convenient to introduce the following notation:

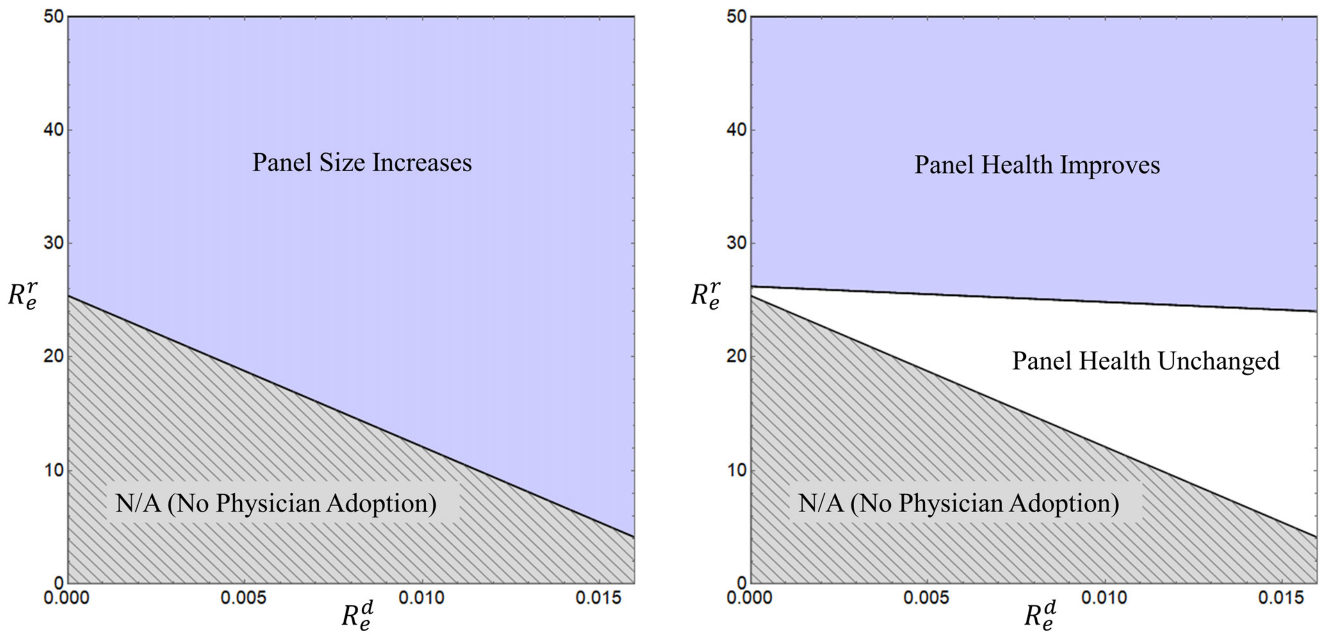
$$\tilde{q}^\alpha=\bar{q}^\tau_e\left(\frac{1-\left(1-Q^T\right)\alpha^r_e\left(1-\frac{\tau^e}{\tau^r}\right)}{1-\left(1-\bar{q}^\tau_e\right)\alpha^r_e\left(1-\frac{\tau^e}{\tau^r}\right)}\right), \tag{47}$$

$$\bar{q}^\alpha=\bar{q}^\tau\left(\frac{1-Q^T\alpha^r_e\left(1-\frac{\tau^e}{\tau^r}\right)}{1-\bar{q}^\tau\alpha^r_e\left(1-\frac{\tau^e}{\tau^r}\right)}\right), \tag{48}$$

$$G(I,I_e)=\frac{\bar{R}_e+\left(\frac{q-\bar{q}^R_e}{\bar{q}^R_e\left(Q^T-q\right)}\right)I_e}{1+\left(\frac{q-\bar{q}^\tau_e}{\bar{q}^\tau_e\left(Q^T-q\right)}\right)I_e}-\frac{\bar{R}+\left(\frac{q-\bar{q}^R}{\bar{q}^R\left(Q^T-q\right)}\right)I}{1+\left(\frac{q-\bar{q}^\tau}{\bar{q}^\tau\left(Q^T-q\right)}\right)I}, \tag{49}$$

where $I=1$ if $\hat{r}=T_h$, and $I=0$ if $\hat{r}=T_l$; similarly, $I_e=1$ if $\hat{r}^e=T_h$, and $I_e=0$ if $\hat{r}^e=T_l$. The function $G(I,I_e)$ compares physician revenue under e-visits and the traditional mode such that $G(I,I_e)<0$ means lower revenue for the physician under e-visits

Figure 3 Changes in System Outcomes Upon the Introduction of E-Visits as a Function of Fee-For-Service, R_e^r, and Capitation, R_e^d, E-Visit Payments ($q = 0.49$, $\delta = 0.25$, $c = 2$, $c_0 = 50$, $\Delta = 0.9$, $T_h = 120$, $T_l = 60$, $\tau^r = 1$, $\tau^u = 2$, $\tau_e^r = 0.2$, $R^r = 200$, $R^u = 400$, $R^d = 0.1$, $\alpha_e^r = 0.4$, $A = 20$) [Color figure can be viewed at wileyonlinelibrary.com]



(a) Panel Size (b) Panel Health

compared to the case without e-visits. The values of $\tilde{q}^\alpha$ are $\bar{q}^\alpha$ adjust the values of $\bar{q}_e^\tau$ and $\bar{q}^\tau$, respectively, accounting for the panel size impact of routine and urgent visits in the presence of e-visits.

Proposition 6 (Capitation e-visit compensation). *Consider a setting where patients choose to adopt e-visits. Under "capitation e-visit compensation"* ($R_e^r = 0$, $R_e^d > 0$) *and the conditions described by Equation* (44), *and Equation* (46), *suppose that patients stay flexible after e-visits are introduced, that is,* $\alpha_e^r \le \bar{\alpha}_e^r(q)$. *Then, the introduction of e-visits produces the following effects:*

(a) *Panel health decreases if* $\bar{q}^\tau < q \le \frac{\bar{q}_e^\tau}{(1+\Sigma_e)^+}$, *improves if* $\frac{\bar{q}_e^\tau}{(1+\Sigma_e)^+} < q \le \bar{q}^\tau$, *and remains unchanged otherwise.*
(b) *Panel size decreases if and only if* $\tilde{q}^\alpha \le q \le \frac{\bar{q}_e^\tau}{(1+\Sigma_e)^+}$.
(c) *Physician revenue decreases if and only if*

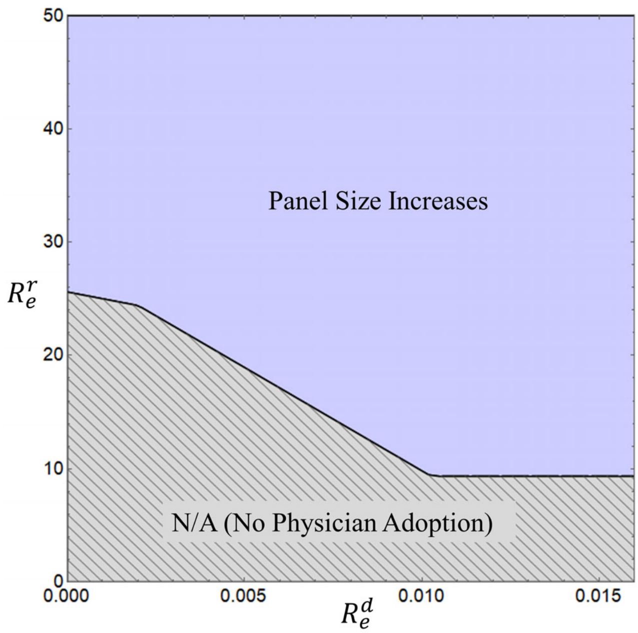
$$\begin{aligned}&\left\{q<\min\left\{\frac{\bar{q}_e^\tau}{(1+\Sigma_e)^+},\bar{q}^\tau\right\},G(1,1)<0\right\}\\&\cup\left\{q>\max\left\{\frac{\bar{q}_e^\tau}{(1+\Sigma_e)^+},\bar{q}^\tau\right\},G(0,0)<0\right\}\\&\cup\left\{\bar{q}^\tau<q\le\frac{\bar{q}_e^\tau}{(1+\Sigma_e)^+},G(0,1)<0\right\}\\&\cup\left\{\frac{\bar{q}_e^\tau}{(1+\Sigma_e)^+}<q\le\bar{q}^\tau,G(1,0)<0\right\}.\end{aligned} \tag{50}$$

Similar to the previous Proposition, Proposition 6 considers a setting in which patients are flexible both before and after the introduction of e-visits. In the present setting, however, the physician is compensated for providing e-visits on a capitation basis.

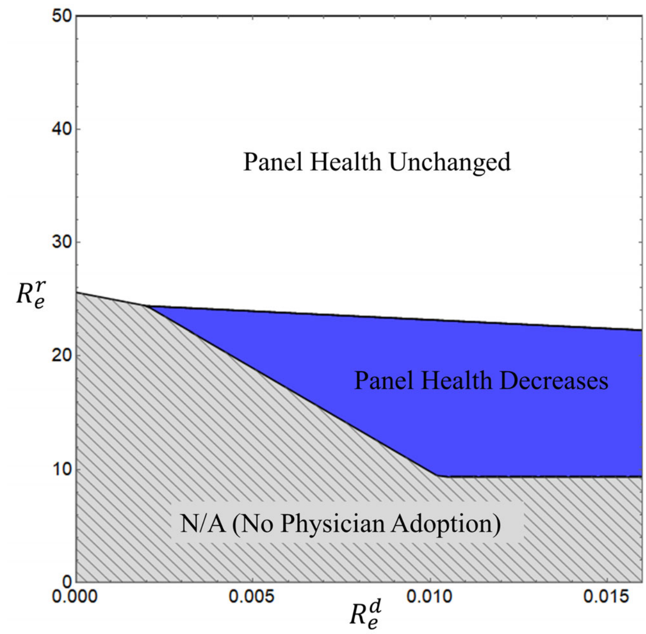
Compared to the setting without e-visits, panel health stays the same if patients are either very healthy or rather sick. If patient health level is in the intermediate range, however, panel health may improve or worsen. The change in panel health depends on the amount of e-visit capitation payment as noted by the presence of Σ_e in the conditions of part (a) of Proposition 6. Recall that Σ_e is a composite measure that combines heterogeneity in revenue and capacity consumption between urgent and routine visits. To see the impact of the e-visit capitation payment, consider the extreme scenario in which $R_e^d \to \infty$. (This is an extreme scenario as patients will not adopt e-visits if $R_e^d \to \infty$; we use it for building intuition here and show a realistic scenario in the numerical analysis.) Then, $\Sigma_e \to 0$ and hence $\frac{\bar{q}_e^\tau}{(1+\Sigma_e)^+} \to \bar{q}_e^\tau$. Knowing that $\bar{q}_e^\tau < \bar{q}^\tau$, the proposition states that for $\frac{\bar{q}_e^\tau}{(1+\Sigma_e)^+} < q \le \bar{q}^\tau$ panel health improves.

Overall, if patient health level is in the intermediate range, panel health may improve (worsen) for sufficiently large (small) values of the e-visit capitation payment. A capitation-only e-visit compensation changes the balance of physician incentives from FFS (R^r, R^u, R_e^r) and capitation (R^d, R_e^d) payments. For sufficiently small e-visit capitation payments, the physician changes the RVIs from T_l to T_h upon the introduction of e-visits. We explain the intuition

Figure 4 Changes in System Outcomes Upon the Introduction of E-Visits as a Function of Fee-For-Service, R_e^r, and Capitation, R_e^d, E-Visit Payments ($q = 0.51$, $\delta = 0.25$, $c = 4$, $c_0 = 50$, $\Delta = 0.9$, $T_h = 120$, $T_l = 60$, $\tau^r = 1$, $\tau^u = 2$, $\tau_e^r = 0.2$, $R^r = 200$, $R^u = 400$, $R^d = 0.1$, $\alpha_e^r = 0.3$, $A = 20$) [Color figure can be viewed at wileyonlinelibrary.com]



(a) Panel Size



(b) Panel Health

behind this result with a simple example. Suppose (1) $q > \bar{q}^\tau$, and (2) e-visits take almost as long as office visits, that is, $\tau^e \to \tau^r$; in such a case, e-visits provide no time-saving advantage to the physician, and $\bar{q}_e^\tau \to \bar{q}^\tau$. Recall that, in the absence of e-visits and under proportional compensation of office visits, the physician chooses an RVI of T_l for $q > \bar{q}^\tau$ (Corollary 1). After the introduction of e-visits, if the physician keeps the RVI value at T_l, her FFS revenue decreases because $R_e^r = 0$. The capitation revenue, however, increases since $R_e^d > 0$ with no change in panel size. The physician can shift a higher fraction of office visits to the urgent category and increase the FFS revenue by increasing the RVI values to T_h, but that is guaranteed to decreases the capitation revenue as the panel size will decrease (see discussion after Corollary 1). Also, note that the higher the value of q, the larger the decrease in panel size if the RVI value increases. Therefore, the physician's optimal choice of RVI depends on the value q and the capitation payments. In particular, for sufficiently small q and e-visit capitation payment, it is optimal for the physician to increase the RVI to T_h.

Panel size may decrease if patient health level is in the intermediate range and e-visit capitation payment is small. In this case, the physician uses high RVI values to divert care from routine appointments to urgent ones to earn more revenue because e-visits provide no per-visit compensation to the physician. The changes to physician revenue under capitation e-visit compensation are more complex compared to the proportional FFS e-visit compensation. Specifically, there are four possible cases to consider depending on the RVI values under the traditional mode and e-visits. These conditions are listed in part (c) of Proposition 6, and we illustrate them further in section 5.1 where we conduct numerical analyses.

Below, we analyze settings where patient flexibility changes upon the introduction of e-visits.

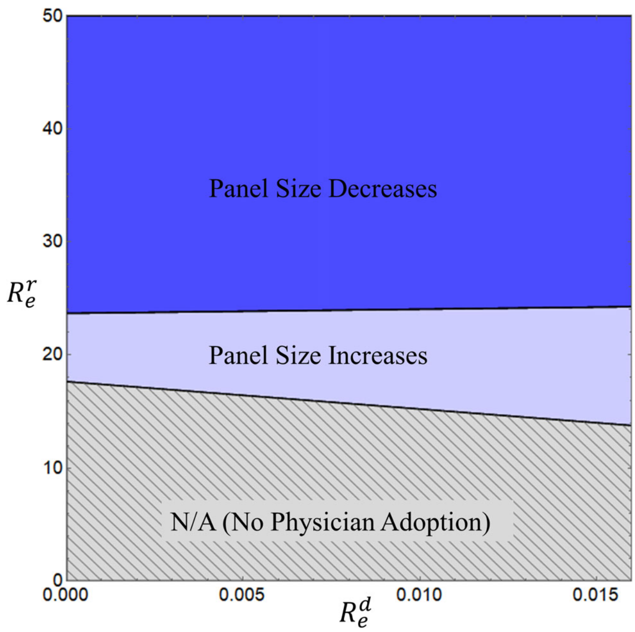
PROPOSITION 7 (Impact of e-visits when patient flexibility changes). *Consider a setting where patients choose to adopt e-visits. Under the conditions described by Equations* (44) *and* (46), *suppose that patients are not flexible after e-visits are introduced, that is,* $\alpha_e^r > \bar{\alpha}_e^r(q)$. *Then, the introduction of e-visits produces the following effects:*

(a) *Panel health improves if* $q \le \bar{q}^\tau$, *and remains unchanged otherwise.*
(b) *Panel size decreases if and only if* $q \le \bar{q}^\alpha$.
(c) *Physician revenue increases under proportional FFS e-visit compensation if and only if* $q > \bar{q}^\alpha$. *Physician revenue decreases under capitation e-visit compensation if and only if*

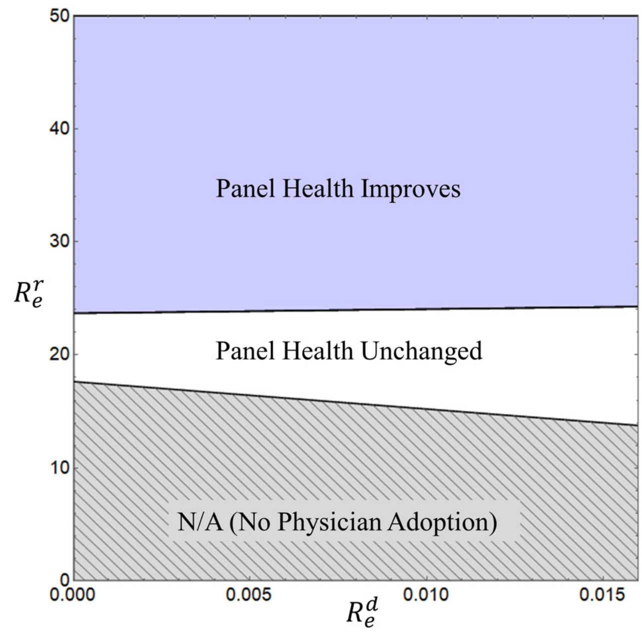
$$\{q \le \bar{q}^\tau,\ G(1,0) < 0\} \cup \{q > \bar{q}^\tau,\ G(0,0) < 0\}. \quad (51)$$

In the settings described by Proposition 7, patients accept both RVI values, T_l and T_h, in the

Figure 5 Changes in System Outcomes Upon the Introduction of E-Visits as a Function of Fee-For-Service, R_e^r, and Capitation, R_e^d, E-Visit Payments ($q = 0.3$, $\delta = 0.75$, $c = 4$, $c_0 = 50$, $\Delta = 0.9$, $T_h = 120$, $T_l = 60$, $\tau^r = 1$, $\tau^u = 2$, $\tau_e^r = 0.1$, $R^r = 200$, $R^u = 400$, $R^d = 0.1$, $\alpha_e^r = 0.2$, $A = 20$) [Color figure can be viewed at wileyonlinelibrary.com]



(a) Panel Size



(b) Panel Health

absence of e-visits, while insisting on T_l upon the introduction of e-visits. We described this setting in part (b) of Proposition 3. Changes in patient flexibility have no effect on RVI values when $q > \bar{q}^{\tau}$ because, in the absence of e-visits, for those values of q the RVI value that maximizes physician revenue is also T_l (Corollary 1). When $q \leq \bar{q}^{\tau}$, however, the physician chooses the RVI of T_h before e-visits are introduced, but patients become inflexible with RVI equal to T_l when they adopt e-visits. Proposition 7 shows that changes in RVIs as a result of patients becoming inflexible under e-visits will improve panel health but may make e-visits unsustainable as they do not encourage physician participation by negatively impacting physician revenue and panel size. Combining Propositions 5 and 7, we learn that e-visits will not lead to smaller panel sizes under proportional FFS e-visit compensation. In particular, Proposition 5 showed that if patients remain flexible, panel size increases. Part (b) of Proposition 7 states that panel size decreases if and only if $q \leq \bar{q}^{\alpha}$, but, as noted in part (c) of the Proposition, the physician will not adopt e-visits if $q \leq \bar{q}^{\alpha}$.

5. Numerical Results

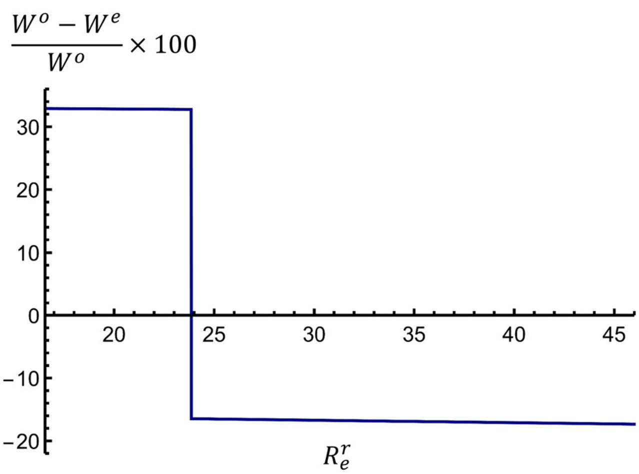
In this section, we illustrate our theoretical results in Propositions 5 and 6. We use proportional compensation for office visits (routine and urgent), and show how the capitation and FFS elements of e-visit compensation affect system outcomes. In Section 5.1, we highlight three possible effects: (1) e-visits increasing panel health, (2) e-visits decreasing panel health, and (3) e-visits decreasing panel size. We also discuss the patient welfare implication of e-visits in Section 5.2.

In terms of e-visit compensation parameters for the numerical analysis, we use \$50 as the maximum value for R_e^r because the FFS e-visit compensation is currently in the \$20–\$50 range (MedInfoTech 2012). For the e-visit capitation payment, we use \$0.016 as the maximum value of R_e^d. Reijonsaari et al. (2005) study a health system that charges a \$60 annual fee for e-visits with 10% patient adoption. The daily capitation payment for such a system is about \$0.016.[3]

5.1. The Impact of E-Visits on Panel Size and Panel Health

In Figures 3–5, the hatched areas represent the set of parameters that result in no e-visit adoption (through either patients or physician). As the patient is the first mover, we first examine whether the patients adopt e-visits, and then consider whether the physician also adopts. Patients will not adopt e-visits when the e-visit fees are sufficiently large, as discussed earlier in Proposition 2 and Figure 1. The physician will not adopt e-visits if the compensation is sufficiently low. In what follows we focus on the "feasible" region in which both the patients and physician adopt e-visits.

Figure 6 Changes in Patient Welfare, $\frac{W^o - W^e}{W^o} \times 100$, Upon the Introduction of E-Visits as a Function of Fee-For-Service E-Visit Payment, R_e^r ($q = 0.3$, $\delta = 0.75$, $c = 4$, $c_0 = 50$, $\Delta = 0.9$, $T_h = 120$, $T_l = 60$, $\tau^r = 1$, $\tau^u = 2$, $\tau_e^r = 0.1$, $R^r = 200$, $R^u = 400$, $R^d = 0.1$, $\alpha_e^r = 0.2$, $R_e^d = 0.005$, $M = 2000$, $\nu = 0.5$) [Color figure can be viewed at wileyonlinelibrary.com]



We begin with Figure 3, which demonstrates an example in which patient health improves for a certain set of FFS (R_e^r) and capitation (R_e^d) e-visit payments. Figure 3a and b show the impact of e-visits on panel size and panel health, respectively. Panel health is driven by the RVI values, so the areas in which RVI values change from T_h to T_l are the ones with improved patient health. One of the insights from this figure is that reducing e-visit compensation can eliminate gains in panel health under e-visits. For example, consider the following two points: $(R_e^r, R_e^d) = (20, 0.01)$ and $(R_e^r, R_e^d) = (30, 0.01)$. Both points have the same e-visit capitation compensation, but the first point has smaller e-visit FFS compensation. Larger e-visit compensation in the second point provides the physician with enough incentives to reduce the RVIs even though the FFS e-visit compensation is less than the proportional value of \$40.[4] In particular, because e-visits have shorter duration, shifting patient demand to routine visits by reducing the RVIs leads to a larger panel size and more capitation payments which in turn increase the physician's revenue.

In terms of the connection between Figure 3 and the analytical results, note that $q = 0.49$ in the figure. This value is chosen such that it is between $\bar{q}^\tau = 0.5$ and $\bar{q}_e^\tau = 0.34$, the measures of heterogeneity in the time that the physician has to invest in routine and urgent visits under the traditional and e-visit modes, respectively. Therefore, as stated in part (a) of Proposition 5, we observe that panel health improves for proportional e-visit compensation, that is, $(R_e^r, R_e^d) = (40, 0)$.

Figure 4 demonstrates a case where panel health decreases when e-visits are adopted. The values of R_e^r and R_e^d that lead to lower panel health in the figure are not included in Proposition 6 because they represent a combination of FFS and capitation e-visit compensation. The intuition that was developed in Proposition 2, however, is applicable here: for sufficiently low values of R_e^d and R_e^r, the physician picks an RVI of T_h for patients who had an RVI of T_l under the traditional case. This increase in RVI values improve physician revenue by diverting patient demand from routine visits to urgent visits. Note that, under e-visits, routine visits are a combination of office and e-visits, so a less than proportional e-visit compensation[5] makes routine visits less attractive for the physician compared to urgent visits (from a FFS compensation standpoint). Another observation based on Figure 4 is that the points close to $(R_e^r, R_e^d) = (40, 0)$ are consistent with Proposition 5 which states that there is no change in patient health when e-visit compensation is proportional and $0.51 = q > \bar{q}^\tau = 0.5$.

Figure 5 shows an example in which e-visits lead to smaller panel sizes.[6] As expected, we observe that under proportional e-visits compensation, $(R_e^r, R_e^d) = (20, 0)$,[7] and $0.3 = q < \bar{q}_e^\tau = 0.41$, patient health is unchanged and panel size increases (Proposition 5). As the FFS element of e-visit compensation (R_e^r) increases, however, we observe improvements in patient health and decreases in panel size. The reason for this change is that as per e-visit compensation becomes disproportionately generous, routine visits become more attractive to the physician as these visits include e-visits. Thus, the physician shifts patient demand from urgent visits to routine visits by assigning the RVI of T_l to patients who have the RVI of T_h under the traditional mode. The reduction in RVI values leads to a smaller panel size even after accounting for time savings associated with e-visits. This is an important result that shows one of the downsides of overgenerous e-visit compensation.

Note that physicians have the ability to increase their panel sizes by accepting more new patients to their panel; also, they can decrease their panel sizes by doing the opposite. For example, Bavafa et al. (2018) show physicians accept 15% fewer new patients each month following e-visit adoption; as patients exit a physician's panel over time, accepting fewer new patients leads to gradual reductions in panel size.

5.2. The Impact of E-Visits on Patient Welfare

From an individual patient's standpoint, an RVI of T_l provides the best health outcome, but health in the model holds value to patients only via costs which measure the overall burden of the disease. To understand patient welfare implications, one must also account for panel size in addition to the disease burden on individual patients on the physician's panel. Consider a patient population of M individuals that need healthcare. The physician can provide her service only to N patients, and $M - N$ patients are left outside of the physician's panel. The burden of disease for each patient on the panel is $D^o(\hat{r})$ under the traditional mode and $D^e(\hat{r}^e)$ under e-visits. The patients who are not covered by the physician ($M - \hat{N}$ and $M - \hat{N}^e$ under the traditional and e-visits modes, respectively) experience a disease burden of ν. Note that the implicit assumption here is that patients are worse off by not being included in the physician's panel, that is, $\nu > D^o(\hat{r}) \geq D^e(\hat{r}^e)$.[8] Thus, the total disease burden under the traditional mode is given by the following:

$$W^o = \hat{N} D^o(\hat{r}) + \nu\left(M - \hat{N}\right), \tag{52}$$

and, similarly, the total disease burden under e-visits is given by

$$W^e = \hat{N}^e D^e(\hat{r}^e) + \nu\left(M - \hat{N}^e\right). \tag{53}$$

We define patient welfare in terms of disease burden: lower disease burden means higher patient welfare. The change in total patient disease burden or welfare under e-visits is

$$W^o - W^e = \hat{N}(D^o(\hat{r}) - \nu) - \hat{N}^e(D^e(\hat{r}^e) - \nu). \tag{54}$$

Figure 6 provides insights related to changes in patient welfare after e-visits are introduced. The y-axis in the plot is $\frac{W^o - W^e}{W^o} \times 100$, the percent change in the disease burden due to e-visits. Positive values of this measure map to improved patient welfare under e-visits because they mean that total disease burden decreases when e-visits are introduced. To illustrate patient welfare implications, we use the same parameters as in Figure 5 because panel size can increase or decrease depending on the value of e-visit FFS payment, R_e^r. Similar to Figure 5, in Figure 6, panel size decreases under e-visits for $R_e^r > 24$ and increases otherwise.

We observe that when e-visits increase panel size, patient welfare increases. There are two forces involved in this observation. First, patients adopt e-visits because it reduces their cost of care (Proposition 2), so, holding panel size constant, patient welfare increases. Second, when panel size increases, more patients are covered by the physician's services, so the population's disease burden is reduced. When panel size decreases under e-visits, however, there is loss in patient welfare. In this case, although e-visits reduce the burden of disease for each individual patient on the panel, the welfare loss from decreased patient coverage leads to loss in the overall patient welfare.

In this section, we discussed how patient welfare is affected by e-visits. Another important problem that we leave outside of our analysis is the one faced by the social planner. Taking such a viewpoint introduces new considerations to the model, but note that we identify the inputs to the social planner's perspective: adoption of e-visits by patients and physicians, patient health, panel size, physician compensation, and patient welfare. A fruitful direction for future research is building on our analysis to explicitly model e-visits in the way they are approached by the social planner. For example, the social planner is likely to care about the overall healthcare spending, a substantial part of which is influenced by the contract offered to the physicians. In the past few years, CMS has introduced new payment models such as "Comprehensive Primary Care Plus" (https://innovation.cms.gov/innovation-models/comprehensive-primary-care-plus) and "Primary Care First" (https://innovation.cms.gov/innovation-models/primary-care-first-model-options) with the goal of inducing physicians to engage in non-visit-based care and holding them accountable for patient outcomes (Bliss et al. 2020). Also, to the extent that e-visits increase physician income and make work more flexible, there may be labor market effects of such service delivery channels on selection into the profession. For example, an important consideration regarding e-visits is their negative effect on physician work-life balance and burnout as shown by prior literature (Barber and Santuzzi 2015, Barley et al. 2011, Bavafa and Terwiesch 2019). Future research could measure the magnitude of labor supply effects as a result of e-visits.

6. Conclusion

The US healthcare system is facing challenging times as an increasing fraction of the population needs care, and the government and private insurers experiment with new approaches for compensating care providers. To control costs and provide care for a larger number of patients, the primary care system may have to augment the traditional care delivery mode with other approaches such as e-visits. Both patients and physicians are likely to adjust their behavior in the presence of these new approaches, impacting critical system metrics such as patient panel size and office RVIs. Understanding these changes is crucial for designing effective policies that aid a safe transition in primary care without compromising patient health or physician panel size.

Our study addresses the complexity of physician and patient interactions under different modes of primary care delivery. In our model, patients respond to changes in the way care is delivered by adjusting the range of office RVI values they are willing to accept. On the physician side, we consider FFS and capitation compensation schemes, and model the physician's choice of patient panel size and office RVIs consistent with patient preferences. We characterize the optimal RVI and panel size values with and without e-visits, and show how e-visits impact panel health, panel size, and physician earnings.

We show that patient and physician responses to the changes in primary care delivery influence the magnitude and even the direction of changes in system outcomes. A key focus in our study is on the pricing (physician compensation) of e-visits, which is a topical policy question as healthcare systems attempt to price them accurately. Our work yields several insights for system outcomes depending on how e-visits are compensated relative to office visits. The main conclusion from our exercise is that healthcare systems should attempt to match the revenue rates on e-visits and office visits as much as possible (e.g., ensuring both channels provide a similar "per minute" revenue to the physician) so as to avoid distorted incentives. Thus, our work shows that one of the major opportunities and obstacles for implementing e-visits is in the process of finalizing the correct compensation. As detailed in the analysis, patient and physician behavior and ultimately system outcomes under e-visits are dictated by the parameters of e-visit compensation.

Specifically, we show that if the compensation of e-visits, as well as that of routine and urgent visits, is proportional to their duration, physician revenue and panel size increase, and panel health either improves or remains unchanged. In contrast, if physician e-visit compensation has large enough deviations from proportional compensation, all of the three mentioned outcomes may suffer. We illustrate the resulting outcomes via numerical analysis for a range of plausible model parameters. Our parsimonious model has a limited number of parameters, which make it analytically tractable. These parameters are easy to estimate in practice. Thus, in addition to providing qualitative insights regarding the direction of changes in system outcomes as a result of e-visits, we are able to provide quantitative, order-of-magnitude estimates for the outcomes of interest.

Our model relies on several simplifying assumptions. In our model, a patient that falls sick receives same-day access to treatment, and there is no backlog of patient appointments. The key feature that we captures is that the physician must provide buffer capacity for urgent visits; this buffer capacity could either be for the same day or backlogs. This assumption allows for closed-form characterization of system outcomes. While the "open access" model has been gaining a wider acceptance in recent years, appointment backlogs are very common in practice. The existence of backlog will be important if we consider wait sensitivity of patients or deterioration of conditions as a result of the wait. Thus, a potential extension to our work would be a model that is at the tactical level and includes the analysis of alternative care delivery modes in the presence of backlogs.

Our analysis relies on an open-loop model which assumes pre-set RVI values that are not adjusted dynamically. A natural extension to our approach would be dynamic adjustment of RVIs based on information gathered by the physician regarding the patient health state between office visits. From that point of view, e-visits are a channel not only for care flow, but also for information flow that can dynamically affect RVI values. Similarly, our model includes a general decision regarding e-visit adoption by the patients and physicians that does not change over time. With the evolution of patient health over time, however, the decision to adopt e-visits may change dynamically as sicker patients may not be able to use e-visits for a substantial portion of their care. Thus, a possible extension of our model is injecting the dynamic flexibility of e-visit adoption and usage based on the type of demand that is identified at the time of care.

Actual patient health is best considered as a multidimensional vector that includes chronic conditions (e.g., diabetes, hypertension) and the urgent needs (e.g., skin rash). In our model, we reduce these to a one-dimensional scalar which represents an average over all conditions. In a model that captures these heterogeneous health conditions, the realization of an office visit would depend on the type of health failure; for example, a patient may have his blood pressure under control but not his diabetes. Additionally, the reality of primary care includes patients with different values of T_l and T_h, and the value of patient health parameter, q, can change dynamically. We made these simplifications to focus on building a model from a macroscopic view that can capture the key driving forces of outcomes such as panel size and physician compensation. We believe that although our approach is quantitatively not accurate, it is informative from a qualitative standpoint.

Finally, we characterize physician compensation using a mix of two standard forms in current practice, FFS and capitation payments. While significant changes to the physician compensation structure may not be likely in the short run, there has been interest in performance-based incentives that reward physicians for improvements in the quality of patient care. Future research could examine the impact of such incentives on system outcomes in primary care.

Notes

[1]Details of these calculations are in the proof of Lemma 1.
[2]CPT stands for Current Procedural Terminology.
[3]Calculated as $\frac{60 \times 0.1}{365} = 0.016$.
[4]The proportional e-visit compensation is Figure 3 is $R_e^r = 40$, calculated as $200 \times \tau^e$.
[5]Similar to Figure 3, the proportional e-visit compensation in Figure 4 is \$40.
[6]Note that there are few changes between the parameters in Figure 5 and the ones in Figures 3 and 4. The e-visits replace a lower fraction of routine visits, $\alpha_e^r = 0.2$, and take less time to conduct, $\tau^e = 0.1$. Also, the patient panel is healthier, $q = 0.3$, and the proportion of physician compensation that is on a FFS basis increases to 75%.
[7]Proportional e-visit compensation is calculated as $\frac{R^r}{\tau^r} \times \tau^e = 200 \times 0.1 = 20$.
[8]Our focus is on providing macro-level insights, so to maintain model simplicity, we analyze the monopoly case in which the care provided by the focal physician is superior to the outside option. This is in line with panel size representing the overall patient coverage in the model. In practice, patients can receive care from other physicians (i.e., competitors). This is further facilitated by the emergence of online health platforms that offer patients more choices to access care.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix A: Proofs of Analytical Results.

Appendix B: Heterogeneous Effects.

Appendix C: The Possibility of “Unsuccessful” e-Visit Attempts.

Appendix D: Summary of Modeling Notation.