Overview Increasingly, durable goods are becoming software-dependent and internet-connected. For example, so-called smart light bulbs are now able to turn on, off, or even change color in response to a person entering a room or leaving the house, and Tesla's cars are able to automatically download updates that add new functionality to the vehicle. This *digitization* of durable goods is changing the manner in which consumers and firms interact, and therefore how firms compete. Consumer-firm interactions can now extend long past the point of sale as firms show ads in products where that was previously impossible or update a product even after the consumer has purchased it.

One particular way the digitization of durable goods is changing competition is through product innovation. Traditionally, firms innovate in order to compete over new consumers to the market, or over an existing consumer's next purchase. Digital durable goods, however, allow for constant product-updating, even after the consumer has purchased the product, which changes how and why a firm might invest in updating its product. In light of this change, it is worth considering whether the digitization of durable goods is changing the relationship between competition and innovation.

Within the theoretical literature, there is a long-standing debate regarding the effect of competition on innovation. While Schumpeter (1942) states that competition will diminish the incentive to innovate, Arrow (1962) argues that the opposite is true. The empirical evidence is similarly mixed. Cohen and Levin (1989) describes the literature on this topic as "inconclusive" (p. 1061), and support for the Schumpeterian view as "fragile" (p. 1078). More recently, Goettler and Gordon (2011) find support for Schumpeter in the microprocessor industry, and Aghion, Bloom, Blundell, Griffith, and Howitt (2005) find evidence of an inverted-U relationship between competition and innovation, as first posited by Scherer (1967).

The theoretical effect of digitization on the relationship between competition and innovation is ambiguous. On one hand, firms in highly competitive markets may earn higher returns to innovation following digitization because the ability to ad-finance their goods and/or update already-purchased products provides new opportunities to monetize a firm's consumer base, or because product updates may increase consumers' switching costs. Innovation may also rise as a result of firms falling into a Prisoner's Dilemma-like scenario where they must frequently update their products or risk falling behind their many competitors. On the other hand, digitization may reduce the incentive to innovate in competitive industries as the increasingly digital nature of the products lowers the cost of copycat updating by competitors, thus reducing the returns to innovation.

The effect is similarly ambiguous in highly concentrated markets. As in competitive industries, dominant firms may see increased returns to innovation as digitization provides new opportunities to monetize the existing customer base. That said, the returns to innovation could also fall in concentrated markets. Goettler and Gordon (2011) argue that one reason they find a support for the Schumpeterian view is that in durable good markets a monopolist is in "competition with the installed base to induce consumers to upgrade" (p. 1188). Digitization may limit the ability of a monopolist to differentiate newer models of a product from previous models. For example, a monopolist manufacturer of smart light bulbs would likely have to ensure that both new and old models of the product are compatible with each other, which reduces the degree to which the firm can differentiate the new models from the old, and therefore limits the degree to which the firm can induce upgrades.

My Research I am studying the effect of digitization on the relationship between competition and innovation in the context of smartphone applications (apps). Apps are an ideal case to study, as they are an example of fully digital durable goods. Studying how digitization affects the relationship between competition and innovation in app markets will provide insight into how digitization might

affect this relationship in other durable good markets as the products in those markets become increasingly digital.

In my work, I develop and estimate a structural model of the supply and demand of apps, which in turn will allow me to estimate the causal effect of competition on innovation across many app markets. After estimating this model, I will conduct a series of counterfactual analyses where the digital aspects of the product – e.g., the ability to update the product after a consumer has purchased it – are removed. By comparing the relationship between competition and innovation across these counterfactual scenarios and the initial estimate of this relationship, I will show how digitization has affected the competition/innovation relationship.

Uses of Funding I have collected data on all of the apps sold on Apple's iOS platform from January 2015 to present. The NBER PIE Program grant will provide significant help by allowing me to purchase additional data on how consumers use apps, which is collected by Nielsen. This additional data will allow me to estimate a more detailed model of consumer behavior in app markets. Additionally, the grant would assist in paying for the computational resources used to estimate my model and to collect and store the large amount of data used for this project.

Policy Relevance The question of how digitization changes the relationship between competition and innovation is an important one for policy makers. As durable goods become increasingly digital, it is important to understand how this relationship is changing if we want to successfully regulate competition in these industries and/or incentivize innovation.

As an example, suppose digitization moves the competition/innovation relationship more toward the Schumpeterian view, where innovation is increasing in concentration. Under this hypothetical scenario, the welfare effects of mergers in affected industries could be very different than in more traditional (i.e., non-digitized) industries. In this case, regulators likely should take a more lenient view toward mergers and acquisitions, even in cases where they traditionally would block such actions. Were digitization to have this effect on the competition/innovation relationship, blocking mergers in concentrated industries could in fact be welfare reducing, even when the merger does not result in any gains in productive efficiency.

This research is also relevant to policy makers looking to encourage innovation. Understanding how digitization is affecting this relationship will allow policy makers to more precisely target incentive programs. Continuing with the prior example, if digitization increases the incentive to innovate in highly concentrated industries, then policy makers looking to encourage innovation would be better off targeting concentrated markets as opposed to more competitive markets. My research will provide a foundation for making such decisions.

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