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HOUSEHOLD INNOVATION AND R&D: BIGGER THAN YOU THINK

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Despite recent interest in measuring household activities, investment in household R&D (or household innovation), has not been considered in any of the literatures on national-accounts-style measurement. Household R&D is the dedication of household resources to creating a product or process that will generate a service flow in the future; that is a household intangible asset. This paper takes a step toward valuing household innovation in the U.S. by developing time series of nominal and real investment and capital stocks for household R&D. We find that household investment in R&D was more than 11 percent of R&D funded by the private business sector in 2017 and about half of what businesses spent on R&D to develop new products for consumers. If household R&D were judged to be in scope for GDP, GDP would have been 0.2 percent higher in 2017. We conclude that household R&D is important and warrants closer attention.

JEL Codes: E22, E01, O31

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1. INTRODUCTION AND OVERVIEW

The rise of free goods and the digital revolution have generated new interest in household activities and how they should be measured to best capture GDP and social welfare.[1] This renewed interest builds on earlier work on household and non-market activities by economists and national income accountants. One important strand of this work includes valuing the time devoted to the production of household services (such as child care and cooking) as well as the service flow from consumer durable assets.[2] Another important strand has focused on human capital

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[1]For two recent examples, see Brynjolfsson *et al*. (2019) and Nakamura *et al*. (2017).

[2]Early mentions include Gilman (1898), Leontieff (1941), Marshall (1920), and Pigou (1932). More recent work is extensive and a sample includes Bridgman (2016), Nordhaus (2006), Abraham and Mackie (2006), Stiglitz *et al*. (2009), Ironmonger (2000), and Poissonnier and Roy (2017). Jorgenson pioneered the idea of counting household purchases of durable goods as investment rather than consumption. This issue is discussed in Jorgenson and Landefeld (2006), which provides an overview of the issues surrounding the structure of National Income and Product Accounts.

accumulation.[3] Although household production and human capital accumulation largely have been judged to be outside the scope of GDP (and therefore, not included in official measures), satellite GDP accounts have provided estimates of their value.[4]

While this research has provided important insights into the value of various household activities, it misses an entire category. Namely, household research and development (R&D) or innovation, which is neither explicitly included nor distinguished in prior research. What is household R&D or innovation? It is the dedication of household resources to creating a product or process that will generate a service flow to the household (and often to other households) in the future. Accordingly, these activities lead to the accumulation of long-lived intangible capital by households. For example, an individual householder may develop a new type of sport (say, mountain biking) or sport-related equipment for her or his own use, and then, diffuse it to many others. Another householder, a medical patient with a chronic disease like sleep apnea, may develop a significantly improved medical device to manage his or her disease, and then tell others about it.

Recent research has shown household innovation (R&D) to be a significant phenomenon.[5] Nationally representative surveys, conducted in 10 nations to date, document that, in just these ten nations, tens of millions of consumers (11.7 million individuals in the U.S. alone) engage in household sector innovation to fill personal needs, and collectively spend tens of billions of dollars annually on this activity (Table 1). As the table highlights, there is interesting variation across countries in the intensity of household innovation, with Russia on the high end, China on the low end, and the United States falling in about the middle of the pack.

Despite the prevalence indicated by household surveys, household R&D largely has, as noted, fallen between the cracks of existing work on economic measurement. To see this, consider the different strands of the literature on household activity. First, in the literature on household production, time spent developing household R&D is considered leisure. Moreover, that literature largely focuses on the production of services that are consumed roughly concurrently with their production, rather than on the production of new intangible capital.

Second, in the literature on human capital, time spent developing household R&D also would be considered non-market consumption or leisure. That classification as consumption or leisure (rather than as an activity creating capital) occurs both in the lifetime-income approach to measuring human capital (pioneered by Jorgenson and Fraumeni, 1989, 1992) as well as in the cost approach (developed by Kendrick, 1976).[6] The indicators approach to measuring human capital also would not count household R&D as investment.[7]

Third, the more recent literature related to the digital revolution and free goods also largely misses household innovation. The strand of this literature

[3]See Jorgenson and Fraumeni (1989) and updates, including Christian (2016).

[4]For recent vintages of satellite accounts, see Bridgman (2016), Landefeld *et al*. (2009) for household production and Fraumeni *et al*. (2017) for human capital.

[5]For a review of work on household innovation see von Hippel (2017).

[6]In the Jorgensen-Fraumeni framework, time spent on R&D would be considered non-market consumption, and in the Kendrick approach this time would be counted as leisure.

[7]See Barro and Lee (2013) for an example.

TABLE 1

Household Sector Innovators Developing or Improving Consumer Products for Personal Use

Nation	UK	USA	Japan	Canada	Finland	S. Korea	Sweden	Russia	UAE	China
% of population	6.1[a]	5.2[b]	3.7[c]	5.6[d]	5.4[e]	1.5[f]	7.3[g]	9.6[h]	3.0[i]	1.5[j]
Millions of individuals	2.9	11.7	4.7	.6	0.17	0.54	0.72	13.9	.28	20.7
% protected by any type IP	1.9	8.8	0.0	2.8	4.7	7.0	1.4	na	4.0	6.5

Sources: [a]von Hippel et al. (2012); [b,c]von Hippel *et al*. (2011); [d]de Jong (2013); [e]de Jong et al. (2015); [f]Kim (2015); [g]Bengtsson (2016); [h]Fursov *et al*. (2017); von Hippel *et al*. (2017); [j]Chen *et al*. (2020).

estimating the value of the free (largely digital) goods consumed by households focuses on consumption rather than investment.[8] Another strand (see Brynjolfsson *et al*., 2013) assesses the value of Internet firms' capital that is generated by users. Much of this activity should be characterized as business capital developed by users of a platform rather than as investment by households in R&D for their own use.

Finally, an even broader focus on household activities is taken by Coyle and Nakamura (2019) and Hulten and Nakamura (2019). Coyle and Nakamura highlight the steps needed to develop a framework for assessing the relationship between household time use and social welfare, while Hulten and Nakamura focus on how the digital revolution has changed the technology through which consumption translates into consumer welfare. Both of these papers provide useful insights into changes in consumer behavior but do not focus on household investment in R&D.

One recent paper, Miranda and Zolas (forthcoming), has focused on household innovation. That paper develops estimates of the value of household innovations that are patented and shows that the valuation is relatively small. While that research takes an important step forward, it focuses on a narrow slice of the universe of household innovation. As Miranda and Zolas note, "Admittedly this [patented innovations] excludes perhaps what might be the lion's share of household innovation; that which is not patented" (p. 3). Indeed, as we discuss in Section 5 below, their estimate of the number of innovations patented each year amounts to well under 1 percent of the universe of household innovations estimated from survey data. That small share is, perhaps, not surprising, given that—as reported in Table 1—just 8.8 percent of household innovations captured in survey for the United States receive any type of intellectual property protection (ranging from nondisclosure agreements to patents), and patenting is the most expensive type of protection. As we discuss below, their estimate of the value of household innovation is a tiny fraction of our estimate.

Given the survey evidence highlighting the importance of household innovation and its omission from most prior work on household activities, we believe that household R&D warrants more focused attention from a national income accounting perspective. This focus on a new category of household intangible capital mirrors earlier efforts to expand the measurement of business investment and capital to include intangible capital.[9] Our effort also can be seen as connecting the literatures on household innovation with work on economic measurement from a national income accounting perspective.

International organizations also recently have recognized the potential importance of household innovation. In particular, the great bulk of household sector R&D had previously fallen outside the OECD's official definition of innovation. That definition (Oslo Manual, 3rd edition) required, in part, that to qualify as an innovation, a novel product, process or service must be "implemented on the

[8]For example, see Nakamura *et al*. (2017), Brynjolfsson and Oh (2012), Goolsbee and Klenow (2006), and Brynjolfsson *et al*. (2018, 2019).

[9]For early papers on intangibles, see Corrado *et al*. (2005, 2009). For a more recent discussion, see Haskel and Westlake (2017). For recent work on innovation, see Corrado *et al*. (forthcoming) and National Academy of Sciences (2017).

market." However, the great bulk of household sector developments are not mediated through markets. Indeed, evidence from the above-mentioned national surveys shows that 90 percent or more of the innovations developed are not market mediated. Fortunately, this definitional problem now has been eliminated with the publication of the 4th edition of the Oslo Manual 2018 (OECD/Eurostat, 2018). Responding in part to the new evidence for the extent and importance of "free" household sector innovation, a new general definition of innovation has been promulgated that no longer requires that a development be placed on the market:

> The general definition of an innovation for all types of units is as follows:
>
> *An **innovation** is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process).*
>
> The general definition uses the generic term "unit" to describe the actor responsible for innovations. It refers to any institutional unit in any sector, including households and their individual members. The definition is appropriate for measuring innovation developed by individuals, a key goal identified at the 2016 Blue Sky Forum. (¶1.25 and 1.26, Oslo Manual, 4th edition, p. 32)

To take a step toward classifying this category of household activity as capital accumulation, this paper provides illustrative estimates of nominal and real quantities for this type of household capital. Obtaining such estimates is a daunting task, given challenging conceptual issues and data limitations. That being said, we rely on available survey and other data, and plow ahead to build up a set of estimates. For the United States, our estimates suggest that household R&D is sizable, with our preferred estimates of nominal investment in 2017 at $44 billion and our preferred estimate of the nominal capital stock in that year at about $252 billion. According to these estimates, household R&D represents an important feature of household activity and, more generally, of the overall landscape of innovation. Indeed, household investment in R&D in 2017 amounted to 11.2 percent of R&D funded by the private business sector and more than half of business R&D devoted to developing consumer goods. Moreover, if household investment in R&D were considered in scope for GDP and included in official measures, nominal GDP would have been 0.2 percent higher in 2017.

To be sure, our estimates should be regarded as an effort to establish an approximate order of magnitude. The survey evidence covers a single year, and we had to use extrapolators to create time series for investment. In addition, we must rely on strong assumptions to obtain price trends to convert nominal to real investment. Still, even though necessarily imprecise, we hope that our rough estimates demonstrate the importance of undertaking an effort to correctly classify these activities as accumulation of household R&D.

The remainder of the paper is organized as follows. Section 2 defines household R&D and highlights how this category is not captured in extant estimates of household production or human capital. In Section 3, we review what is currently known about the nature of household R&D. Section 4 develops estimates of nominal and real investment and capital stocks for household R&D. In Section 5, we describe a number of different metrics for assessing the magnitude and importance of household R&D. Section 6 presents some initial thoughts on how to improve measures of household R&D. Section 7 concludes.

2. Defining Investment in Household Research and Development

Returning to the earlier discussion about the definition of household innovation, prior surveys for all ten countries used a standard definition for developments by householders that qualified for inclusion as innovations. To be counted as a household innovation in the U.S. survey, an individual or collaborating groups must have:[10]

- Developed a new product or product modification;
- For personal or family use;
- That provided useful functional improvements over products already available on the market.

Innovations that individuals developed at home for their jobs, for sale, or for pay, were not counted as innovations in the household sector study samples. Similarly, because the definition focuses on products developed for personal or family use, innovations developed in hacker or makerspaces would be included or excluded depending on the innovator's intention (personal or commercial) with respect to use. In addition, the survey screens out and does not count as innovation social media posts, Wikipedia entries, artistic originals, and activities like, for example, personal efforts to contribute to identifying astronomical phenomena. The surveys are designed to identify innovations that represent functional improvements, and this standard is applied stringently in the interests of obtaining conservative estimates of household innovation.

To translate this definition and the survey evidence to aggregate figures on investment in household innovation, we follow in the spirit of Corrado *et al.* (2005, 2009) and Kendrick (1976), defining household investment as any use of resources within a household to create an asset that will generate a flow of services to that household or to other households in the future. This definition of household investment covers both market and non-market investment as well as tangible and intangible capital. To highlight how household R&D relates to other types of household investment, consider each category of household investment in turn.

[10]This definition is in line with OECD requirements for a product innovation developed by a business as spelled out in the 2018 Oslo Manual: "Product innovations must provide significant improvements to one or more characteristics or performance specifications. This includes the addition of new functions, or improvements to existing functions or user utility." See OECD/Eurostat (2018), p. 71.

Household tangible capital is acquired both through market transactions and non-market channels. Purchases of household durables are tangible capital typically acquired via market transactions, such as the purchase of a car. Non-market or own-account tangible investment would include a homeowner building raised garden beds or a deck. While these own-account examples may not seem particularly consequential, own-account tangible household investment was important in the past. For example, estimates of own-account farm structures reach well back into the 19th century and are important for getting a full picture of capital used in the production of food in those earlier time periods.[11] Today, households purchase most food outside the home, so estimates of own-account farm structures receive little attention.

Regarding intangible household capital, the most recognized and studied form is human capital. However, households also devote resources to developing other types of intangible capital, and our category of household innovation falls squarely into this category.

All of these types of household investment (market and non-market and tangible and intangible) are not counted as investment in the National Income and Product Accounts. Household purchases of durable goods are counted as consumption. Own-account investment by households in durable goods is not currently included in GDP except through the purchase of materials. And, neither human capital nor household R&D is included in official GDP accounts.

While estimates have been developed for human capital and for purchased household durables counting as investment, household R&D is nowhere to be seen.[12] Thus, to gauge the magnitude and importance of household R&D, we must develop new numbers.

3. What We Know Today About Household Innovation and Diffusion

Before we describe our new estimates of household R&D, this section discusses the types of innovations undertaken by households and what is known about their diffusion to other households and businesses.

3.1. *Overview of Household Innovation*

Nationally representative surveys have taught us that household sector innovation activity is present in essentially all products of interest to consumers, ranging from medical devices to sporting equipment. The figures reported in Table 2—the fraction of household innovations in different categories—shows this pattern clearly for the first 6 national surveys.

Categories showing high levels of product innovation map well into major categories of unpaid time activities reported by consumers. For example, in the United Kingdom, sports, gardening, household chores, caring for children, and

[11]See Gallman (1966).

[12]For recent estimates of human capital for the U.S., see Christian (2016). For other countries, see World Bank (2018). For recent estimates of how accounting for consumer durables as investment changes GDP accounts in the United States, see Bridgman (2016).

TABLE 2
Scope of Product Development by Household Sector Users in Various Innovation Categories

	UK[a]	Japan[b]	US[b]	Finland[c]	Canada[d]	S. Korea[e]
Craft and shop tools	23.0%	8.4%	12.3%	20%	22%	16.4%
Sports and hobby	20.0%	7.2%	14.9%	17%	18%	17.9%
Dwelling-related	16.0%	45.8%	25.4%	20%	19%	17.9%
Gardening-related	11.0%	6.0%	4.4%	na	na	na
Child-related	10.0%	6.0%	6.1%	4%	10%	10.9%
Vehicle-related	8.0%	9.6%	7.0%	11%	10%	6.5%
Pet-related	3.0%	2.4%	7.0%	na	na	na
Medical	2.0%	2.4%	7.9%	7%	8%	5.5%
Computer software	na	na	na	6%	11%	na
Food and clothes	na	na	na	12%	na	na
Other	7.0%	12.0%	14.9%	3%	3%	23.9%

Sources: [a]von Hippel et al. (2012); [b]von Hippel *et al*. (2011); [c]de Jong et al. (2015); [d]de Jong (2013); [e]Kim (2015).

using computers were significant activities (Lader *et al*., 2006). Note that software does not appear as a separate line item for some countries, including the United States. Nonetheless, much software will be counted as household innovation because software is imbedded within many innovations.

In the U.S., 11 percent of household sector innovations were developed by collaborating groups of individuals, and 89 percent by individuals working alone. For groups working together, collaboration at a distance has been increasingly enabled by advances in digital design tools, and also by advances in communication via the internet. Examples of innovations developed by group collaboration include:

- Personal 3D printers (de Bruijn, 2010). Developed by household innovators, these devices are used today by millions with annual equipment sales of $500 million in 2017.[13]
- DIY artificial pancreas developed by Type 1 diabetics for their own use and successfully applied in everyday life by thousands (OpenAps.org, 2018). The innovators only offer free transfers of the design to others.
- Many new sports practiced by millions—ranging from skateboarding to white-water kayaking to mountain biking—and the novel equipment needed to practice those novel sports. Equipment sales for these many new sports in aggregate are in the tens of billions of dollars annually.

For individuals working alone, three examples of (relatively modest) product innovations include:

- Craft and shop tools: "I created a jig to make arrows. The jig holds the arrow in place and turns at the same time, so I can paint according to my own markings. Jigs available on the market do not rotate."

[13]For more on the development of 3D printers, see https://www.forbes.com/sites/tjmccue/2018/06/04/wohlers-report-2018-3d-printer-industry-rises-21-percent-to-over-7-billion/#716996712d1a

- Child-related: "I created a cloth expansion panel to enable me to fasten my winter coat while wearing a baby carrier underneath. Helps keep me and my baby warm."
- Computer software related: "I am colorblind. I developed an iPhone camera app that identifies the colors of objects in a scene, and codes them for easy recognition."

Survey results show that individuals' expenditures on innovation projects generally are "person-sized," ranging from a few hundred to a few thousand dollars in out-of-pocket expenses and expenditures of unpaid discretionary time (calculated at the average wage rate of each country surveyed). In the U.S., innovators spent an average of 9.9 days a year on developing innovations (valued at $1,531) and incurred out-of-pocket expenditures that averaged $194 for a total of $1,725 a year (von Hippel *et al*., 2011).

Regarding the quality of the nationally representative survey data, note that the survey questionnaires used in national studies of household sector product innovation have been designed to stringently screen out false positives with respect to determining national percentages of household sector innovators.[14] So, if anything, we suspect that the data collected on innovation frequencies is likely to be conservative.

Our estimates are conservative for another reason as well. At the time of this writing, household sector national innovation surveys have collected data on product innovations only—not on services and process improvements. Case studies have shown that householders are very important sources of consumer service and process innovations as well, so future empirical surveys will likely fill in this temporary gap (Oliveira and von Hippel, 2011; van der Boor *et al*., 2014).

3.2. *Diffusion of Household Innovations*

National survey data results show that significant numbers of householder-developed innovations diffuse beyond the innovator(s) to additional adopters. There are two possible paths for diffusion of innovations developed in the household sector: direct peer-to-peer transfers and transfers to commercializing firms that in turn sell copies to consumers. In the U.S. household sector innovation survey, respondents were asked a combined question: Did your innovation diffuse via peer-to-peer transfer and/or via transfer to commercializing firms? In response, 6.1 percent of respondents reported that diffusion had occurred by one or both pathways. Given that there were 11.7 million household sector innovators in the U.S. in 2010 and that, on average, each of them created 1.9 projects per year, this equates to well over a million projects per year being diffused to peers and/or commercial producers. The great bulk of this diffusion likely takes place without compensation for the household sector innovators: only 8.8 percent of U.S. household sector innovations were protected by any form of IP including patents, trademarks, copyrights, and confidentiality agreements (von Hippel *et al*., 2011).

[14]For details, see von Hippel *et al*. (2012).

Case studies show that the value over time of household innovations diffused for free and commercialized by producers can be significant. Specifically, a study of the sources of the most important innovations over the 50-plus year history of whitewater kayaking found that 63 percent of the 54 most important product innovations in the sport were developed by household sector kayakers. In addition, 100 percent of the 39 most important process or technique innovations (the things you *do* with a whitewater kayak like flips and rolls) were also developed by household sector kayakers (Baldwin *et al*., 2006, Table 1). A second study explored the sources of 16 important service innovations that had been first introduced into retail banking in computerized form between 1975 and 2010. It found that 44 percent of these (and 80 percent of the manual precursors to these computerized services) had been developed originally by household sector banking customers rather than banks (Oliveira and von Hippel, 2011). For example, as documented by Hemenway and Calishain (2004), "computerized aggregation of account information across multiple institutions was first implemented by individual 'hackers' for their own use in the 1980s." A third study explored the sources of the most basic services supplied by mobile banking in developing countries, such as money transfer between customers. The authors determined that at least 50 percent of these had been pioneered originally by "unbanked" consumer service users (van der Boor *et al*., 2014).

4. Measuring Household R&D Investment and Capital

4.1. *Nominal Investment*

To measure nominal investment in household R&D, we follow the literatures on household innovation and intangible business capital. In particular, we rely on the nationally representative survey conducted for the United States described above. As noted, the U.S. survey focused on *product* innovations undertaken to meet personal needs, and was conducted in December of 2010. A questionnaire was sent to 25,200 household sector individuals and 1,992 responded. The results provide a snapshot in time of the resources devoted to household R&D. Respondents were asked about time spent on their most recent innovation, the cost of materials used for that innovation, and the number of other innovations completed over the past three years.

The survey data were used to construct an estimate of total nominal expenditure on household innovation (which we are calling investment in household R&D) for 2010.[15] In particular, for a person reporting an innovation on the survey, the value of time devoted to their innovation (valued at an average wage rate) was combined with the cost of purchased inputs. As noted above, these costs combined to an average of $1,725 per innovator over the course of a year. This figure then is multiplied by an estimate of the total number of innovators aged 18 and above (the product of the 5.2 percent share of innovators reported in Table 1 multiplied by the noninstitutional population) to obtain a number for aggregate investment. For the U.S., this procedure yields an estimate of aggregate nominal investment in household R&D for 2010 of $20.2 billion.

[15]See von Hippel *et al*. (2011). For a summary, see von Hippel (2017), Table 2.5.

This methodology for gauging the value of household innovations relies on the cost—time plus out-of-pocket—of producing innovations. The rationale for this approach implicitly assumes that household innovators devote resources to an innovation up to the point at which the marginal cost of an innovation equals the marginal benefit. In that situation, the dollar cost of the innovation (investment) would equal the present value of the flow of services the innovator expected to receive from the innovation. To the extent that household innovations diffuse to other households or to businesses without any compensation to the innovator, then, spillovers would be created, but the value of these spillovers would be missed by our valuation methodology. Accordingly, we believe that our cost-based approach provides a conservative estimate of the value of household innovations.

As noted earlier, the U.S. figures focus on innovations undertaken to meet personal or family needs. Analysis of data from China, Finland, and the United Arab Emirates captures household R&D undertaken for a wider range of motivations, including fun and learning, altruism, and financial gain. Chen *et al*. (2020) report that, based upon a comparison of the relative scale from these three nations of "need only" versus "all motive" innovations developed by householders, the U.S. results should be grossed up by about 1.5 to obtain a measure of household R&D that more completely covers a wider range of motivations. Accordingly, we gross up the $20.2 billion estimate for 2010 to $30.3 billion. We recognize that this blowup factor brings in some household innovations that were developed for financial gain. Ideally, we would exclude these because such innovations may more appropriately be classified as adding to (small) business capital. However, the fraction of innovations whose original motivation was financial gain is quite small and so we are comfortable with this adjustment so as to incorporate innovations undertaken for fun and learning and altruism as well as personal needs.

We used two different extrapolators to extend the 2010 estimate to a time series. First, we assumed that nominal household R&D grows in line with nominal GDP. Second, we assumed that nominal household R&D grows in line with nominal business investment in R&D. While both of these extrapolators are plausible, we suspect that they may understate the more recent growth rate of household R&D. Increased sophistication of digital design tools available to householders for free, and also an increased ability to coordinate multi-person projects via the Internet have both greatly reduced costs and facilitated household innovation (von Hippel, 2017, pp. 51–2). As a consequence, this activity may have increased more rapidly in the past two decades than has nominal GDP or business R&D investment. Still, to be conservative, we use GDP and business R&D as plausible extrapolators.

The two estimates of nominal investment in household R&D are shown in Figure 1, and we refer to these as our base case estimates. Both of the base case nominal investment series rise from a modest value in 1949 to a more substantial value in 2017 of $39 billion (series extrapolated by nominal GDP) and $44 billion (series extrapolated by nominal business R&D spending). We do not have a strong preference between these estimates though the R&D extrapolator seems more appropriate to us so we identify those figures as our "preferred" estimates.

We believe that the estimates reported in Figure 1 are conservative because they largely cover R&D related to new *products*. Recall from Section 3.2 that case studies have shown that households also develop important new consumer services, such as

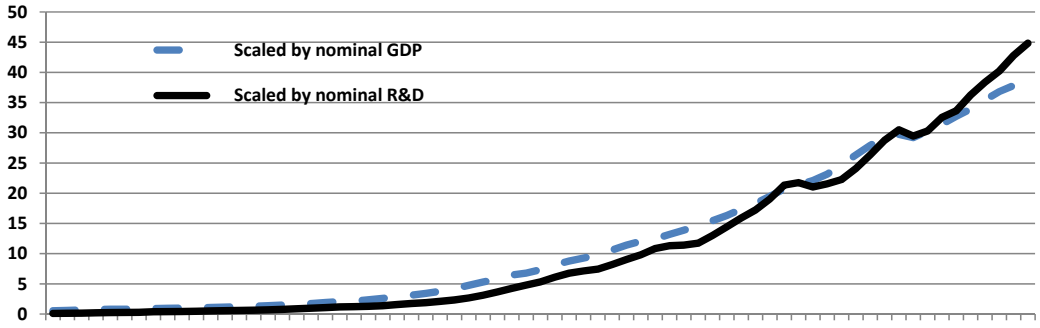

Figure 1. Nominal Investment, Household R&D, 1949–2017 (billions of $)

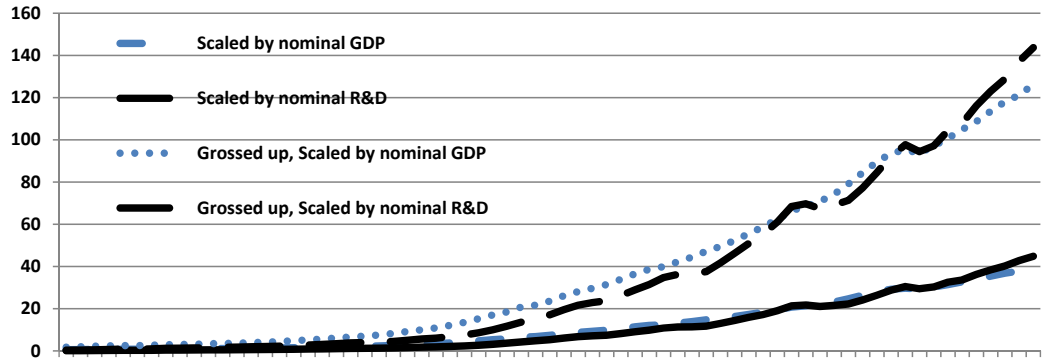

Figure 2. Nominal Investment, Household R&D Grossed Up to Include Services, 1949–2017 (billions of $)

basic new retail banking services (Oliveira and von Hippel, 2011; van der Boor *et al.*, 2014). Accordingly, we should, in principle, gross up the investment series to account for household R&D that develops new services. We do not know of a reliable way to do this, but by way of illustrating the possible magnitude, we gross the investment series up to account for the ratio of consumer services expenditure relative to consumer goods expenditures in the US economy—a ratio that was 2.2 in 2017.

The resulting investment series are reported as the upper two lines in Figure 2, which also includes the investment series shown in Figure 1. With this blow-up factor included, our estimates of nominal investment in household R&D now range between $126 and $143 billion in 2017. The estimates with the services blow-up factor are presented for illustrative purposes only because the adjustment for services is so speculative given the methodological difficulties encountered to date in getting reliable information on process or service innovations via questionnaire.[16] Going forward, we focus on the estimates without this services blow-up as our base case and preferred estimates.

[16]Researchers have found that respondents do not tend to recall service or process innovations when asked about them via questionnaire, even though they have in fact created these types of innovations as has been revealed by follow up personal interviews. For example, householders are much more likely to recall designing and building a special device to help an invalid family member get out of bed, than they are to recall devising a novel series of physical lifting movements to accomplish that same task.

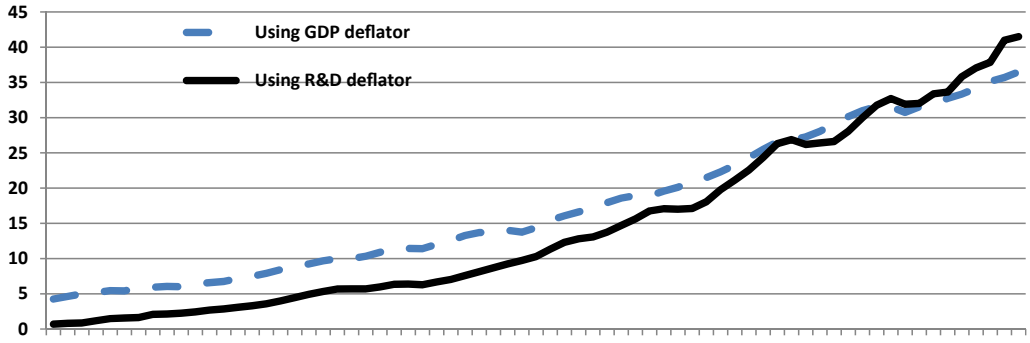

Figure 3. Real Investment, Household R&D, 1949–2017 (billions of 2012 $)

4.2. *Real Investment*

To obtain real investment, we need a price series with which to deflate figures on nominal investment. Measuring changes in prices over time for household R&D (and for most categories of business intangibles) is very challenging. Because these types of intangible investment and the accumulated capital are rarely acquired or exchanged through market transactions, prices will, in most cases, be unobservable. With sufficiently detailed surveys, one could track the cost of the inputs needed for an investment in intangible capital, and then, construct a price index of how those costs for wages and materials have changed over time. One could also, as was done in early studies of business intangible capital, use the GDP deflator, a wage index, or some other price or wage index as a proxy to track changes in the price of household intangible capital over time.[17]

We consider two proxies for prices of household R&D, both drawn from the National Income and Product Accounts: the GDP deflator and the price index for business R&D. The GDP deflator could be considered a general proxy for prices, and we apply it to the series that used nominal GDP as an extrapolator. Implicitly, this series assumes that growth rates of real household R&D match those of real GDP. Alternatively, we apply the business R&D deflator to the nominal series that was extrapolated using nominal business R&D investment. Using this deflator implicitly assumes that prices for business and household R&D follow similar trends and that growth rates for real household R&D match those of real business R&D. Using these two alternative deflators and our base case nominal investment series, the resulting real investment series are reported in Figure 3. We refer to these series as our base case real estimates of investment. These series start at modest levels and rise to $36 and $41 billion (2012 $) by 2017. The series that grows in line with real business R&D (the red line) increases somewhat more rapidly in most periods and is a bit more volatile than the series that grows in line with real GDP (the blue line).

[17]Corrado *et al.* (2009) used the GDP deflator as a proxy for the price of business intangible capital.

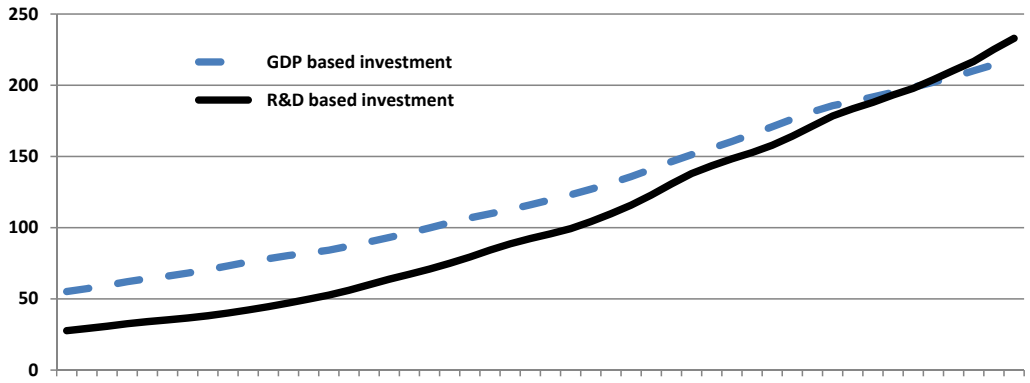

Figure 4. Real Capital Stock, Household R&D, 1970–2017 (billions of 2012 $)

4.3. *Capital Stocks*

We use the perpetual inventory method to construct real capital stocks of household R&D. Specifically, we assume:

$$K_t = (1-\delta)\, K_{t-1} + I_t \tag{1}$$

where K_t, I_t and δ are the real capital stock, real investment, and depreciation rate for household R&D, respectively. For depreciation, we use a rate of 15 percent, based on Haskel and Westlake's (2017, p. 57) estimate for business R&D. To start the iterations for the perpetual inventory method in equation (1), we need a value of the capital stock in an initial period. Because we do not have an initial stock estimate, we use the 1949 value of real investment as the initial stock estimate. This assumption will create some distortion for years relatively close to 1949; accordingly, we only report capital stock figures beginning in 1970, by which time any distortions should have faded.[18]

Following this procedure and using our base case estimates of real investment in household product R&D, the resulting capital stock series are shown in Figure 4. These series show steady and significant growth in the real capital stock of household product R&D, rising to about $219 and $233 billion by 2017 (2012 $) for the series extrapolated by GDP and R&D, respectively. Nominal stocks reach $236 billion and $252 billion in 2017, respectively.

5. How Important is Household Product R&D?

In this section, we highlight several metrics for gauging the magnitude of household innovation. Each of the metrics described below indicate that household R&D is big enough to matter and warrants further attention.

[18]An alternative approach to obtaining an estimate of the initial level of the real capital stock would be to use the steady-state level capital implied by the level of real investment in 1949. A standard formula for the steady-state real capital stock is real investment divided by the sum of the growth rate of real investment and the depreciation rate. Plugging in numbers for those values and redoing our recursions generates almost the same estimate of the real stock in 1970 and beyond. That outcome obtains because, with a 15 percent depreciation rate, bias introduced by using an incorrect value for the initial capital stock in 1949 has largely washed out by 1970.

First, household R&D is a significant share of business R&D. In particular, our preferred estimate of nominal investment in household R&D in 2017 is 11.2 percent of R&D funded by the private business sector.[19] Even as a share of a broader category that also includes nondefense R&D funded by the government, our estimate of household R&D represented a 9.1 percent share in 2017. These shares would be even larger if we also included an estimate of household R&D for service innovations.

Second, household R&D has an even larger share if the focus is narrowed to business R&D devoted to developing consumer goods. To focus on this category, von Hippel *et al*. (2011) used input-output tables to calculate the amount of business R&D (investment) devoted to developing consumer goods (just products, not services), and they estimated this figure to be $62 billion in 2010. Our estimate for household R&D (investment) in 2010 is about $32 billion, more than half of what businesses were spending. By this metric, household R&D is indeed an important source of innovation in the consumer product space.

Third, household R&D represents a noticeable amount of additional investment not currently included in GDP. Our preferred series (without the services blowup factor) estimates nominal investment in household R&D of $44 billion 2017. About $5 billion of this additional investment reflects out-of-pocket expenditures that, under current accounting methodology, would count as consumption. That portion of household R&D would be new investment but would not boost GDP as it would be reallocating GDP from consumption to investment. Accordingly, if household R&D were included in nominal GDP, GDP would have been 0.2 percent higher in that year (=39/19,519). This is not a huge difference, but still consequential in a $19 trillion dollar economy.

Fourth, given that we estimate the stock of household R&D to be substantial, that stock would generate a significant flow of services to households that would be an unmeasured boost to welfare. To gauge the size of these flows, we use the Jorgenson user cost formula. In particular, we estimate the service flow as:

$$[r+\delta-\eta]\,PK$$

where r is the nominal rate of return (assumed to be 7 percent), δ is the depreciation rate for household R&D (assumed to be 15 percent), η captures expected capital losses proxied by the three-year moving average of the percent change in the deflator for household R&D), and PK is the nominal stock of household R&D capital. Using this formula, the service flow for 2017 is $47 billion when the GDP-related extrapolators are used and $50 billion when R&D-related extrapolators are used. With 126.2 million households in the U.S. in 2017, the $50 billion figure translates to $396 per household.

[19]R&D funded by the business sector was $393.7 billion in 2017, compared with $44 billion of household R&D on our preferred estimate.

For the reasons discussed above, we believe that these estimates are conservative. They do not include the service flow from the stock of capital related to household innovations in services, and our rough estimates suggest that total household R&D capital (reflecting both product and service innovations) could be three times as large as that related to product innovations alone. Even if that adjustment factor is too large, including additional R&D capital related to service innovations would significantly increase the estimate of the flow of benefits to households. In addition, as noted, our estimates only include the cost of creating an innovation and not any spillovers to other households or businesses that might be generated.

Fifth, how does the stock of household R&D compare in magnitude with that of other major categories of household assets? Our preferred estimate of the nominal stock of household *product* R&D in 2017 is $251.3 billion. This is a little under half the size of the stock of household autos ($545.7 billion)[20] and about equal to the size of the stock of household appliances ($259.6). While household innovations are used in very different ways than autos and appliances, these comparisons highlight that the stock of household innovation makes up an important element of household economic activity.

A sixth metric for gauging the importance of household R&D is to consider the diffusion of household R&D to the business sector; that is, the innovations developed in the household sector that later are commercialized by the business sector. As described in Section 3 above, this path of diffusion appears to be large enough to be consequential.

Admittedly, all of these metrics for gauging the importance of household innovation are rough. Nonetheless, each of these metrics leads us to believe that household innovation is large enough to warrant further attention.

Finally, how can our estimates be reconciled with the much lower figures in Miranda and Zolas (forthcoming)? Miranda and Zolas estimate that the value of household innovations patented between 2000 and 2011 is $5 billion. This figure is far below our preferred estimate of the nominal capital stock of household R&D of $188 billion in 2011. The most important source of difference between these estimates is what is covered by each estimate. Our estimate covers all reported household innovations (based on survey data), while the Miranda and Zolas figure covers only patented innovations. Between 2000 and 2011, Miranda and Zolas identify 277,000 innovations patented by households, implying a yearly average of about 23,000 patented innovations. This figure is a tiny fraction of our estimate of about 22 million household innovations in the United States in 2010.[21] This relationship is not surprising given that only 8.8 percent of household innovations in the U.S. receive any intellectual property protection and only a modest fraction of that share would have received patent protection given that patents are expensive to obtain. Indeed, the cost of obtaining a patent is currently estimated at between one and two orders of magnitude larger than the total of all other expenses incurred by

[20]A significant share of autos is leased, and these vehicles would be included in the business capital stock of autos rather than the household stock.

[21]Von Hippel *et al*. (2011) reports 11.7 million innovators in the United States in 2010 generating an average of 1.9 innovations per year (reported in von Hippel (2017)), implying a total of about 22 million innovations.

household sector innovators to execute an average project documented in the U.S. household innovation survey.[22]

6. How to Improve Data on Household Innovation

To date, and in the absence of official statistics collected by governments, statistics on household innovation have been collected by *ad hoc* empirical studies such as those we have described. We believe that the measurement community should develop more systematic ways to measure household sector innovation for incorporation into relevant national analyses of innovation going forward.

Measurement of household sector innovation is not a straightforward task. Because only a fraction of innovations created by householders are protected by intellectual property rights such as patents, there is no record of who the innovators actually are. Further, when a household sector innovation is diffused for free, there is no price information to serve as a proxy for value. Still further, the number and nature of adopters are generally not tracked, just as is the case for free diffusion of open source software, with the exception of special examples such as Greenstein and Nagle's (2014) work on software for computer servers. Nonetheless, in view of the extent and importance of household innovation, work toward better measurement clearly would be valuable. Attempts to assign value to unpriced product flows have already begun, and improvements will doubtless follow. (See, e.g. Brynjolfsson and Oh, 2012; Brynjolfsson *et al*., 2018; Greenstein and Nagle, 2014).

We suggest that measurement of household sector innovation expenditures will involve surveys of householders. Building upon success with nationally representative surveys conducted to date, we propose that periodic social surveys should be developed to explore innovation in the household sector. To gain a rich understanding, these should ask individuals in the household sector about their innovations and their entrepreneurial innovation activities, the inputs they expended, the outputs they created, and information on what kind and how much diffusion has been achieved. As a near-term alternative, it may be that, for the specific purposes of the measurement community, just a few questions added to existing social surveys—such as the American Time Use Survey—could provide the most crucial basic information such as time spent on developing innovations each year and out-of-pocket expenses.[23]

To collect information on commercialization of household sector innovations by producers, governmental surveys of enterprises can be modified to ask about the incidence of and the value of adopting designs from household sector innovators. Initial experiments in this direction have been conducted by adding experimental questions to Community Innovation Surveys (CIS) in both Finland and Switzerland. These experiments demonstrate that valuable information can be collected via the CIS. Specifically, responses to the experimental questions added to the Finland CIS have shown that producers do report adoption of customer

[22]Personal correspondence with Andrew Torrance, a leading scholar specializing in patents and patenting at the University of Kansas Law School, suggests that the cost of obtaining a U.S. patent ranges from $10,000 to $100,000 per patent depending on its complexity.

[23]See Bureau of Labor Statistics (2018) for results of the 2017 American Time-Use Survey.

designs as the basis for new commercial products, and that this can be important for their success in the marketplace (Kuusisto *et al*. 2014; Statistics Finland, 2016, Appendix Tables 6 and 7).

7. Conclusion

We have argued that household R&D is an important type of innovation that largely has been overlooked in research related to national accounts. Indeed, it is not counted as investment in the literatures on household production, human capital, or the value of free and other digital goods. Based on survey data for 2010 for the U.S., we develop time series estimates of nominal and real investment and capital stocks for household R&D. Our preferred estimate of nominal investment in household R&D in 2017 is $44 billion, and our estimate of the nominal capital stock in that year is $252 billion.

We fully recognize the tentative and incomplete nature of our time series estimates given that they embed a host of assumptions. Yet, they illustrate an important point. Namely, that household R&D is large enough to be consequential for household welfare and likely generates spillovers to the business sector that, in some industries, could be quite important. We believe that additional focus on gathering the necessary data and refining estimates of this type of intangible capital for the United States and for other countries would enhance our understanding of household and business activity and innovation.

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