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HOUSEHOLD INNOVATION, R&D, AND NEW MEASURES OF INTANGIBLE CAPITAL

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ABSTRACT

Household R&D (or household innovation) is an important source of innovation that has to date been largely overlooked in research related to national accounts. Indeed, it is not currently counted as investment in the literatures on household production and human capital. This paper develops time series estimates of nominal investment, real investment, and real capital stocks for household R&D for product innovations in the United States. (We focus on product innovations because survey data on services innovations in the household sector are not yet available.) In the U.S., we find that household product R&D is significant. Our estimate of real investment in 2017 is $41 billion (2012 dollars). This is about half of what producers spend in R&D to develop new products for consumers – a sizable fraction. Our estimate of the real capital stock of household product R&D in 2017 is $233 billion. We conclude that household R&D is an important feature of household activity and, more generally, of the overall landscape of innovation.

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1. Introduction and overview

Household and non-market activities have long been of interest to economists and national income accountants. One important strand of this work includes the development of estimates of the value of time devoted to the production of household services (such as child care and cooking) as well as the service flow from consumer durable assets.[1] Another important strand has focused on human capital accumulation.[2] Household production and human capital accumulation largely have been judged to be outside the scope of GDP and thereforenot included in official measures. That being said, satellite GDP accounts have been developed for both household production (including the service flow from household durables) and human capital accumulation.[3]

While these extensions have provided important insights about household activities, they largely miss an important type of intangible capital accumulated by households. In particular, they neither explicitly include nor distinguish household research and development (R&D) and innovation. What are household R&D and 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. For example, an individual householder may develop a new type of sport and related sporting equipment for his or her own use, and then find it diffuses 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 to be a significant phenomenon.[4] Nationally-representative surveys, conducted in 10 nations to date, document that, in just these ten nations, tens of millions of consumers (16 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).

[1] 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, Sen and Fitoussi, and (2009), 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.

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

[3] For recent vintages of satellite accounts, see Bridgman (2016) for household production and Fraumeni, Christian, and Samuels (2017) for human capital.

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

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	16	4.7	1.6	0.17	0.54	0.72	13.9	0.28	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, Su, et al. (2017).

Regarding the definition of household innovation, all ten surveys used a standard definition for developments by householders that qualified for inclusion as innovations. Each survey included only new products and product modifications that had been developed by individuals or collaborating groups for personal or family use and that provided useful functional improvements over products already available on the market.[5] (This requirement 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."[6]) Innovations that individuals developed at home for their jobs or for sale, or were paid to develop, were not included in the household sector study samples. Accordingly, because household production entails the "production of goods and services by members of a household, for their own consumption, using their own capital and their own unpaid labor" (Ironmonger 2000, p. 3), household sector innovation as defined in these surveys is a form of household production.

Despite the prevalence indicated by household surveys, household R&D largely has, as noted, fallen between the cracks of existing work on economic measurement. Indeed, 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. In the literature on human capital, time spent developing household R&D 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 and 1992)) as well as in the cost approach (developed by Kendrick (1976)).[7] The indicators approach to measuring human capital also would not count household R&D as investment.[8] None of these approaches consider household R&D as an investment that generates a long-lived capital stock and affect economic

[5] 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.

[6] See OECD/Eurostat (2018), p. 71.

[7] In the Jorgenson 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.

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

welfare in ways that are missed when household R&D is counted as consumption or leisure.

That being said, a handful of papers has estimated values for household activity that would fall outside the prior literatures on household production and human capital.[9] Miranda and Zolas (2018) develop estimates of the value of household innovations that are patented. That research takes an important step forward. However, as Miranda and Zolas point out about their estimates, "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 in the United States captured in surveys receive any type of intellectual property protection (ranging from nondisclosure agreements to patents), and patenting is the most expensive type of protection.

In addition, several recent papers have assessed the value of online activity by household members. One strand of this literature has focused on the value of time consumers spend in various online activities.[10] And, Brynjolfsson, Kim, and Oh (2013) have assessed the value of Internet firms' capital that is generated by users. However, much of the household activity considered by these papers—social media, search, or posting reviews—would not be categorized as household innovative activity by the definition in this paper but rather as business capital developed by users of a platform.

Just as the existing methodologies for measuring economic activity largely have omitted household R&D, the great bulk of household sector product and service development also 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 market." However, the great bulk of household sector developments are not mediated through markets. Indeed, evidence from the above-mentioned national surveys show 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). 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:

[9] More generally, Coyle and Nakamura (2019) highlight needed steps to develop a framework for assessing the relationship between household time-use and social welfare.

[10] For example, see Nakamura, Samuels, and Soloveichik (2017), Brynjolfsson and Oh (2012), Goolsbee and Klenow (2006), Brynjolfsson, Eggers, and Gannamaneni (2018), and Diewert and Fox (2017).

> "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)

In line with the change in the OECD general definition of innovation, 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.[11] Our effort also can be seen as connecting the literatures on household innovation and R&D with work on economic measurement from a national income accounting perspective.

To take a step toward classifying this category of household activity as capital accumulation, this paper provides illustrative estimates of quantities and prices 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. In the U.S. alone, our estimates suggest that household R&D is sizable, with our preferred estimates of real investment in 2017 at $41 billion (2012 dollars) and our preferred estimate of the real capital stock at about $233 billion. According to these estimates, household R&D represents an important feature of household activity and, more generally, of the overall landscape of innovation.

To be sure, our estimates should be regarded as an effort to establish a rough order of magnitude. The survey evidence covers a single year, and we had to use extrapolators to create a time series for investment. In addition, we must rely on rough 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 our 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. In section 4, we develop estimates of nominal investment, real investment, and the real capital stock for household R&D. In Section 5, we

[11] For early papers on intangibles, see Corrado, Hulten, and Sichel (2005 and 2009). For a more recent discussion, see Haskel and Westlake (2017). For one collection of recent work on innovation, see National Academy of Sciences (2017).

describe a number of different metrics for assessing the magnitude and importance of household R&D. In section 6, we present some initial thoughts on how to improve measures of household R&D. Section 7 concludes.

2. Defining Investment in Household Research and Development

Following in the spirit of Corrado, Hulten, and Sichel (2005 and 2009) and Kendrick (1976), household investment can be defined 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 covers both market and non-market investment as well as tangible and intangible capital. Let's consider these in turn.

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.[12] 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, such as new products or services. We call the development of new products and services household innovation or R&D.

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 at all except through the purchase of materials. And, neither human capital nor household R&D are included in official GDP accounts. While satellite accounts have been developed for human capital and for purchased household durables counting as investment, household R&D is nowhere to be seen. Thus, to gauge the magnitude and importance of household R&D we must look elsewhere.

3. What we know today about household innovation and diffusion

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

[12] See Gallman (1966).

temporary gap (Oliveira and von Hippel 2011, van der Boor, Oliveira, and Veloso 2014).

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.

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[f]	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%

a. Source: von Hippel, de Jong, and Flowers 2012
b. Source: von Hippel, Ogawa, and de Jong 2011
c. Source: de Jong, von Hippel, Gault, Kuusisto, and Raasch 2015
d. Source: de Jong 2013
e. Source: Kim 2015

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 using computers were significant activities (Lader, Short, and Gershuny (2006)).

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, they 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 hundreds (Openaps.org 2018). Only free transfers of the design to others are offered by the innovators.
- 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 along, 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."
- 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., time spent on respondents' most recent project averaged 14.7 days, and out-of-pocket expenditures averaged $1,065. In the U.S., total annual expenditures on this activity by householders, with time valued at the U.S. average wage rate in 2010 was $20.2 Billion (von Hippel, Ogawa, and de Jong 2011).

Finally, 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.

[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/#714996712d1a

[14] For details, see von Hippel, de Jong, and Flowers (2012).

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 16 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 1.85 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, Ogawa, and de Jong (2011)).

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+ year history of the field of whitewater kayaking found that 63 percent of the 54 most important equipment innovations in the history of 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 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, such as money transfer between customers. The authors determined that at least 50 percent of these had been pioneered originally by consumer service users (van der Boor, Oliveira, and Veloso 2014).

4. Measuring Household R&D Investment and Capital

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 a nationally-representative survey conducted for the U.S. 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 1,192 responded. The results provide a snapshot in time of the nominal investment in

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 latest innovation (valued at an average wage rate) was combined with the cost of purchased inputs, providing the investment in a single innovation. This figure then is grossed up by the average number of innovations completed in a year for those who undertook innovations based on responses to the question on the average number of innovations completed over the past three years. Finally, this figure is multiplied by an estimate of the total number of innovators in the civilian non-institutional population aged 18 and above. For the U.S., this estimate of aggregate nominal investment in household R&D for 2010 is $20.2 billion.

As noted earlier in the paper, 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. Chin, Su, de Jong, and von Hippel (2018) 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.[16] Accordingly, we gross up the $20.2 billion estimate for 2010 to $30.3 billion.

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, p 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 $39 billion (series extrapolated by nominal GDP) and $44 billion (series extrapolated by nominal business R&D spending) in 2017. We do not have a strong preference between these estimates though the R&D

[15] See von Hippel, Ogawa, and de Jong (2011). For a summary, see von Hippel (2017), table 2.5.
[16] This blowup factor brings in some household innovations that were developed for financial gain; however, the fraction of innovations whose original motivation was financial gain is quite small.

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 basic new retail banking services (Oliveira and von Hippel (2011) and van der Boor, Oliveira, and Veloso (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.[17] Going forward, we focus on the estimates without this services blow-up as our base case and preferred estimates.

Real 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.[18]

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

[17] 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.

[18] Corrado, Hulten, and Sichel (2009) used the GDP deflator as a proxy for the price of business intangible capital.

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).

Capital Stocks

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

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

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.

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 $218 and $233 billion by 2016 (2012 $) for the series extrapolated by GDP and R&D, respectively.

5. How important is household product R&D?

In this section, we highlight several metrics to demonstrate that household R&D is big enough to matter and to warrant further attention.

First, how big is household R&D for developing new products compared with *business* R&D for consumer products? von Hippel, Ogawa, and de Jong (2010) used input-output tables to calculate the amount of business R&D 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 in 2010 is about $32 billion, more than half of what businesses were spending. By this metric, household R&D is an important source of innovation in the consumer product space.

Second, 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 is the expected rate of inflation for household R&D (calculated as the three-year moving average of the actual 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.

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 suggested 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.

Third, how do our estimates compare with those in Miranda and Zolas (2018)? 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 30 million household innovations in the United States in 2010.[19] 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 fraction would have received patent protection.)

Fourth, 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 R&D in 2017 is $251.3 billion. This is a little under half the size of

[19] Von Hippel (2017) reports 16 million innovators in the United States in 2010 generating an average of 1.9 innovations per year, implying a total of about 30 million innovations.

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 component of household economic activity.

A final 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 illustrates that household innovation is large enough to warrant further attention.

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 it would be highly valuable for the measurement community to 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. Still, 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), and Greenstein op cit.)

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 could be developed to explore innovation in the household sector. To gain a rich understanding, these could ask individuals in the household sector about their innovations and their entrepreneurial innovation activities, the inputs they expended, the outputs they created, and their 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

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

Survey—could provide the most crucial basic information such as time spent on developing innovations each year and out of pocket expenses.

To collect information on commercialization of household sector innovations by producers, governmental surveys of enterprises could 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 designs as the basis for new commercial products, and that this can be important for their success in the marketplace (Kuusisto, Niemi, and Gault 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 and human capital. Based on survey data for 2010 for the U.S., we develop time series estimates of nominal investment, real investment, and real capital stocks for household R&D. Our preferred estimate of real investment in household R&D in 2017 is $41 billion (2012 $), and our estimate of the real capital stock in that year is $233 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 would enhance our understanding of household and business activity and innovation.

References

Abraham, K. and C. Mackie, "A framework for nonmarket accounting," in D. W. Jorgenson, J. S. Landefeld, and W. D. Nordhaus (eds), *A New Architecture for the US National Accounts*, vol. I., 2006.

Barro, R. and J. Lee, "A New Data Set of Educational Attainment in the World, 1950-2010," *Journal of Development Economics*, 104©, 184-98, 2013.

Bengtsson, Lars "How big and important is consumer innovation in Sweden? – A comparison with five other countries," Lund University Working Paper, 2016.

Bridgman, Benjamin, "Accounting for Household Production in the National Accounts: An Update, 1965-2014," *Survey of Current Business,* February 2016.

Brynfolfsson, E., Eggers, F. & Gannamaneni, A., "Using massive online choice experiments to measure changes in well-being." National Bureau of Economic Research working paper no. 24514, 2018.

Brynjolfsson, Erik. and Joo Hee Oh, "The attention economy: measuring the value of free digital services on the Internet," presented at the 33rd International Conference on Information Systems, Orlando, FL, 2012.

Brynjolfsson, Erik, Seon Tae Kim, and JooHee Oh, "User Investment and Firm Value: Case of Internet Firms". Proceedings of the Workshop on Information Systems and Economics, Milan, December 2013.

Bureau of Labor Statistics, *American Time Use Survey – 2017 Results,* released June 28, 2018.

Chen, Jin, Yu-Shan Su, Jeroen P.J. de Jong, Eric von Hippel, "Household Sector Innovation in China: Impacts of Income and Development" MIT Sloan School of Management Working Paper, 2018.

Christian, Michael S., "Net Investment and Stocks of Human Capital in the United States, 1975-2013," working paper, available at: https://www.bea.gov/papers/pdf/Christian%20human%20capital%2020160104.pdf.

Corrado, Carol, Charles Hulten, and Daniel Sichel, "Intangible Capital and U.S. Economic Growth," *Review of Income and Wealth,* Series 55, Number 3, pp. 661-685, 2009.

Corrado, Carol, Charles Hulten, and Daniel Sichel, "Measuring Capital and Technology: An Expanded Framework," in *Measuring Capital in the New Economy,* edited by Carol Corrado, John Haltiwanger, and Daniel Sichel, NBER and University of Chicago press, 2005.

Coyle, Diane and Leonard Nakamura, "Towards a Framework for Time Use, Welfare and Household-centric Economic Measurement," ESCoE Discussion Paper 2019-01, 2019.

de Jong, Jeroen P.J. "User innovation by Canadian consumers: Analysis of a sample of 2,021 respondents," Unpublished paper commissioned by Industry Canada 2013.

de Jong, Jeroen P.J., Eric von Hippel, Fred Gault, Jari Kuusisto, and Christina Raasch "Market failure in the diffusion of consumer-developed innovations: Patterns in Finland." *Research Policy* 44, no.10 p. 1856-1865, December, 2015

Diewert, E. and Fox, K. (2017), "The Digital Economy, GDP, and Consumer Welfare," presented at the NBER Summer Institute CRIW Workshop, July 17-18.

Fraumeni, Christian, and Samuels (2017), "The Accumulation of Human and Nonhuman Capital Revisited," in RIW Dec 2017.

Fursov, Konstantin, Thomas Thurner, and Alena Nefedova "What user-innovators do that others don't: A study of daily practices" *Technological Forecasting & Social Change* 118 p. 153–160, 2017.

Gallman, Robert E., "Gross National Product in the United States, 1834-1909," in *Output, Employment, and Productivity in the United States after 1800,* National Bureau of Economic Research, p. 3-90, 1966.

Gilman, Charlotte Perkins, *Women and Economics,* 1898.

Goolsbee, A. and Klenow, P. J. (2006), "Valuing consumer products by the time spent using them: An application to the Internet," *American Economic Review,* 96**,** 108-113.

Greenstein, Shane, and Frank Nagle, "Digital dark matter and the economic contribution of Apache" *Research Policy* 43 p. 623–631, 2014.

Halbinger, Maria "The role of makerspaces in supporting consumer innovation and diffusion: An empirical analysis" *Research Policy in press* 2018.

Haskel, Jonathan and Stian Westlake, *Capitalism without Capital,* Oxford University Press, 2017.

Hemenway, K., Calishain, T., 2004. "Spidering Hacks." O'Reilly Media Inc., Cambridge, MA.

Ironmonger, D. 2000. "Household production and the household economy." Research paper, University of Melbourne, Department of Economics. Accessed January 16, 2019. https://minerva-access.unimelb.edu.au/bitstream/handle/11343/33646/65772_00000059_01_759.pdf?sequence=1&isAllowed=y

Jorgenson, Dale, and Barbara Fraumeni (1989), "The Accumulation of Human and Nonhuman Capital, 1948-84," in Robert Lipsey and Helen Stone Tice, eds., The Measurement of Saving, Investment, and Wealth (Chicago: University of Chicago Press).

Jorgenson, Dale and Steven Landefeld (2006), "Blueprint for Expanded and Integrated U.S. Accounts: Review, Assessment, and Next Steps," in *A New Architecture for the U.S. National Accounts,* edited by Dale Jorgenson, Steven Landefeld, and William Nordhaus, NBER and University of Chicago Press, p. 13-112.

Kendrick, John (1976), *Formation and Stocks of Total Capital,* National Bureau of Economic Research.

Kim, Y. Consumer user innovation in Korea: An international comparison and policy implications. *Asian Journal of Technology Innovation* 23 (1): p. 69–86, 2015.

Landefeld, J. S., B. M. Fraumeni, and C. M. Vojtech, "Accounting for Household Production: a Prototype Satellite Account Using the American Time Use Survey," *Review of Income and Wealth*, **55**(2), 205–225, 2009.

Leontieff, Wassily, *The Structure of the American Economy,* 1941.

Marshall, Alfred, *Principles of Economics: An Introductory Volume,* 1920.

Miranda, Javier and Nikolas Zolas (2017), "The Impact of Household Innovation Using Administrative Data," NBER working paper No. 25259.

Nakamura, L. I., Samuels, J. D. and Soloveichik, R. H. (2017), "Measuring the "free" digital economy within the GDP and productivity accounts," Philadelphia Federal Reserve Bank working paper No. 17-37..

National Academy of Sciences, Engineering, and Medicine (2017), "Advancing Concepts and Models for Measuring Innovation," Proceedings of a Workshop, Washington, D.C.

Nordhaus, W., "Principles of national accounting for nonmarket accounts," *A new architecture for the US national accounts*, 2006.

OECD/Eurostat (2018), *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, 4th Edition*, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris/Eurostat, Luxembourg.

Ogawa, S., and K. Pongtanalert, "Visualizing Invisible Innovation Content: Evidence from Global Consumer Innovation Surveys" Working paper, Kobe University 2011.

Oliveira, Pedro and Eric von Hippel (2011) "Users as Service Innovators: The Case of Banking Services" *Research Policy,* vol. 40, Nr 6, pp. 806-818.

OpenAPS Outcomes https://openaps.org/outcomes/ (accessed Oct 10, 2018)

Pigou, Arthur, *The Econoomics of Welfare,* 1932.

Poissonnier, A. and Roy, D. (2017), Household Satellite Account for France. Review of Income and Wealth, 63: 353–377. doi:10.1111/roiw.12216

Stiglitz, J. E., A. Sen, and J.-P. Fitoussi, "Report by the Commission on the Measurement of Economic Performance and Social Progress," Discussion paper, 2009.

Vanoli, A., *Une histoire de la comptabilité nationale—A History of National Accounting*. La Découverte—IOS Press (English translation), 2002.

von Hippel, Eric, *Free Innovation,* MIT Press, 2017.

von Hippel, Eric, Jeroen P.J. de Jong, and Daan Rademaker, "Household Sector Innovation" Mohammed Bin Rashid Centre for Government Innovation, UAE, (July, 2017)

von Hippel, Eric, S. Ogawa, and P.P.J. de Jong, "The age of the consumer innovator," *Sloan Management Review* 53 (1); p. 27-35, 2011.

von Hippel, Eric, Jeroen P.J. de Jong, and Stephen Flowers "Comparing business and household sector innovation in consumer products: Findings from a representative survey in the UK." *Management Science,* Vol. 58, No. 9, p. 1669–1681, September, 2012.

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

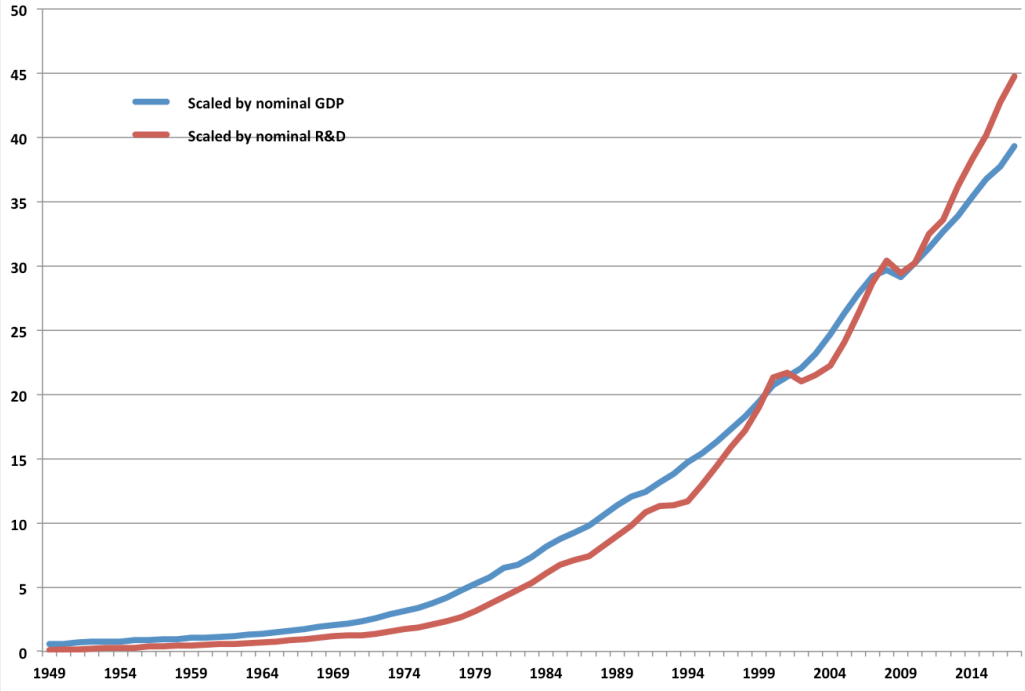
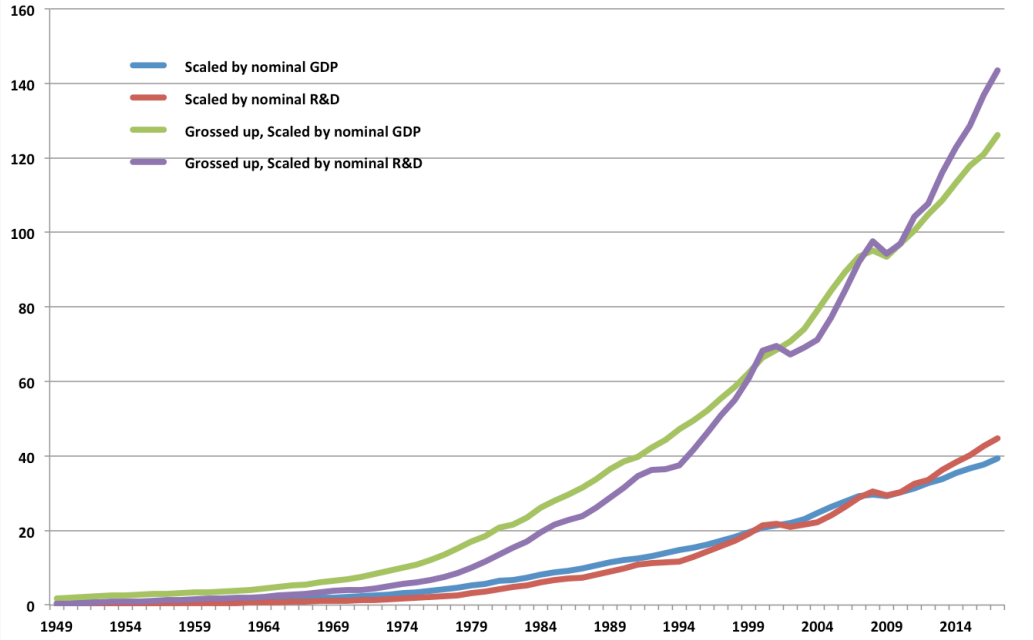


Figure 2
Nominal Investment, Household R&D
Grossed up to include Services, 1949-2017
(billions of $)



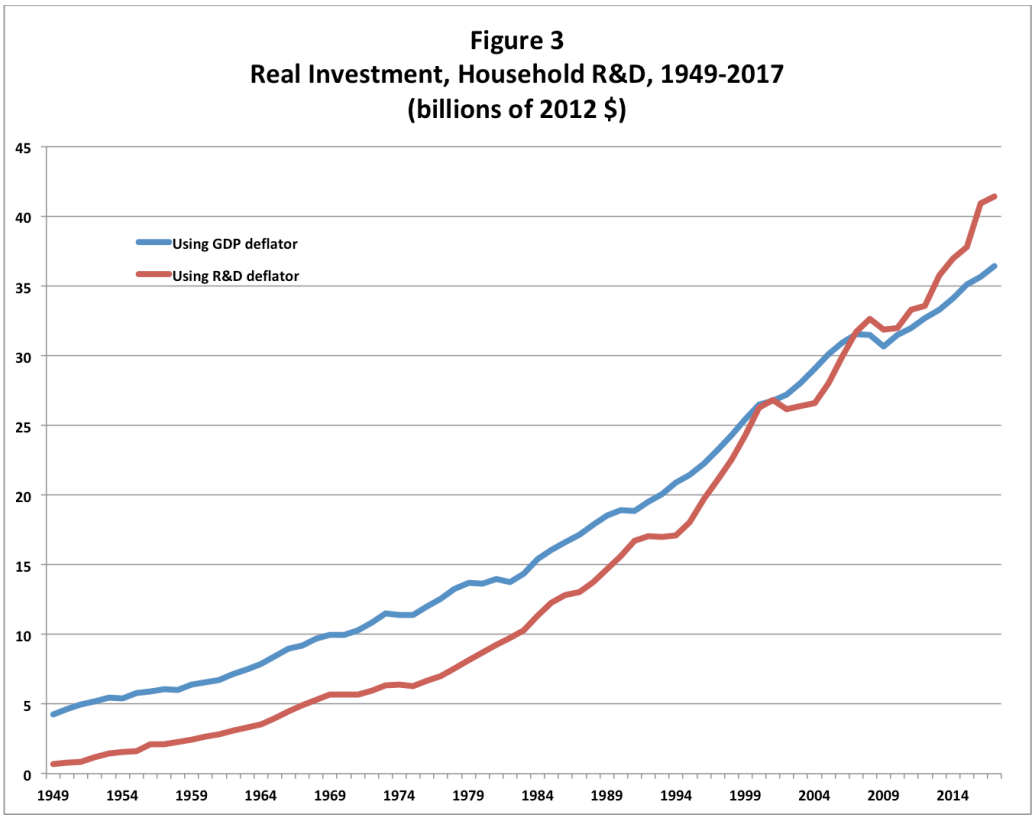


Figure 3
Real Investment, Household R&D, 1949-2017
(billions of 2012 $)
45
40
35
30
25
20
15
10
5
0
Using GDP deflator
Using R&D deflator
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009
2014

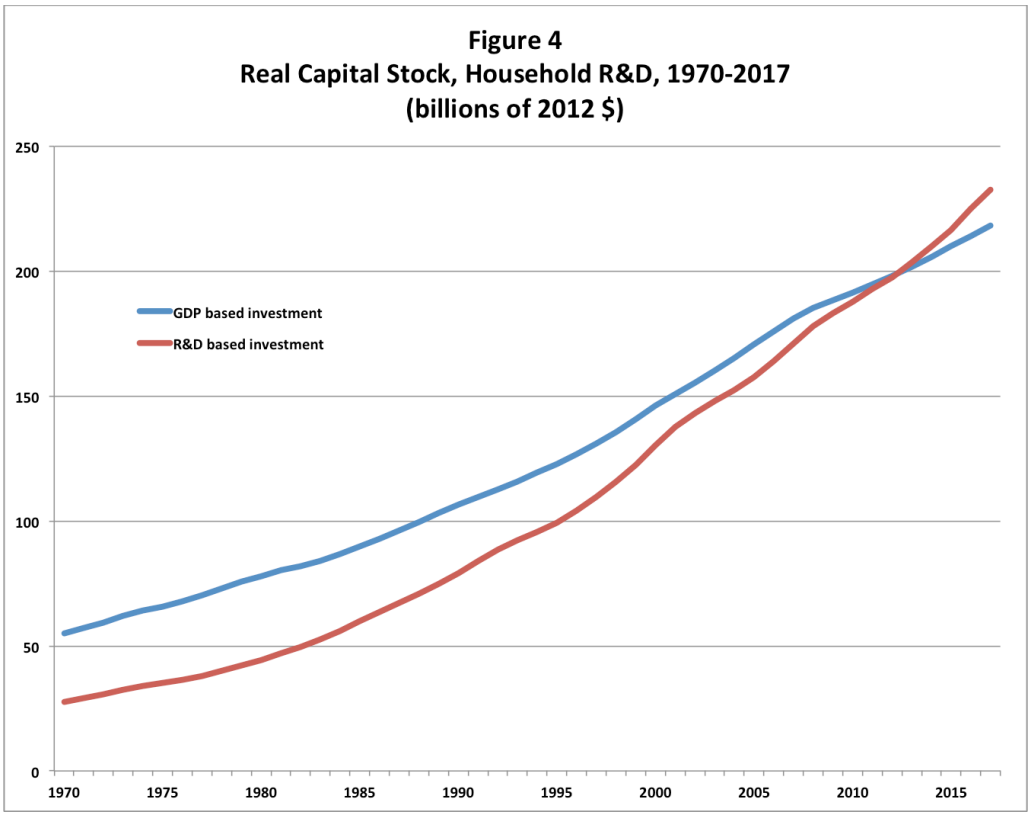


Figure 4
Real Capital Stock, Household R&D, 1970-2017
(billions of 2012 $)
250
200
150
100
50
0
GDP based investment
R&D based investment
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015